HYDROGEOLOGY AND WATER BUDGET FOR GOSHEN VALLEY, UTAH COUNTY, UTAH

by Stefan M. Kirby, J. Lucy Jordan, Janae Wallace, Nathan Payne, and Christian Hardwick

SPECIAL STUDY 171
UTAH GEOLOGICAL SURVEY
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Cover image: *View from Long Ridge, across southern Goshen Valley, of the groundwater discharge and wetland system associated with Goshen Warm Springs.*

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ABSTRACT

Goshen Valley contains extensive areas of agriculture, significant wetlands, and several small municipalities, all of which rely on both groundwater and surface water. The objective of this study is to characterize the hydrogeology and groundwater conditions in Goshen Valley and calculate a water budget for the groundwater system. Based on the geologic and hydrologic data presented in this paper, we delineate three conceptual groundwater zones. Zones are delineated based on areas of shared hydrogeologic, geochemical, and potentiometric characteristics within the larger Goshen Valley. Groundwater in Goshen Valley resides primarily in the upper basin fill aquifer unit (UBFAU) and lower carbonate aquifer unit (LCAU) hydrostratigraphic units. Most wells in Goshen Valley are completed in the UBFAU, which covers much of the valley floor. The UBFAU is the upper part of the basin fill, which is generally less than 1500 feet thick in Goshen Valley. Important spring discharge at Goshen Warm Springs issues from the LCAU. Relatively impermeable volcanic rocks (VU) occur along much of the upland parts of the southern part of Goshen Valley. Large sections of the southwest part of the Goshen Valley basin boundary have limited potential for interbasin flow. Interbasin groundwater flow is likely at several locations including the Mosida Hills and northern parts of Long Ridge and Goshen Gap in areas underlain by LCAU. Depth to groundwater in Goshen Valley ranges from at or just below the land surface to greater than 400 feet. Groundwater is within 30 feet of the land surface near and north of Goshen, in areas of irrigated pastures and wetlands that extend east toward Long Ridge and Goshen Warm Springs, and to the north towards Genola. Groundwater movement is from upland parts of the study area toward the valley floor and Utah Lake. Long-term water-level change is evident across much of Goshen Valley, with the most significant decline present in conceptual zone 2 and the southern part of conceptual zone 1. The area of maximum groundwater-level decline—over 50 feet—is centered a few miles south of Elberta in conceptual zone 2. Groundwater in Goshen Valley spans a range of chemistries that include locally high total dissolved solids and elevated nitrate and arsenic concentrations and varies from calcium-bicarbonate to sodium-chloride-type waters. Overlap in chemistry exists in surface water samples from Currant Creek, the Highline Canal, and groundwater. Stable isotopes indicate that groundwater recharges from various locations that may include local recharge, from the East Tintic Mountains, or far-traveled groundwater recharged either in Cedar Valley or east of the study area along the Wasatch Range. Dissolved gas recharge temperatures support localized recharge outside of Goshen. Most groundwater samples in Goshen Valley are old, with limited evidence of recent groundwater recharge. An annual water budget based on components of recharge and discharge yields total recharge of 32,805 acre-ft/yr and total discharge of 35,750 acre-ft/yr. Most recharge is likely from interbasin flow and lesser amounts from precipitation and infiltration of surface water. Most discharge is from well water withdrawal with minor spring discharge and groundwater evapotranspiration. Water-budget components show discharge is greater than recharge by less than 3000 acre-ft/yr. This deficit or change in storage is manifested as long-term water-level decline in conceptual zone 2, and to a lesser degree, in conceptual zone 1. The primary driver of discharge in conceptual zone 2 is well withdrawal. Conceptual zone 3 is broadly in balance across the various sources of recharge and discharge, and up to 1830 acre-ft/yr of water may discharge from conceptual zone 3 into Utah Lake. Minimal groundwater likely flows to Utah Lake from zones 1 or 2.

INTRODUCTION

Goshen Valley contains extensive areas of agriculture, significant wetlands, and several small municipalities, all of which rely on groundwater and surface water. The potential for future growth and land-use changes in this area and consequent increases and changes in groundwater use are of concern to groundwater managers. The Utah Division of Water Rights (UDWRi) requested the Utah Geological Survey (UGS) create a hydrogeologic framework, revised conceptual model, and water budget for Goshen Valley to provide groundwater managers with updated and accurate information on which to base future management decisions.

The objective of this study is to characterize the hydrogeology and groundwater conditions in Goshen Valley and calculate a water budget for the groundwater system. This study defines the primary hydrogeologic units and focuses on the extent and character of the basin-fill and important bedrock aquifers within the study area. The study uses newly collected groundwater samples to better determine groundwater flow paths, residence time, sources of recharge and discharge, and baseline water quality. New water-level measurements are used to construct a revised potentiometric surface map for the basin-fill aquifer. New gravity data are used to model basin-fill thickness in Goshen Valley. These new data and analyses were used to construct a hydrogeologic framework and revised conceptual model for groundwater in Goshen Valley.

Using geologic and hydrologic characteristics three conceptual groundwater zones were delineated based on areas of shared hydrogeologic, geochemical, and potentiometric characteristics within the larger Goshen Valley (figure 1; see additional discussion in the Conceptual Model of Groundwater Flow section below). These conceptual zones are subbasins within the larger Goshen Valley study area. This methodology is meant to facilitate simplification and understanding of an otherwise complex and heterogenous groundwater system. Conceptual zone 1 is in the northwestern part of the Goshen Valley study area. The western boundary of this zone is the drainage divide that trends along Lake Mountains through the Mosida Hills and into the East Tintic Mountains. The eastern boundary of this zone is Utah Lake. The southern boundary extends west to east across the west part of Goshen Valley. Conceptual zone 2 covers the southwestern part of Goshen Valley. It is bounded by conceptual zone 1 to the north and conceptual zone 3 to the east. The eastern boundary is Currant Creek along the floor of Goshen Valley. To the south the boundary is defined by the drainage divide along Long Ridge and the East Tintic Mountains. Conceptual zone 3 covers the eastern part of Goshen Valley from the channel of Currant Creek to the drainage basin boundary. This zone includes the western slopes of West Mountain and areas west of the drainage divide along Long Ridge. This zone extends to Utah Lake along its northwestern edges.

Groundwater in Goshen Valley resides in either basin-fill or consolidated bedrock aquifers. Most existing wells are completed in the basin-fill aquifer along the valley floor. Locally, supply wells are completed in bedrock aquifers that are composed of Paleozoic carbonates, Tertiary volcanic rocks, and a variety of other geologic units. Recharge to these aquifers may occur from direct infiltration of precipitation, seepage of perennial and ephemeral streams, seepage from unconsumed irrigation, and subsurface inflow from adjoining mountain blocks and areas of interconnected basin fill (Brooks and Stolp, 1995). Discharge from the groundwater system occurs as pumping from wells, spring discharge, evapotranspiration (ET) from natural vegetation and irrigated agriculture, subsurface discharge to Utah Lake, and subsurface outflow. This study used detailed hydrogeologic, geochemical, and potentiometric data in conjunction with refined water budget techniques to define the hydrogeology and water budget for Goshen Valley.

GEOGRAPHIC SETTING

Physiography and Land Use

Goshen Valley is a north-south elongate hydrologic basin that covers approximately 300 square miles in the southwestern corner of Utah County (figure 1). The southwestern arm of Utah Lake (Goshen Bay) extends southward into Goshen Valley and covers nearly 50 square miles of the northern part of the valley. Along its western margin the valley is bounded by the Lake Mountains, the Mosida Hills, and the East Tintic Mountains. Along its eastern boundary the valley is separated from the southern part of Utah Valley by West Mountain and a low drainage divide west of Santaquin. To the southeast Goshen Valley is separated from Juab Valley by Long Ridge. The floor of Goshen Valley ranges in elevation from 5500 feet along the toe of the East Tintic Mountains to 4500 feet near Utah Lake. Topographic highpoints in the ranges that bound Goshen Valley include Tintic Mountain in the East Tintic Mountains (8200 feet), West Mountain (6800 feet), and Lake Mountain (7700 feet). Several miles east of the study area, the Wasatch Range includes several peaks over 10,000 feet in elevation.

Land use in Goshen Valley is dominated by various types of agriculture. Irrigated orchards predominate the eastern slopes of the valley floor near Genola, and to the north along the western slopes of West Mountain. Along the floor of Goshen Valley near and to the north of the town of Goshen, flood irrigated pastures comprise the typical land use. The western part of Goshen Valley contains significant areas of sprinkler irrigated crops that include corn, alfalfa, and other crops. This part of Goshen Valley also contains several active dairies and areas that were previously used as dairies and feedlots.

Surface Water

Surface water hydrology in Goshen Valley is dominated by Goshen Bay, the southwest arm of Utah Lake, which extends southward into Goshen Valley. Goshen Reservoir impounds tens of acres of the flow of Currant Creek west of the town of Goshen. Other surface water includes small ephemeral stock ponds and perennial and ephemeral ponds that lie in an extensive area of wetlands east of the town of Goshen.

Springs in Goshen Valley include several small upland springs whose flow does not reach the valley floor and several major valley-floor spring complexes. Several small springs occur in the upper reaches of the East Tintic Mountains south of Eureka. Significant upland springs occur along the Kimball Creek drainage, providing flow to the creek as it drains northward. The lower reach of Kimball Creek is ephemeral as it traverses Goshen Valley. Ercanbrack Spring issues from volcanic bedrock along the Currant Creek channel in Long Ridge. The largest spring complex in the study area is Goshen Warm Springs, which issues at the base of Long Ridge.

Perennial stream flow across the floor of Goshen Valley is limited to Currant Creek and outflow from Goshen Warm Springs that is channelized in the Goshen Warm Spring Canal. Currant Creek flows northward into the study area from Juab Valley where it is the outflow of Mona Reservoir. The creek cuts a canyon through bedrock of Long Ridge before flowing along the floor of Goshen Valley to Goshen Reservoir. Below Goshen Reservoir, water is routed through a series of canals for irrigation with a smaller amount discharging along the lower Currant Creek channel, locally termed Job Creek. Little if any surface flow reaches Goshen Bay, neither from

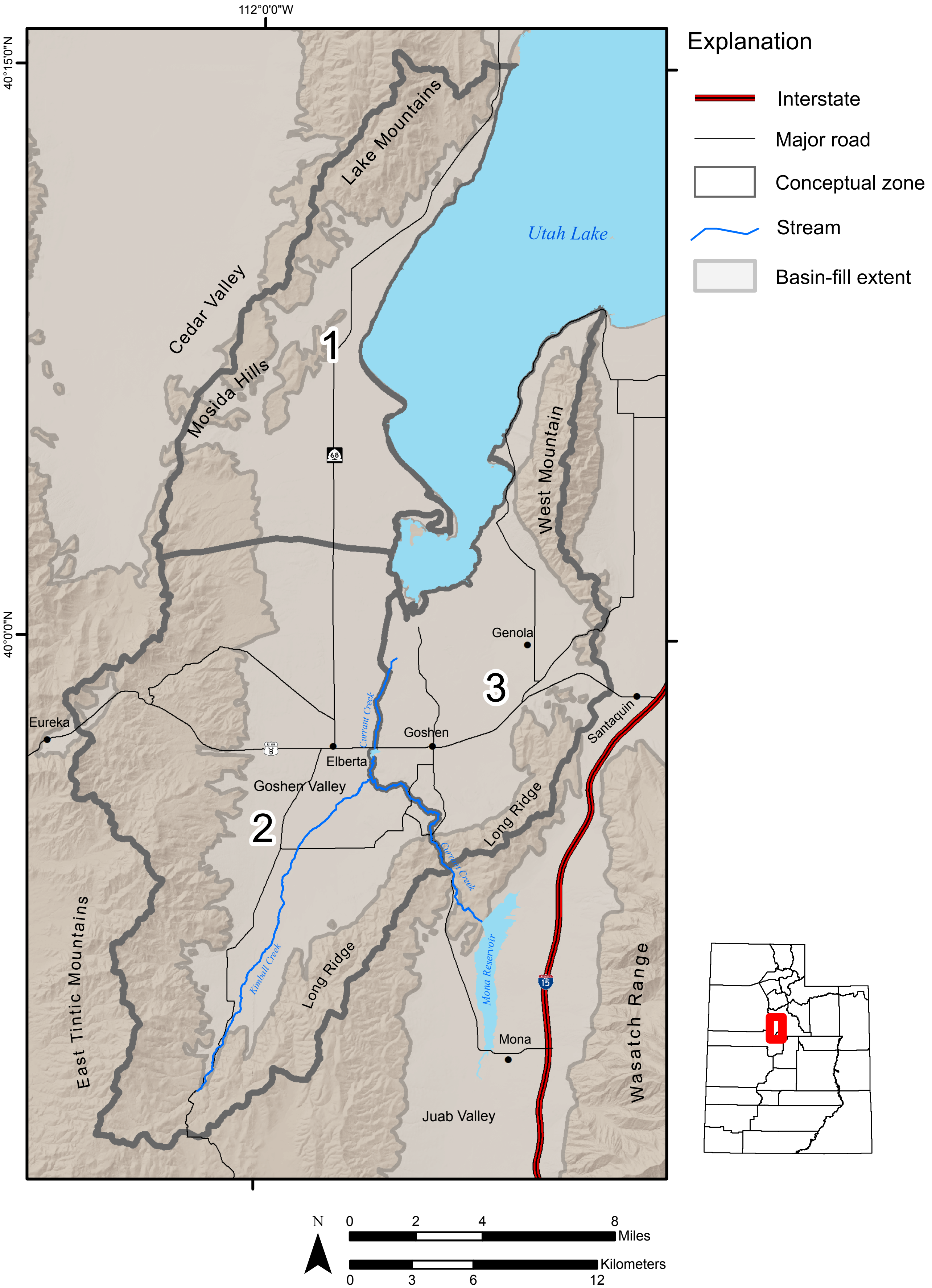


Figure 1. *Physiographic overview of the Goshen Valley study area. Numbers correspond with conceptual zones discussed in the text.*

the Currant Creek drainage nor outflow from Goshen Warm Springs in years with normal or low precipitation.

Along the eastern part of Goshen Valley, the Strawberry Highline Canal system provides significant quantities of irrigation. This water is distributed across a complex network of canals and pipelines that extend from near Genola to the north along the flanks of West Mountain. The Elberta canal system extends from Currant Creek in Goshen Canyon to the south and west. During the period of this study, the canal system was inactive except for several weeks at the highest flows in spring of 2017.

GEOLOGIC AND HYDROGEOLOGIC SETTING

Introduction

Goshen Valley is in the eastern Great Basin physiographic province. This area is characterized by broad alluvial valleys bounded by bedrock mountain ranges. Normal faults commonly define the boundaries between mountain block uplands and the adjoining valley floors. The area has a long and complicated geologic history that controls the distribution of groundwater resources and their availability.

Geologic Background

Goshen Valley is a graben formed in the hanging wall of the Wasatch normal fault system that defines the eastern margin of the valleys of the Wasatch Front. The rocks of this area record a long history of quiescent sedimentation that began in the Precambrian and included deposition of a thick sequence of clastic rocks followed by long-lived deposition of shelf and marginal carbonates throughout the Paleozoic. These rocks were folded and faulted during prolonged east-directed thin-skinned thrusting of the Sevier fold and thrust belt that occurred between the middle Mesozoic and early Tertiary. During this time, uplifted and deformed Paleozoic and Precambrian rocks shed detritus that accumulated as localized synorogenic clastic rocks. Beginning in the middle Tertiary a broad eastward sweep of volcanism culminated locally in deposition and emplacement of extrusive and intrusive volcanic rocks of the East Tintic Mountains. In the late Tertiary, typical Great Basin extensional tectonism began and formed the mountain range and valley topography common to the area today. Sediments shed from uplifting mountain blocks slowly filled adjoining basins; these processes continue today.

Hydrostratigraphy

Introduction

The water-yielding characteristics and spatial extent of hydrogeologic units place fundamental constraints on groundwater processes. We subdivided the geology of the Goshen Valley study area into a series of permeable and impermeable units based on an aquifer classification scheme that follows that used by the U.S. Geological Survey in adjoining areas of the eastern Great Basin (Heilweil and Brooks, 2010; Gardner and Kirby, 2011).

The hydrostratigraphic units are greatly simplified conceptual packages of formations that form discernable groups having similar water-yielding characteristics. In Goshen Valley these units are composed of numerous correlative formations generally of a given type and age range that share hydrogeologic characteristics. Goshen Valley contains seven hydrostratigraphic units that represent the mapped and inferred geologic formations present in the study area subsurface (figures 2 and 3). Units are described in ascending stratigraphic order from oldest to youngest (Hintze and others, 2000; Clark, 2009a, 2009b; Gardner and Kirby, 2011; McKean and others, 2015).

Hydrostratigraphic Units

The non-carbonate confining unit (NCCU) consists of thick sequences of Precambrian-age quartzite, phyllite, slate, and shale (figure 2). These rocks include a range of different formations that vary across the study area. Total thickness of this unit is at least 10,000 feet and the unit generally increases in thickness from east to west. No productive wells are completed in this unit and the unit is assumed to be impermeable.

Overlying the NCCU is a thick sequence of limestone, dolomite, sandstone, and minor shale termed the lower carbonate aquifer unit (LCAU). Total thickness of these rocks in the study area is greater than 8000 feet and thickness of the unit generally increases from east to west across the study area. The formations included in the LCAU range in age from early Cambrian to Middle Mississippian. These carbonate rocks compose the most important bedrock aquifer. The LCAU readily yields water to wells and facilitates regional groundwater flow where the unit is laterally contiguous (Gardner and Kirby, 2011).

Immediately overlying the LCAU is the upper siliciclastic confining unit (USCU). This unit consists entirely of shale, minor sandstone, and limestone of the Late Mississippian- to Early Pennsylvanian-age Manning Canyon Shale. Total thickness of this unit is up to 500 feet. This unit is known to be an aquiclude based on regional hydrogeologic studies (Gardner and Kirby, 2011; Jordan and Sabbah, 2012).

Stratigraphically above the USCU is the upper carbonate aquifer unit (UCAU). The UCAU consists of interbedded carbonate, sandstone, quartzite, and shale of the Pennsylvanian Oquirrh Group. Total thickness of these rocks is greater than 10,000 feet in the study area. The UCAU is considered an important aquifer regionally (Jordan and Sabbah, 2012). However, in Goshen Valley, its extent is limited and few wells are completed in this unit.

Unconformably overlying all the units described above is the upper siliciclastic aquifer unit (USAU). This unit includes undivided Tertiary- and Cretaceous-age clastic deposits that consist primarily of conglomerate, sandstone, and mudstone deposited during thrust faulting of the Sevier orogeny. Total thickness of this unit is less than 400 feet. The spatial extent of this unit is limited, but it does yield water to wells in the eastern part of the study area.

The volcanic unit (VU) is the most lithologically heterogeneous hydrostratigraphic unit in the study area. It includes a broad range of Tertiary-age volcanic rocks related to the East Tintic volcanic field. Lithologies include various compositions of effusive lava, intrusive rocks, agglomerates, and volcaniclastic deposits. Total thickness of these rocks is greater than 6000 feet with the thickness and extent decreasing markedly to the north and east away from the southwest part of the study area. These rocks locally yield water to wells but generally in limited quantities. For this study, the VU is broadly considered to be impermeable based on the limited and extremely variable yield to wells.

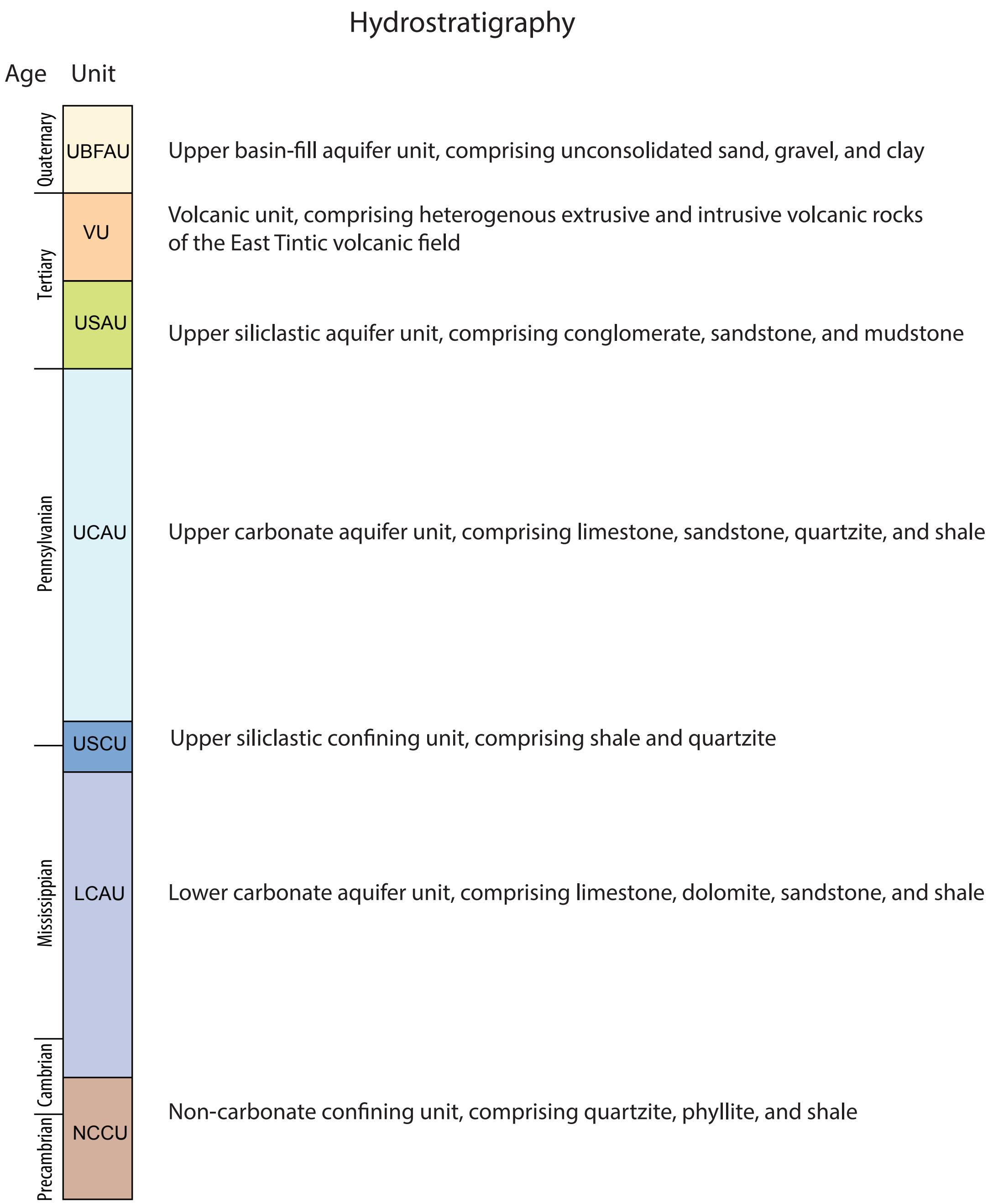


Figure 2. *Goshen Valley hydrostratigraphic units. Column is diagrammatic and describes representative stratigraphic units that were assigned to hydrostratigraphic units. Diagram does not depict unit thickness or accurate age range. Hydrostratigraphic units modified from Gardner and Kirby (2011).*

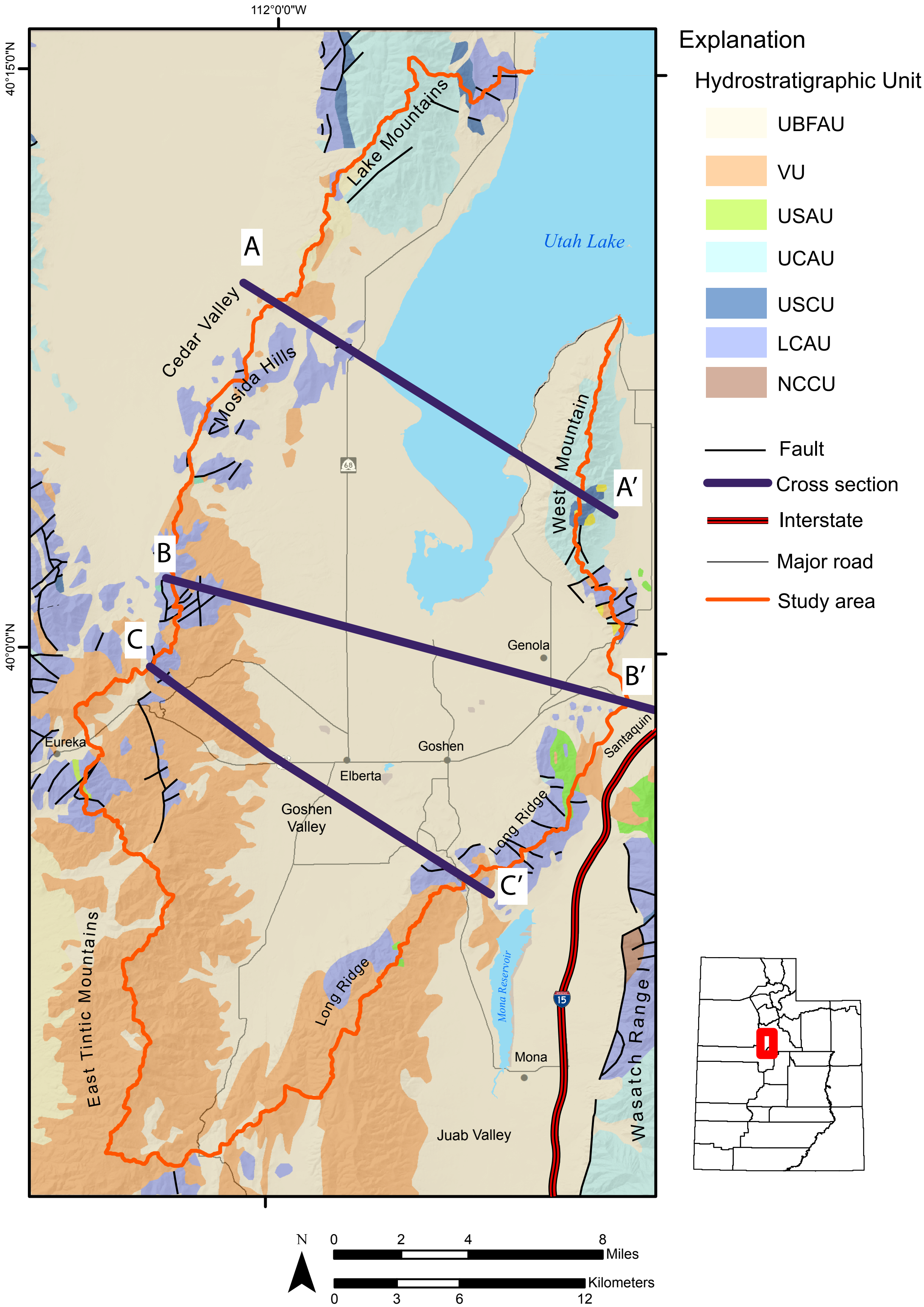


Figure 3. *Hydrostratigraphy of Goshen Valley. For complete unit descriptions see text. Map is compiled and modified from Hintze and others (2000), Clark (2009a, 2009b), and McKean and others (2015). Cross sections are shown on figure 4.*

Overlying all the bedrock units previously described are two basin-fill units, the lower basin-fill aquifer unit (LBFAU) and the upper basin-fill aquifer unit (UBFAU). Both units consist of semiconsolidated to unconsolidated alluvial, fluvial, and lacustrine deposits. The units are dominated by interbedded, locally derived sand, gravel, clay, and silt. The lithologies of these units vary spatially across the floor of Goshen Valley. Coarse-grained sand and gravel deposits are typical of the valley margin areas adjoining upland mountain blocks, whereas fine-grained clays are interbedded and laterally continuous across the floor of Goshen Valley. These units readily yield water to wells, and most of the groundwater supply in Goshen Valley is from the UBFAU. Due to a general lack of well constraints and observable lithologic contrasts, UBFAU and LBFAU are not subdivided on our cross sections or in subsequent sections of this report. In subsequent discussions concerning the basin fill, both LBFAU and UBFAU are represented as UBFAU.

The extent of these units and their geologic setting is shown on figure 3. This simplified geologic map is based on existing geologic mapping (Hintze and others, 2000; Clark, 2009a, b; McKean and other, 2015). The southwestern corner of Goshen Valley is dominated by exposures of VU across the East Tintic Mountains and the southern part of Long Ridge. North and east of these areas, LCAU rocks are exposed as the bedrock that defines the basin boundary. Exposures of the USAU occur along the northern extent of Long Ridge. UCAU rocks are exposed across West Mountain and the southern end of the Lake Mountains. Much of the floor of Goshen Valley is covered by the UBFAU unit. Descriptions of the subsurface relationships of the hydrostratigraphic units are discussed below based on simple cross sections.

Cross Sections

We created three simplified cross sections based on the hydrostratigraphic map, well logs, preexisting cross sections (Clark, 2009b; McKean and others, 2015), and geophysical data (figure 4). These cross sections provide simplified views of the subsurface extent of the aquifers and aquitards on a regional scale. The cross sections depict the subsurface extent of hydrogeologic units and are not considered balanced geologic cross sections capable of depicting the complex structural relationships at the scale of the compiled map.

Cross section A to A′ extends roughly northwest to southeast from the southern part of Cedar Valley and the Mosida Hills across Goshen Valley and the southwest arm of Utah Lake to West Mountain (figures 3 and 4). Along the cross section's western extent, carbonate rocks of the LCAU are covered by the shallow UBFAU or exposed along the Mosida Hills. Aquifers are in close communication in this area and generally elsewhere where they directly abut each other. To the east, the UBFAU thickens markedly beneath Utah Lake and the axis of Goshen Valley, before thinning again towards West Mountain. West Mountain consists primarily of exposed carbonates of the UCAU. These UCAU rocks are underlain by impermeable USCU rocks that overlie LCAU rocks at depth.

Cross section B to B′ extends roughly west to east across the center of Goshen Valley (figures 3 and 4). The cross section begins in the East Tintic Mountains where rocks of the LCAU occur in the shallow subsurface. Total UBFAU thickness is about 3000 feet along the valley axis. Based on well logs, the UBFAU contains continuous clay layers along the valley axis. To the east and west, the UBFAU lacks continuous clay layers and is assumed to be unconfined. The cross section extends east through Goshen gap and Genola, where the UBFAU is relatively thin and directly overlies the LCAU.

Cross section C to C′ extends northwest to southeast across the southern part of Goshen Valley from the East Tintic Mountains to Long Ridge and Goshen Canyon (figures 3 and 4). The cross section depicts a thick section of VU over LCAU beneath the East Tintic Mountains. To the east across the floor of Goshen Valley the cross section depicts basin fill (UBFAU) bounded by normal faults that offset both VU and LCAU rocks at depth. These basin faults are depicted by recent geologic mapping by McKean and others (2015) as significant normal faults that offset all units. To the east the UBFAU is thin and overlies VU and LCAU rocks. LCAU rocks are exposed along Long Ridge and in Goshen Canyon.

Hydrogeologic Boundary Conditions

Hydrogeologic boundary conditions are the aggregate of hydrogeologic units along a study area boundary and local groundwater conditions that influence groundwater flow. Mountain blocks that likely have a groundwater mound or zone of high potentiometric surface relative to adjoining valleys are assumed to limit interbasin flow. These areas are delineated where groundwater levels at springs and/or wells in the mountain blocks are higher than groundwater levels in adjoining basins. Lacking defined or assumed groundwater mounds, areas of contiguous aquifer rocks may facilitate interbasin groundwater flow. Based on these simple qualitative assumptions, the boundary of the Goshen Valley study area is defined by the potential for interbasin flow into three categories: interbasin flow likely, interbasin flow possible, and interbasin flow unlikely. Boundary conditions on figure 5 show large sections of the Goshen Valley basin boundary being unlikely for interbasin flow. These areas include the southwestern part of the study area where relatively impermeable VU rocks and probable groundwater mounding in the East Tintic Mountains likely limit interbasin groundwater flow. West Mountain and the southern part of the Lake Mountains are also assumed to be areas unlikely to have interbasin groundwater flow based on the propensity for groundwater mounds in these mountain blocks. Interbasin groundwater is likely along contiguous areas underlain by LCAU rocks in the Mosida Hills and northern parts of Long Ridge and Goshen Gap near Genola. These low-elevation ridges and saddles likely lack significant groundwater mounds and potentiometric data support gradients conducive to interbasin flow into Goshen Valley in these areas.

Well Data

Overview

To better constrain the properties of the hydrogeologic units in Goshen Valley, available well logs from the UDWRi (2016) were summarized based on hydrogeologic unit, lithology, and specific capacity. Well locations were checked and corrected, if necessary, based on the fit with aerial photography and water right location information. Surface elevation for each well log location is taken from the U.S. Geological Survey 3DEP elevation dataset (U.S. Geological Survey Geospatial Data Program, 2017). For each well log, a total depth is noted and additional parameters that include depth to water, well diameter, and screen interval are listed when available. Well logs were categorized based on the lithology of the screened interval and include Quaternary unconsolidated basin fill (Q), Paleozoic carbonates (Pz), Tertiary conglomerates (Tk), Tertiary volcanic rocks (Tv), and Tertiary volcanic sediments (Tva). Only well logs having sufficient detail describing the lithology of completion are included in the dataset. For wells that intersect basin fill, clay layers thicker than 20 feet are noted as well as the total thickness of basin fill.

Most wells in Goshen Valley are completed in the unconsolidated basin fill in the upper several hundred feet of the aquifer (appendix A, figure 6). Many of the wells completed in basin fill on the floor of Goshen Valley intersect at least one clay interval. The distribution of these clay layers is important to define

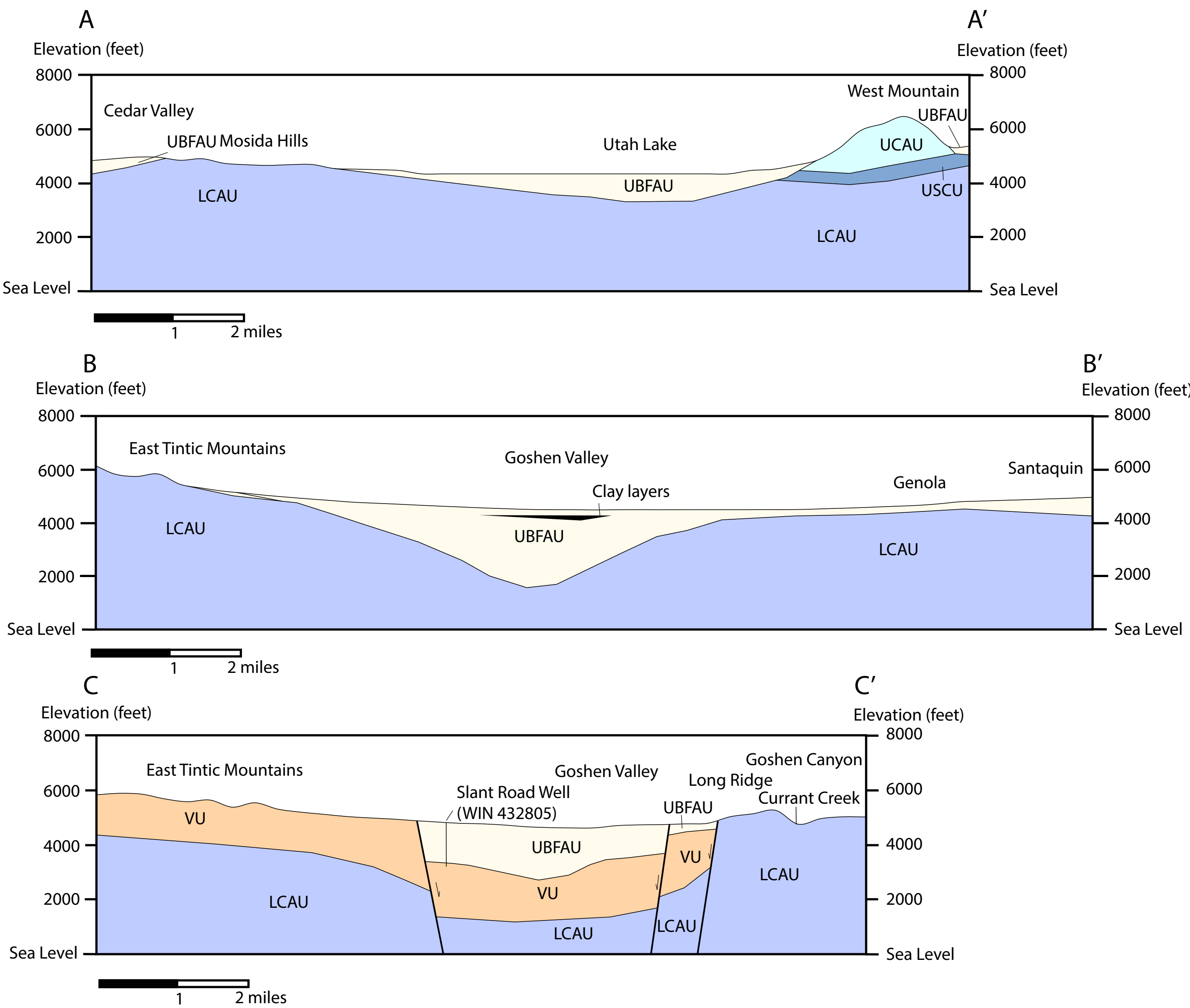


Figure 4. *Simplified hydrostratigraphic cross sections. Vertical exaggeration is 2x for all sections. See text for description of hydrostratigraphic units. Cross section A to A′ is modified from Clark (2009b). Cross section C to C′ is modified from McKean and others (2015).*

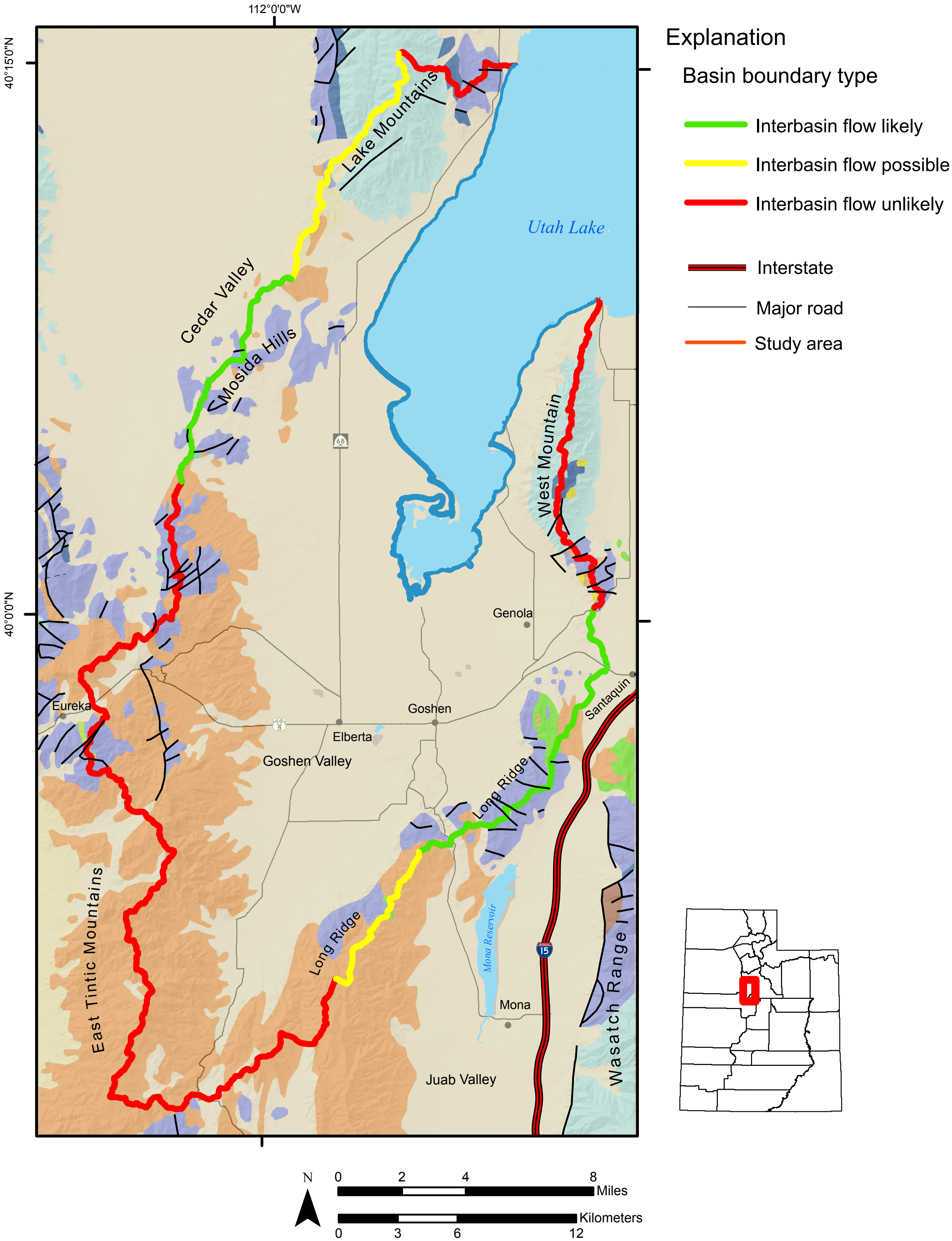


Figure 5. *Hydrogeologic boundary conditions for Goshen Valley. Hydrostratigraphic units are described on figure 2.*

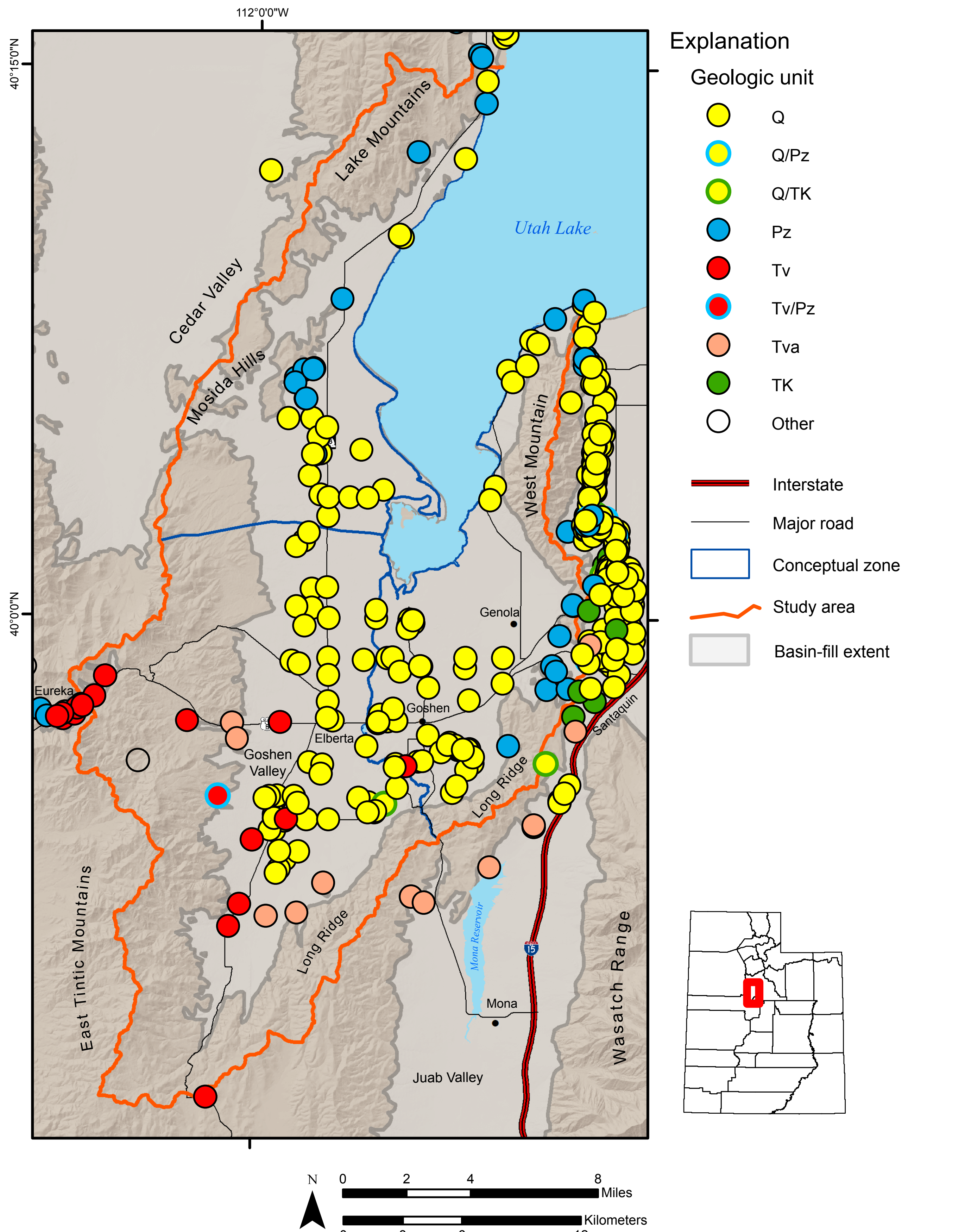


__Figure 6.__ Location and screened-interval lithology of wells in Goshen Valley. Geologic units: Q=Quaternary basin fill, Pz=Paleozoic carbonates, Tv=Tertiary volcanics, TK=Tertiary-Cretaceous conglomerates, Tva = Tertiary volcanics and alluvium.

recharge conditions of the basin-fill aquifer. Wells completed in Paleozoic carbonate units are common in conceptual zone 1 in the western part of the study area and in conceptual zone 3 near West Mountain. In the southwestern part of the study area, several wells are completed in various Tertiary volcanic units. A few wells near and south of Genola are completed in Tertiary conglomerates. In the upland part of the study area in the East Tintic Mountains near Eureka, wells are completed in either Tertiary volcanics or underlying Paleozoic carbonate units.

Aquifer Properties Based on Well Logs

The transmissive properties of aquifers may vary over several orders of magnitude and be highly spatially variable. Transmissivity represents the basic ability of an aquifer to yield water to wells and transmit groundwater, and characterizes the permeability of an aquifer. The ability of an aquifer to transmit and yield water is based on the properties of transmissivity and storativity. To better constrain aquifer properties in the Goshen Valley, all publicly available well logs were examined for specific capacity or aquifer test data. Specific capacity is a basic measure of water yield from a well or borehole. It is most commonly reported as discharge per unit drawdown (gallons per minute per foot of drawdown [gpm/ft]) which is based on three values including a pumping rate, water-level drawdown, and duration of pumping (Domenico and Schwartz, 1997). Specific capacity tests generally lack the rigor and detail of longer-duration aquifer tests but are commonly completed during drilling and are therefore available for many wells and parts of aquifers that otherwise lack estimates of aquifer properties. Because of the relative abundance of specific capacity data, previous work has focused on techniques to estimate aquifer transmissivity from specific capacity tests and well construction. For this study, we chose the simple empirical method of Driscoll (1986) to convert specific capacity to transmissivity. This method was chosen due to its simplicity, transparency, and the relatively large error that must be assumed with specific capacity data. As such, these results are best viewed as order of magnitude estimates of transmissivity for the various well locations.

Of the 406 well logs available within the study area, 148 contained usable specific capacity data from which transmissivity was calculated via the Driscoll (1986) method (appendix A). These data were then binned by aquifer type, and most wells were completed in a single geologic unit. However, some wells have open intervals that cross unit contacts and include two geologic units. For these well logs, the open interval includes both unconsolidated basin fill and underlying bedrock. Specific capacity data from these cross-completed wells was grouped with the appropriate bedrock group. Figure 7 shows the statistical distribution of well-log-derived transmissivity by aquifer type.

Recharge Type Mapping

According to the methods of Anderson and others (1994), recharge and discharge type for basin-fill aquifers can be delineated using well-log-based groundwater levels and the presence or lack of extensive fine-grained clay layers greater than 20 feet thick. Recharge-type mapping can be an important tool for land managers to control potential contamination to basin-fill aquifers and may also show the extent of potential confining layers and diffuse areas of groundwater discharge within these aquifers. Primary recharge areas are characterized by a lack of clay layers or clay layers less than 20 feet thick and a downward groundwater gradient. Secondary recharge may occur in areas having clay layers thicker than 20 feet and a downward groundwater gradient (groundwater pressure heads at or below thick clay layers). Discharge areas are mapped in areas of upward groundwater gradients (groundwater levels at or above thick clay layers) and clay layers greater than 20 feet thick (Anderson and others, 1994). Basin fill across the study area is subdivided into primary recharge, secondary recharge, and discharge zones using well log data (figure 8; appendix A).

Confining layers of clay are uncommon, and most well logs indicate unconfined and primary recharge conditions for the upper portion of the basin-fill aquifer in Goshen Valley and adjoining areas to the east (Utah Division of Water Rights, 2016) (figure 8; appendix A). Primary recharge zones are along the eastern and western peripheries of the basin-fill aquifer and nearly all of conceptual zone 1 is mapped as primary recharge. Primary recharge is mapped across approximately two-thirds of conceptual zone 2, and in the southwestern corner of conceptual zone 3. A significant discharge zone is mapped across the western part of conceptual zone 3 between Goshen, Goshen Warm Springs, and Genola. Well logs in this area show thick, near-surface clay confining layers, and upward groundwater gradients relative to the confining layers. Secondary recharge zones are mapped in an arcuate zone from the southeastern corner of conceptual zone 1 through the eastern part of conceptual zone 2 and into the southern part of conceptual zone 3. In these areas, one or more clay layers are noted with water levels below the layers. A small primary recharge zone is mapped along the southern boundary of conceptual zones 2 and 3 along Currant Creek. In this area, significant clay layers are lacking and any seepage from Currant Creek and nearby canals may directly recharge the basin-fill aquifer. The eastern part of conceptual zone 3, including Genola and the Goshen gap area, is a primary recharge area. Any unconsumed irrigation water in this area may enter the basin-fill aquifer.

Geophysical Data

Overview

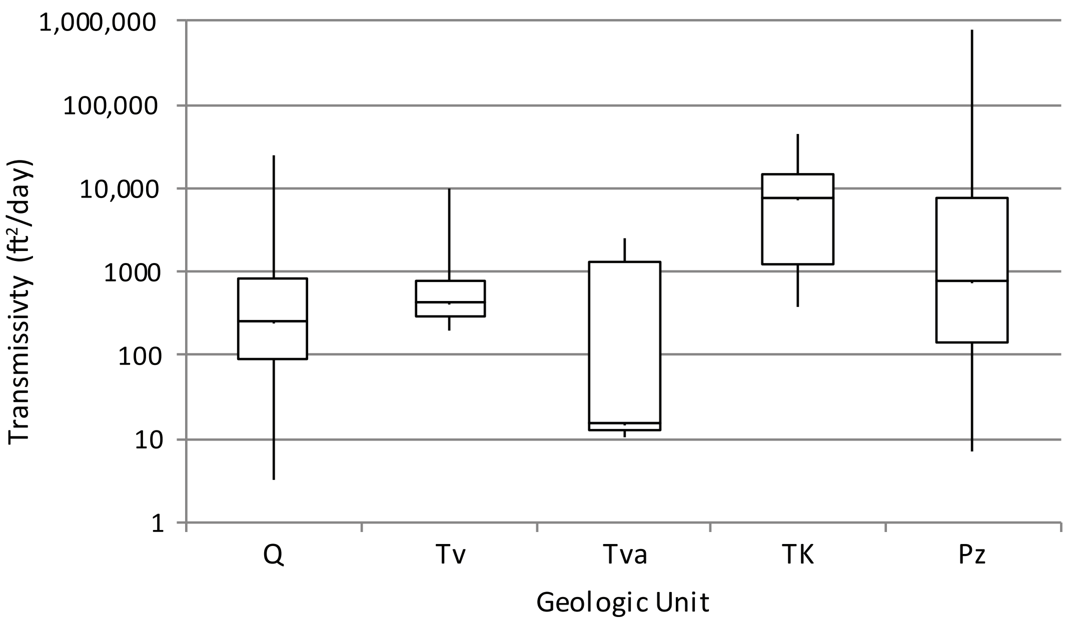
The complex basin and range geology of Goshen Valley and a relative lack of well control warrant additional examination of geophysical data sets to evaluate the extent and geometry of the basin fill in the study area. New gravity data were collected in summer 2015 and combined with existing gravity to create a gravity anomaly map for Goshen Valley.

These data were then combined with bedrock well control, estimates of rock and basin-fill density, and regional gravity signals to model the depth-to-bedrock or basin-fill thickness across the study area.

Isostatic Gravity Anomaly

To better define the subsurface basin geometry of Goshen Valley, a new isostatic gravity anomaly map of the study area was created and used to estimate depth to basement rocks across the study area. Isostatic gravity anomalies represent the local density distribution of middle and upper crustal rocks and unconsolidated deposits after accounting for elevation, terrain, deep crustal density, and regional effects (Simpson and others, 1986; Saltus and Jachens, 1995). These data are a useful tool to evaluate subsurface basin geometry and correlation with surficial geology in areas such as the eastern Great Basin.

A total of 205 unique gravity stations were established to achieve better coverage in the Goshen Valley study area. Field measurements were made using two Scintrex CG-5 gravimeters following the methods of Gettings and others (2008); we used a 10-minute time series and reoccupation of local bases only. Elevation control in the range of 30 cm to 10 cm (12 to 4 in) was achieved through post-processing of data collected by Trimble GeoXT GPS instrumentation which allows for gravity accuracy of better than 0.1 mGal. The complete Bouguer gravity anomaly was computed by



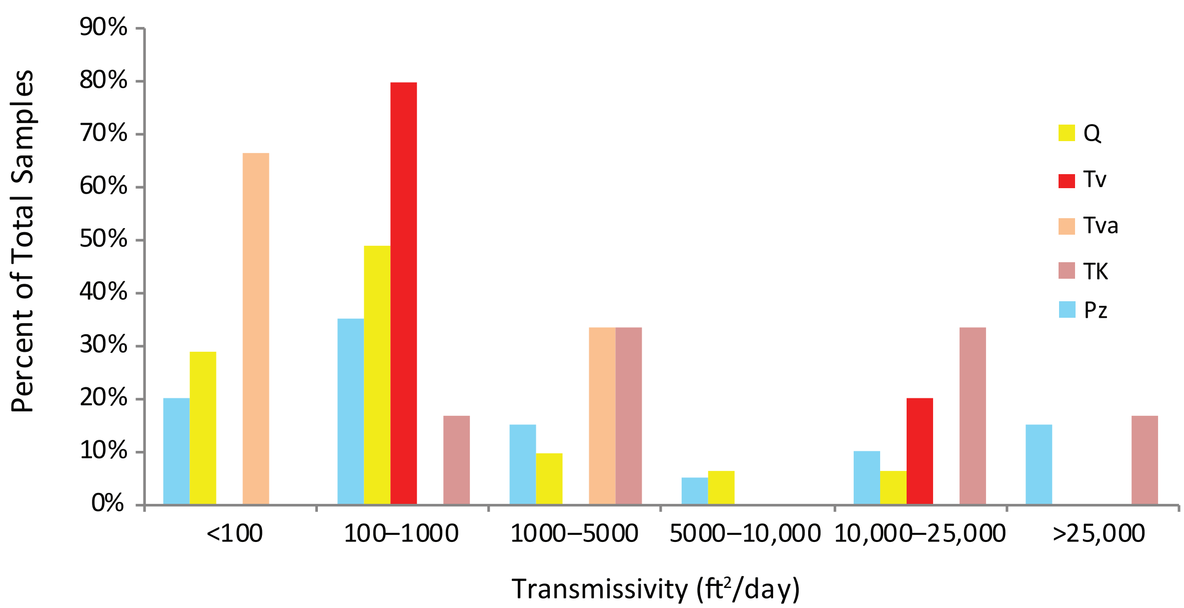


Figure 7. *Well-log specific capacity statistics binned by well-log unit.*

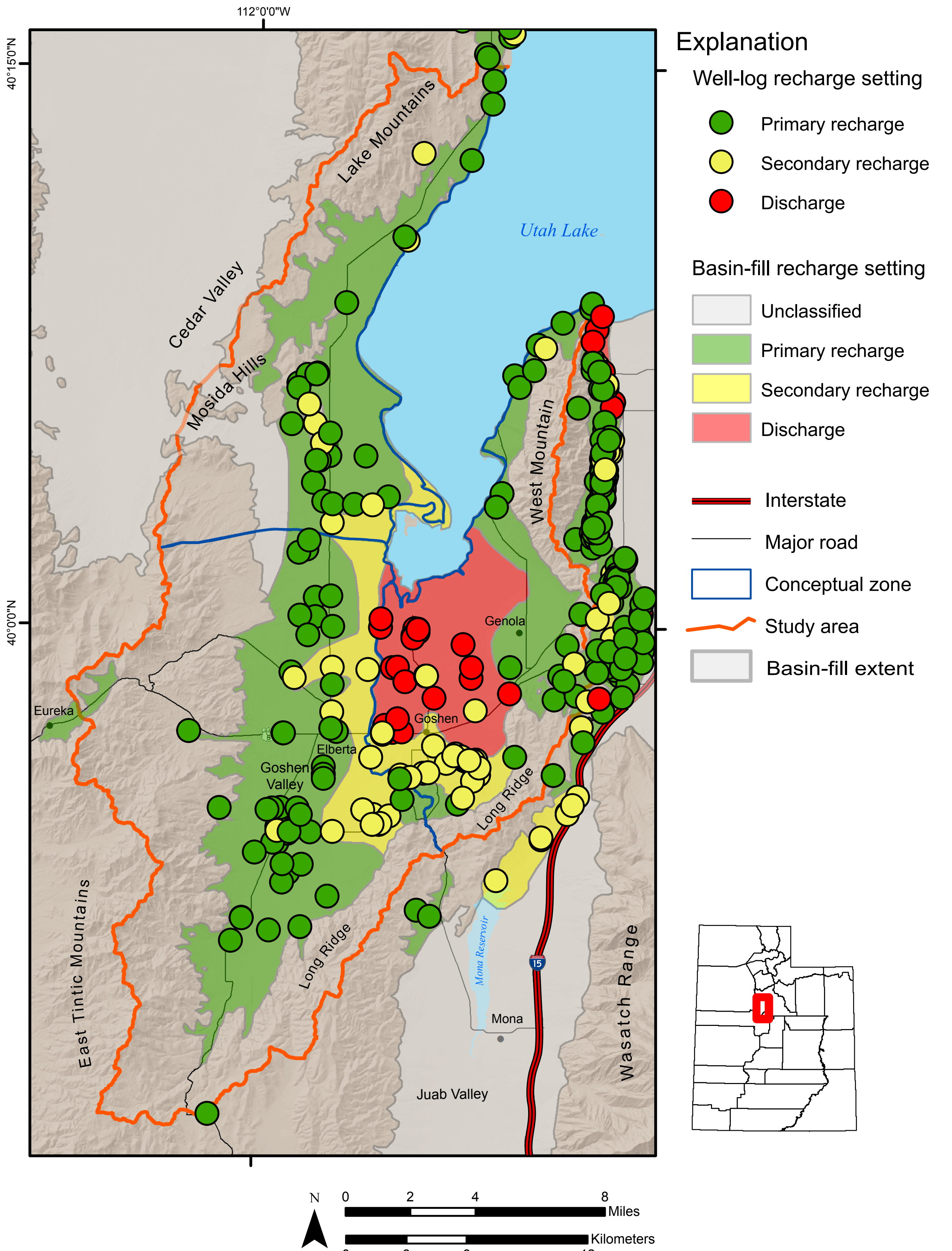


Figure 8. *Recharge-discharge area map. Most of UBFAU in Goshen Valley has primary recharge conditions.*

combining new gravity stations with the existing national dataset sourced from the Pan American Center for Earth and Environmental Studies (PACES, 2012) and using a reduction density of 2.67 g/cm^2. The regional effects on the local gravity field were removed using two-dimensional (2D) trend fitting techniques to obtain the residual gravity field. By identifying the "zero-depth" to the bedrock interface using outcrop exposures and well log data, we further refined the Goshen Valley gravity field to allow accurate inversion of basin-fill thickness. Basin-fill thickness was computed using a pseudo 2D approach (semi-constrained 1D approximations) directly tied to the zero-depth values.

The complete Bouguer gravity anomaly indicates that the dominant gravity low (mass deficiency) resides below Utah Lake to the northeast of Goshen Valley (figure 9) and the dominant gravity high (mass excess) is centered below the Lake Mountains, north of Goshen Valley. The difference in amplitude from the highest to lowest gravity anomaly is approximately 50 mGal. In the residual gravity field (figure 9), the local anomalies were further refined, and the amplitude of the gravity low associated with the Goshen Valley basin fill is -12 mGal.

Modeled Basin-Fill Thickness

The extent and geometric conditions of the basin fill and underlying bedrock place fundamental constraints on groundwater flow paths and storage. To constrain these relationships across the study area, particularly away from areas of existing well logs, a gravity inversion for basin depth was created (figure 10). The gravity inversion is based on simple assumptions of density for the basin fill and underlying bedrock, well constraints of basin-fill depth, the mapped extent of basin fill, and the gravity field previously presented. The resulting grid gives an estimate of basin-fill depth with a pixel dimension of 250 meters on each side.

Basin-fill thickness shown on figure 10 indicates that the thickest area of fill is located to the northwest of Goshen where total thickness is slightly greater than 3000 feet. Away from this area, basin-fill thickness declines to values that are generally less than 1500 feet across most of the Goshen Valley floor. Areas near Goshen Gap along the eastern margin of the study area have basin fill that is less than 750 feet deep, and most of this area has fill thickness of less than 500 feet. West of the Mosida Hills, basin-fill thickness is less than 500 feet. The eastern boundary of the area of deepest basin fill west of Goshen may represent an interbasin fault termed the Goshen fault (Mckean and others, 2015). East of this area of deep basin fill, basin fill is less than 1000 feet thick along Currant Creek and areas adjoining Long Ridge. In the southern part of Goshen Valley, basin-fill thickness gradually decreases from about 1250 feet thick along Kimball Creek to less than 200 feet thick near adjoining bedrock exposures along Long Ridge.

GROUNDWATER LEVELS

Potentiometric Surface

Groundwater movement across an interconnected aquifer system is controlled by relative head conditions that can be visualized as a potentiometric map. For this study, a series of groundwater level measurements were collected in spring 2014. These data were combined with groundwater levels measured by the U.S. Geological Survey (USGS) (2016) during the same time and measurements compiled from a variety of sources including towns and agricultural operators. The measurements include both water levels in wells and spring head elevations from the basin-fill aquifer. A smaller number of measurements represent wells completed in carbonate aquifers. These data (appendix B) were then contoured using an iterative approach that included kriging using ArcGIS and manually adjusting the resulting contours where necessary to fit both the available water-level information and topographic constraints. The resulting potentiometric surface is shown on figure 11.

For this potentiometric surface, it is assumed that groundwater is largely interconnected across the various near-surface aquifers. In upland areas of the East Tintic Mountains, groundwater elevation is taken largely from springs that issue from volcanic aquifers that are likely localized and disconnected. As such, contours in these areas are generalized. Error in the potentiometric map is driven by data density and areas along the axis of Goshen Valley where numerous measurements have an assumed error of less than 25 feet. Areas with few direct measurements, particularly areas of upland bedrock, could have error up to 100 feet or greater.

The potentiometric surface elevation in Goshen Valley ranges from less than 4500 feet near Utah Lake to over 7000 feet in the East Tintic Mountains. Most groundwater in the basin-fill aquifer has potentiometric head less than 4600 feet. Potentiometric surface elevations decrease uniformly from Cedar Valley, east and southeast into Goshen Valley. A similar uniform decrease in groundwater surface elevation is mapped from the northern end of Juab Valley, near Mona Reservoir, and the Santaquin area. Potentiometric surface elevations are largely unconstrained in the bedrock aquifers of West Mountain and the Lake Mountains. Groundwater surface elevations in Goshen Valley decrease markedly away from bedrock areas before gradually declining towards Utah Lake across much of the valley floor. In the southeastern part of Goshen Valley, a prominent convex bend in the 4525-foot elevation contour corresponds to an area of higher groundwater levels that is centered on Currant Creek. This feature represents a groundwater mound in the basin-fill aquifer. In the southwestern part of the floor of Goshen Valley, groundwater potentiometric surface is relatively flat and at least several measurements support a cone of depression in this area. Groundwater elevations depicted on the potentiometric map indicate groundwater inflow into

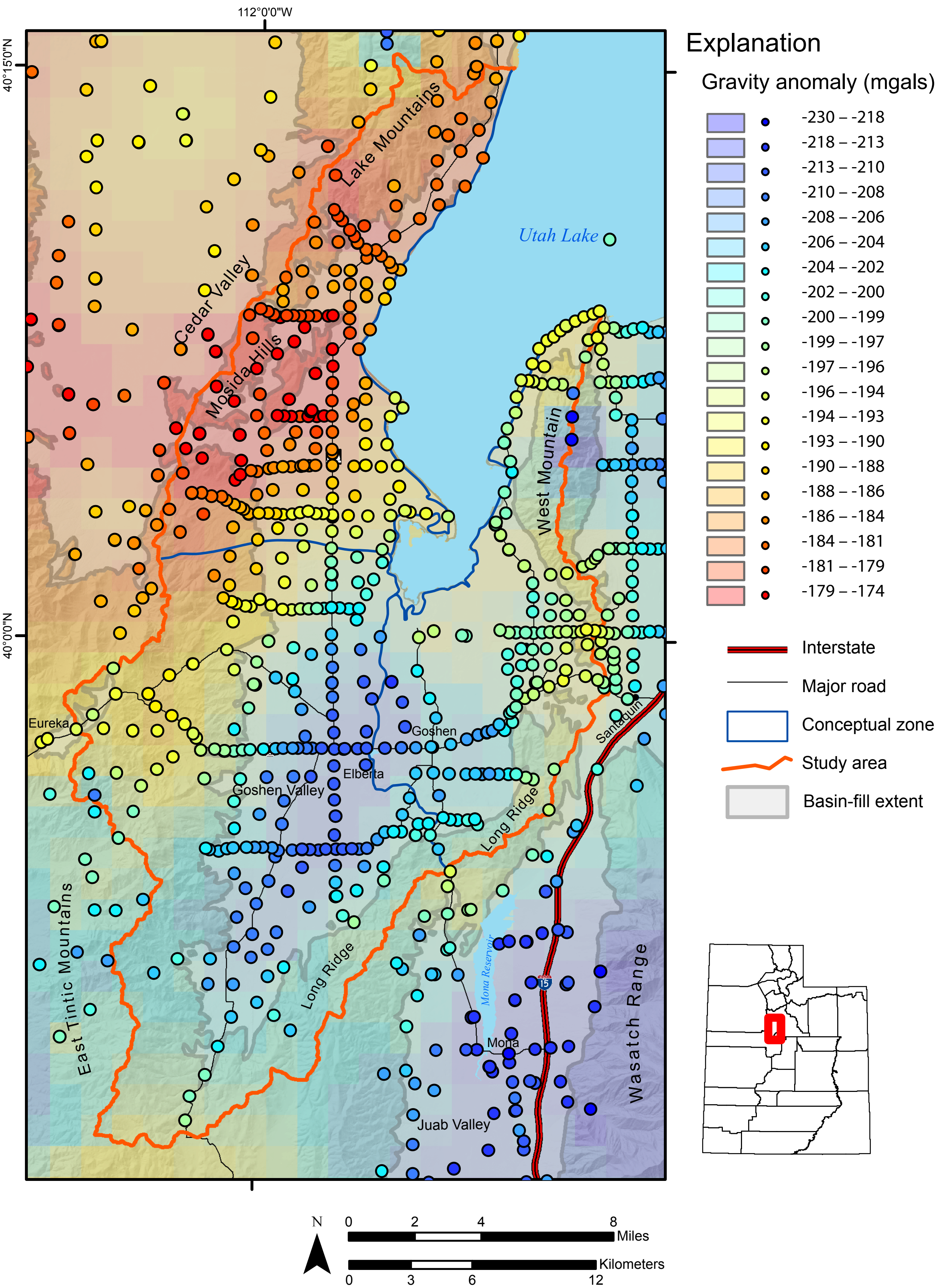


Figure 9. *Isostatic gravity anomaly for Goshen Valley based on new and compiled gravity data.*

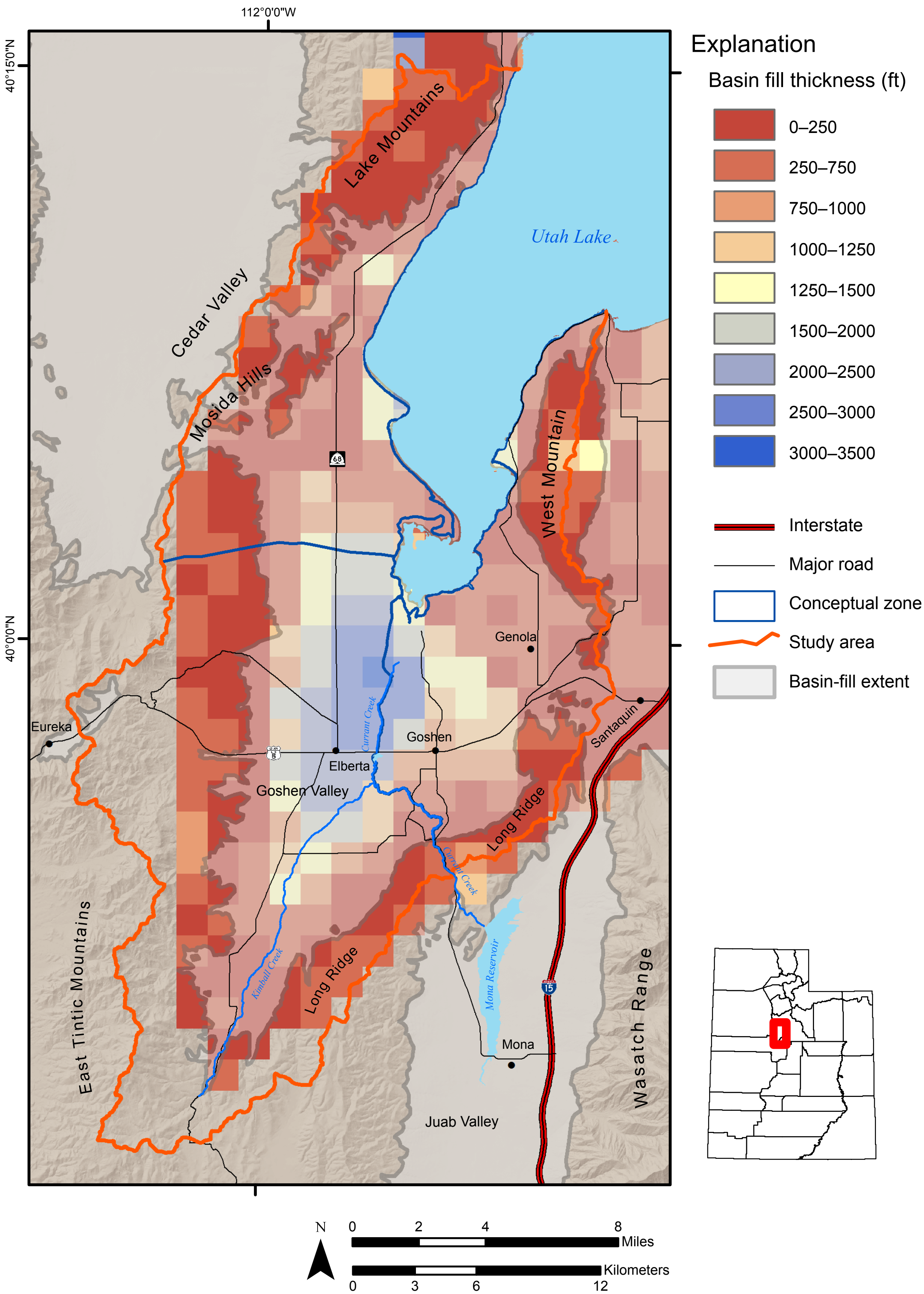


Figure 10. *Modeled basin-fill thickness for Goshen Valley.*

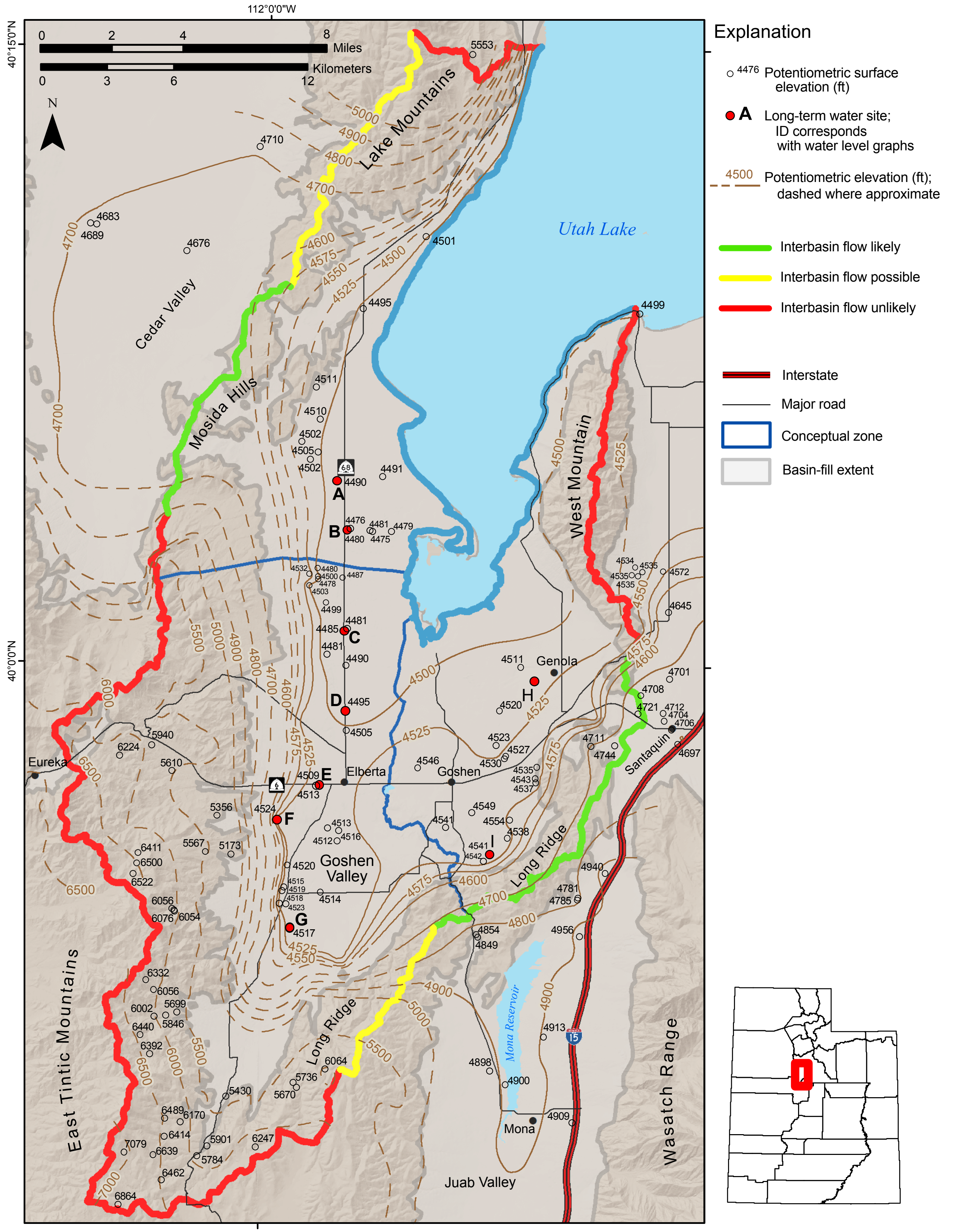


Figure 11. *Potentiometric surface elevation from mean sea level in Goshen Valley, spring 2014. Contour intervals vary from 100 feet for potentiometric elevations greater than 4600 feet to 25 feet for potentiometric elevations less than 4600 feet. Potentiometric elevation points are listed in Appendix 2. Long term water level site ID's correlate with those in figure 13.*

Goshen Valley from Cedar Valley and northern Juab Valley, as well as from the adjoining East Tintic Mountains. The potentiometric surface shows groundwater mounds in both the East Tintic Mountains and the Lake Mountains that would inhibit groundwater flow across these areas. Across the floor of Goshen Valley, groundwater flows towards Utah Lake with a subtle area of elevated groundwater centered on Currant Creek and an area of relatively low groundwater levels in the southwest, south of Elberta.

Depth to Groundwater

The depth to groundwater in an aquifer system directly affects water availability and the recharge and discharge processes. Depth to groundwater in the study area (figure 12) is the difference between grids of potentiometric surface (figure 11) and the land surface estimated using a 5-meter elevation dataset. Pixel dimension of the resulting raster is 200 meters (650 feet) on a side. This estimate of depth to water does not account for localized perched aquifers. Error in this estimate may be at least that of the potentiometric surface from which it was derived. In some areas, error may be greater than 50 feet), particularly in areas of upland bedrock of the adjoining mountain ranges.

Depth to groundwater in Goshen Valley ranges from at or just below the land surface to greater than 400 feet below the land surface. Groundwater is within 30 feet of the land surface near and north of Goshen, in areas of irrigated pastures and wetlands that extend east towards Long Ridge and Goshen Warm Springs, and to the north towards Genola. Where groundwater is within 30 feet of the land surface, discharge via evapotranspiration may occur. These areas of shallow groundwater near Utah Lake correlate with significant areas of wetland phreatophytes that are discussed in the water budget section. Shallow groundwater also occurs along the margin of Utah Lake and in the southwestern corner of Goshen Valley. Away from these areas, groundwater is encountered at depths less than 300 feet across much of Goshen Valley. Shallow groundwater depicted in the East Tintic Mountains southeast of Eureka likely represents localized perched groundwater systems. Upland areas that include West Mountain, the Lake Mountains, and Long Ridge have groundwater at depths greater than 400 feet below land surface. The depth to groundwater is greater than 200 feet in areas of potential groundwater inflow into Goshen Valley: between Santaquin and Genola, along the northern end of Long Ridge, and in the Mosida Hills.

Long-Term Water-Level Changes

Groundwater elevations depicted in the potentiometric surface (figure 11) and depth to water (figure 12) maps represent static depictions of the groundwater surface in spring 2014. Groundwater elevations fluctuate continuously through time, and to assess potential changes in the groundwater system it is necessary to examine temporal changes in groundwater potentiometric surface elevation. For this report, two complimentary techniques are presented. First, a series of wells have been measured annually for over 40 years and these data are used to show water-level change at discrete locations through time (figure 13). Second, a map of long-term potentiometric change was created based on a comparison of an earlier potentiometric surface (Montgomery, 1975) and the one created for this study (figure 14).

Discrete estimates of water-level change are provided by data collected by the USGS (2016). Long-term yearly or bi-yearly water-level measurements have been collected at nine sites across Goshen Valley (figure 11). Hydrographs of long-term water levels at these sites are delineated by conceptual zone (figure 13). Two sites in the northwestern part of Goshen Valley in conceptual zone 1 show water-level changes less than 5 feet at well A and water-level decline of approximately 25 feet at well B. Long-term monitoring sites in conceptual zone 2, in the southwestern part of Goshen Valley, all have groundwater-level decline greater than 30 feet and well F has declined 50 feet. Nearly all decline has occurred since 1990. Groundwater levels in conceptual zone 3 on the eastern side of Goshen Valley have remained steady through time with less than 5 feet of water-level change. Long-term water-level change is limited to the southwestern part of Goshen Valley, primarily in conceptual zone 2 and the southern part of conceptual zone 1. Water-level decline in these areas is the result of water being removed from storage. Water-level decline shown at these discrete points is augmented by a water-level change map (figure 14).

To examine water-level changes through time at sites away from the discrete long-term measurement sites discussed above, a water-level change map was created (figure 14). This map represents the difference between an unpublished potentiometric map completed by a groundwater consultant (Montgomery, 1975) and the potentiometric map created by this study for spring 2014 (figure 11). The extent of mapped water-level changes in Goshen Valley is limited to areas covered by the 1975 map. Water-level change in adjoining parts of northern Juab Valley is based on data taken from the National Water Information System (NWIS) database (U.S. Geological Survey, 2016), and water-level change in Cedar Valley is adapted from the NWIS database and data presented in a hydrogeologic study of Cedar Valley (Jordan and Sabbah, 2012; U.S. Geological Survey, 2016).

Potentiometric levels between 1975 and 2014 have declined across most of Goshen Valley. Potentiometric decline is greater than 20 feet across most of conceptual zone 2 and generally less than 20 feet across conceptual zone 1. Significant decline, between 30 and 50 feet, is mapped across much of the valley floor in conceptual zone 2. This area of decline includes the town of Elberta and the greatest decline of over 50 feet occurs approximately 4 miles southwest of Elberta. Two areas of between 3 and 7 feet of potentiometric surface increase exist in conceptual zone 3. Outside of Goshen Valley, groundwater levels have declined less than 10 feet in the southern part of Cedar Valley and by less than 15 feet in northern Juab Valley.

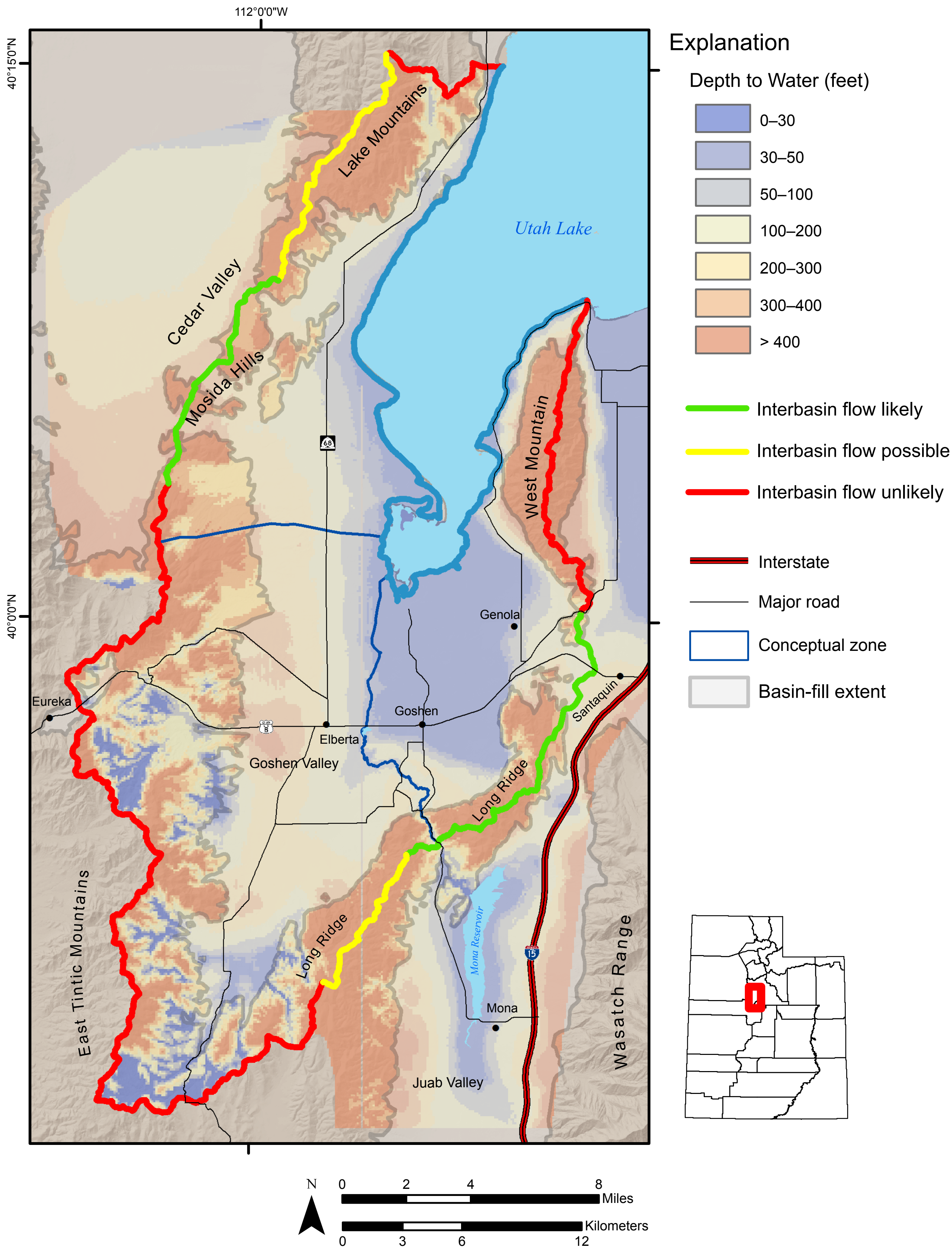


Figure 12. *Approximate depth to water in Goshen Valley, spring 2014.*

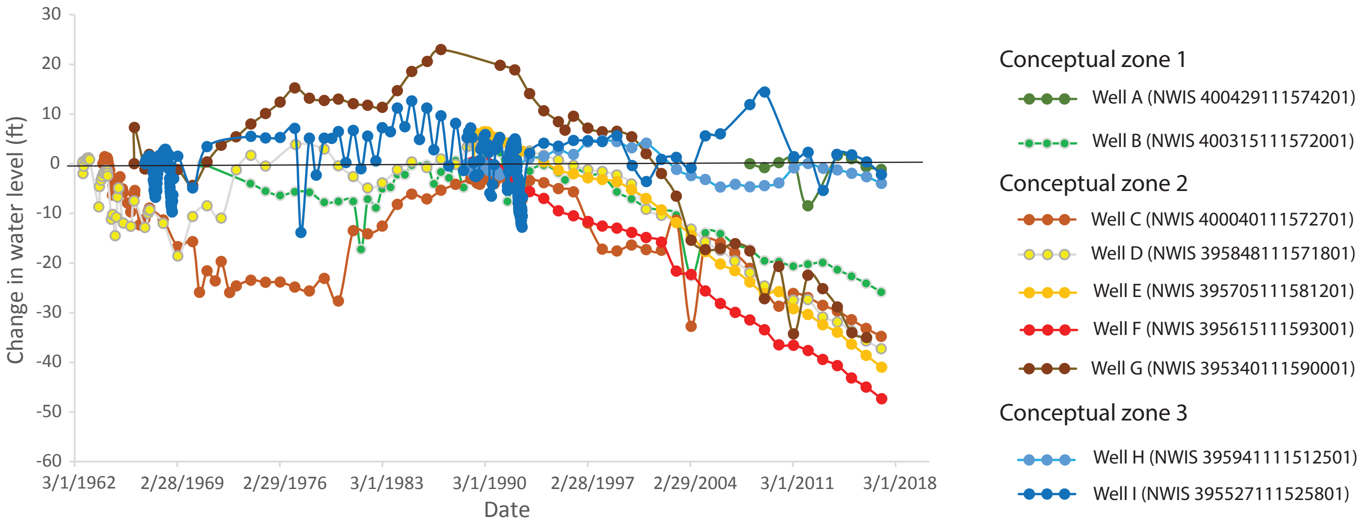


Figure 13. *Long-term water-level graph. Well locations are shown on figure 11. Water levels have declined by up to 50 feet in the southwestern part of Goshen Valley.*

Water levels at a single well in the northern part of Juab Valley have increased by several feet. A comparison of the long-term water-level change graphs and water-level change map shows correlative trends of decline. The southwestern part of Goshen Valley has experienced the most significant groundwater-level decline and the decline of water levels began in the 1990s (figure 13). Agriculture relies heavily on groundwater extracted from wells in this area.

GROUNDWATER CHEMISTRY AND ENVIRONMENTAL TRACER DATA

Introduction

Groundwater and surface water have distinct chemical and isotopic characteristics that can be used to better understand groundwater flow, its relation to surface water, and areas of groundwater recharge and discharge. For this study, new water samples were collected from 46 well, spring, and surface water locations (figure 15; table 1). Sample sites were chosen to maximize geographic coverage, hydrogeologic setting, and constrain water chemistry in both surface water and groundwater in Goshen Valley. Simple field parameters including temperature, pH, conductivity, and dissolved oxygen were collected at each sampling site (table 1).

Sample Collection and Analysis

Samples were collected for major ion and trace element chemistry including nitrate and arsenic; stable isotopes of deuterium, oxygen-18, and nitrogen-15; radiogenic isotopes of carbon-14 and tritium, and dissolved gases. Sample collection followed techniques presented by Wilde and others (1998) for major and trace element chemistry. Samples for stable and radiogenic isotopes were collected via techniques that minimized exposure to the atmosphere. Dissolved gases were collected in either copper tubes at flowing wells or equilibrated diffusion samplers at spring sites. Concentrations of major dissolved anions and cations, trace elements, nitrate, and arsenic (table 2) were determined using standard techniques presented in Fishman and Friedman (1989) and Fishman (1993) at the Brigham Young University Hydrogeochemistry Laboratory.

Samples for stable isotope analysis were filtered through a standard 4-micron filter and collected in 10 mL sealed glass vials with minimum head space. Stable isotope samples were analyzed at the Brigham Young University Hydrogeochemistry Laboratory via a cavity ring-down spectrometer, and values were normalized to VSMOW/SLAP scale (Coplen and others, 2000; Nelson, 2000). Samples for nitrogen isotopes were filtered using a 4-micron filter and collected in 500 mL HDPE bottles that were promptly frozen. Nitrogen and oxygen isotopes in nitrate ($\delta^{15}N_{NO3}$ and $\delta^{18}O_{NO3}$, respectively) were analyzed at the University of Waterloo following standard techniques presented in McIlvin and Altabet (2005) and Spoelstra and others (2014). Samples for carbon isotopes were filtered and collected in sealed HDPE one-liter bottles. All bottles were prerinsed and filled from the bottom up and sealed with a minimum headspace to limit atmospheric contamination following the techniques described by Zhu and Murphy (2002). Carbon samples were then processed to solid carbonate at Brigham Young University and then analyzed via accelerator mass spectrometry (AMS) at the University of Georgia CAIS laboratory. Samples were analyzed for ^{13}C and ^{14}C using a National Electrostatics Corporation Model 1.5SDH-1 AMS. Measurements of ^{14}C in groundwater use percent modern carbon (PMC) or the percent of ^{14}C relative to an atmospheric standard taken in the 1950s. Measurements of ^{13}C are presented as an isotopic ratio ($^{13}C/^{12}C$) and reported as delta (δ) values in units of parts per thousand (per mil, or ‰) relative to the standard Pee Dee Belemnite (PDB) reference sample

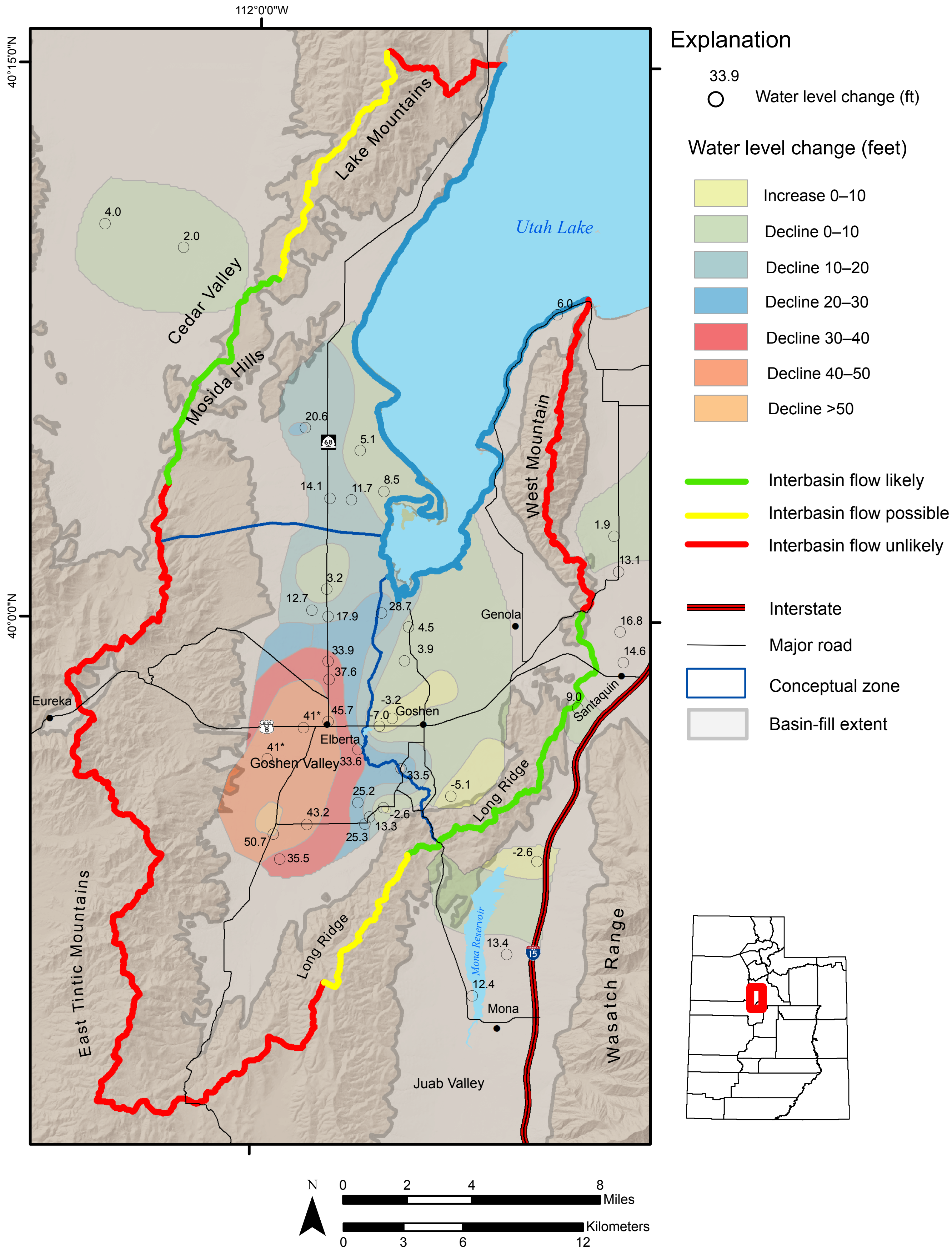


Figure 14. *Change in potentiometric surface and change in water level at wells, 1975 to 2014. Most groundwater decline has occurred in the southwestern part of Goshen Valley.*

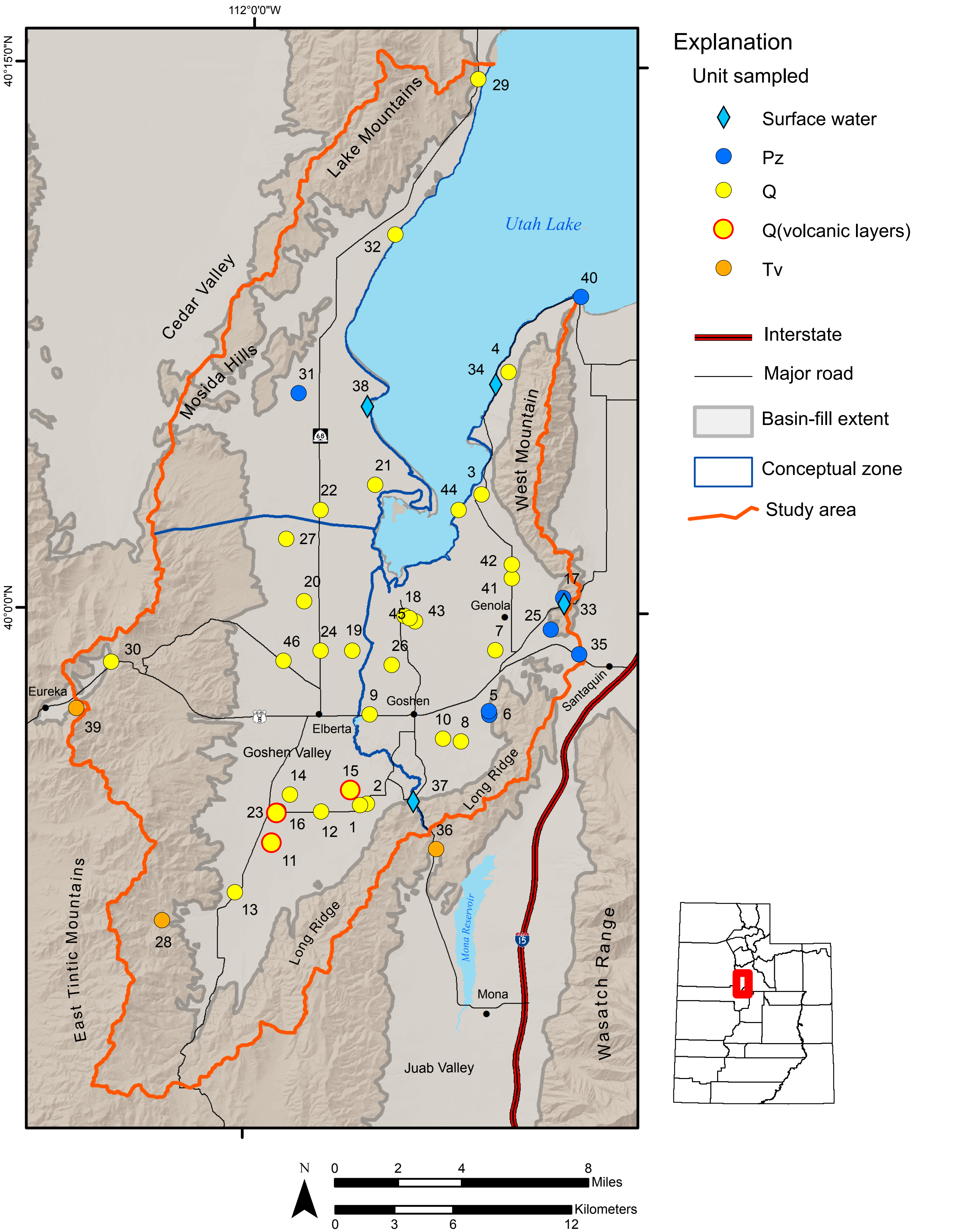


Figure 15. *Ground and surface water sampling sites in Goshen Valley. Units are described in the text; Q(volcanic layers) are logs with interbedded volcanic and unconsolidated deposits. Numbers correspond to sample IDs in tables 1, 2, 3, 4, and 5.*

Table 1. *Summary information for new water samples collected for this study.*

ID	Easting (m)	Northing (m)	Elevation (ft)	WIN	Screen/Source (ft)	Geo unit	Date	Source	pH	Temp (°C)	Cond (µS/cm)	DO (mg/L)
1	420674	4418394	4579	30342	682-1002	Q	4/23/13	UGS	7.07	14.4	2260	2.3
2	420319	4418316	4603	433337	390-395,400-420	Q	4/23/13	UGS	6.17	13.4	2970	-
3	426488	4434104	4537	8305	No screen info	Q	4/24/13	UGS	7.52	12.2	690	8.8
4	427862	4440319	4576	15637	160-180	Q	4/24/13	UGS	6.38	20	5780	5.0
5	426881	4422913	4498	NA	Spring	Pz	4/24/13	UGS	6.92	20.5	2460	3.5
6	426858	4423082	4508	NA	Spring	Pz	4/24/13	UGS	6.9	20.7	2370	3.3
7	427198	4426180	4430	8051	168-177	Q	4/25/13	UGS	7.04	13.9	3250	-
8	425456	4421547	4450	22503	80-110	Q	4/25/13	UGS	7.4	15.6	1240	0.6
9	420818	4422922	4519	13699	240-245,260-265	Q	4/25/13	UGS	7	14.6	5450	0.3
10	424546	4421694	4395	8704	100-120	Q	4/25/13	UGS	7.4	13.5	1490	-
11	415823	4416398	4689	35397	290-603	Q(volcs layers)	4/29/13	UGS	7.33	19.6	670	8.5
12	418333	4418000	4629	428702	162-195,228-246,408-411,420-428,532-695	Q	4/29/13	UGS	6.8	17.3	5640	4.8
13	413957	4413894	4870	429642	540-600	Q	4/29/13	UGS	7.4	26.7	870	-
14	416751	4418841	4702	30822	460-480,550-770	Q	4/29/13	UGS	7	18.6	1060	7.4
15	419841	4419084	4659	31080	746-760	Q(volcs layers)	4/29/13	UGS	7.25	26.4	1370	-
16	416185	4418016	4639	31639	283-296	Tv	4/29/13	UGS	7.07	15.5	3100	9.0
17	430644	4428847	4523	13634	220-365	Pz	5/20/13	UGS	7.5	16.5	790	4.4
18	422577	4427937	4513	433125	open hole 140-145	Q	5/20/13	UGS	7.2	14	2390	0.2
19	419918	4426153	4525	2616	320-580,587-650	Q	5/21/13	UGS	7.13	16.6	2320	0.6
20	417485	4428689	4714	13649	280-380,380-405,426-700	Q	5/21/13	UGS	7.47	16.5	1800	8.5
21	421089	4434605	4501	13641	190-205,225-338,365-565	Q	5/21/13	UGS	7.49	15	1600	2.4
22	418321	4433325	4627	27598	320-460,480-880	Q	5/21/13	UGS	7.58	15.6	810	6.3
23	416084	4417914	4645	35547	open hole 300-302	Q(volcs layers)	5/22/13	UGS	7.4	15.4	2800	-
24	418321	4426159	4738	13644	525-860	Q	5/23/13	UGS	7.5	19.5	2400	7.0
25	430011	4427239	4754	13633	open hole 140-300	Pz	5/23/13	UGS	7.77	17.5	790	-
26	421928	4425435	4576	13703	No screen info	Q	5/23/13	UGS	7.55	12.3	2070	-
27	416562	4431836	4775	NA	350-445,450-500	Q	5/23/13	UGS	7.66	20	680	8.1
28	410254	4412464	5785	NA	Spring	Tv	5/22/13	UGS	7.3	12.5	840	4.1
29	426333	4455215	4386	801	45-90	Q	6/3/13	UGS	6.6	28.3	2620	1.0
30	407675	4425604	6174	NA	No screen info	Q	6/3/13	UGS	7.25	15.6	660	-
31	417197	4439250	4633	33655	No screen info	Pz	6/3/13	UGS	7.14	25.8	1350	2.7
32	422112	4447321	4475	31157	100-190	Q	6/3/13	UGS	7.47	13.7	770	4.4
33	430680	4428531	4830	NA	Canal	NA	5/5/14	UGS	7.5	16	370	-
34	427214	4439698	4487	NA	Lake	NA	5/5/14	UGS	7.4	16.6	2420	-
35	431445	4425969	4890	3293	189-297	Pz/Q	5/5/14	UGS	7.4	14.4	670	-
36	424192	4416079	4850	NA	Spring	Tv	5/5/14	UGS	7.2	18.6	1460	-
37	423015	4418509	4670	NA	Creek	NA	5/12/14	UGS	7.6	14.5	1190	-
38	420686	4438590	4487	NA	Lake	NA	5/12/14	UGS	7.6	13.5	1880	-
39	405896	4423255	6686	NA	Spring	Tv	8/14/14	BYU	7.93	20.9	1118	6.6
40	431543	4444134	4367	NA	Spring	Pz/Q	8/15/14	BYU	6.59	24.6	4691	2.6
41	428023	4429838	4514	NA	Drain	Q	2/27/15	BYU	7.24	9.7	2203	9.3
42	428026	4430535	4507	NA	Drain	Q	11/19/14	BYU	6.97	10.8	3235	3.4
43	423116	4427652	4511	NA	Spring	Q	11/7/14	BYU	8.46	12.8	4081	-
44	425337	4433317	4501	NA	Spring	Q	11/7/14	BYU	7.53	12.7	1777	3.5
45	422838	4427816	4511	NA	Spring	Q	2/6/15	BYU	7.59	9	10514	10.4
46	416431	4425652	4840	432805	865-895,965-1085,1110-1230,1280-1360	Q	3/24/16	UGS	7.75	20.8	819	4.5

Table 2. *General chemistry and water-quality results.*

ID	TDS (mg/L)	Water Type	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	Cl (mg/L)	SO_4 (mg/L)	HCO_3 (mg/L)	As (µg/L)	NO_3+NO_2 (mg/L)	Ca (meq/L)	Mg (meq/L)	Na (meq/L)	K (meq/L)	Cl (meq/L)	SO_4 (meq/L)	HCO_3 (meq/L)	DIC (meq/L)	Sum cations (meq/L)	Sum anions (meq/L)	Electroneutrality
1	1364	Na-Cl	112.90	59.18	228.00	23.77	570.98	112.45	256.70	NA	0.15	5.63	4.87	9.92	0.61	16.11	2.34	4.21	4.21	21.03	22.65	-3.72%
2	1491	Na-Cl	178.80	81.82	206.30	34.53	814.47	68.18	107.20	2.1	0.05	8.92	6.73	8.97	0.88	22.97	1.42	1.76	1.76	25.51	26.15	-1.23%
3	590	Na-HCO_3	35.60	28.48	68.46	16.25	43.70	59.01	338.70	14	0.6	1.78	2.34	2.98	0.42	1.23	1.23	5.55	5.55	7.51	8.01	-3.21%
4	3800	Ca-Cl	1032.00	92.53	84.75	106.30	1325.63	772.25	386.90	4.6	5.9	51.50	7.61	3.69	2.72	37.39	16.08	6.34	6.34	65.52	59.81	4.55%
5	1486	Na-Cl	86.75	36.30	356.30	17.20	619.67	108.71	260.60	3.9	0.76	4.33	2.99	15.50	0.44	17.48	2.26	4.27	4.27	23.25	24.01	-1.60%
6	1462	Na-Cl	88.51	37.04	365.00	14.52	586.76	110.21	260.10	NA	0.81	4.42	3.05	15.88	0.37	16.55	2.29	4.26	4.26	23.71	23.11	1.29%
7	1910	Na-Cl	77.18	37.89	454.00	31.37	726.35	110.45	472.60	2.2	0.03	3.85	3.12	19.75	0.80	20.49	2.30	7.75	7.75	27.52	30.53	-5.19%
8	826	Na-HCO_3	47.15	30.93	167.20	8.17	188.71	57.83	325.80	3.5	<0.008	2.35	2.55	7.27	0.21	5.32	1.20	5.34	5.34	12.38	11.87	2.12%
9	3382	Mg-Cl	316.20	283.00	366.60	16.15	1650.76	445.98	303.50	7.9	0.04	15.78	23.29	15.95	0.41	46.56	9.29	4.97	4.97	55.43	60.82	-4.64%
10	905	Na-Cl	99.87	44.42	123.90	11.20	233.55	111.87	291.80	11	0.03	4.98	3.66	5.39	0.29	6.59	2.33	4.78	4.78	14.31	13.70	2.20%
11	501	Ca-Cl	83.08	29.04	27.91	9.80	111.36	54.27	185.10	4.2	7.89	4.15	2.39	1.21	0.25	3.14	1.13	3.03	3.03	8.00	7.30	4.55%
12	2362	Ca-Cl	412.50	121.10	196.10	23.26	922.32	542.77	143.50	8.3	256	20.58	9.97	8.53	0.59	26.02	11.30	2.35	2.35	39.67	39.67	0.01%
13	625	Ca-HCO_3	79.92	23.99	55.34	10.23	74.01	138.27	243.10	NA	0.5	3.99	1.97	2.41	0.26	2.09	2.88	3.98	3.98	8.63	8.95	-1.82%
14	532	Ca-Cl	98.17	29.02	32.02	11.51	169.16	49.22	142.70	1.6	15.4	4.90	2.39	1.39	0.29	4.77	1.02	2.34	2.34	8.97	8.13	4.91%
15	813	Na-Cl	66.96	33.01	132.60	19.95	319.78	42.31	197.90	NA	<0.009	3.34	2.72	5.77	0.51	9.02	0.88	3.24	3.24	12.34	13.14	-3.17%
16	1432	Ca-Cl	353.00	79.61	69.01	15.38	663.33	119.45	132.40	3.9	66.7	17.62	6.55	3.00	0.39	18.71	2.49	2.17	2.17	27.56	23.37	8.24%
17	631	Na-HCO_3	44.72	20.80	89.28	11.61	80.22	83.60	300.70	10.3	1.85	2.23	1.71	3.88	0.30	2.26	1.74	4.93	4.93	8.12	8.93	-4.74%
18	1435	Na-Cl	73.80	45.15	306.60	22.49	536.21	107.71	343.10	17.3	0.05	3.68	3.72	13.34	0.58	15.12	2.24	5.62	5.62	21.31	22.99	-3.79%
19	1482	Ca-Cl	175.20	102.00	142.00	11.83	615.65	192.91	242.20	5	6.84	8.74	8.39	6.18	0.30	17.37	4.02	3.97	3.97	23.62	25.35	-3.54%
20	850	Ca-Cl	123.70	47.27	78.03	10.31	340.80	100.94	149.10	6.3	20.2	6.17	3.89	3.39	0.26	9.61	2.10	2.44	2.44	13.72	14.16	-1.57%
21	970	Na-Cl	78.01	28.49	178.00	11.08	366.21	101.65	206.40	7.8	0.98	3.89	2.34	7.74	0.28	10.33	2.12	3.38	3.38	14.26	15.83	-5.20%
22	534	Na-Cl	47.91	14.76	91.20	8.14	131.55	53.80	186.40	11.8	1.01	2.39	1.21	3.97	0.21	3.71	1.12	3.05	3.05	7.78	7.89	-0.67%
23	-	-	-	-	-	-	-	-	-	-	4.96	-	-	-	-	-	-	-	-	-	-	-
24	1327	Ca-Cl	169.80	53.84	186.30	15.42	659.15	85.57	157.10	4.5	3.13	8.47	4.43	8.10	0.39	18.59	1.78	2.57	2.57	21.40	22.95	-3.49%
25	609	Na-HCO_3	54.84	24.14	69.79	7.41	73.39	70.02	309.20	5.4	1.61	2.74	1.99	3.04	0.19	2.07	1.46	5.07	5.07	7.95	8.60	-3.91%
26	1334	Na-Cl	98.23	65.45	215.30	11.65	387.64	303.44	252.30	12.3	0.05	4.90	5.39	9.37	0.30	10.93	6.32	4.13	4.13	19.95	21.39	-3.47%
27	502	Na-HCO_3	29.61	13.25	93.18	6.57	66.63	72.34	220.10	18.7	1.08	1.48	1.09	4.05	0.17	1.88	1.51	3.61	3.61	6.79	6.99	-1.48%
28	712	Ca-HCO_3	73.93	42.52	48.81	2.08	44.16	99.40	400.80	<1	0.34	3.69	3.50	2.12	0.05	1.25	2.07	6.57	6.57	9.36	9.88	-2.70%
29	1828	Na-Cl	209.10	56.13	253.30	24.41	424.73	519.35	340.60	15.4	0.39	10.43	4.62	11.02	0.62	11.98	10.81	5.58	5.58	26.70	28.37	-3.05%
30	408	Ca-Cl	75.82	13.02	23.38	9.35	116.00	22.23	157.30	3.5	0.41	3.78	1.07	1.02	0.24	3.27	0.46	2.58	2.58	6.11	6.31	-1.62%
31	903	Na-Cl	75.00	35.35	136.10	7.30	218.69	98.58	331.90	19.9	1.01	3.74	2.91	5.92	0.19	6.17	2.05	5.44	5.44	12.76	13.66	-3.41%
32	535	Ca-HCO_3	66.37	31.65	45.35	3.26	108.61	51.17	228.70	3.6	1.16	3.31	2.60	1.97	0.08	3.06	1.07	3.75	3.75	7.97	7.88	0.60%
33	224	Ca-HCO_3	56.40	12.20	4.79	1.46	4.42 J	8.46 J	214.00	<1	<0.0706	2.81	1.00	0.21	0.04	0.12	0.18	3.51	3.51	4.06	3.81	3.25%
34	1418	Na-Cl	78.50	68.40	300.00	25.90	405.00	284.00	266.00	8	<0.0746	3.92	5.63	13.05	0.66	11.42	5.91	4.36	4.36	23.26	21.70	3.47%
35	418	Ca-HCO_3	63.20	28.60	37.70	3.16	44.40	76.20	256.00	3.3	0.96	3.15	2.35	1.64	0.08	1.25	1.59	4.20	4.20	7.23	7.03	1.36%
36	902	Ca-Cl	107.00	45.70	109.00	13.10	248.00	116.00	246.00	3.2	0.99	5.34	3.76	4.74	0.34	7.00	2.42	4.03	4.03	14.18	13.44	2.66%
37	1194	Na-Cl	58.20	46.40	114.00	4.25	183.00	112.00	239.00	3.4	0.11	2.90	3.82	4.96	0.11	5.16	2.33	3.92	3.92	11.79	11.41	1.64%
38	1120	Na-Cl	60.60	64.20	215.00	18.00	281.00	224.00	256.00	10	<0.077	3.02	5.28	9.35	0.46	7.93	4.66	4.20	4.20	18.12	16.79	3.82%
39	806	Ca-SO4	138.70	30.49	41.09	11.21	49.85	262.21	272.20	7	<0.1	6.92	2.51	1.79	0.29	1.41	5.46	4.46	4.46	11.50	11.33	0.78%
40	3038	Na-Cl	201.30	62.76	668.30	75.06	1137.16	427.68	466.00	8.3	1.11	10.05	5.16	29.07	1.92	32.07	8.90	7.64	7.64	46.20	48.62	-2.55%
41	1994	Ca-SO_4	221.60	87.52	248.30	26.97	162.76	818.23	428.00	6.4	18.08	11.06	7.20	10.80	0.69	4.59	17.04	7.01	7.01	29.75	28.64	1.90%
42	3268	Na-SO_4	226.40	118.90	544.00	47.72	308.66	1599.90	422.20	12.1	2.97	11.30	9.78	23.66	1.22	8.71	33.31	6.92	6.92	45.97	48.93	-3.13%
43	2594	Na-Cl	102.80	76.60	696.70	33.98	1041.26	298.44	343.80	20.2	<0.1	5.13	6.30	30.30	0.87	29.37	6.21	5.63	5.63	42.61	41.22	1.66%
44	1270	Na-Cl	68.25	49.42	234.50	25.78	364.58	166.22	361.20	18.9	3.51	3.41	4.07	10.20	0.66	10.28	3.46	5.92	5.92	18.33	19.66	-3.51%
45	8471	Na-Cl	467.20	158.00	2090.00	187.00	4155.90	629.30	782.10	62.9	<0.1	23.31	13.00	90.91	4.78	117.22	13.10	12.82	12.82	132.01	143.14	-4.05%
46	540	Ca-HCO_3	68.48	17.99	62.19	12.00	125.50	52.46	205.00	2.2	1.49	3.42	1.48	2.71	0.31	3.54	1.09	3.36	3.36	7.91	7.99	-0.50%

standard using methods described by Coplen (1996). Unfiltered samples for tritium were collected in 500- or 1000- mL amber glass bottles. Tritium was analyzed either at Brigham Young University using a scintillation counting method or at the University of Utah Dissolved Gas Lab using a tritium helium ingrowth method (Solomon, 2000; Solomon and Cook, 2000). Dissolved gas samples were collected from pumping wells using sealed copper tubes, and springs were sampled with equilibrated diffusion samplers (Kipfer and others, 2002; Gardner and Solomon, 2009). These samples were analyzed at the University of Utah Dissolved Gas Lab following standard methods (Solomon and Cook, 2000). Nitrogen isotopic data are presented in table 3, the remaining isotopes are presented in table 4, and dissolved gas data are presented in table 5. The geochemical data discussion below is limited to summary data of the most relevant features and those that may best aid in understanding the basin-fill groundwater system.

Groundwater Chemistry

Major ion composition of groundwater records both the water-rock equilibration and processes such as mixing and other chemical reactions that may occur during groundwater recharge and discharge. The most abundant and diagnostic dissolved ions in groundwater and surface water are calcium, magnesium, sodium, potassium, bicarbonate, sulfate, and chloride. In most natural waters, these constituents comprise most of the dissolved chemical load, and their relative proportions to one another is the basis for a simple classification of water chemistry. Major ion water types for the samples collected in this study are shown on figure 16. Groundwater chemistry ranges from calcium- or sodium-bicarbonate type, typical of upland parts of the study area, to sodium-chloride type more commonly associated with low-elevation thermal waters and areas of discharge.

Table 3. *Nitrogen and oxygen isotope results.*

ID	Nitrate (mg/L)	δ^{15}N‰	δ^{18}Onitrate‰
4	5.9	5.50	0.77
11	7.89	5.20	0.74
12	256	5.31	0.60
14	15.4	5.24	3.47
16	66.7	6.32	3.39
17	1.85	4.78	4.29
19	6.84	7.82	3.39
20	20.2	5.14	-0.15
21	0.98	8.54	-2.86
22	1.01	4.92	-4.53
23	4.96	5.25	-2.66
24	3.13	5.91	-3.44
25	1.61	6.25	-3.75
27	1.08	5.1	-6.1
31	1.01	6.58	-1.61
32	1.16	5.34	-4.64

Most groundwater and surface water samples in the study area are sodium-chloride type. Sodium-chloride water types are found in groundwater samples from both the basin-fill and carbonate aquifer systems. The source of sodium and chloride in the groundwater samples is likely tied to extended periods of water-rock interaction produced by low recharge rates, long flow paths, and potentially evaporative concentration (Scanlon and others, 2006; Kirby, 2012). A significant number of samples collected across the floor of Goshen Valley are calcium-chloride water type. This water type is found primarily in and near agricultural areas in conceptual zone 2 and a single sample in conceptual zone 3. This water type is likely derived from infiltration of unconsumed irrigation and agricultural effluent and is correlated with samples having high nitrate (Selck and others, 2018).

Samples collected from the study area represent a continuum of major-ion chemistry that varies from calcium-bicarbonate to sodium-chloride type waters (figure 17). There is significant overlap of major ion chemistry across the plot and localized trends are poorly resolved, likely due to the spatial distribution of the samples and heterogenous aquifer matrix. Samples from the eastern part of the study area in conceptual zone 3 have higher sulfate than other samples and tend to contain greater proportions of sodium than other areas. Samples from the southern part of the valley southwest of Goshen contain relatively high fractions of calcium and chloride compared to other areas. Samples from the northwestern part of the study area tend to contain greater fractions of calcium and bicarbonate. There is overlap in chemistry between samples from Currant Creek, the Highline Canal, and adjoining groundwater samples implying at least localized recharge of the groundwater from surface water.

Total dissolved solids (TDS) is a measure of the mass of dissolved chemical constituents in a fluid. TDS concentrations for the samples collected in Goshen Valley range from 224 mg/L for water in the Strawberry Highline Canal to over 8000 mg/L for groundwater sampled from the Triple Middle spring (site ID 45 on figure 16 and in table 2) north of Goshen. Most groundwater has TDS concentrations less than 2000 mg/L and surface waters all have TDS less than 1500 mg/L. Figure 18 shows the highest TDS along the low-elevation parts of conceptual zone 3. Several samples near West Mountain also have TDS greater than 2000 mg/L. Away from this area, TDS generally decreases toward upland areas and the margin of the Goshen Valley study area. A localized zone of high TDS occurs in conceptual zone 2, southwest of Currant Creek where a TDS concentration greater than 2400 mg/L was measured for sample 12 (table 2). The lowest concentration of groundwater TDS occurs between Genola and Santaquin along the margin of conceptual zone 3 and in the southwestern part of conceptual zone 2, including the adjoining upland areas. A simple bar graph of TDS for samples shows that most

Table 4. *Isotopic data for samples in Goshen Valley.*

ID	δD‰	δD error	δ^{18}O‰	δ^{18}O error	δ^{13}C‰	pmc [1]	pmc error	Tritium (TU)	Tritium error	Tritium source	Tritium age [2]	Tritium error	Uncorrected [3]	Ave modern (65 pmc) [4]	Simple ^{13}C [5]	Clark and Fritz ^{13}C [6]	P-H [7]	F-G [8]	Average age [9]	Qual age [10]
1	-122.1	1	-15.82	0.4	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
2	-122.5	1	-15.88	0.4	-2.64	8.78	0.05	0.06	0.02	UofU	>60	--	20,100	16,500	2400	6600	14,400		10,000	Old
3	-112.9	1	-14.6	0.4	-8.73	55.13	0.16	4.7	0.3	BYU	--	--	--	--	--	--	--	--	--	Modern
4	-99.6	1	-12.01	0.4	-0.85	11.75	0.06	3.15	0.11	UofU	--	--	17,700	14,100			12,000		13,100	Mix
5	-121.8	1	-16.07	0.4	-6.37	25.12	0.09	1.59	0.05	UofU	--	--	11,400	7900	1000	5200	5700		4900	Mix
6	-120.8	1	-16.02	0.4	-6.34	25.27	0.1	1.39	0.07	UofU	--	--	11,400	7800	900	5100	5600		4900	Mix
7	-124.7	1	-16.2	0.4	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
8	-119.2	1	-16.1	0.4	-11.86	34.21	0.12	0.04	0.01	UofU	--	--	8900	5300	3600	7800	3100	900	4100	Old
9	-118.6	1	-15.69	0.4	-12.56	64.41	0.19	1.14	0.09	UofU	24.2	3.20	--	--	--	--	--	--	--	Modern
10	-121.1	1	-15.88	0.4	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
11	-117.7	1	-15.28	0.4	-11.25	49.96	0.16	0.32	0.02	UofU	10.4	3.79	5700	2200		4200			1600	Premodern
12	-113.6	1	-14.3	0.4	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
13	-120.4	1	-15.37	0.4	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
14	-117.7	1	-15.25	0.4	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
15	-132.6	1	-16.91	0.4	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
16	-113.9	1	-14.47	0.4	-10.53	33.11	0.14	0.06	0.05	UofU	>60	--	9100	5600	2900	7100	3400		4700	Old
17	-123.4	1	-15.65	0.4	-6.99	34.74	0.12	2.03	0.08	UofU	--	--	8700	5200		3300	3000		3800	Mix
18	-126.1	1	-16.12	0.4	-8.58	30.98	0.11	0.07	0.02	UofU	>60	--	9700	6100	1700	5900	4000	100	3600	Old
19	-121.6	1	-16	0.4	-13.17	27.37	0.1	0.15	0.02	UofU	>60	--	10,700	7200	6300	10,500	5000		7200	Old
20	-114.5	1	-15.37	0.4	-10.18	36.88	0.13	0.12	0.01	UofU	>60	--	8200	4700	1700	5900	2500	800	3100	Old
21	-122.2	1	-15.87	0.4	-9.85	11.22	0.06	0.05	0.06	UofU	>60	--	18,100	14,500	11,300	15,500	12,400	8900	12,500	Old
22	-124.6	1	-16.03	0.4	-9.63	15.38	0.07	0.06	0.08	UofU	>60	--	15,500	11,900	8500	12,700	9700	6000	9800	Old
24	-119.7	1	-15.49	0.4	-11.46	26.21	0.1	0.2	0.09	UofU	56.2	3.56	11,100	7500		9700	5300		7500	Old
25	-120.3	1	-15.87	0.4	-7.58	42.44	0.14	2.86	0.11	UofU	--	--	7100	3500		2300	1400		2400	Mix
26	-120	1	-16.31	0.4	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
27	-133.9	1	-17.15	0.4	-9.96	7.88	0.05	0.04	0.01	UofU	>60		21,000	17,400	14,300	18,500	15,300		16,400	Old
28	-114.6	1	-14.99	0.4	-10.27	76.24	0.22	4.61	0.15	UofU	2.5	0.36	--	--	--	--	--	--	--	Modern
29	-122	1	-16.59	0.4	-3.49	4.84	0.04	0.17	0.02	UofU	>60		25,000	21,500	9600	13,900	19,300	11,500	15,200	Old
30	-122.4	1	-15.99	0.4	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
31	-120.9	1	-16.59	0.4	-5.04	8.04	0.05	0.07	0.02	UofU	>60	--	20,800	17,300	8500	12,700	15,100	7600	12,200	Old
32	-122.4	1	-16.52	0.4	-8.16	15.86	0.07	0.14	0.02	UofU	>60	--	15,200	11,700	6800	11,100	9500	1100	8000	Old
33	-109.6	3.3	-15.47	0.08	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
34	-65.43	3.3	-6.37	0.08	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
35	-111.29	3.3	-15.1	0.08	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
36	-110.29	3.3	-14.72	0.08	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
37	-98.23	3.3	-12.56	0.08	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
38	-57.48	3.3	-5.97	0.08	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
39	-85.2	1	-10.69	0.4	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
40	-119.1	1	-15.81	0.4	--	--	--	0.8	0.3	BYU	--	--	--	--	--	--	--	--	--	--
41	-114.3	1	-15.07	0.2	--	--	--	4.5	0.3	BYU	--	--	--	--	--	--	--	--	--	--
42	-116.3	1	-14.84	0.2	--	--	--	5.2	0.3	BYU	--	--	--	--	--	--	--	--	--	--
43	-110.3	1	-14.19	0.4	--	--	--	7.8	0.3	BYU	--	--	--	--	--	--	--	--	--	--
44	-109.6	1	-14.76	0.4	--	--	--	2.6	0.3	BYU	--	--	--	--	--	--	--	--	--	--
45	-113.5	1	-13.5	0.2	--	--	--	2.6	0.3	BYU	--	--	--	--	--	--	--	--	--	--
46	-118.8	1	-14.31	0.2	-11.2	20.85	0.09	0.6	0.3	BYU	--	--	13,000	9400	7200	11,400	7200	--	8800	Old

[1] Percent modern carbon see Clark and Fritz (1997) for complete description.
[2] Modeled age of recharge based on dissolved gas data. Only calculated for sites with tritium greater 0.5 and complete dissolved gas data.
[3] Apparent age pmc corrections; Uncor = age calculated using initial pmc = 100 and standard decay equation, see text for details.
[4] Ave modern = age calculated using initial pmc of 65 and standard decay equation, see text for details.
[5] Simple ^{13}C correction model presented by Clark and Fritz (1997).
[6] Clark and Fritz ^{13}C age calculated using correction of Clark and Fritz (1997), see text for details.
[7] P-H = age calculated using correction of Pearson and Hanshaw (1970), see text for details.
[8] F-G = age calculated using the correction of Fontes and Garnier (1979), see text for details.
[9] Average apparent age of the old fraction for samples with < 50 pmc. Average apparent age calculated as the mean of the previous age corrections.
[10] Qualitative age based on tritium and pmc; modern = tritium > 0.5 and pmc >50, premodern = tritium < 0.5 and pmc > 50, mix = tritium > 0.5 and pmc < 50, old = tritium < 0.5 and pmc < 50.

Table 5. *Dissolved gas data and recharge temperatures.* .

ID	Temp (°C)	Total dissolved gas pressure (mmHg) [1]	Ar total (ccSTP/g)	Ne total (ccSTP/g)	Kr total (ccSTP/g)	Ar/Xe	Xe total (ccSTP/g)	He^4 (ccSTP/g)	R/Ra [2]	Rterr - assumed	Average recharge temperature (C)	Average recharge elevation (m)	Sample salinity(‰)	Ae (ccSTP/g) [3]	F [4]	X(chisquare) [5]
2	13.4	693	3.18E-04	1.98E-07	2.85E-08	45827.79905	6.93E-09	5.96E-06	0.21	2.01E-07	20.2	2519	0.742	0.0123	0.3156	0.516
4	20	556	3.06E-04	2.95E-07	5.81E-08	37696.00001	8.12E-09	1.02E-05	0.12	2.01E-07	21.1	1736	3.8	0.0041	0.245	0.56745
5	20.5	652	3.00E-04	1.74E-07	7.12E-08	29713.89451	1.01E-08	6.94E-06	0.16	2.01E-07	9.4	2503	1.485	0.0015	0.0737	0.32228
6	20.7	660	3.22E-04	1.82E-07	7.63E-08	29334.35677	1.10E-08	7.22E-06	0.17	2.01E-07	7.1	2505	1.462	0.0031	0.4228	0.05549
9	14.6	668	3.62E-04	2.26E-07	7.26E-08	34190.64504	1.06E-08	5.42E-08	1.09	2.01E-07	10.3	2506	3.382	0.0315	0.5619	0.000000375
11	19.6	665	2.91E-04	1.89E-07	5.19E-08	35463.90238	8.20E-09	5.38E-08	0.89	2.01E-07	19.1	1967	0.5	0.0247	0.6975	0.000000433
16	15.5	829	3.81E-04	2.69E-07	6.80E-08	36917.40109	1.03E-08	6.78E-08	0.92	2.01E-07	13.6	1959	1.432	0.0262	0.43	0.00000261
17	16.5	674	3.25E-04	1.88E-07	6.01E-08	36332.81263	8.94E-09	1.40E-06	0.12	2.01E-07	16.2	2507	0.63	0.1	0.716	0.96
18	14	657	3.52E-04	2.19E-07	8.01E-08	29897.97178	1.18E-08	1.61E-05	0.19	2.01E-07	2.4	2505	1.435	0.0094	0.349	0.002811
19	16.6	688	3.71E-04	2.29E-07	6.20E-08	36002.8969	1.03E-08	6.47E-07	0.26	2.01E-07	15.9	1942	1.481	0.085	0.6246	0.00000246
20	16.5	701	2.87E-04	1.96E-07	6.18E-08	33861.5832	8.46E-09	2.43E-07	0.34	2.01E-07	16.9	1971	0.85	0.0038	0.2372	0.0000165
21	15	612	3.19E-04	1.93E-07	6.50E-08	33378.42984	9.56E-09	1.05E-06	0.22	2.01E-07	12.1	2304	0.969	0.0267	0.68289	18.0989
22	15.6	649	2.76E-04	1.77E-07	4.80E-08	35108.27506	7.87E-09	9.98E-07	0.25	2.01E-07	18.8	2323	0.533	0.0254	0.727205	1.88E-06
24	19.5	690	2.91E-04	1.94E-07	5.80E-08	35070.20317	8.30E-09	3.99E-07	0.27	2.01E-07	18.2	1974	1.327	0.0139	0.615	0.000000946
25	17.5	-	3.41E-04	2.05E-07	7.16E-08	34750.61114	9.80E-09	1.50E-06	0.14	2.01E-07	11.0	2542	0.608	0.0369	0.63389	22.6
27	20	726	3.31E-04	2.00E-07	5.84E-08	36098.01246	9.18E-09	3.35E-07	0.28	2.01E-07	14.6	1980	0.501	0.0418	0.6935	18.4
28	12.5	598	3.52E-04	2.01E-07	8.43E-08	27803.23389	1.27E-08	4.84E-08	1.00	2.01E-07	5.4	2134	0.711	0.002	0.0104	0.654
29	28.3	662	2.47E-04	1.51E-07	5.21E-08	27760.47118	8.92E-09	1.11E-05	0.15	2.01E-07	15.8	2287	1.827	0.0004	0.2285	0.00251
31	25.8	632	2.60E-04	1.61E-07	4.58E-08	32893.56704	7.90E-09	2.08E-06	0.25	2.01E-07	17.2	2324	0.902	0.0052	0.70062	0.00000269
32	13.7	630	3.25E-04	1.85E-07	6.31E-08	32713.05079	9.93E-09	6.61E-08	0.65	2.01E-07	13.3	2300	0.535	0.1	0.78034	0.0000294
46	20.8	-	3.29E-04	2.31E-07	7.28E-08	3.26E+04	1.01E-08	9.95E-07	0.23	2.01E-07	10.44	2356	0.473	0.0052	0.097504759	0.0001

[1] Total dissolved gas pressure measured at position of sampling.
[2] Ratio of He^3/He^4 (R) to atmospheric He^3/He^4 (Ra) following Aeschbach-Hertig and others (1999).
[3] Excess air concentration parameter following method of Aeschbach-Hertig and others (2000).
[4] Excess air fractionation parameter following method of Aeschbach-Hertig and others (2000).
[5] Chi-squared misfit between measured and modeled recharge parameters.

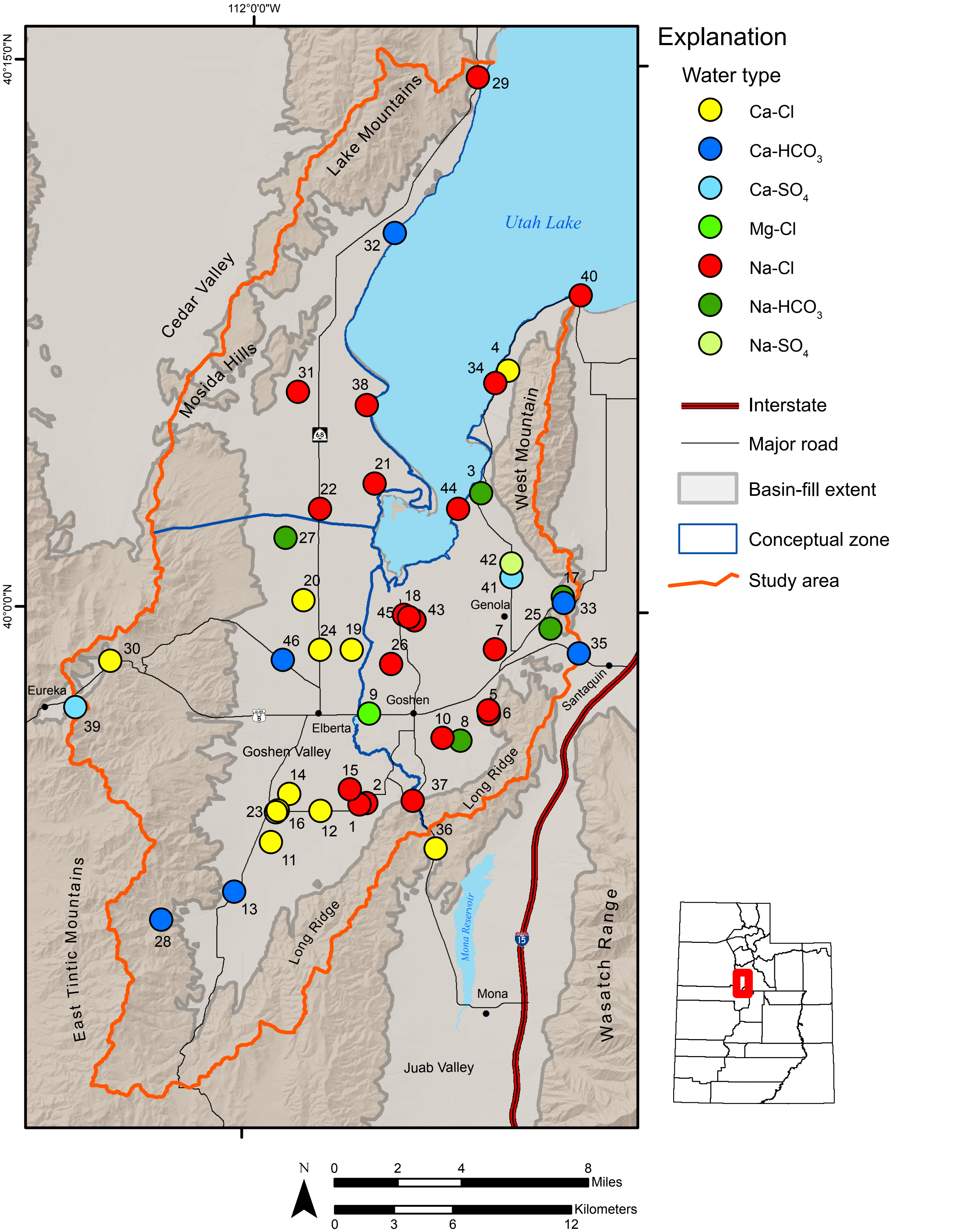


Figure 16. *Major ion chemistry in Goshen Valley. Numbers correspond to sample IDs in table 2. Most groundwater in Goshen Valley is sodium-chloride type.*

groundwater has TDS concentration ranging from 1000 to 1500 mg/L (figure 19). A significant but smaller fraction of the samples has TDS concentration between 1500 and 2000 mg/L. Several sites have TDS concentration greater than 2000 mg/L or less than 500 mg/L.

In addition to TDS, arsenic and nitrate are common constituents of concern for drinking water in the alluvial basins of western Utah. Samples for these constituents were collected at most sites. Arsenic values across Goshen Valley range from less than 1 µg/L to 62.9 µg/L (figure 20). Nearly one-third of all samples had arsenic concentrations greater than the Utah Division of Drinking Water Quality maximum contaminant level (MCL) threshold of 10 µg/L. Most of these high-arsenic samples are located across the central and eastern part of the study area with several other high-arsenic samples sporadically distributed across the central and northwestern part of Goshen Valley. High arsenic values are found in samples collected primarily from basin fill, although a few noteworthy samples with high concentrations were detected in wells completed in the LCAU. Based on companion work completed by Selck and others (2018), localized high arsenic is assumed to be the result of complex water-rock interactions with alluvial and/or carbonate rocks driven at least in part by changes in redox conditions and aquifer material.

Most samples have nitrate concentrations less than 2.5 mg/L (figure 21). These lower values are shown across much of the eastern and northwestern part of the study area. Significant concentrations of nitrate occur primarily in the southern part of Goshen Valley, south and west of the town of Goshen. Six samples from this area have nitrate concentrations greater than 10 mg/L and the highest value exceeds 250 mg/L. This zone of high nitrate corresponds to an area of livestock feed lots and land application of dairy-farm waste. We, along with Selck and others (2018), propose that the high-nitrate zone results from infiltration of nearby irrigation water or leaching from these operations. Further discussion and interpretation of nitrate in groundwater of Goshen Valley is presented below.

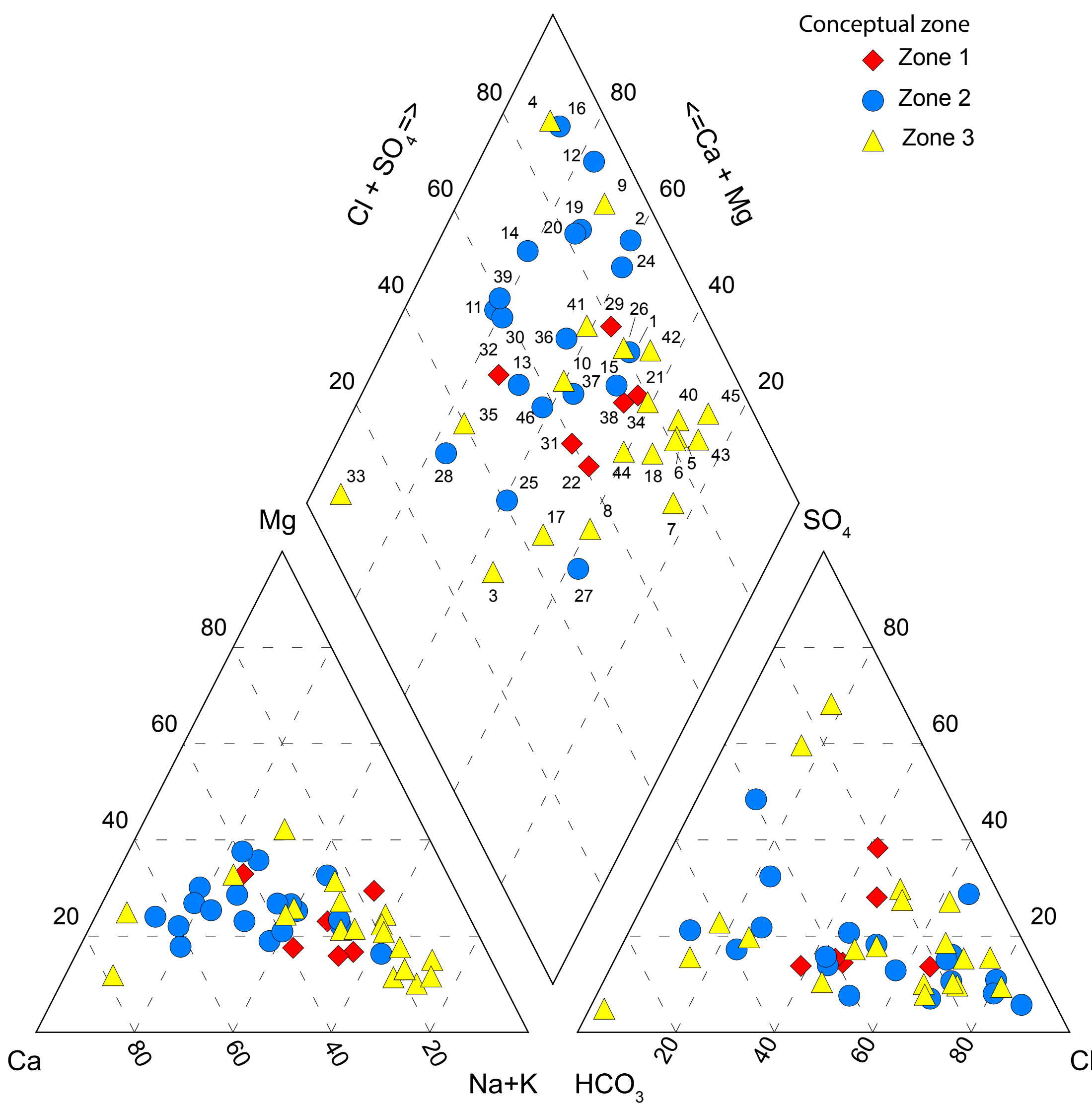


Figure 17. *Piper plot of ground and surface water chemistry in Goshen Valley. Numbers correspond to sample IDs in table 2.*

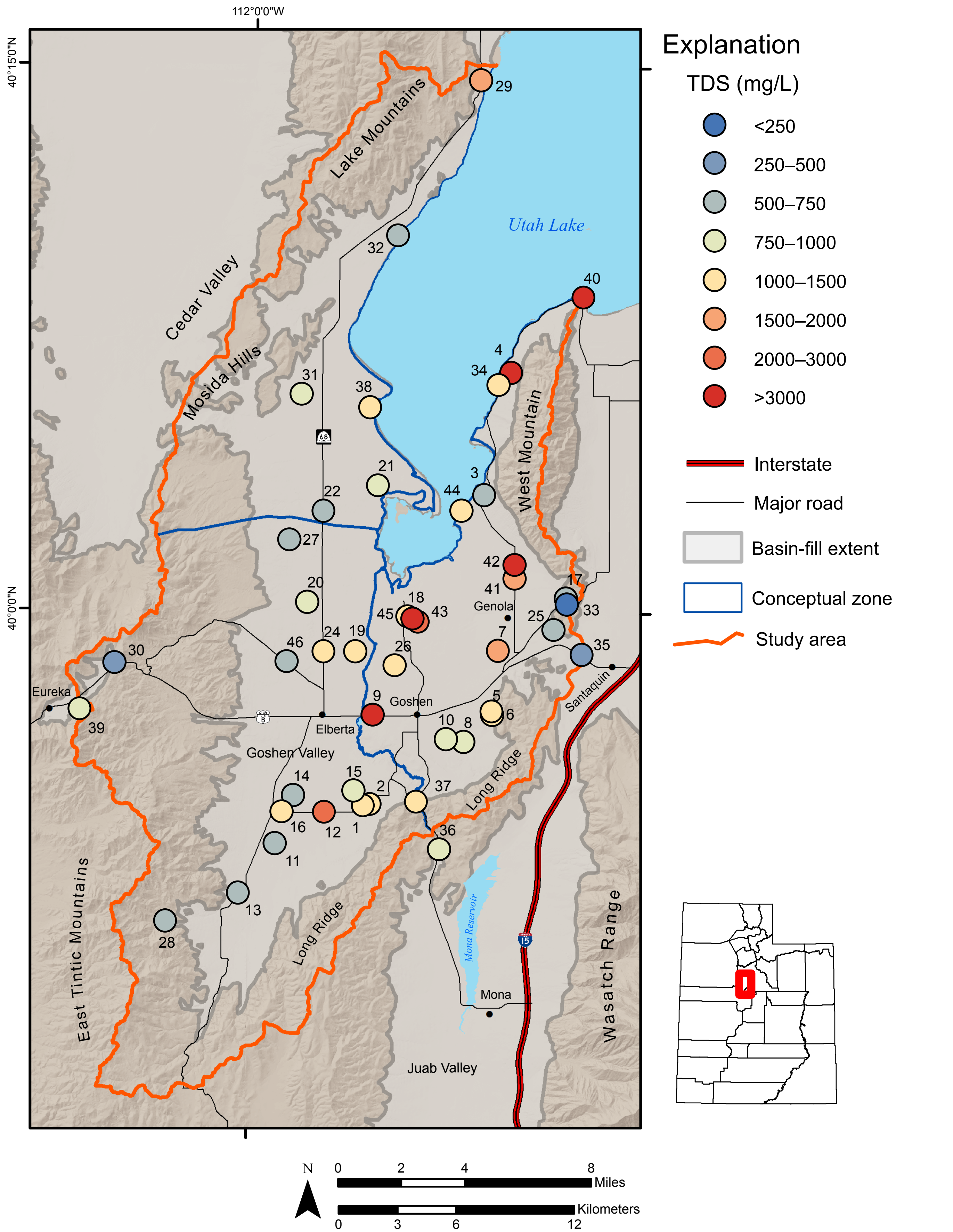


Figure 18. Total dissolved solids concentrations for wells and springs in Goshen Valley. Numbers correspond to sample IDs in table 2.

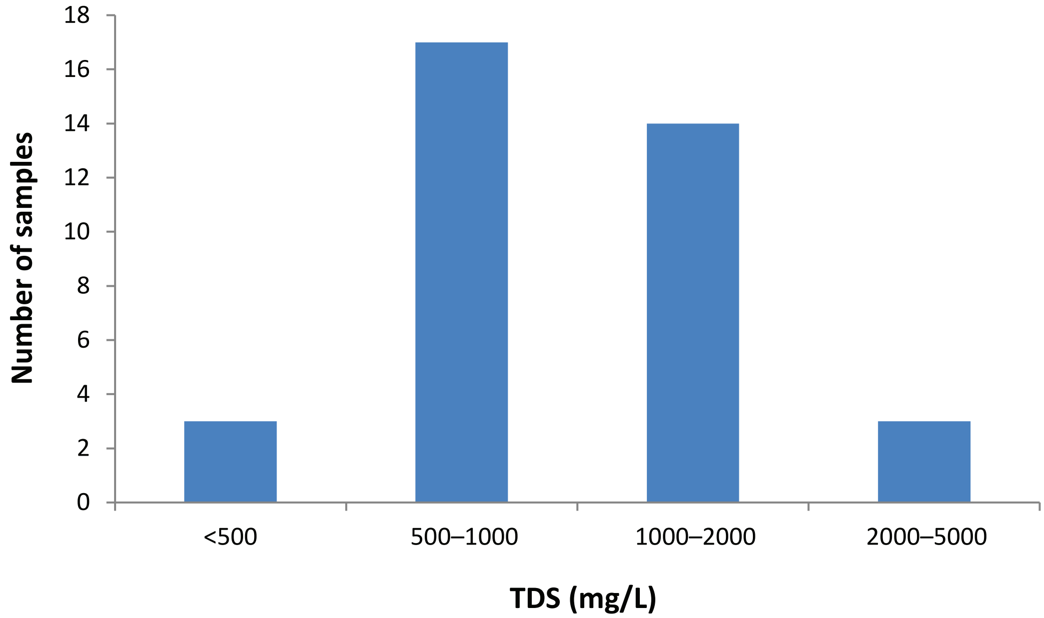


Figure 19. *Distribution of samples by total dissolved solids concentration for Goshen Valley.*

Nitrogen Isotopes

The relative abundances of the stable isotopes of nitrogen ^{14}N and ^{15}N vary systematically in nitrogen-bearing compounds. These compounds, particularly nitrate and nitrite, can be significant groundwater pollutants and the relative abundances of nitrogen isotopes can record the sources of nitrate pollution and its chemical evolution in a groundwater system (Clark and Fritz, 1997; Kendall, 1998).

Nitrogen isotopes were analyzed on a subset of 14 samples collected in Goshen Valley (table 3). Sample sites were chosen to cover the valley floor including important agricultural areas. Values for $\delta^{15}N_{NO3}$ are expressed relative to an atmospheric air sample, in units of per mil (‰), and samples for this study range between 4.5‰ and 8.52‰. Previous work by Wallace and Jordan (2015) found $\delta^{15}N_{NO3}$ and $\delta^{18}O_{NO3}$ values in Goshen Valley consistent with nitrate coming from a variety of sources that could include agriculture effluent (manure), fertilizer, and possibly septic systems (Kendall and Aravena, 2000; Green and others, 2008). Figure 22 is a plot of the nitrate concentration versus $\delta^{15}N_{NO3}$. Samples are symbolized based on the water types previously discussed. The highest nitrate concentration is more than 250 mg/L at site 12 in the southwestern part of the Goshen Valley (figure 21). This site is located near a historical feed lot and is assumed to represent nitrate input from agricultural effluent into the groundwater system. This sample represents an end member to the nitrogen isotope system (figure 22). Remaining samples plot to the left of sample 12 owing to lower concentrations of nitrate and varying abundance of $\delta^{15}N_{NO3}$. Samples 21 and 22 (table 3) likely represent low nitrate background groundwater. Two trends are apparent on this plot: one that parallels the x axis is based solely on changes of nitrate concentration, and one that is controlled by changes in both nitrate concentration and $\delta^{15}N_{NO3}$. The trend controlled by nitrate concentration can be assumed to represent a dilution trend whereby a nitrate source into the system like site 12 is diluted in varying proportions with background nitrate concentrations similar to site 22. These results support dilution as the dominant process of nitrate reduction in Goshen Valley. The second trend, controlled by changes in nitrate concentration and changes in $\delta^{15}N$, is likely produced by denitrification or the natural breakdown of nitrate within the aquifer (Kendall, 1998; Kendall and Aravena, 2000). Nitrate concentrations in Goshen Valley appear to be driven primarily by localized input of agricultural effluent that is then modified by either dilution, or local denitrification. Wallace and Jordan (2015) discussed that nitrate in Goshen Valley having a depleted $\delta^{15}N$ signature, as found in soil and fertilizer, is mixing with nitrate enriched in ^{15}N, likely from a manure source. Their results indicated that dilution, not denitrification, was the dominant process of nitrate removal from the environment in Goshen Valley, which is consistent with redox conditions (oxic) observed in groundwater across most of Goshen Valley.

Stable Isotopes

Sources of recharge to an aquifer may be qualitatively evaluated by analyzing the composition of stable isotopes of oxygen and hydrogen in groundwater. Measured isotopic ratios of oxygen (^{16}O and ^{18}O) and hydrogen (^{1}H and ^{2}H) in precipitation vary systematically with topography, temperature, and distance from the ocean (Craig, 1961; Dansgard, 1964; Clark and Fritz, 1997; Bowen and Revenaugh, 2003). Isotopic ratios in near-surface water may be altered by evaporation following precipitation, but generally remain unchanged in groundwater after recharge if no mixing occurs. The groundwater isotopic

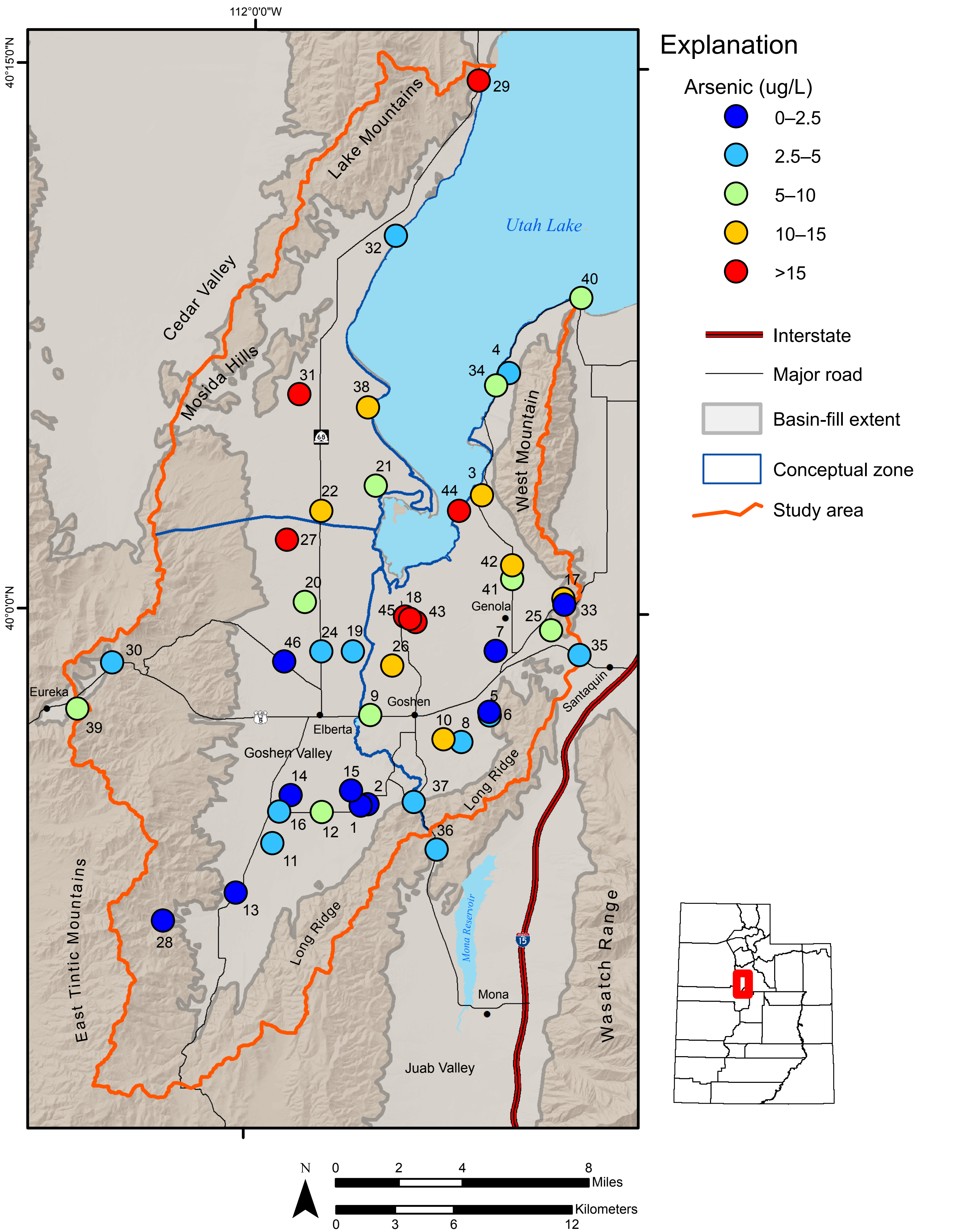


Figure 20. Arsenic concentrations in Goshen Valley. Sample IDs correspond with table 2.

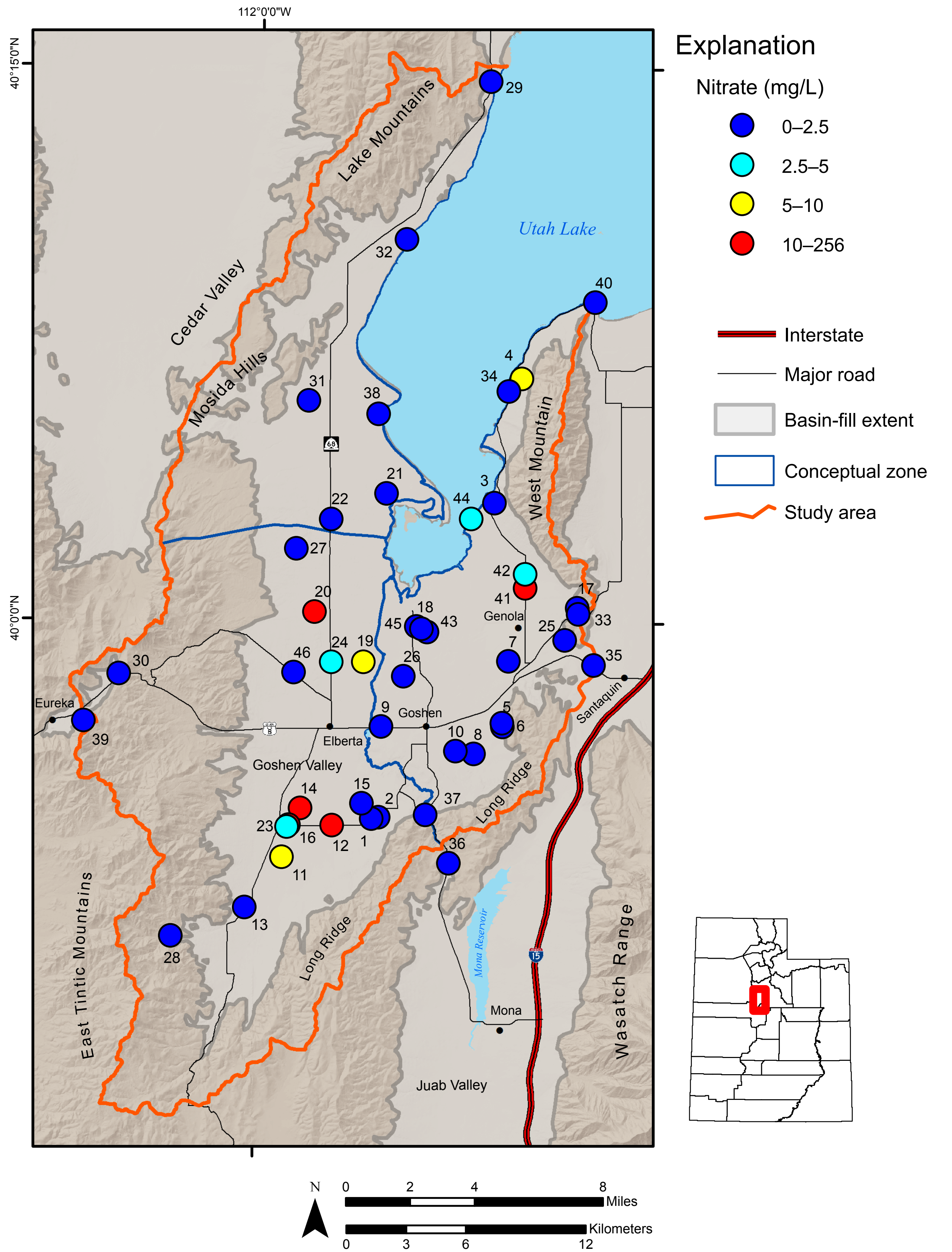


Figure 21. *Nitrate concentrations in Goshen Valley. Sample IDs correlate with table 4.*

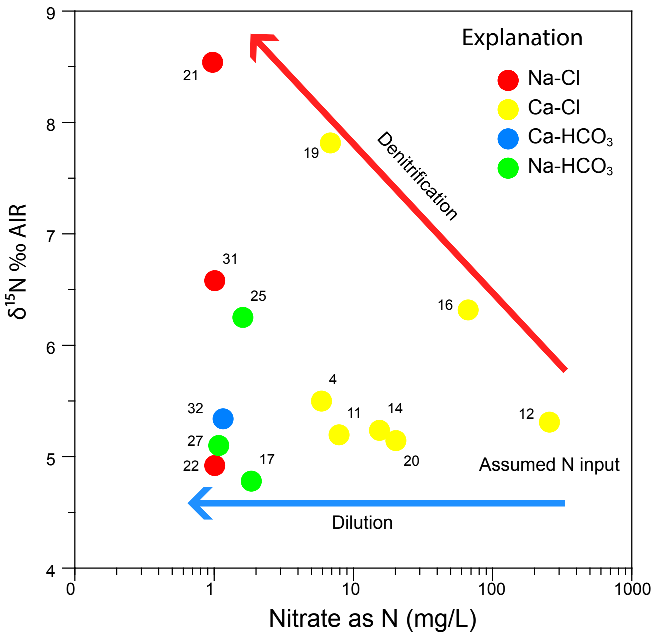


Figure 22. Plot of nitrogen isotopes and major ion chemistry. Numbers correspond to sample IDs in tables 2 and 3. Trends for dilution and denitrification follow those presented by Clark and Fritz (1997) and Kendall and Aravena (2000).

ratios therefore record the isotopic signature of meteoric or surface waters at the time of recharge and any subsequent mixing (Clark and Fritz, 1997).

Water samples collected during this study (table 3) were analyzed for the stable isotopic ratios of hydrogen (δD) and oxygen ($\delta^{18}O$). Stable-isotope ratios $\delta^{18}O$ and δD were measured at the Brigham Young University Hydrogeochemistry Laboratory with a Finnigan Delta^{plus} isotope ratio mass spectrometer. Values of $\delta^{18}O$ and δD were normalized to the VSMOW/SLAP scale following the procedures of Coplen (1988), Nelson (2000), and Nelson and Dettman (2001).

Isotopic ratios of hydrogen ($^2H/^1H$) and oxygen ($^{18}O/^{16}O$) are calculated in delta (δ) units per mil or parts per thousand (‰) relative to a reference standard (Standard Mean Ocean Water) (Craig, 1961) via the following equation:

$$\delta x = \frac{R_{sample} - R_{standard}}{R_{standard}} \cdot 100 \qquad (1)$$

where:

δx = isotopic ratio of ^{18}O or ^2H (‰).

R_{sample} = $^{18}O/^{16}O$ or $^2H/^1H$ in the sampled water

$R_{standard}$ = $^{18}O/^{16}O$ or $^2H/^1H$ in the reference standard

Most samples plot along or adjoining the Utah meteoric water line of Kendall and Coplen (2001) (figure 23). There is significant overlap in stable isotopic composition amongst the samples. End-member compositions are defined by samples 27 and 15 from wells completed in the UBFAU in conceptual zone 2, which are on the depleted end and sample 39 collected from Utah Lake on the enriched end. Most groundwater, and surface water samples from Currant Creek and the Highline Canal, cluster in the middle of the plot.

Samples plot broadly along the meteoric waterline trends with most samples lying below the Utah meteoric water line (Kendall and Copeland, 2001). Similar trends may be produced by partial evaporation during recharge, and are consistent with groundwater in relatively arid regions elsewhere (Clark and Fritz, 1997). Nearly one-half of all samples plot in a relatively tight cluster (figure 23 inset). This cluster has δD values that range between -117‰ and -127‰ and $\delta^{18}O$ that ranges between -15‰ and -17‰. Most of these samples represent groundwater from the floor of Goshen Valley that, depending on location, may be local recharge primarily from the East Tintic Mountains, or far-traveled groundwater recharged either in Cedar Valley to the west or east of the study area along the Wasatch Range front. Alternately, some of this groundwater may represent infiltration of surface water from Currant Creek or the Strawberry Highline Canal system.

Mapped deuterium values generally show spatial correlation where closer samples are more similar (figure 24). The most enriched (i.e., least negative) δD values exist in samples collected from Utah Lake (samples 34 and 38). Other surface water samples from Currant Creek and the Highline Canal (samples 37 and 33, respectively) are less enriched than Utah Lake water but have deuterium values higher than most groundwater samples. The values of the surface water samples likely reflect significant evaporation occurring from the lake and lesser evaporation occurring in Currant Creek (and Mona Reservoir) and the Highline Canal. Most groundwater samples have comparable deuterium values between -140‰ and -120‰. Groundwater samples in much of conceptual zone 2 have deuterium that is enriched relative to conceptual zones 1 and 3. This difference may result from most recharge being sourced from relatively low-elevation precipitation similar to the recently recharged water at sample 28 (figure 23). Groundwater samples in conceptual zone 1 are depleted relative to groundwater in conceptual zone 2. This relative depletion may result from groundwater being sourced from cooler upland, or older precipitation in the upper parts of Cedar Valley that has entered Goshen Valley as underflow. Groundwater in conceptual zone 3 spans a greater range of deuterium values including relatively depleted values at and near Goshen Warm Springs, and relatively enriched samples north and west of Genola. Depleted values may represent cool recharge from the Wasatch Range that has entered Goshen Valley as underflow. Enriched values may represent a mix of depleted cooler recharge with enriched, unconsumed irrigation water, and/or lower-elevation warmer recharge.

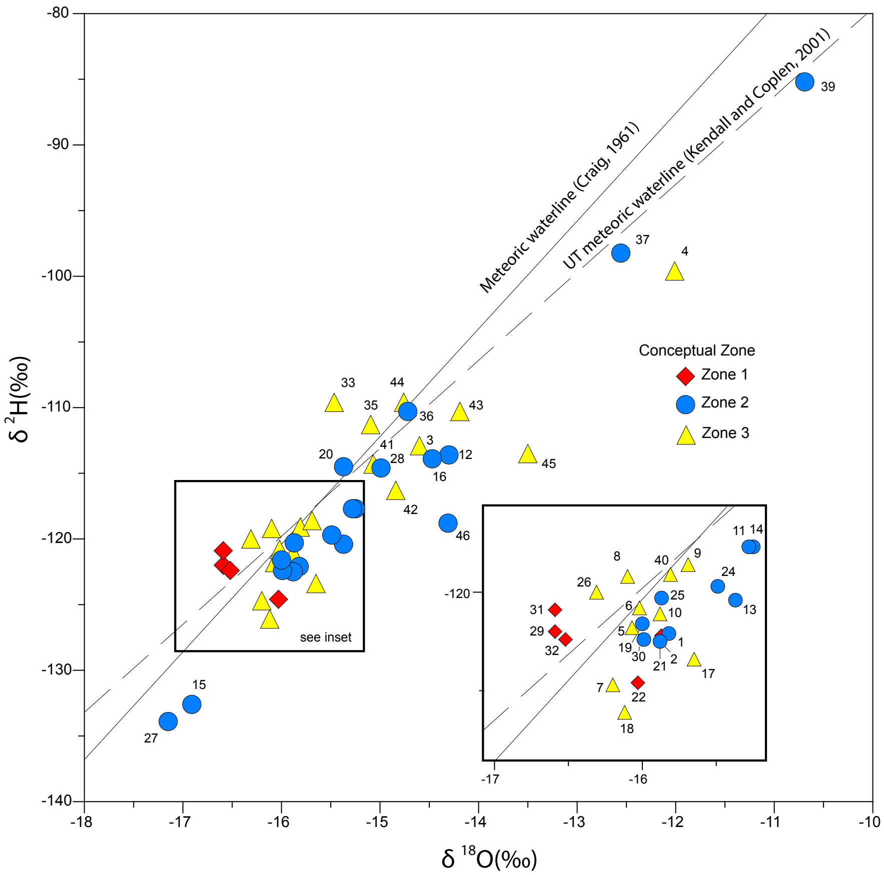


Figure 23. *Stable isotopes of samples collected during this study. Samples are symbolized by conceptual zone and plotted along with the global meteoric and a Utah-specific waterline (Craig, 1961; Kendall and Coplen, 2001). Numbers correspond to sample IDs in table 4.*

Tritium

Tritium-count data provides qualitative evidence for the presence of modern water recharged since 1950. All samples having tritium concentrations greater than 0.5 tritium units (TU) likely contain at least a portion of modern water recharged since 1950, and samples having tritium values less than 0.5 TU likely represent water recharged prior to 1950, whereas sites with tritium greater than 2 TU likely consist primarily of water recharged since 1950 (Clark and Fritz, 1997).

Samples for tritium analysis were collected at 32 sites across Goshen Valley (figure 25). Tritium concentrations range between 0.05 and 7.8 TU. Fourteen of the 32 samples have tritium less than 0.5 TU. All tritium samples collected in conceptual zone 1 contain less than 0.5 TU. Samples in conceptual zone 2, both north of Elberta and in the southwest corner of Goshen Valley, also have tritium less than 0.5 TU, and groundwater at site 46 contained 0.6 TU. A single sample collected at an upland spring in the East Tintic Mountains of conceptual zone 2 has a tritium value of 4.6 TU and likely consists entirely of recently recharged groundwater. The highest tritium concentrations and likely most recently recharged groundwater is found in conceptual zone 3. Most samples near West Mountain and between Santaquin and Genola, and north of Goshen, contain tritium concentrations greater than 2 TU and likely consist primarily of recently recharged groundwater. Samples from Goshen Warm Springs and a site just west of Goshen near Currant Creek have tritium between 0.5 and 2 TU. These samples must contain at least a fraction of recently recharged groundwater. Two sites in conceptual zone 3 have tritium less than 0.5 TU. Taken together, the tritium results indicate that most young water and active recharge occurs across the eastern part of Goshen Valley in conceptual zone 3. Elsewhere, across conceptual zones 1 and 2, tritium concentrations are low and indicate little if any recharge to groundwater since 1950. A few sites located in conceptual zones 2 and 3 have moderate tritium concentrations and these locations, including Goshen Warm Springs and a well near Currant Creek, have at least a component of recently recharged groundwater.

Carbon Isotopes

The isotopes of carbon, carbon-13 (^{13}C) and carbon-14 (^{14}C), can provide quantitative information about residence time, recharge rates, flow paths, and the geochemical evolution of the aqueous and mineral phases of a groundwater system (Plummer and Glynn, 2013). The relative amount of stable carbon-13 ($\delta^{13}C$) represents a measure of carbon isotope fractionation and evolution in the aqueous system. Generally, more-enriched $\delta^{13}C$ (higher values) correspond with increased residence time and carbon mass transfer (Clark and Fritz, 1997).

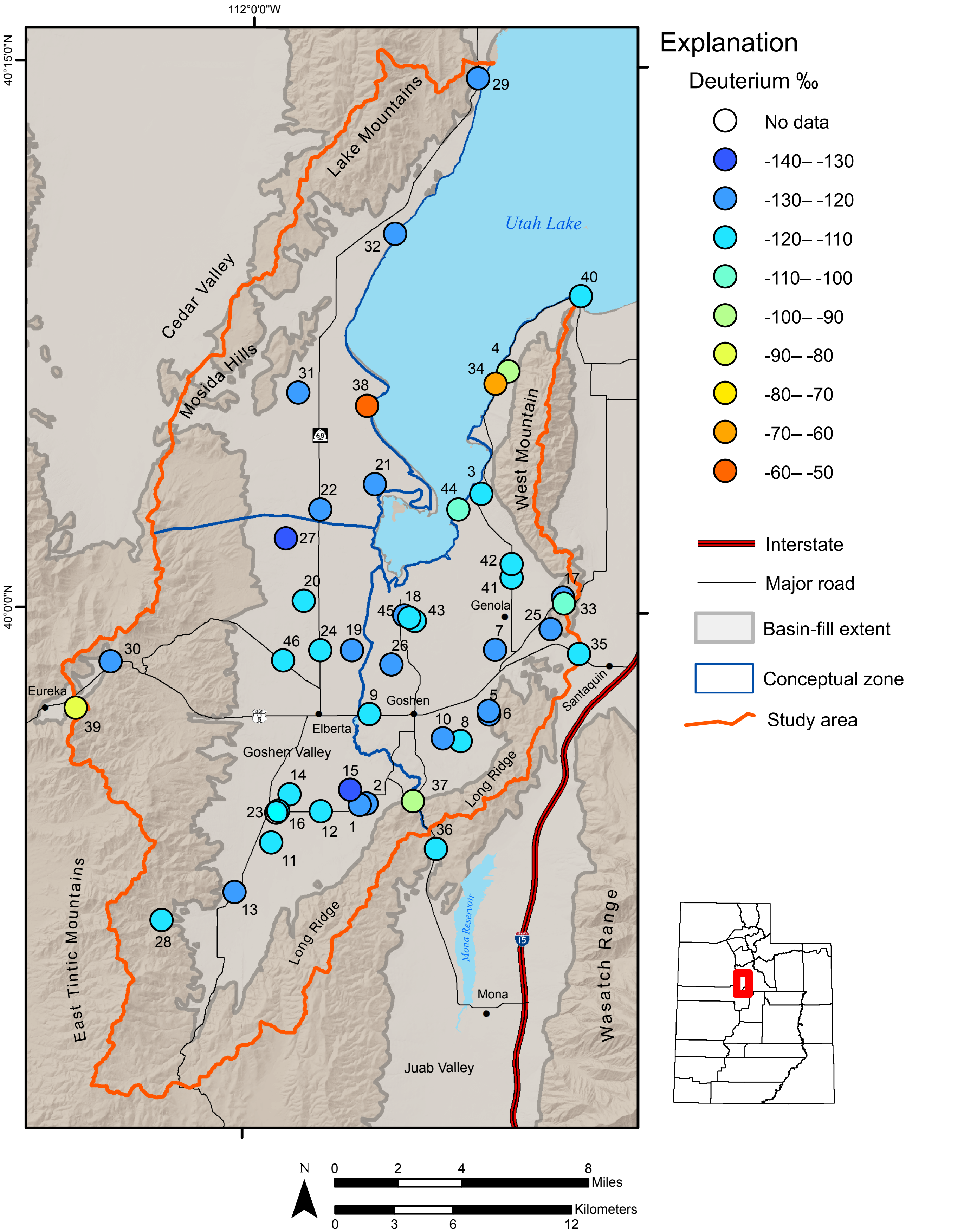


Figure 24. *Deuterium values for Goshen Valley. Most samples have similar deuterium values other than the enriched values collected from Utah Lake. Numbers correspond with sample IDs in table 4.*

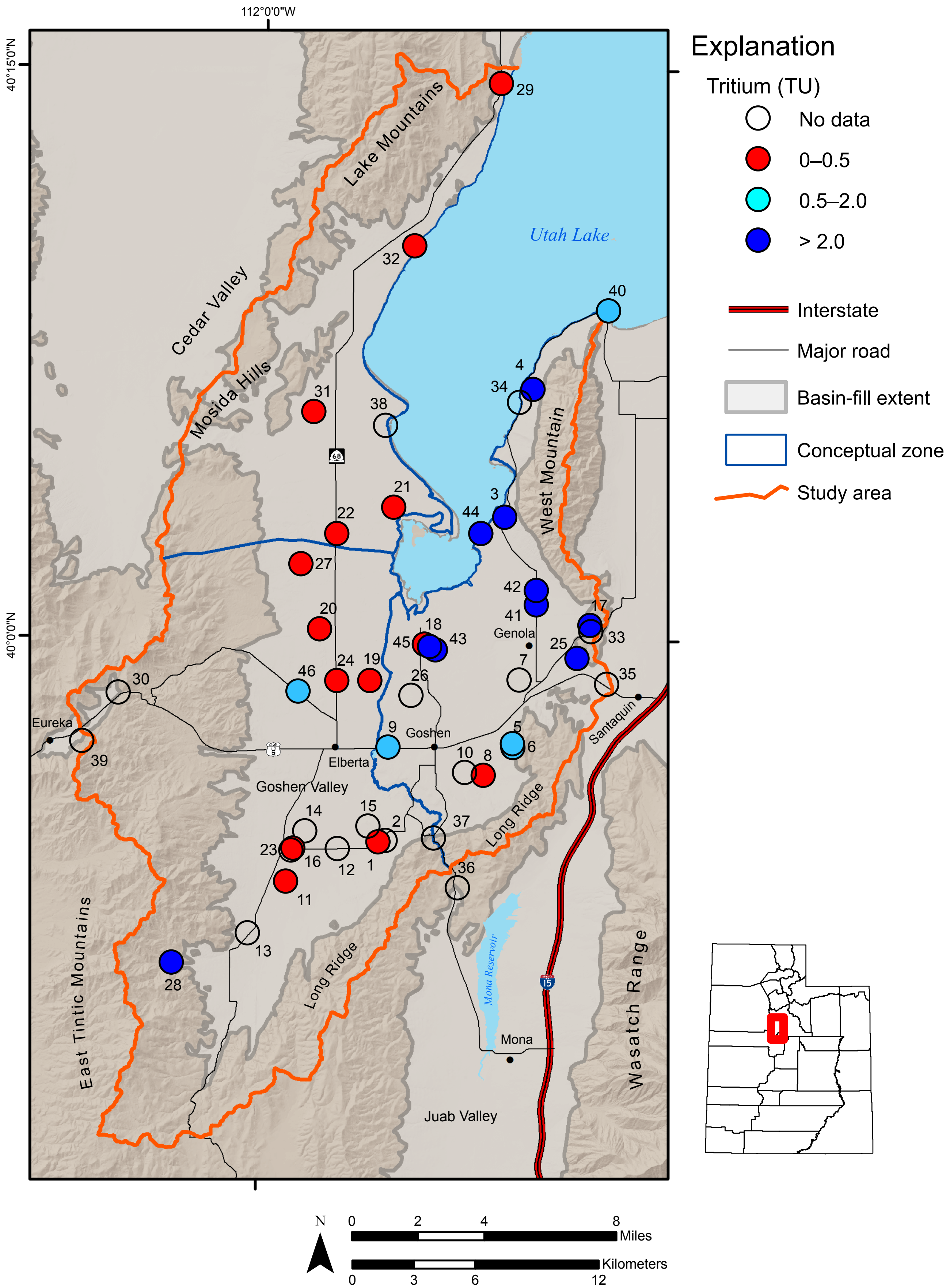


Figure 25. *Tritium concentrations in Goshen Valley. Numbers correspond to sample IDs in table 4.*

Relatively depleted $\delta^{13}C$ values (lower values) likely represent systems where the carbon isotopic composition is less evolved and there is less geochemical evidence of aquifer matrix and groundwater interaction (Plummer and others, 1994). The radiogenic isotope ^{14}C has a known half-life, and assuming geochemical sources and sinks for this isotope in the groundwater system, allows for the calculation of residence time in the principal aquifer (Plummer and others, 1994). These values are commonly expressed as percent modern carbon (PMC) where 100 PMC is equivalent to a modern atmospheric concentration (Plummer and Glynn, 2013). Changes in the PMC concentration are assumed to be due to either isotopic exchange or fractionation, and natural decay of ^{14}C. Lower PMC therefore generally indicates greater age or time since recharge. Exact calculation of age is complicated due to isotopic exchange and fractionation both during recharge and residence in an aquifer (Clark and Fritz, 1997). Samples with PMC greater than 50 could be interpreted as essentially modern owing to the potential for isotopic fractionation and mineral exchange in the unsaturated zone (Hart and others, 2010). For this study, a series of reasonable age estimates are made for samples with PMC less than 50. These estimates rely on a range of approaches, from an uncorrected age that assumes initial ^{14}C concentrations equal to 100%, to various correction methods that assume or estimate initial carbon isotopic concentrations based on the fluid chemistry and stable isotopic compositions (Pearson and Hanshaw, 1970; Fontes and Garnier, 1979; Clark and Fritz, 1997). Due to site-specific variations in sample chemistry, not all age estimates yield values for a given site (table 4). For consistency across the study area, an average age is calculated based on the available ages calculated from the various models, and this value is taken as the preferred age for the old fraction of a given sample. Total error in these age estimates is large, and the age of any sample could range between at least the maximum and minimum age for a given sample.

Carbon isotopes were analyzed for a subset of 23 samples in Goshen Valley that include groundwater from wells completed in bedrock and basin fill and several springs (figure 26; table 4). Values range from 4 to 76 PMC across Goshen Valley. PMC values greater than 50, indicating recent recharge, occur at three sites that include an upland spring in the East Tintic Mountains, a well near Currant Creek west of Goshen, and a well west of West Mountain. Most of the remaining samples have PMC concentrations below 40% with age of the old fraction of at least several thousand years. The lowest PMC values occur in conceptual zone 1 where samples have average ages that range from 15,000 to 8000 years. PMC increases and average age decreases to the south in conceptual zone 2 where most samples along the valley floor have PMC less than 30 and average ages that range from 1600 to 10,000 years. A single sample near the northern edge of conceptual zone 2 has the greatest average age of 16,400 years. Conceptual zone 3 has generally higher PMC values and younger groundwater. A pair of groundwater samples from Goshen Warm Springs both have an average age of 4900 years. Elsewhere, in conceptual zone 3, average ages are generally less than 4100 years. A single well sample from the western side of West Mountain yielded the oldest water on the eastern side of the study area, with an average age of 13,100 years. The carbon isotope data and apparent groundwater ages indicate that the oldest water occurs in the northern and western parts of Goshen Valley. This may be due to far-traveled groundwater entering Goshen Valley from Cedar Valley in conceptual zone 1 and generally low recharge rates in the dry southwestern corner of the valley that is conceptual zone 2. Groundwater in conceptual zone 3 is generally younger, likely due to more recharge in the form of precipitation, surface water infiltration, and significant underflow into Goshen Valley from the east. The age of groundwater at Goshen Warm Springs implies significant travel times and distances for these springs. Much of the flow at Goshen Warm Springs may represent underflow of groundwater recharged along the foot of the Wasatch Range.

Tritium and carbon isotopes provide independent constraints on groundwater age for the young (less than 50 years) and old (greater than 1000 years) fractions. Combining these two tracers at a given site allows for a qualitative binning of groundwater age that is useful in understanding the conceptual setting of groundwater. Samples are grouped into four categories that include modern, premodern, mixed, and old (Lindsey and others, 2019) (figure 27). Modern samples have tritium greater than 2 TU and PMC greater than 50; premodern have tritium less than 0.5 TU and PMC greater than 50; mixed sites have tritium greater than 0.5 TU and PMC less than 50; and old sites have tritium less than 0.5 TU and PMC less than 50. Figure 27 shows qualitative ages based on the concentrations of tritium and PMC.

Most samples collected in Goshen Valley are old, with little if any evidence of recent groundwater recharge. All samples in conceptual zone 1 and most samples in conceptual zone 2 consist of old groundwater. These waters may be either far traveled or in areas with very low modern recharge. Conceptual zone 3 also contains several old samples that are located along the floor of Goshen Valley. East of these samples, much of the groundwater, including Goshen Warm Springs in conceptual zone 3, is mixed with varying proportions of young and old groundwater. These samples include both recently recharged water and older, possibly far-traveled groundwater recharged to the east of the study area. Three samples across Goshen Valley represent modern groundwater. Two of these samples are located along the flanks of West Mountain and the East Tintic Mountains, and a third sample is located near Currant Creek west of Goshen. Many of the nitrate-contaminated wells in conceptual zone 2 contained old groundwater, suggesting that re-infiltration of pumped groundwater may be a source of elevated concentrations of nitrate (Selck and others, 2018).

Dissolved Noble Gases

Dissolved noble gases in groundwater provide an indication of the temperature and pressure conditions at which recharge occurred and a measure of the time since recharge. Noble gases

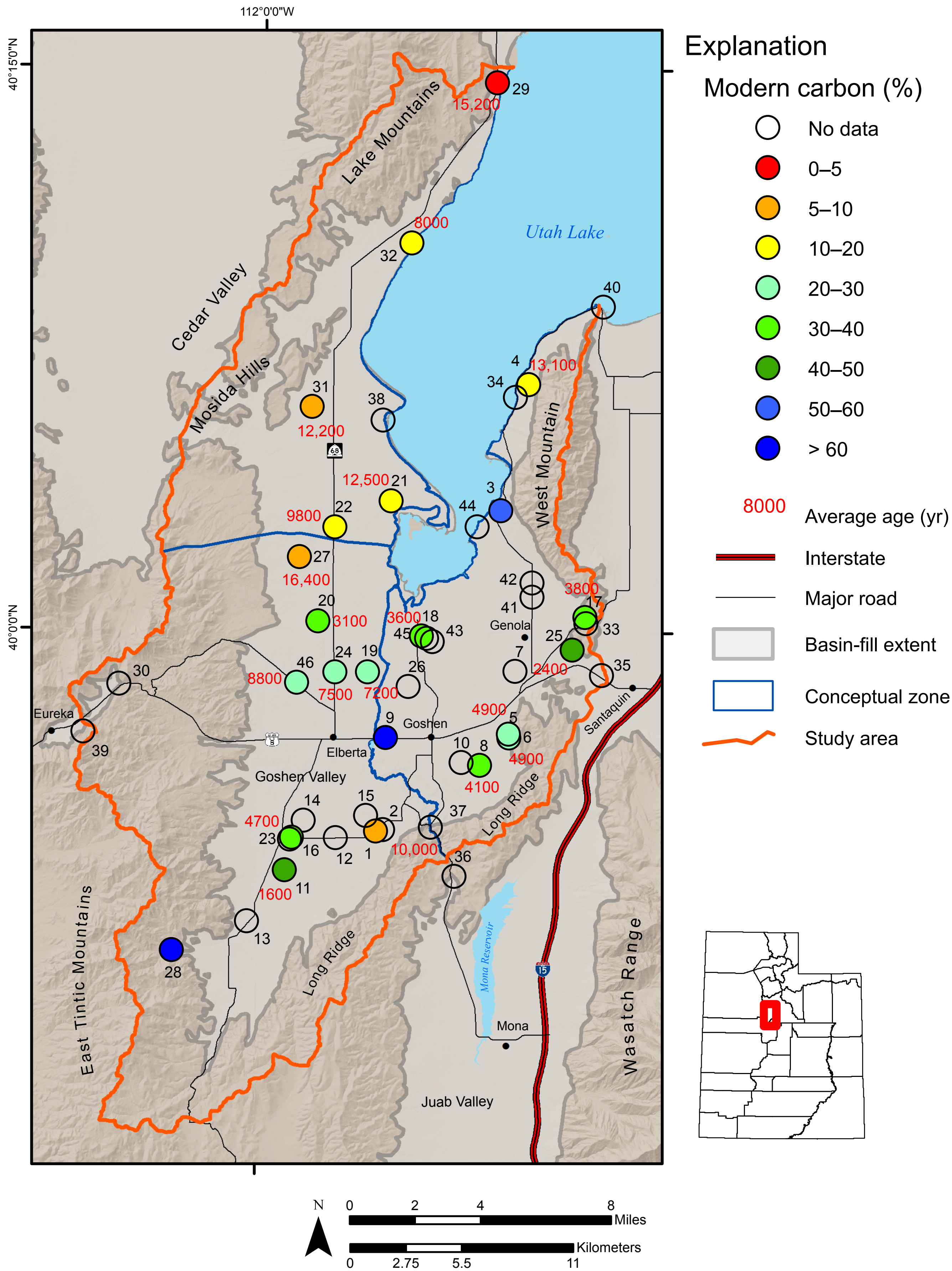


Figure 26. *Percent modern carbon in groundwater of Goshen Valley. Numbers correspond with sample IDs in table 4.*

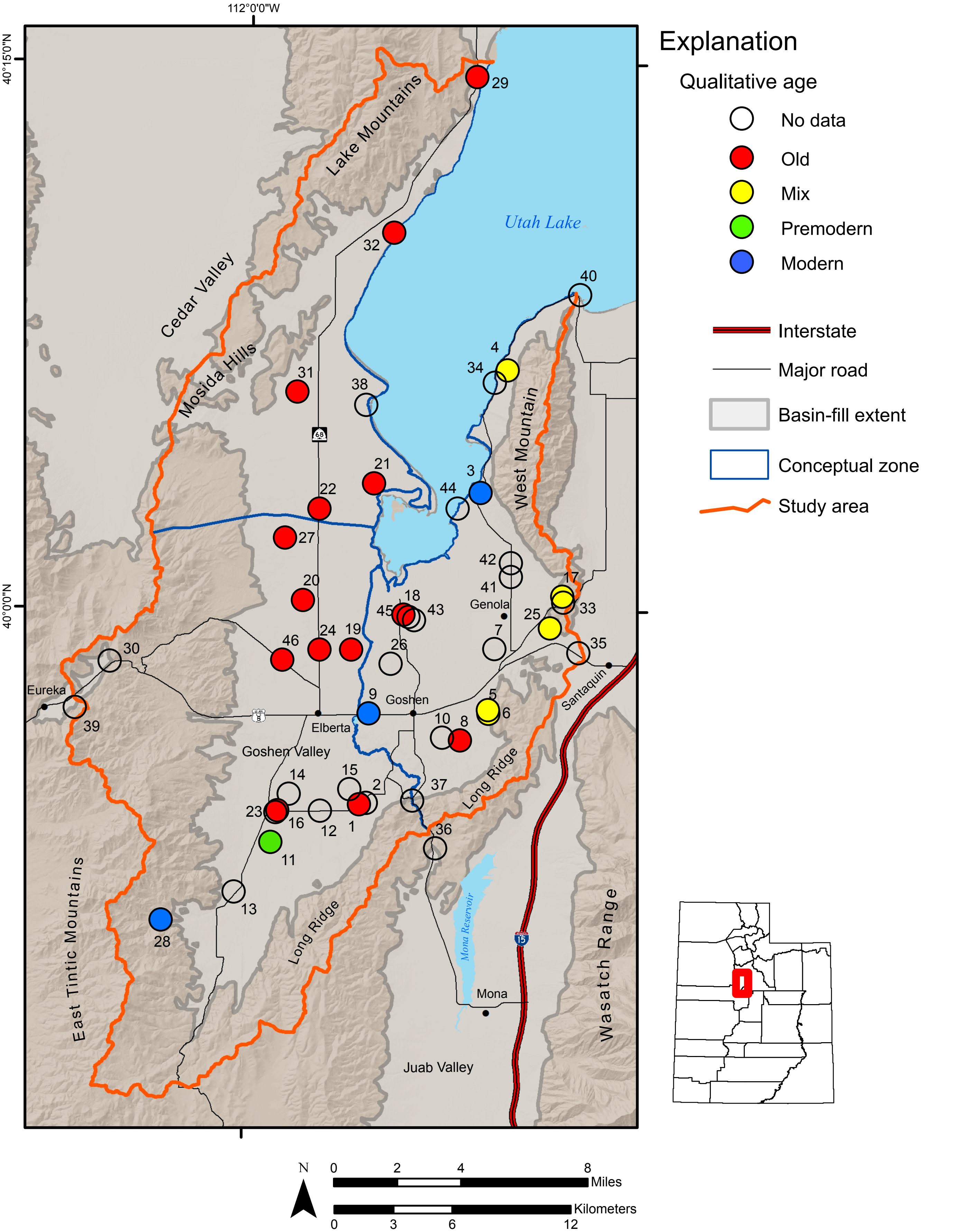


Figure 27. Qualitative groundwater age in Goshen Valley. Most groundwater sampled is old. Numbers correspond with sample IDs in table 4.

(helium, neon, argon, krypton, and xenon) are chemically inert and occur in known concentrations in the atmosphere. The relative concentrations of these gases are determined by Henry's Law solubility equations that relate concentrations of noble gases to changes in temperature, pressure (elevation), and fluid salinity (Stute and Schlosser, 2000). As groundwater is recharged, it dissolves noble gases present in the vadose zone in concentrations that are dependent on the temperature, pressure, and salinity conditions at the time of recharge (Aeschbach-Hertig and others, 1999). By assuming elevation (pressure) at the time of recharge and the effect of excess air dissolved in recharging groundwater, it is possible to model the temperature under which recharge occurred (Aeschbach-Hertig and others, 2000). In addition to estimates of the recharge conditions, the concentrations of dissolved helium isotopes may be used to estimate time of residence, as well as conditions relating to the crustal- or mantle-driven helium flux to the groundwater system. The dissolved concentrations of helium and tritium in groundwater may be used to constrain the time since recharge and provide quantitative ages for the tritiogenic (young) component of groundwater (Solomon and Cook, 2000) and the qualitative age of the old component of groundwater (Solomon, 2000).

Water that recharges within a few hundred feet of the land surface generally equilibrates at a temperature equal to the mean annual temperature at a given location. Areas of the eastern Great Basin have significant topographic relief, which can create a wide range of potential groundwater recharge temperatures. Estimates of recharge temperature can therefore provide constraints on the spatial distribution of recharge and the potential connectivity of flow paths (Manning and Solomon, 2003). In the Goshen Valley area, mean annual temperature ranges from near 14°C (57°F) at low elevations (approximately 4500 feet) near Utah Lake to below 5°C (41°F) at the highest elevations (greater than 11,000 feet) of the Wasatch Range. Recharge temperatures in shallow water-table settings without significant geothermal heat flux within the study area should therefore be between 0 and 14°C (32°–57°F) for groundwater in the Goshen Valley area. Calculated recharge temperatures greater than 14°C (57°F) may result from thick vadose zone (greater than several hundred feet) recharge and/or where the geothermal gradient significantly affects the temperature of the base of the vadose zone. In Goshen Valley, water table temperatures are greater than 20°C (68°F) near the East Tintic Mountains, across the western part of the valley floor. High calculated recharge temperatures may also result from contaminated samples, poor recharge model fit, or re-equilibration of dissolved gas during groundwater residence in the aquifer system. Long-term climate change may also affect recharge temperatures, and groundwater recharged during the late Pleistocene may have lower calculated recharge temperatures for a given elevation.

Modeled dissolved gas recharge temperatures are strongly dependent on assumptions and methods used to calculate the equilibrium concentrations of noble gases during recharge. Chief among these is the compensation for excess air incorporated in the recharging water as it moves through the vadose zone. Excess air can result in the inclusion of dissolved gas concentrations that are greater than atmospheric concentration at the location of recharge (Aeschbach-Hertig and others, 2000). The modeled dissolved gas recharge temperature is based on assumptions of the composition and amount of excess air and estimates of the background flux of helium-4 (^{4}He) in a groundwater system (Solomon, 2000).

Samples for dissolved gas analysis were collected at 20 springs and wells across the valley floor and several upland locations in Goshen Valley (table 5). These data along with sample temperature, salinity, and total dissolved gas pressure were then entered into Microsoft Excel spreadsheets that use the excess air method to calculate equilibration or recharge temperatures for a given sample (Solomon, 2000; Aeschbach-Hertig and others, 2008). For each model solution, a pressure or elevation must be assumed and because the elevation of recharge is unknown, elevation is assumed to range between the approximate water-table elevation at the sampled well or spring and the maximum elevation upgradient of the sampling site. This method yields a minimum (corresponding to the highest altitude) and a maximum (corresponding to the lowest altitude) temperature of recharge. These values were then used to create a simple average temperature of recharge (figure 28; table 5).

The calculated average temperature of recharge ranges from 2.4° to 21.1°C (36° to 70°F), and most average recharge temperatures are between 10° and 20°C (50° to 68°F). The lowest recharge temperatures, less than 10°C (50°F), are found at Goshen Warm Springs, an upland spring in the East Tintic Mountains, and a flowing well north of Goshen. Samples at Goshen Warm Springs have average recharge temperatures that are less than those that would result if recharge occurred upgradient of the spring heads along Long Ridge. Instead, these temperatures likely result from recharge of relatively cool water east of Santaquin along or in the Wasatch Range that flows to Goshen Warm Springs. The 2.4°C (36° F) temperature for the flowing well north of Goshen is significantly lower than the expected temperatures of recharge near or upgradient of this site in Goshen Valley. This temperature may also represent groundwater recharged along or in the Wasatch Range. The lowest average temperature of recharge in the East Tintic Mountains is from an upland spring that contained significant amounts of tritium and therefore likely represents current or recent recharge temperatures in the upland parts of the East Tintic Mountains. Samples with average recharge temperatures between 10° and 15°C (50° and 59°F), occur across the floor of Goshen Valley including at sites near Goshen and in the southwestern corner of the valley. Other sites with these average recharge temperatures occur between Genola and Santaquin and near the shore of Utah Lake. Groundwater encountered at all these sites could have recharged within the Goshen Valley study area either near or upgradient of the sites, either along the floor of Goshen Valley or near the valley

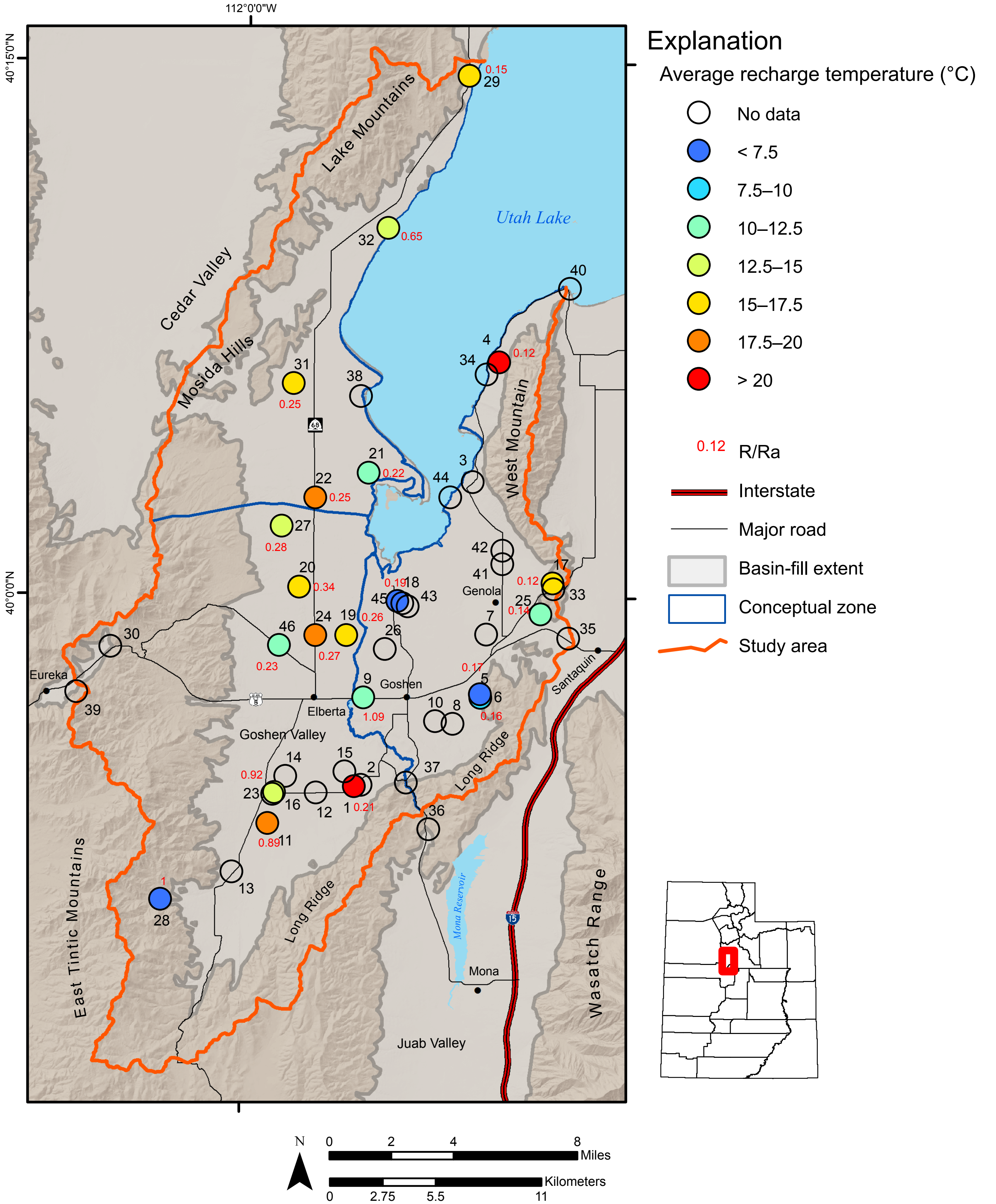


Figure 28. Modeled recharge temperatures derived from dissolved-gas compositions for groundwater in Goshen Valley. R/Ra is the He^3/He^4 ratio normalized to the atmospheric standard (Aeschbach-Hertig and others, 1999) Numbers correspond to IDs in table 5.

margin. The remaining dissolved gas samples have average recharge temperatures greater than 15°C up to 21°C (59° to 70°F). These samples may have equilibrated in areas of elevated water-table temperatures such as the southwestern part of Goshen Valley and the adjoining low-elevation parts of the East Tintic Mountains.

CONCEPTUAL MODEL OF GROUNDWATER FLOW

Introduction

Groundwater in Goshen Valley occurs in a range of settings that include unique head conditions, chemistry, and flow paths. Generally, groundwater moves from upland areas of recharge near the edge of the basin-fill aquifer toward areas of discharge near Utah Lake and the valley floor. Areas of contiguous LCAU occur along the northern part of Long Ridge, beneath Goshen Gap, and along the Mosida Hills. These interconnected areas likely allow for significant interbasin flow of groundwater into Goshen Valley from upgradient areas west, southeast, and east of the study area. Groundwater chemistry, isotopes, and dissolved gas data support this simplified model of groundwater flow. Significant discharge at Goshen Warm Springs is likely sourced from groundwater recharged to the east of Goshen Valley near the foot of the Wasatch Range. Most groundwater in Goshen Valley is old and contains little evidence of recent recharge, likely due to low recharge rates and long-traveled groundwater sourced outside of Goshen Valley. Based on hydrogeologic and geochemical details, we subdivide Goshen Valley into three distinct conceptual zones (figure 1). These conceptual zones are discussed below and used for subsequent water-budget calculations.

Summary of Conceptual Zone Characteristics

Based on the geologic and hydrologic data presented in this paper, we delineated three conceptual groundwater zones. Zones are delineated based on areas of shared hydrogeologic, geochemical, and potentiometric characteristics within the larger Goshen Valley.

Conceptual zone 1 is delineated in the northwestern part of the Goshen Valley study area (figure 1). The principal aquifers in this zone are the UBFAU and LCAU. Part of the western boundary of this zone, along the Mosida Hills, is considered a likely area of interbasin flow. The UBFAU is generally less than 750 feet thick across this zone. Groundwater elevations decrease from west to east, and depth to water is greater than 30 feet across conceptual zone 1. The southern part of this zone has experienced declines in the groundwater potentiometric surface elevation of up to 20 feet. Elsewhere in this zone groundwater elevations are consistent across the period of record. Groundwater chemistry in this zone features areas of high arsenic and moderate TDS concentrations. Based on environmental tracer data, most of the groundwater in this zone is old with little evidence of recent recharge.

Conceptual zone 2 covers the southwestern part of Goshen Valley and is bounded by conceptual zone 1 to the north and conceptual zone 3 to the east (figure 1). The eastern boundary is Currant Creek. The principal hydrostratigraphic units are VU and UBFAU. LCAU rocks occur in the subsurface and along the northern and eastern boundary of this zone. Groundwater potentiometric surface elevations decline toward the center of basin fill in this zone. Depth to groundwater is greater than 300 feet below land surface along the upper reaches of the UBFAU in the southern part of this zone. Groundwater levels have declined by greater than 50 feet across part of this conceptual zone. Groundwater chemistry shows a significant zone of high nitrate and elevated TDS concentrations that roughly corresponds with the area of greatest groundwater decline. Most groundwater in this zone is old with little evidence of significant recent recharge. A single site near Currant Creek shows some evidence of recent recharge near the eastern boundary of the zone.

Conceptual zone 3 covers the eastern part of Goshen Valley from the channel of Currant Creek to the drainage basin boundary (figure 1). The principal hydrostratigraphic units include LCAU rocks that comprise Long Ridge and UBFAU that covers most of the valley floor in this zone. The distribution of LCAU rocks along the eastern boundary of this zone supports the potential for interbasin flow across much of this boundary. UBFAU overlies LCAU in the shallow subsurface in the Goshen Gap and Genola area. Groundwater elevations are shallow, less than 30 feet, across most of the valley floor of this zone. Groundwater potentiometric surface elevations are consistent across the period of record. Groundwater chemistry spans the range of TDS observed in this study. High arsenic is prevalent in this conceptual zone, particularly in low-elevation parts. Environmental tracer data indicate that a significant fraction of groundwater in this zone has been recently recharged. Points of significant groundwater discharge in zone 3 at Goshen Warm Springs are a mixture of young and old groundwater.

WATER BUDGET

Introduction

An annual water budget represents the balance of groundwater recharge and discharge plus or minus any change in storage in the principal aquifer (Freeze and Cherry, 1979). The principal sources of groundwater recharge are direct infiltration of precipitation, infiltration of surface water, and subsurface inflow. Components of discharge include evapotranspiration, consumptive well withdrawals, spring flow and seepage, and subsurface outflow.

Components of recharge and discharge were estimated separately for each of the three conceptual zones. No delineation of recharge and discharge was made based on aquifer type or hydrogeologic group; instead, estimates were made for the groundwater system in each of the three subbasins. Because of basin geometry and spatial extent of the principal aquifer, much of the groundwater is assumed to reside in the basin-fill aquifer.

Change in storage represents water either added to or removed from the principal aquifer on an annual basis and usually results in water-level changes in the principal aquifer (Freeze and Cherry, 1979). In Goshen Valley, long-term decline in water levels in conceptual zone 2 is consistent with annual and ongoing decline in storage. Minor long-term water-level decline of less than 20 feet is apparent along the southern boundary of conceptual zone 1. In conceptual zone 3, water levels have been steady through time. For subsequent calculations, no change in storage is assumed for both conceptual zones 1 and 3 where long-term changes in groundwater levels are less than 10 feet.

The annual water budget components estimated below are assumed to be valid for 2007–2018. This period was chosen based on consistent land use characteristics and available well withdrawal data. Other water budget components are broadly consistent across this period despite incomplete or truncated data sets. The potential error in the water budget components is large. Error is at least plus or minus the 10% assumed for flow measurements and possibly up to 50% assumed for the Basin Characterization Model recharge estimates (see Basin Characterization Model Recharge section below).

Recharge

Groundwater recharge may occur from direct infiltration of precipitation or surface water and from subsurface inflow (Freeze and Cherry, 1979; Fetter, 1988). Subsurface inflow of groundwater into the study area is likely because of a combination of relatively permeable rock units (figures 3 and 5) and a potentiometric surface (figure 11) that generally slopes toward Goshen Valley through areas of contiguous permeable units that straddle its boundaries.

The amount and rate of recharge in semiarid environments is controlled by a variety of factors, including precipitation, soil and rock characteristics, climate, vegetation, and depth to the water table (Scanlon and others, 2002, 2006). Among these variables, precipitation asserts the greatest control over the total amount of recharge, and consequently most recharge occurs in and near well-watered upland areas. Basin-scale recharge may be estimated by a variety of techniques that most commonly include empirical estimates based on precipitation, numerical soil water-balance modeling, and various methods that indirectly quantify recharge at various scales (Scanlon and others, 2006).

Surface Flow

Introduction: Surface water in Goshen Valley comprises a significant component of potential recharge, and of both applied agricultural water and water available for natural vegetation. Surface water may also infiltrate and contribute recharge to the groundwater system in certain parts of the valley. To constrain surface water flow and its relationship to groundwater, continuous flow monitoring was used in conjunction with seepage transects, episodic measurements, and existing flow data for canals and pumping from Utah Lake. Continuous monitoring was conducted at two existing weir locations along Currant Creek (figure 30). Flow at seepage transects was measured at defined channel cross sections along Currant Creek and several canals within Goshen Valley (figure 31). Flow was measured using the velocity-area discharge method with an electromagnetic handheld current velocity meter following standard open-channel flow measurement techniques. Transects were repeated during fall baseflow and spring runoff at all sites to constrain flow changes related to stage.

Continuous flow monitoring: Continuous surface flow was measured at two existing concrete flumes along Currant Creek between July 2015 and July 2017 (figure 29). The upper and lower sites were cleaned and checked for condition before establishing continuous monitoring. At the upper site a pressure transducer was set in the pool above the flume; at the lower site a pressure transducer was set in the existing stilling well built into the flume. Flow was measured and stage (level) was recorded manually approximately bimonthly at both sites. Ratings curves were created by correlating measured flow to measured stage. The ratings curves were then applied to transducer stage data, recorded every 10 minutes, to construct continuous flow records for each site. For annual water-budget estimates, data were further simplified to average monthly flow values using a simplified moving average technique (figure 31 and table 6). During the period of measurement from July 2015 to July 2017, a maximum average monthly flow of 63 cfs occurred in May 2017 at the upper Currant Creek flume (table 6). The average annual flow at the upper Currant Creek flume, calculated as the average of the monthly averages, is 14 cfs. A graph of average monthly flow at the two continuous sites shows a consistent 23% to 45% decrease in measured flow between the upper and lower Currant Creek sites (figure 31). The average reduction in flow is assumed to be 34%, which equates to 4.8 cfs (3480 acre-ft/yr). Error in this estimate is assumed to be at least the plus or minus 5% typical for these types of measurements. Based on subsequent seepage data and a relative lack of significant diversions along this part of Currant Creek, this volume of 3480 acre-ft/yr is assumed to recharge the groundwater system and is split equally between conceptual zones 2 and 3 in subsequent water-budget calculations.

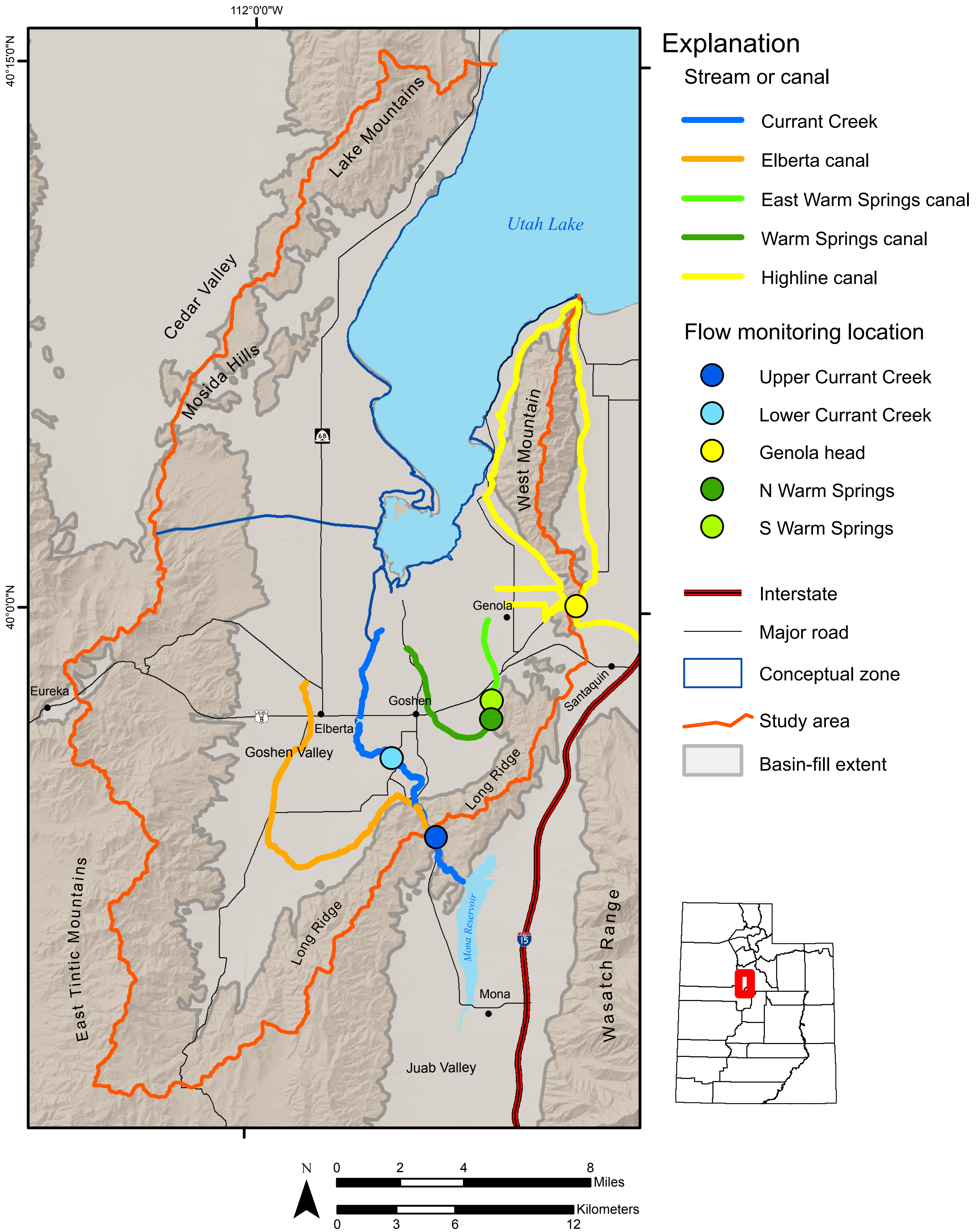


Figure 29. Surface flow sites, streams, and canals in Goshen Valley.

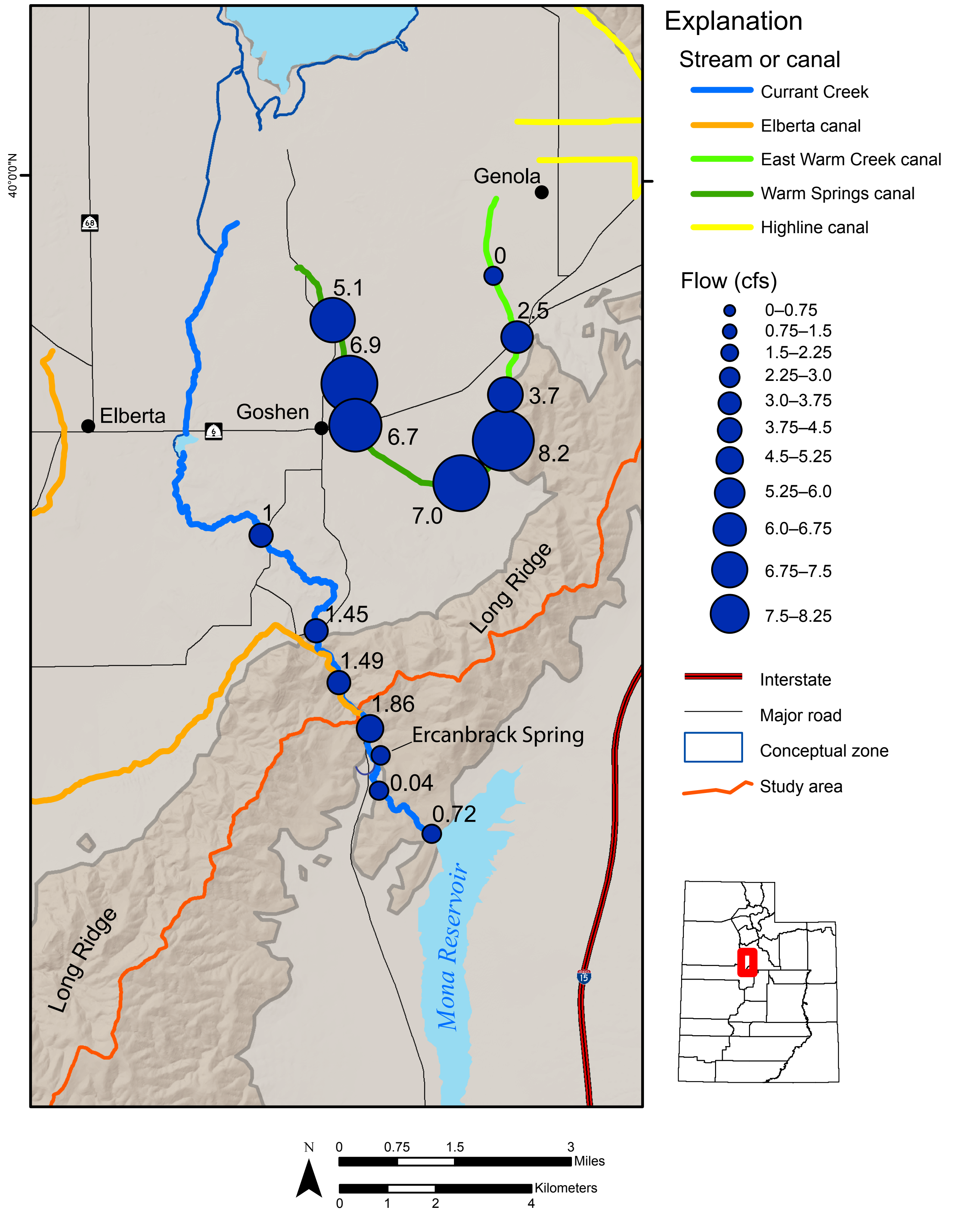


Figure 30. *Seepage transect flow measurements from August 2015.*

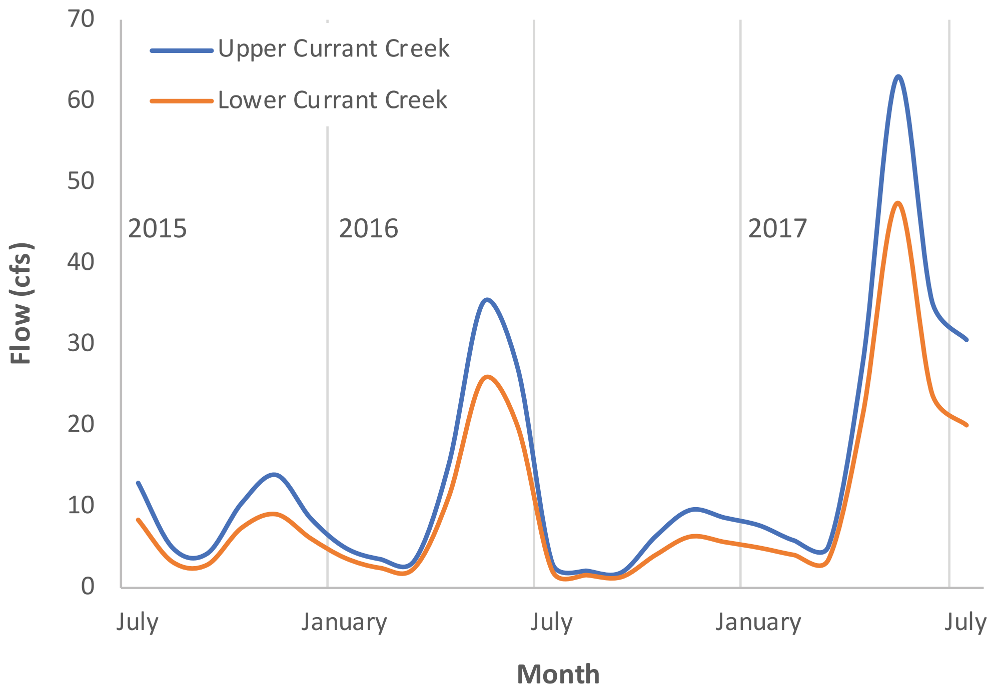


Figure 31. *Continuous flow measurements along Currant Creek.*

Table 6. *Average monthly streamflow (cfs) along Currant Creek.*

Year	Month	Upper Currant Creek flume	Lower Currant Creek flume
2015	July	12.9	8.4
	August	4.9	3.2
	September	4.2	2.9
	October	10.4	7.4
	November	13.9	9.1
	December	8.5	6.1
2016	January	4.9	3.7
	February	3.5	2.5
	March	3.3	2.5
	April	15.2	11.2
	May	35.2	25.7
	June	27	19.8
	July	3	2.1
	August	2.1	1.6
	September	1.9	1.4
	October	6.3	4.1
	November	9.6	6.4
	December	8.6	5.7
2017	January	7.7	5
	February	5.8	4.1
	March	5.1	3.5
	April	27.9	21.4
	May	63	47.3
	June	35.3	23.9
	July	30.6	20
	Average	14	10
	Median	8.6	5.9

Seepage transects: Seepage runs involve measuring streamflow at multiple transects along a watercourse, ideally in as short a time span as possible, to quantify the volume of water gained or lost from the watercourse at a point in time. Seepage runs were conducted on Currant Creek and several canals within Goshen Valley (figure 30). Discharge was measured at stream and canal transects using an inductive electromagnetic current velocity meter using standard open-channel flow measurement techniques. Transect locations were chosen based on access and the ability of a given location to yield a good in-channel measurement. Each transect location was marked with stakes and measured during baseflow in August 2015 and again during runoff in May 2017. Measurements were all collected on the same day within a period of four to five hours.

On Currant Creek, the most upstream (southern) transect was measured just downstream from the head of Currant Creek immediately below Mona Reservoir (figure 30). Downstream of this site another four transects were measured that included the upper Currant Creek flume and lower Currant Creek flume. During the August flow measurement, Mona Reservoir was nearly dry, and outflow from the reservoir in the Currant Creek channel was 0.72 cfs (figures 30 and 32). The next measurement downstream was less than 0.1 cfs, and this reduction in flow implies nearly all flow from Mona Reservoir infiltrated by this point. Moving downstream to the north, the next measurement at the upper Currant Creek flume had a flow of 1.8 cfs. At low flows, nearly all the flow at the upper Currant Creek flume originates at the developed Ercanbrack Spring and enters the Currant Creek channel approximately one-quarter of a mile upstream of the flume. Stream flow below this point declined to 1.45 cfs near the mouth of Currant Creek canyon, implying some loss of groundwater to the bedrock carbonate aquifers that underlie Currant Creek in this area. Two small canals informally called east and west canals, periodically divert Currant Creek flow near the canyon mouth. At the time of measurement, west canal was dry and east canal had a flow of 0.02 cfs based on the reading of a permanent Parshall flume, implying irrigation diversions are not responsible for flow reductions along this reach during the measurement. Lastly, flow was measured as 1 cfs at the lower Currant Creek flume, located on the valley floor between Currant Creek canyon and Goshen Reservoir. This reduction of flow is assumed to represent streamflow lost to the alluvial aquifer system along the floor of this part of the valley.These results mirror long-term flow data that show a consistent reduction in flow between the upper and lower Currant Creek flumes.

The same transects on Currant Creek were remeasured at runoff in May 2016 to constrain changes in stream seepage resulting from changes in total discharge. The upstream measurement below Mona Reservoir was 40.7 cfs, followed by 32.8 cfs at the next downstream flow measurement location, confirming a loss of streamflow in this reach also implied by the baseflow measurements (figure 32). Streamflow again increased below Ercanbrack Spring at the upper Currant Creek flume to 41.2 cfs. At the mouth of Currant Creek canyon, total flow was 41.4 cfs and flow measured at the lower Currant Creek flume was 32 cfs. During the time of measurement, east canal had a flow of 0.02 cfs and west canal was dry. These results corroborate the baseflow results and continuous flow data that show a decline in flow between the upper and lower Currant Creek flumes.

Below the lower Currant Creek flume, Currant Creek flows into Goshen Reservoir. Storage in Goshen Reservoir is released and managed for irrigation in areas west and north of Goshen. Based on personal communication with the water master, none of this irrigation directly reaches Utah Lake. Several field reconnaissance trips during times of runoff and irrigation in the area near Utah Lake support a lack of surface discharge from the Currant Creek drainage to Utah Lake. Based on this and the presence of shallow groundwater less than 10 feet from the surface in this area, it is likely that flow from Goshen Reservoir is directly consumed by agricultural and natural evapotranspiration (discussed in subsequent sections).

Groundwater discharge from the Goshen Warm Springs is channelized into two canals termed East Warm Springs canal and Warm Springs canal. The East Warm Springs canal delivers water to flood-irrigated farmlands and pastures north of Highway 6. Five seepage transects were measured along these canals to constrain surface water flow (figure 33). Each measurement in a seepage run was remeasured within several hours. At the head of the East Warm Springs canal, flow in August 2015 was 3.7 cfs (figure 30). To the north, where the canal crosses Highway 6, flow was 2.5 cfs. Visible leakage from the canal between these points supports the measured reduction in flow. The leakage results in westward off flow from the canal onto a large area of natural plant evapotranspiration that extends north to Utah Lake. North of Highway 6, the remaining flow was shunted onto several irrigated fields and pastures close to the highway. To the north, investigations of areas where this outflow could reach Utah Lake showed no evidence of surface flow, indicating all the flow in the East Warm Springs canal is consumed via natural and irrigated evapotranspiration. The Warm Springs canal channels flow from the southern springheads and feeds areas of irrigated farmland north of Goshen. Total flow from the springheads upstream of a ramp flume was measured on eight occasions between August 2015 and August 2016. Based on these measurements, total flow entering the Warm Springs canal varied between 6.4 and 8.2 cfs with an average flow of 7.1 cfs. To constrain flow changes along the canal above the primary diversion for irrigated agriculture, seepage runs were measured in August 2015 and May 2016 (figure 33). During each seepage run, five transects were measured within approximately five hours. Measured flow along the canal in August 2015 declined from 8.2 cfs upstream of the ramp flume to 5.1 cfs immediately above the primary irrigation diversion near the McLachlan property (figure 30). In May 2016, flow along the canal declined from 6.2 cfs to 5.3 cfs over the same distance

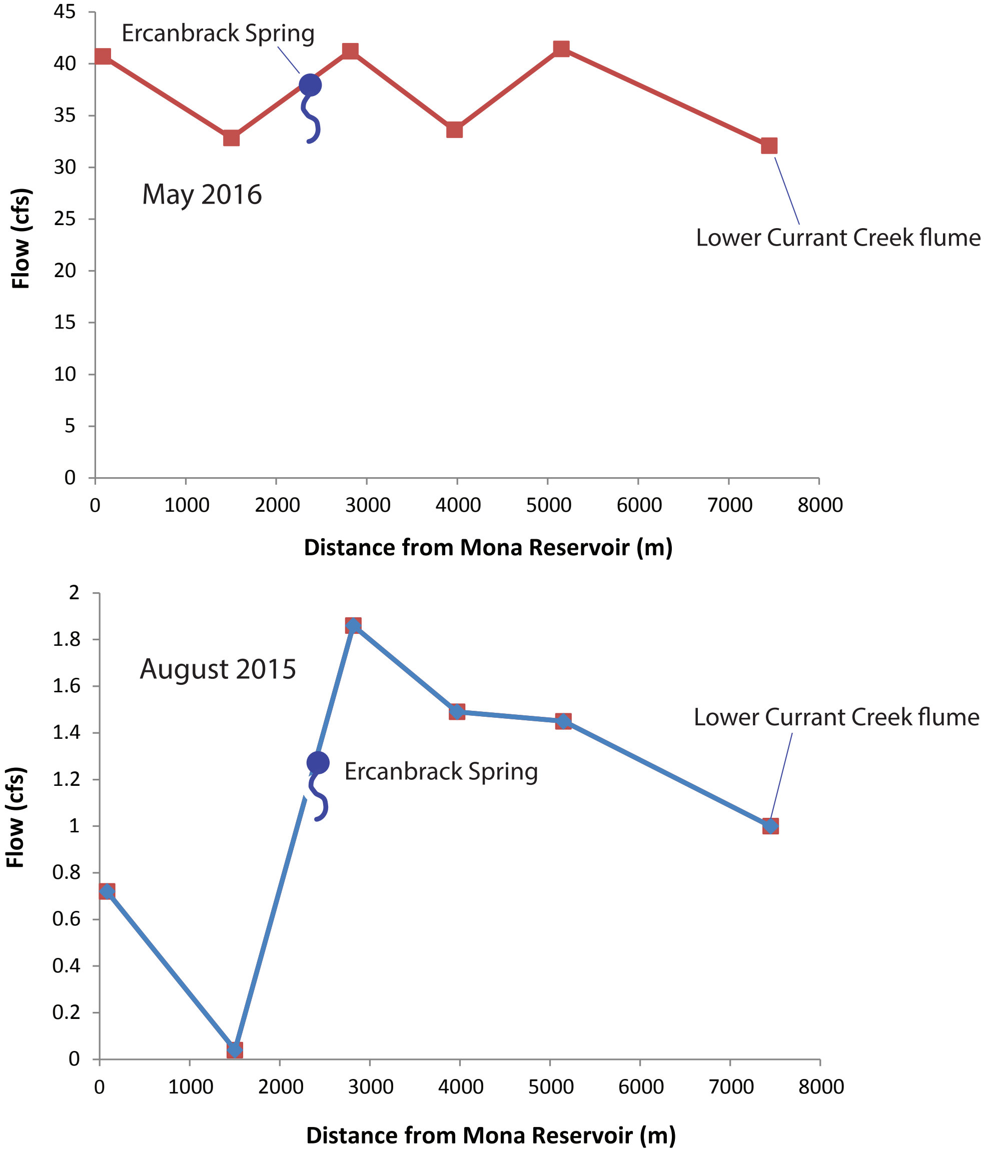


Figure 32. *Seepage flow measurements for Currant Creek.*

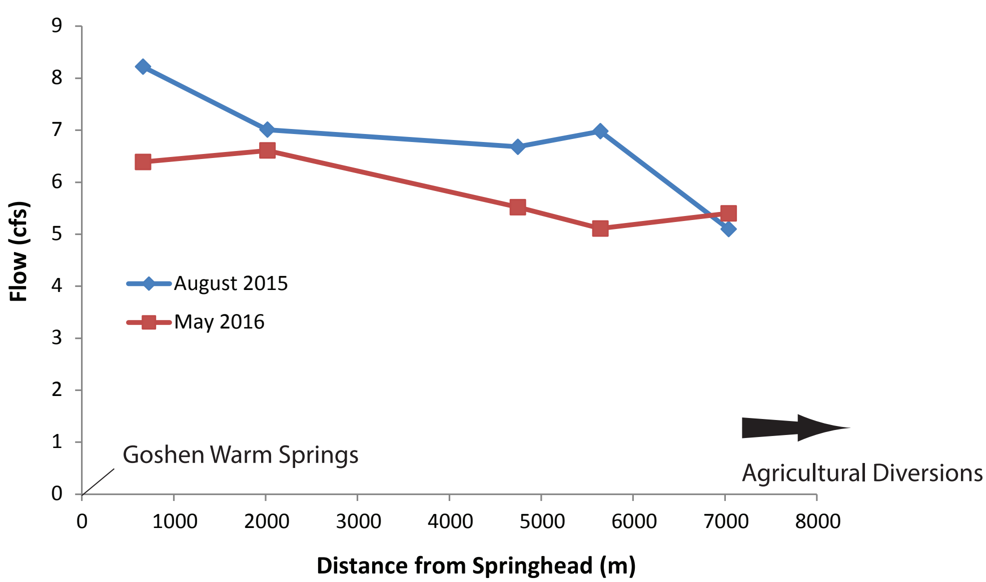


Figure 33. *Seepage flow measurements for Goshen Warm Springs canal.*

(figure 33). Between the upper and lower measurement points, multiple areas of flow leakage were observed that shunted canal water to the north or east onto an area of mixed wetlands and phreatophytes. Therefore, reductions in flow between the uppermost and lowermost measurements likely result from water lost to wetlands. Below the lowermost measurement, canal water is used to irrigate various fields and any remaining water discharges into wetlands and phreatophytes. To the north, investigations of areas where this outflow could reach Utah Lake showed no evidence of surface flow. Therefore, we assume for water-budget calculations that all flow from the Warm Springs canal is consumed by a mix of agricultural and natural evapotranspiration.

Along the east part of Goshen Valley from Genola to the north, irrigated orchards and other agriculture are fed by the Highline Canal system (figure 29). Highline Canal enters Goshen Valley at Genola Head, a prominent diversion at Goshen Gap, that has continuous flow measurement recorded by the Highline Canal Company. Data are available as daily average values for the period from 2013 to 2018 (Strawberry Highline Canal Company, 2018). All water in Highline Canal is distributed in conceptual zone 3. For water-budget calculations, available data for the period of record is averaged on a monthly basis and then averaged again for annual average flow into Goshen Valley. Based on these data, average annual flow into conceptual zone 3 is 19 cfs or 13,760 acre-ft/yr.

Basin Characterization Model Recharge

Basin-scale estimates of recharge from precipitation are taken from simplified soil-water budget models (Flint and others, 2004; Flint and Flint, 2007) and are readily available and commonly used for recharge estimation across arid parts of the western United States. The Basin Characterization Model (BCM) as presented by Flint and Flint (2007) is a digital model that estimates changes in soil moisture for grid cells about 270 x 270 meters using simplified inputs that include topography, soils, geology, vegetation, and monthly time series of precipitation and air temperature. The BCM outputs monthly grids of in-place recharge and runoff based on the computed soil-water budget. Runoff occurs when recharge during a given month causes volumes of soil water greater than the geologic permeability, and when the soil water storage is exceeded. The monthly values of recharge and runoff for the study area were summed to produce annual runoff and recharge grids. Based on the annual grids for the period 1991 to 2007, Heilweil and Brooks (2010) provided a series of grids rescaled to 250- x 250-meter cell size that show average annual recharge and runoff. These grids of calculated recharge and runoff provide the basis for the estimate of recharge from precipitation for Goshen Valley (figures 34 and 35).

Direct recharge (figure 34) is spatially variable and distributed over upland bedrock areas surrounding Goshen Valley. Areas of highest recharge occur across areas of exposed carbonate bedrock on West Mountain and in the East Tintic Mountains and the southern part of Long Ridge. Annual recharge rates in these upland areas range from 0.1 to 0.75 feet, with most upland areas having recharge between 0.1 and 0.2 feet per year. Little if any recharge occurs across the floor of Goshen Valley and recharge rates in the area are less than 0.1 feet per year, with most cells receiving less than 0.01 feet per year of recharge. These results are broadly consistent with radiogenic isotopic results discussed above that show little evidence for recent recharge along most of the valley floor.

Averaged BCM runoff (figure 35) across Goshen Valley generally correlates with in-place recharge (figure 34). Upland areas surrounding Goshen Valley yield the highest runoff, and little runoff occurs across the valley floor. An area of significant runoff shown along the valley floor near Utah Lake in conceptual zone 3 is likely produced by localized impermeable soils in this area.

BCM modeled runoff is not routed away from the cell at which it is calculated, and is assumed to be available for consumption (via evapotranspiration or other surface water uses) and/or outflow (Flint and others, 2004). Some fraction of this runoff is available to reinfiltrate as additional groundwater recharge. Previous work has estimated the amount of runoff that reinfiltrates as recharge is approximately 30%. Therefore total recharge is the sum of recharge plus 30% of runoff (Flint and others, 2004; Heilweil and Brooks, 2010). Based on this method, the average annual recharge from precipitation for Goshen Valley is 8090 acre-ft. Most of this recharge, 4170 acre-ft, occurs in conceptual zone 2. Lesser amounts of 1300 and 2620 acre-ft were calculated for conceptual zones 1 and 3, respectively.

Interbasin Flow

Based on the geology and potentiometric surface, interbasin flow may occur into conceptual zone 1, beneath the Mosida Hills, and into zone 3 along Long Ridge and beneath Goshen Gap. Previous work by Brooks and Stolp (1995) estimated significant interbasin flow into Goshen Valley, 13,000 acre-ft/yr. Their estimate was calculated as the residual component necessary to balance the larger groundwater budget. Along the western boundary of the study area permeable Paleozoic carbonate rocks occur in the Mosida Hills that separate conceptual zone 1 in Goshen Valley from Cedar Valley. Previous work by Feltis (1967), using the Darcy flux method, calculated 2300 to 5000 acre-ft/yr of flow from Cedar Valley into Goshen Valley in this area. These flow estimates were used as starting points for flow from Cedar Valley to Goshen Valley for the Cedar Valley calibrated groundwater flow model (Jordan and Sabbah, 2012). The calibrated flow model produced interbasin flow of 4700 acre-ft/yr. This is the preferred value used in subsequent water budget calculations.

Interbasin flow to conceptual zone 3 likely occurs primarily in Paleozoic carbonate rocks that underlie Long Ridge from approximately Currant Creek north to Goshen Gap and West Mountain. Evidence of this flow is shown by the significant

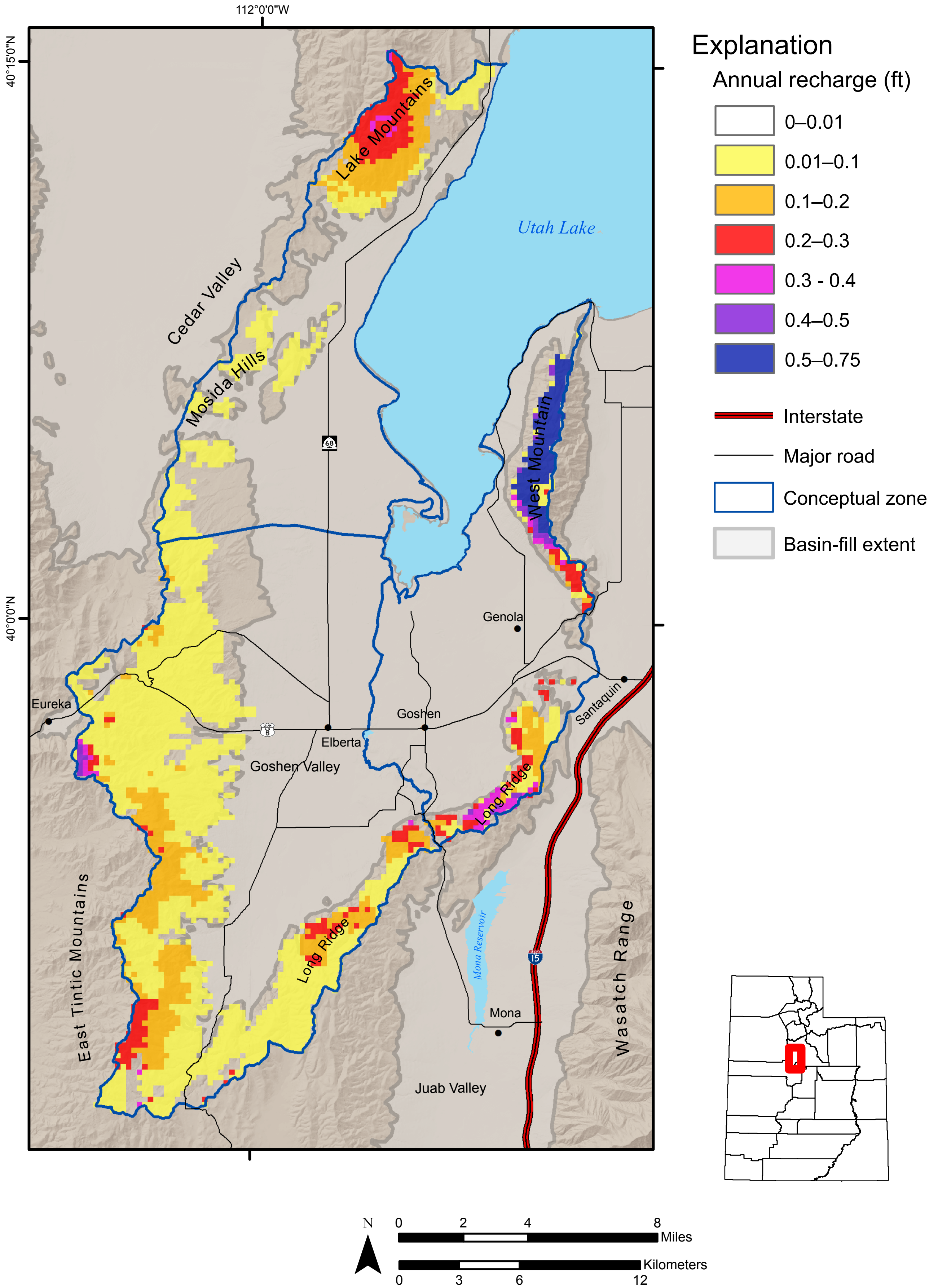


Figure 34. *Basin Characterization Model recharge for Goshen Valley.*

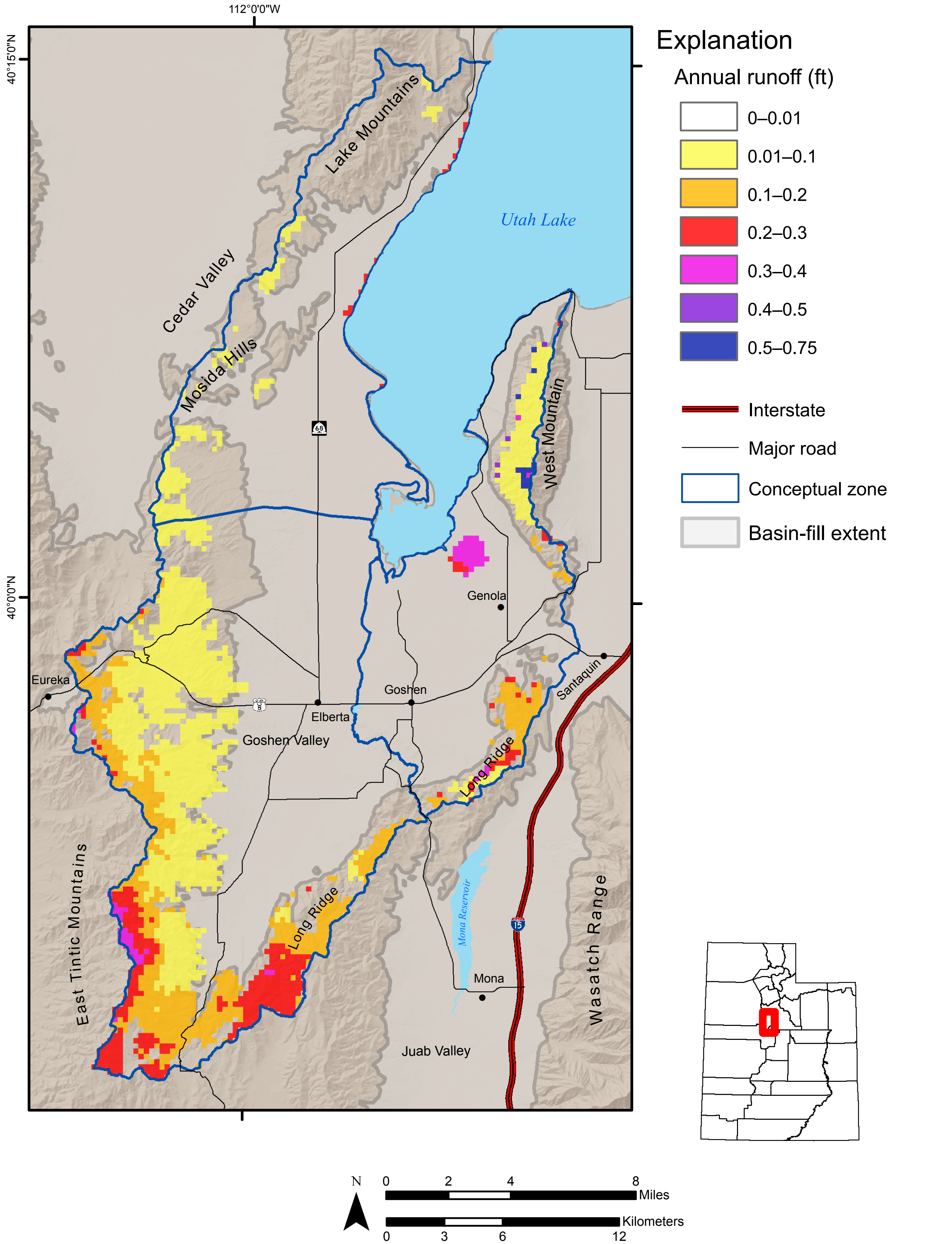


Figure 35. *Basin Characterization Model runoff for Goshen Valley.*

discharge of groundwater likely derived from points outside of Goshen Valley at Goshen Warm Springs as discussed in previous sections. For this study, interbasin flow over a part of the eastern study area boundary is estimated using a modification of the Darcy flux equation:

$$Q = TiL \qquad (2)$$

Where:

Q = total flux (acre-ft/yr)

T = transmissivity of the carbonate rocks (ft^2/day),

i = potentiometric gradient (unitless), and

L = length of the section (ft)

Transmissivity (T) is assumed to be equal to 1000 ft^2/day based on estimates of transmissivity compiled from drillers' logs discussed in previous sections. The potentiometric gradient is taken from the potentiometric surface (figure 11). Gradient (i) is equal to 0.0026 at the northern part of the section and 0.0306 along the southern part. Based on the mapped extent of the Paleozoic carbonates, flow is assumed to be possible along a length (L) of 55,250 feet. Based on these values, the calculated interbasin flow is between 16.6 and 19.5 cfs or 12,000 and 14,200 acre-ft/yr. To be conservative, subsequent water-budget calculations use 12,000 acre-ft/yr for interbasin flow into conceptual zone 3. No attempt was made to delineate the amount of this water that is directly derived from Juab Valley versus water from the Santaquin area. Based on the significant discharge at Goshen Warm Springs and the greater extent of LCAU rocks near Santaquin, it is likely that most of this inflow occurs near Santaquin.

Discharge

Introduction

Groundwater discharge represents the total volume of water lost from the regional groundwater system (Freeze and Cherry, 1979). The principal mechanisms of groundwater discharge include spring flow, evapotranspiration, well withdrawals, subsurface outflow, and change in storage. For this water budget, direct estimates of spring flow, evapotranspiration, and well withdrawals are made. Subsurface outflow or change in storage is estimated as the residual component when all other sources of discharge are balanced against estimates of recharge.

Well Withdrawal

Well water withdrawal for Goshen Valley is based on data collected annually by the USGS and presented periodically in the annual "Groundwater Conditions in Utah" reports (Burden and others, 2017; Smith and others, 2018; Gold and others, 2020) (table 7). These data were published as basin-wide (i.e., all of Goshen Valley) well withdrawal values that are not categorized by location relative to the conceptual zones defined for this study. Unpublished data provided by C. Angeroth (U.S. Geological Survey Utah Water Science Center, written communication, 2018) separated the well discharge by conceptual zone for the period 1964 to 2008. No data by conceptual zone was available for the period of the water budget 2008 to 2017 due to changes in record keeping (C. Angeroth, verbal communication, 2018). To estimate well withdrawal by conceptual zone over the period of interest (2008–2017), the average percent of the total Goshen Valley well withdrawal was calculated for each conceptual zone for data provided for the period from 1964 to 2008. The average relative percentage of the total well withdrawal is 35% for conceptual zone 1, 62% for conceptual zone 2, and 3% for conceptual zone 3. Multiplying the total Goshen Valley withdrawal for the period 2008 to 2017 (19,910 acre-ft/yr) by the relative percentages for each conceptual zone yields estimates of average well withdrawal for each conceptual zone: 6930 acre-ft/yr for conceptual zone 1,12,430 acre-ft/yr for conceptual zone 2, and 550 acre-ft/yr for conceptual zone 3. Figure 36 shows total annual well withdrawal over the period of record for Goshen Valley. Gold and others (2020) examined Goshen Valley when reviewing USGS techniques for estimating groundwater pumping. They noted that 20 of the irrigation wells in Goshen Valley are instrumented with permanent flow meters, allowing for accurate estimates of groundwater pumping in Goshen Valley.

Springs

Water from springs is considered direct discharge from the groundwater system. This water may then reinfiltrate as recharge or be consumed via evapotranspiration. In the study area, significant springs are rare and the few existing springs and seeps lie in the upland mountain areas of Long Ridge south of Currant Creek and the East Tintic Mountains. Fieldwork included visiting most of the spring sites listed on the

Table 7. *Estimated well withdrawal (acre-ft/year).*

Year	Total	Conceptual zone 1	Conceptual zone 2	Conceptual zone 3
2017	23,900	8316	14,926	657
2016	24,100	8386	15,051	663
2015	22,100	7690	13,802	608
2014	22,460	7815	14,027	618
2013	16,070	5592	10,036	442
2012	21,500	7481	13,427	591
2011	16,900	5881	10,555	465
2010	17,200	5985	10,742	473
2009	15,400	5359	9618	424
2008	19,400	6751	12,116	534
Average	19,910	6930	12,430	550

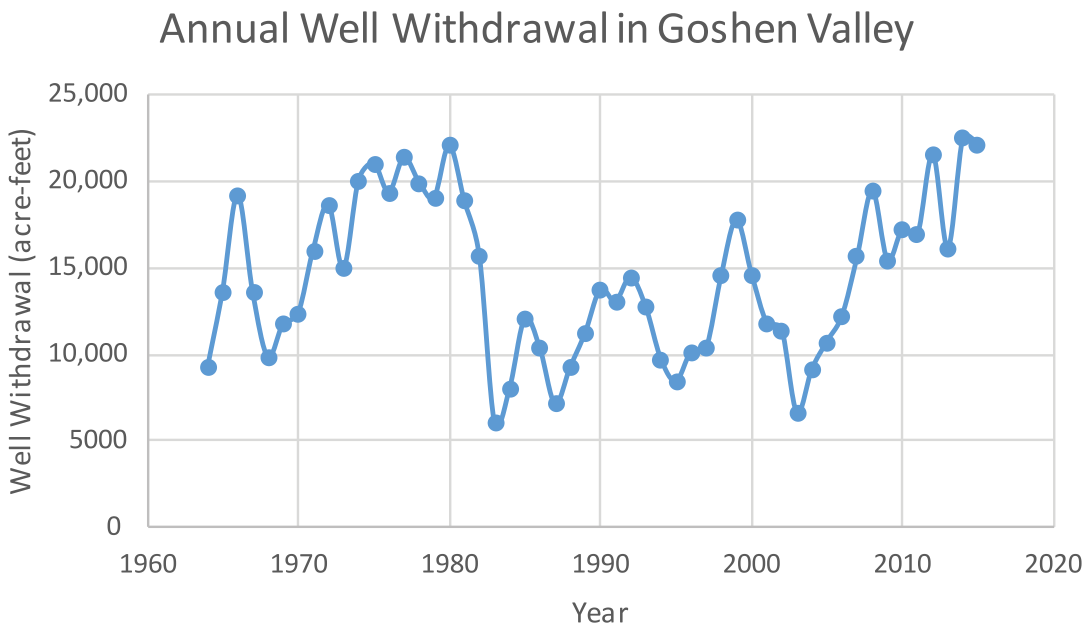


Figure 36. *Annual well withdrawal for Goshen Valley based on data presented by Brooks and Stolp (1995), Burden and others (2017), and Smith and others (2018).*

available 1:24,000-scale topographic maps and verifying flow, or lack of, at these sites. All the observed upland springs are in conceptual zone 2. Water from most of these springs quickly infiltrates or is captured for stock watering. No measurable upland springs were found in conceptual zones 1 or 3. Total flow from all measurable springs in conceptual zone 2 is less than 50 gpm or 80 acre-ft/ yr. Presumably, all upland spring discharge either immediately infiltrates and returns to the groundwater system or is consumed by localized evapotranspiration and is therefore excluded from subsequent water-budget calculations.

The only large springs along the floor of Goshen Valley occur along the central part of Long Ridge, where Goshen Warm Springs consists of a series of spring orifices and pools that issue near the base of carbonate bedrock. Discharge at Goshen Warm Springs is channelized and shunted through a series of large spring pools that ultimately discharge to the Warm Springs and East Warm Springs canals. Surface flow was measured periodically at the head of these canals to capture total spring discharge between summer 2015 and summer 2017. Based on these measurements, total annual discharge at the Goshen Warm Springs is estimated to be 8690 acre-ft/ yr for water-budget calculations. Total measured flow varied by plus or minus 10%. Further details are presented in the Surface Flow section above.

Evapotranspiration

Evapotranspiration (ET) occurs from open water, bare soil, and the transpiration of natural and agricultural plants. Evapotranspiration can account for most of the groundwater discharge and surface-water consumption in arid areas like Goshen Valley. As such, calculation of evapotranspiration is a critical and controlling component of the Goshen Valley water budget. The calculation presented below examines natural evapotranspiration and agricultural evapotranspiration separately via distinct techniques. The calculation uses ET estimates along with estimates of available surface water to determine additional water-budget components, including direct groundwater ET and recharge of unconsumed agricultural irrigation.

Direct evapotranspiration from groundwater systems in the Great Basin commonly occurs in low-elevation areas of phreatophytes and adjoining playa, or bare ground areas where groundwater levels are within 20 feet of the land surface (Nichols, 1993, 1994, 2000). In the central part of the study area, north of Goshen and primarily in conceptual zone 3, much of the valley floor is covered by phreatophytes assumed to account for significant evapotranspiration (Brooks and Stolp, 1995). This area of phreatophytes also includes potentially significant surface water that may be consumed in conjunction with groundwater to supply these evapotranspiration communities. To estimate the total amount of groundwater consumed, an estimate of total natural evapotranspiration was made and balanced with available surface water. The difference was then assumed to represent groundwater discharge from natural evapotranspiration.

Natural evapotranspiration: Natural evapotranspiration occurs from the land surface at varying rates depending on land-cover types. Land-cover types that produce evapotranspiration include open water, bare soil, and plant communities. Previous work in the Great Basin defined a series of common evapotranspiration land-cover types (communities) (Smith and others, 2007) and directly measured evapotranspiration for these communities (Moreo and others, 2007). Each of these communities have representative annual evapotranspiration rates that were obtained by modern micrometeorological methods to the west of the study area (Moreo and others, 2007). Natural evapotranspiration is calculated as the product of the annual rate of a given evapotranspiration community and the area of a given community.

Evapotranspiration communities were mapped using a supervised classification scheme that follows methods presented by Smith and others (2007). The technique uses field data for evapotranspiration community type, in conjunction with supervised analysis of imagery datasets to map evapotranspiration units of defined areas. For this study a total of 61 field sites were classified as a series of evapotranspiration units that represent vegetation communities including moist bare soil, grassland, meadowland, and dense, moderate, or sparse shrubland, riparian forest, and marshland. These sites were augmented with 135 additional sites classified by interpretation of available National Agriculture Imagery Program (NAIP) imagery collected in 2014. Both the field sites and additional sites were input with the four-band summer 2014 NAIP imagery into the Supervised Classification ArcMap toolset to create a grid of evapotranspiration units (figure 37).

The total area of mapped natural evapotranspiration communities covers 9130 acres, primarily east and north of Goshen in conceptual zone 3 (figure 38; table 8). Most of the mapped area consists of various densities of shrubland followed by grassland and riparian woodland. Riparian woodland and marshland are mapped near areas of significant surface water, near Goshen Warm Springs, and the Warm Springs Canal. Elsewhere, the mapped area is a mosaic of shrubland, grassland, and meadowland. Patches of moist bare soil are mapped across the central and northern part of the area.

Annual evapotranspiration rates were calculated for the mapped evapotranspiration communities (table 8). Total annual evapotranspiration from natural communities is 17,613 acre-ft/yr. Riparian woodland and grassland communities account for nearly one-half of the total annual natural evapotranspiration, followed by shrubland and meadowland communities. Marshland and moist bare-ground communities combine for a smaller fraction of the total natural evapotranspiration. Subsequent water-budget calculations rely on this estimate of evapotranspiration in conjunction with available surface water over the mapped area to estimate actual groundwater evapotranspiration.

Crop evapotranspiration: Nearly 40% of the floor of Goshen Valley is used for irrigated agriculture. Crop types range from irrigated pasture to various orchard varieties. Irrigation of these crops uses a mixture of surface water (from canals) and groundwater (from wells and shallow groundwater in conceptual zone 3) depending on location. Because subsequent water-budget calculations require estimates of return flow into the groundwater system from irrigated agriculture and total evapotranspiration from the groundwater, an estimate of crop consumption was calculated and then balanced against applied irrigation water for each of the three subbasins.

Total crop evapotranspiration was calculated based on crop-type maps from land-use data (Utah Division of Water Resources, 2018). Standard rates of ET taken from the Utah State Extension crop consumption values for Santaquin (Hill and others, 2011) were multiplied by the corresponding acreage of these crop types in each of the three conceptual zones. Figure 39 shows the extent of the various crop evapotranspiration units. Total irrigated agricul tural evapotranspiration is 8208 acre-ft/yr for zone 1, 13,557 acre-ft/ yr for zone 2, and 16,827 acre-ft/yr for zone 3 (table 9).

Groundwater evapotranspiration: Groundwater evapotranspiration is the consumption of water at the earth's surface due to direct evaporation of groundwater from soils in areas having shallow groundwater, and water taken up from groundwater that is transpired by plants during the growing process. In much of the arid Great Basin, ET is a dominant water-budget component of discharge for both surface water and groundwater. In Goshen Valley, evapotranspiration occurs across irrigated agricultural lands and a variety of natural plant communities using a combination of precipitation, applied surface water, and groundwater. To calculate groundwater ET, it is therefore necessary to balance multiple sources of surface water against both agricultural and natural ET (table 10). The difference between total ET and total available surface water may therefore come directly from the groundwater system in areas of conceptual zone 3 where groundwater is within 20 feet of the surface. Total groundwater evapotranspiration in conceptual zone 3 is 5320 acre-ft/yr. Depth to water generally greater than 20 feet is assumed to preclude direct evapotranspiration of groundwater across conceptual zones 1 and 2.

Unconsumed irrigation water: Irrigated agriculture covers a significant part of Goshen Valley and includes crop and irrigation types ranging from flood irrigated pasture to sprinkler irrigated corn. Irrigation water not consumed by plant growth may infiltrate and become part of the groundwater recharge budget. In conceptual zones 1 and 2 a mixture of groundwater and water pumped from Utah Lake is used for crop irrigation. To calculate unconsumed irrigation, it is necessary to balance applied irrigation from both well withdrawal and Utah Lake pumpage against agricultural ET. Estimates of total Utah Lake pumpage are based on water-use data reported to the Utah Division of Water Rights (2016) and unreported estimates provided by Farmland Reserve (written communication, 2018). An average of the available data yields 6900 acre-ft/yr of pumpage from Utah Lake for agricultural irri-

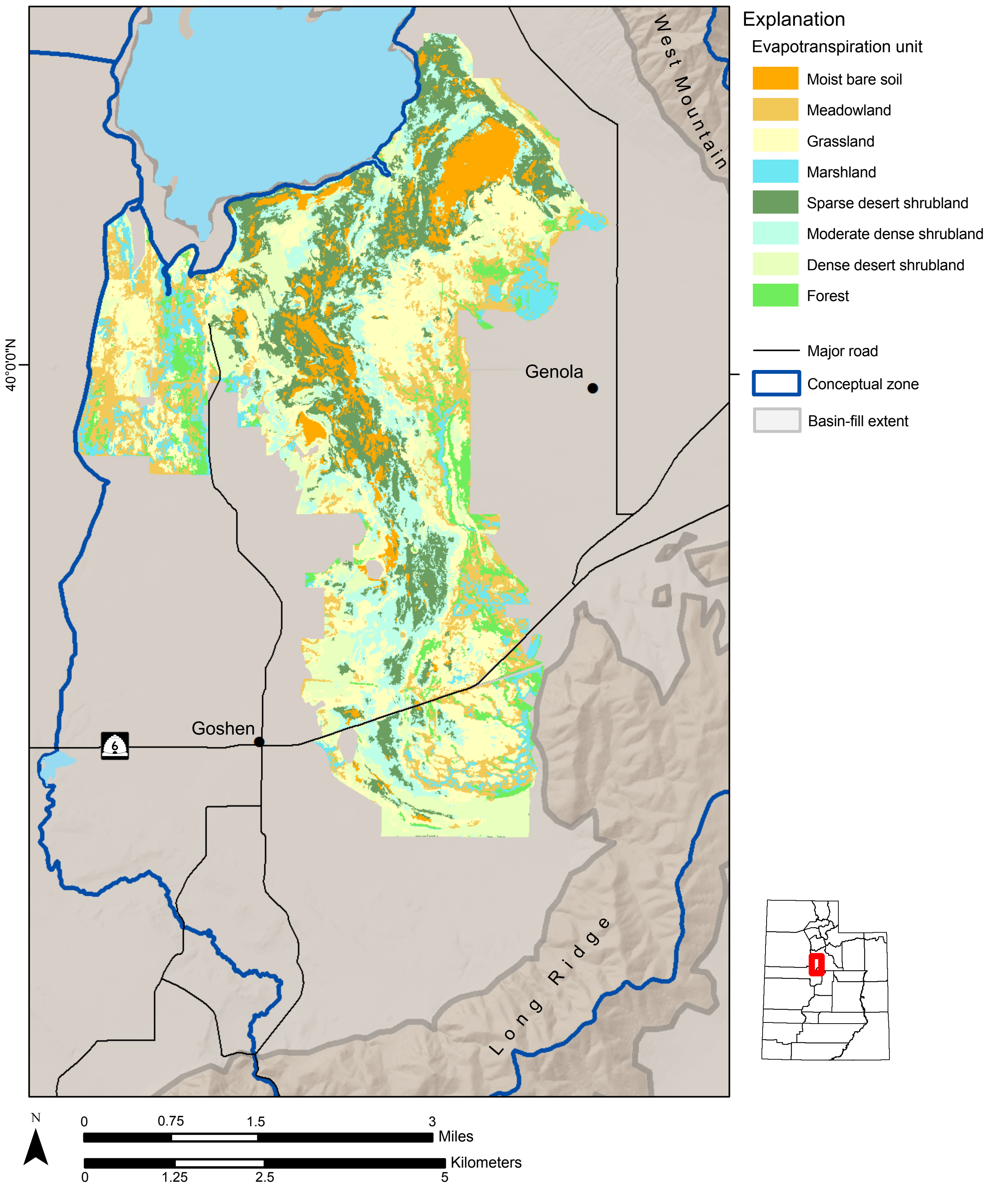


Figure 37. Natural evapotranspiration units in conceptual zone 3.

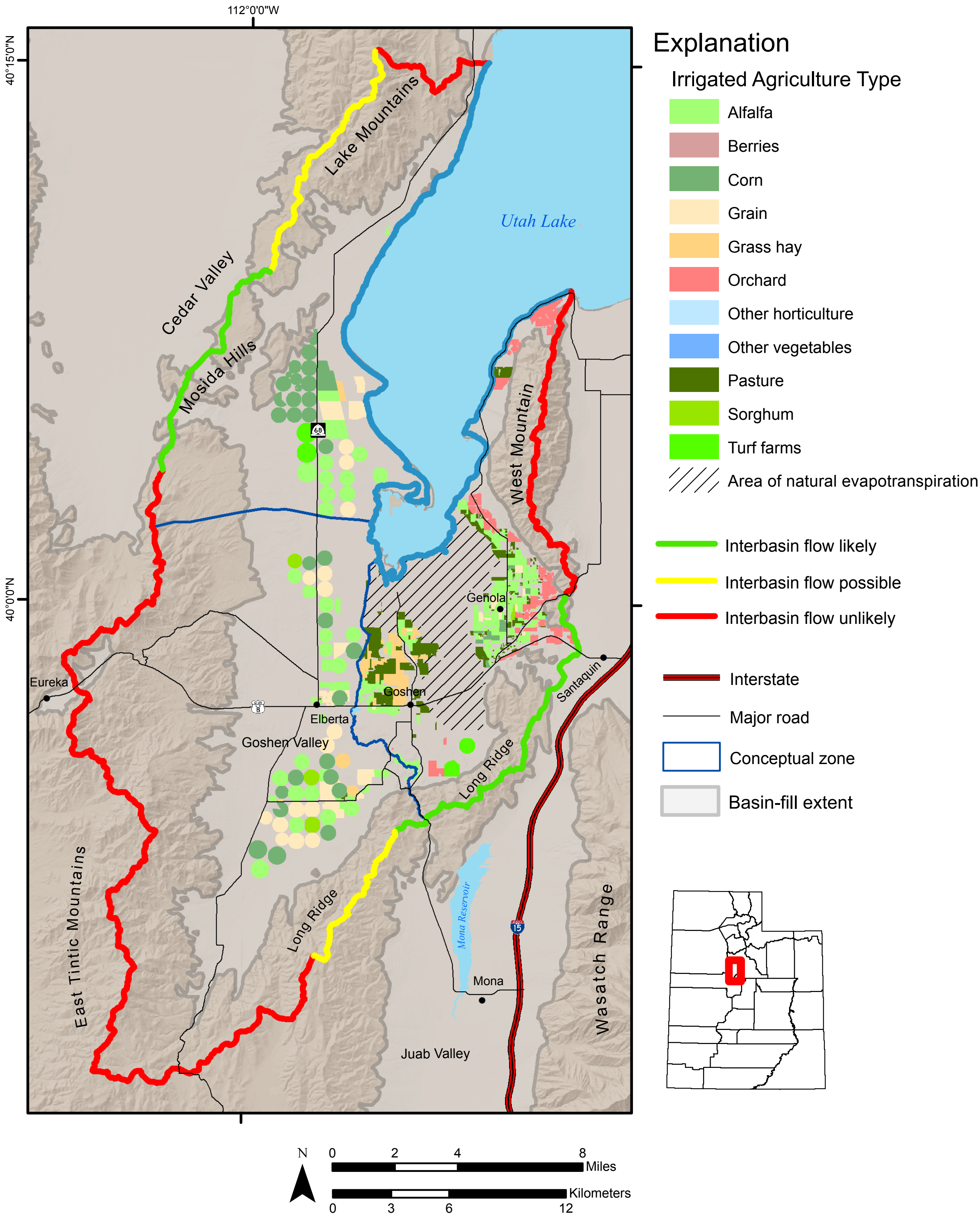


Figure 38. *Irrigated agriculture crop type from the Utah Division of Water Resources (2018).*

Table 8. Wetland evapotranspiration summary.

ET community	Modeled Area (acres)	Annual ET (ft)	Annual ET volume (acre-ft/yr)
Moist bare soil	482	2.00	964
Grassland	1920	2.14	4109
Meadowland	1022	2.59	2647
Sparse desert shrubland	864	0.90	778
Moderate dense shrubland	2152	1.07	2303
Dense desert shrubland	892	1.24	1106
Riparian woodland	1506	3.00	4518
Marshland	292	4.07	1188
Total	9130		17,613

Table 9. Agricultural evapotranspiration by conceptual zone.

Ag unit	Agricultural ET (acre-ft/yr)		
	Zone 1	Zone 2	Zone 3
Alfalfa	3711	6337	5661
Berries	--	--	20
Corn	2670	2946	269
Grain	1132	3373	271
Grass hay	118	284	1343
Orchard	--	--	5119
Other vegetables	--	--	12
Pasture	3	69	3703
Sorghum	--	548	43
Turf farms	574	--	386
Total	8208	13,557	16,827

Table 10. Groundwater evapotranspiration calculation for conceptual zone 3 (acre-ft/yr). Groundwater evapotranspiration is the difference between total applied surface water and the sum of natural and agricultural evapotranspiration.

Applied surface water			Evapotranspiration (ET)		
Currant Creek	Goshen Warm Springs	Highline Canal	Natural ET	Agricultural ET	Groundwater ET
6660	8690	13,760	17,600	16,830	-5320

gation (table 11). No data exist for the relative distribution of Utah Lake pumpage between conceptual zones 1 and 2. Instead, pumpage is divided between zones 1 and 2 based on the relative area of irrigated lands where approximately 30% of Utah Lake pumpage is assumed to be applied to zone 1 and 70% is applied to zone 2. The difference between total applied irrigation water, from well withdrawal and Utah Lake pumpage, and agricultural ET calculated above equals 680 acre-ft/yr in zone 1 and 3810 acre-ft/yr in zone 2 (table 11). Zone 3 does not require an estimate of unconsumed irrigation; i.e., crop ET is greater than applied water, and crops may consume groundwater in shallow depth-to-water areas.

Change in Storage

Change in storage represents water permanently extracted from or added to the groundwater system. Long-term trends in groundwater levels record changes in aquifer storage (Freeze and Cherry, 1979). Areas that show a decline in water levels through time consequently have experienced a change in storage. In Goshen Valley, long-term water-level decline is apparent in conceptual zone 2 and the southern end of conceptual zone 1. For these zones, discharge is greater than recharge and the residual is the change in storage. Therefore, conceptual zone 1 has annual change in storage of -245 acre-ft/yr and conceptual zone 2 has an annual change in storage of -2700 acre-ft/yr.

Discharge to Utah Lake

Discharge to Utah Lake may occur from all conceptual zones. Constraints on this discharge are generally lacking, however, and this component is considered the remainder from a given conceptual zone budget. In this way it is the least constrained of the groundwater-budget terms and may represent a significant source of error. Previous work by Brooks and Stolp

Table 11. *Estimate of unconsumed irrigation (acre-ft/yr) as the difference between total applied water and agricultural evapotranspiration.*

	Well withdrawal	Utah Lake pumpage	Total applied water	Agricultural ET	Unconsumed irrigation
Conceptual zone 1	6930	1960	8890	8210	680
Conceptual zone 2	12,430	4940	17,370	13,560	3810

(1995) also estimated discharge to the lake as the remainder (3600 acre-ft/yr) from the groundwater budget of the entire Goshen Valley.

Conceptual zones 1 and 2 have declining water levels implying discharge exceeds recharge, and this difference is assumed to be accounted for by change in storage and declining water levels (figure 14). Therefore, we assume that there is no discharge to Utah Lake from zones 1 and 2. Conceptual zone 3, along the eastern side of Goshen Valley, has recharge that exceeds discharge, stable groundwater levels, and no change in storage. The difference between recharge and discharge in zone 3 is 1830 acre-ft/yr and this water is assumed to discharge to Utah Lake in the subsurface.

Water-Budget Summary

Water-budget components show that for Goshen Valley, discharge is greater than recharge by less than 3000 acre-ft/yr (figure 39, table 12). This deficit is assumed to be accounted for by long-term water-level decline and consequent change in storage, primarily in conceptual zone 2 and to a lesser degree in conceptual zone 1. The primary driver of discharge in conceptual zone 2 is well withdrawal. Conceptual zone 3 is broadly in balance across recharge and discharge, and up to 1830 acre-ft/yr of water may discharge from conceptual zone 3 into Utah Lake.

DISCUSSION

We delineated three subbasins, or conceptual zones, in Goshen Valley. As described above in the Conceptual Model of Groundwater Flow section, these zones are characterized by unique geochemistry, groundwater-flow paths, recharge components, groundwater basin boundary conditions, water-level trends, groundwater age, and geophysical constraints.

Groundwater flows into conceptual zone 1 in the northwestern part of the Goshen Valley study area as interbasin flow through LCAU rocks from adjacent Cedar Valley (4700 acre-ft/yr). Most of zone 1 is characterized as a primary recharge area, although recharge from precipitation is estimated to be only about 20% of total recharge. Groundwater flows east through the UBFAU toward Utah Lake through agricultural areas where well withdrawal is a moderate 6930 acre-ft/yr compared to the other conceptual zones. Depth to water ranges from greater than 100 feet below land surface in the Mosida Hills to near land surface adjacent to Utah Lake. Basin fill is estimated to thicken eastward from zero feet in the Mosida Hills to about 1000 feet near Utah Lake. Groundwater levels in the northern part of zone 1 have shown little change because recharge (mostly interbasin flow) is in balance with the moderate amount of groundwater use and lack of net ET. Groundwater-level decline in the southern part of conceptual zone 1 is likely a result of the factors contributing to the decline in conceptual zone 2. Groundwater chemistry in zone 1 is dominated by sodium and chloride and has TDS ranging from 500 to 2000 mg/L. Nitrate concentrations are low. Unconsumed irrigation and domestic return flow are only estimated to be 685 acre-ft/yr, which would tend to limit leaching of nitrate from crop lands. However, arsenic is elevated—four of the six wells sampled for arsenic have concentrations exceeding the drinking water standard of 10 µg/L. The elevated arsenic may be due to redox interactions with alluvial and carbonate aquifer materials (Selck and others, 2018). Based on tritium and carbon analysis, groundwater in zone 1 was recharged more than a thousand years ago. Depleted stable isotope concentrations in groundwater samples from this zone relative to those from zone 2 may also indicate an old recharge source or a source from higher elevations than the water in zone 2. Based on groundwater basin boundary conditions, groundwater-flow paths, and groundwater chemistry, underflow from Cedar Valley that recharged long ago and in the mountainous parts of the Cedar Valley groundwater basin dominates groundwater in conceptual zone 1.

The groundwater in conceptual zone 2 in the southwestern part of the study area displays the most impact from land use compared to the other two conceptual zones. Here, an area of heavy agricultural use (well withdrawal of 12,430 acre-ft/yr on average, or 62% of all well withdrawal in the study area) south of Elberta is the likely cause of an eight-square-mile zone of low-gradient potentiometric surface and degraded water quality. The main sources of recharge to conceptual zone 2 are infiltration of precipitation (4170 acre-ft/yr) and unconsumed irrigation (3810 acre-ft/yr) through the primary recharge area that encompasses the western and southern two-thirds of the surface area of the zone. Seepage from Currant Creek provides an additional 1740 acre-ft/yr to the eastern part of conceptual zone 2. The deepest part of the basin occurs north of Elberta and Goshen, where basin-fill thickness is as much as 3500 feet. Depth to water over much of zone 2 is between 100 and 200 feet below land surface. The water table is as much as 400 feet deep in the uplands and shallower than 100 feet deep near the northern reach of Currant Creek on conceptual zone 2's eastern boundary. Recharge is not sufficient to balance discharge in conceptual zone 2, resulting in removal of groundwater from storage as shown by long-term water-level declines. Ground-

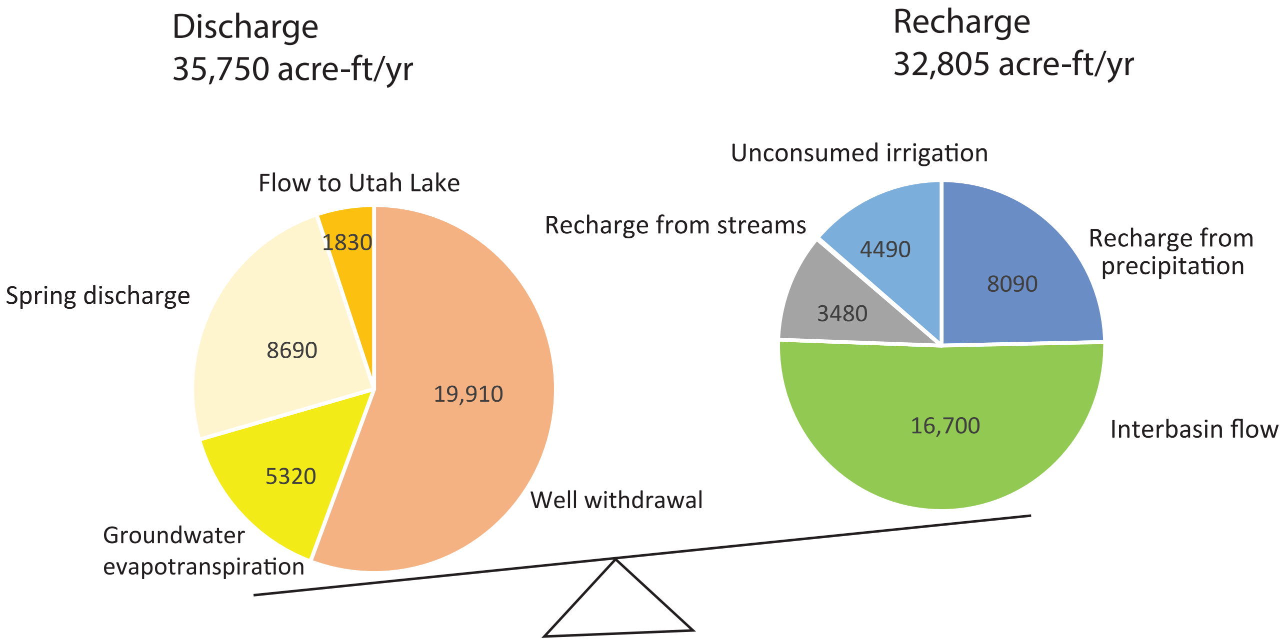


***Figure 39.** Summary of water-budget components for Goshen Valley.*

***Table 12.** Water budget components in acre-ft/yr.*

	Component	Conceptual zone			Total
		1	2	3	
Recharge	Recharge (precip+runoff infil)	1300	4170	2620	8090
	Interbasin flow	4700	0	12,000	16,700
	Perennial stream seepage	0	1740	1740	3480
	Domestic return flow	5	10	30	45
	Unconsumed irrigation	680	3810	0	4490
	Total Recharge	6685	9730	16,390	32,805
Discharge	Well withdrawal	6930	12,430	550	19,910
	Groundwater ET	0	0	5320	5320
	Spring discharge	0	0	8690	8690
	GW discharge to Utah Lake	0	0	1830	1830
	Total discharge	6930	12,430	16,390	35,750
	Change in storage	-245	-2700	0	-2945

water-level elevation at all five long-term water-level monitoring locations in zone 2 show potentiometric-level decline beginning in the mid-1990s of between 25 and 50 feet through 2018. Groundwater chemistry in zone 2 is varied, but the zone of water-level decline impact from agriculture is consistently dominated by calcium-chloride type water. TDS concentrations in samples from wells in the UBFAU of zone 2 generally range from 500 to 1500 mg/L except for one well having a higher TDS of 2362 mg/L. The sample having the high TDS also had the highest nitrate concentration found in the study area (256 mg/L nitrate), which Selck and others (2018) associated with nitrate leaching from land application of dairy waste by unused irrigation water. The median arsenic concentration from well samples in zone 2 is lower than other zones, supporting the conclusion by Selck and others (2018) that arsenic may be associated with groundwater interactions with carbonate rocks, as the bedrock in conceptual zone 2 is VU. As in conceptual zone 1, groundwater in zone 2 is old but was not particularly cool at the time of recharge. The relatively warm noble gas recharge temperature may be a signature imparted from geothermal water recharge from the volcanic terrain in the East Tintic Mountains. Based on groundwater basin boundary conditions, groundwater flow paths, and groundwater chemistry, zone 2 groundwater is a mixture of water that recharges locally and water from Currant Creek (Mona Reservoir) that has been impacted by agriculture uses.

Conceptual zone 3 in the eastern half of the study area has the largest overall water budget of the three conceptual zones identified in this study, despite its intermediate area and basin-fill thickness compared to the other zones. This one zone receives 50% of the total recharge for the study area, primarily as interbasin flow through Long Ridge from Juab Valley. Groundwater flows northwest into the study area through carbonate rocks underlying Long Ridge towards Utah Lake. Along the way, Goshen Warm Springs discharges about 8690 acre-feet of water per year. ET is highest in this zone because the area supports orchards, other crops, and a large community of natural vegetation. Total ET is estimated to be greater than 34,000 acre-ft/yr, which we estimate can be mostly supplied by Goshen Warm Springs and imported water from Currant Creek (Mona Reservoir) and the Highline Canal. The total water from these sources is not enough to support all the ET, and we estimate ET is consuming an additional 5320 acre-feet from groundwater, facilitated by the shallow water table and large groundwater discharge area south of Utah Lake. At the end of the groundwater flow paths, we estimate 1830 acre-feet of groundwater may be discharged to Utah Lake from zone 3. Groundwater quality, as measured by TDS, spans the entire range of concentrations determined by our sampling, with Highline Canal water having low TDS concentration and spring discharge in the wetlands north of Goshen having TDS concentrations over 8000 mg/L. The range of TDS is indicative of the variety of groundwater recharge sources and probable concentration from near-surface ET. Arsenic is high in several wells toward the end of the groundwater flow path, perhaps due to long contact time with carbonate rocks. The prevalence of tritium in most of the groundwater samples collected from conceptual zone 3 indicates a significant fraction of modern recharge, likely from infiltration of Highline Canal water and infiltration of precipitation through a thin vadose zone. Moderate amounts of modern carbon point to some mixing of old groundwater, probably sourced as underflow from Juab Valley. Recharge temperatures are mixed across the zone because the various recharge sources span a large range of elevations. Goshen Warm Springs has a mix of young and old groundwater.

SUMMARY AND CONCLUSIONS

Goshen Valley in Utah County is an agricultural area located at the southern end of Utah Lake that supports significant wetlands and several small municipalities, all of which rely on both groundwater and surface water. The potential for future growth and land-use changes in this area and consequent increases and changes in groundwater use are of concern to groundwater managers. We produced a hydrogeologic framework and revised conceptual model and water budget for Goshen Valley to provide groundwater managers with updated and accurate information on which to base future management decisions.

A principal objective of this study was to characterize the hydrogeology and groundwater conditions in Goshen Valley and calculate a water budget for the groundwater system. We considered primary hydrogeologic units and their extent to characterize the basin-fill and important bedrock aquifers. We collected new groundwater samples to better determine groundwater flow paths, residence time, sources of recharge and discharge, and baseline water quality. We measured stream and canal flow to quantify surface water input to the groundwater system and to use as input in evapotranspiration calculations. We measured water levels in wells to construct a current potentiometric surface map for the basin-fill aquifer. We collected new gravity data used to model basin-fill thickness in Goshen Valley. We used a supervised classification scheme and imagery analysis to estimate ET from natural plant communities and standard ET rates and agricultural land use data to estimate crop ET.C ombined, we incorporated these new data to construct a hydrogeologic framework and conceptual model for groundwater in Goshen Valley. Based on these data, we delineated three sub-basins into three conceptual zones defined by unique characteristics and created a water budget for each zone.

Groundwater in Goshen Valley resides primarily in the upper basin-fill aquifer unit (UBFAU) and lower carbonate aquifer unit (LCAU) hydrostratigraphic units. The LCAU has the highest transmissivity of any aquifer unit in the study area and the UBFAU has slightly lower transmissivity. Most wells in Goshen Valley are completed in the UBFAU, which covers much of the valley floor. The UBFAU is the upper part of the basin fill, which overall is generally less than 1500 feet thick in Goshen Valley based on gravity data inversions. The LCAU crops out along Long Ridge and the Mosida Hills. Important spring discharge at Goshen Warm Springs issues from the LCAU. Relatively impermeable volcanic rocks (VU) occur along much of the upland parts of the southern part of Goshen Valley.

The boundary of the Goshen Valley study area is defined by three categories for potential for interbasin flow: interbasin flow likely, interbasin flow possible, and interbasin flow unlikely. Large sections of the basin boundary are categorized as unlikely for interbasin flow, especially in the southwestern part of the study area due to relatively impermeable VU rocks and probable groundwater mounding. Interbasin groundwater flow is likely along contiguous areas.

Depth to groundwater in Goshen Valley ranges from at or just below the land surface to greater than 400 feet. Groundwater is within 30 feet of the land surface near and north of Goshen, in areas of irrigated pastures and wetlands that extend east toward Long Ridge and Goshen Warm Springs, and to the north towards Genola. The upland areas of West Mountain, the Lake Mountains, and Long Ridge have groundwater greater than 400 feet below land surface. The depth to groundwater is greater than 200 feet in areas of potential groundwater inflow into Goshen Valley: between Santaquin and Genola, along the northern end of Long Ridge, and in the Mosida Hills.

Groundwater movement is from upland parts of the study area toward the valley floor and Utah Lake. The continuity of groundwater-level elevations between upland areas underlain by LCAU along the northern end of Long Ridge and the Mosida Hills with those in the UBFAU suggest good communication between this bedrock aquifer and the adjacent basin fill.

Long-term water-level change is evident across much of Goshen Valley, with the most significant decline present in conceptual zone 2 and the southern part of conceptual zone 1. The area of maximum groundwater-level decline—over 50 feet—is centered a few miles south of Elberta in conceptual zone 2. The VU rocks in the uplands of conceptual zone 2 limit recharge of interbasin flow or precipitation infiltration and there is not enough recharge to offset groundwater removal from storage by agricultural pumping. Groundwater levels in the northern part of zone 1 have shown little change because interbasin flow is in balance with the small amount of groundwater use, and Utah Lake acts as a local base level. Groundwater-level decline in the southern part of conceptual zone 1 is likely due to the imbalance in conceptual zone 2. Groundwater levels show relatively little change across the period of record in conceptual zone 3 in the eastern part of the study area, indicating that recharge and discharge are in balance in this zone. We surmise that the reason for the relative stability of groundwater levels in conceptual zone 3 is because the discharge of groundwater to wetlands and Utah Lake is balanced by (1) recharge to the UBFAU from seepage of water from Goshen Warm Springs and Currant Creek, (2) recharge from interbasin flow from Juab Valley, and (3) lack of heavy groundwater pumping.

Groundwater in Goshen Valley spans a range of chemistries that include locally high TDS and elevated nitrate and arsenic concentrations. Water-quality chemistry varies as a continuum from calcium-bicarbonate to sodium-chloride-type waters. Overlap of major ion chemistry exists across the valley, and localized trends are poorly resolved due to the spatial distribution of the samples and heterogeneous aquifer matrix. Water from the eastern part of the study area in conceptual zone 3 has higher sulfate than other samples and contains greater proportions of sodium than other areas. Water samples from the southern part of the valley southwest of Goshen contain relatively high fractions of calcium and chloride. Water quality in the northwestern part of the study area is characterized by greater fractions of calcium and bicarbonate. Overlap in chemistry exists in water samples from Currant Creek, the Highline Canal, and groundwater.

Nitrate concentrations range from less than 0.1 to 256 mg/L nitrate as nitrogen, with most samples having concentrations less than 2.5 mg/L and a median of 0.8 mg/L. The lower concentrations exist across much of the eastern and northwestern parts of the study area. Higher nitrate concentrations are in wells primarily in the southern part of Goshen Valley, south and west of the town of Goshen. Six samples from this area have nitrate concentrations greater than 10 mg/L, the highest value being 256 mg/L. This zone of high nitrate corresponds to an area of livestock feed lots likely associated with leaching of manure affiliated with these operations. Nitrogen isotopes in nitrate show a depleted $\delta^{15}N$ signature for 16 samples. The dominant isotopic signatures are indicative of a mixture of soil, fertilizer, septic systems, and manure; the anomalously high nitrate concentration (256 mg/L) is from water from an irrigation well. For wells on agricultural land dominated by feed lots, dairy operations, and homes having septic systems, the amount of $\delta^{15}N$ in water is expected to be greater than 10 parts per thousand; most $\delta^{15}N$ values for our samples fall between 5.1 and 7.8 parts per thousand. We suspect that nitrate with a depleted $\delta^{15}N$ signature, as found in soil and fertilizer, is mixing with nitrate enriched in ^{15}N, likely from a manure source. Our results indicate that dilution, not denitrification, is the dominant process of nitrate removal from the environment in Goshen Valley.

Arsenic values across Goshen Valley range from less than 1 µg/L to greater than 62.9 µg/L. Nearly one-third of all samples had arsenic concentrations greater than the maximum contaminant level of 10 µg/L. Most of these high-arsenic samples are located across the central and eastern part of the study area with several other high-arsenic samples sporadically distributed across the central and northwestern part of Goshen Valley. High arsenic values exist in water primarily from basin fill, although a few wells with high concentrations were in samples from wells completed in the LCAU. Localized high arsenic is assumed to be the result of complex water-rock interactions driven in part by changes in redox conditions (Selck and others, 2018).

Stable isotopes of hydrogen and oxygen in water indicate that groundwater recharges from various locations, with most samples showing characteristics of an evaporative component from similar, relatively arid regions described in previous studies. One-half of the isotope samples represent groundwater recharged from the floor of Goshen Valley that, depending on their location, may be local recharge, primarily from the East Tintic Mountains, or far-traveled groundwater recharged either in Cedar Valley to the west, or east of the study area along the Wasatch Range front. Stable isotope compositions of groundwater samples in much of conceptual zone 2 have deuterium that is enriched relative to conceptual zones 1 and 3. This may result from most recharge being sourced from relatively low-elevation precipitation. Groundwater samples in conceptual zone 1 are depleted relative to groundwater in conceptual zone 2. This relative depletion may result from groundwater being sourced from cooler uplands, or older precipitation in the upper parts of Cedar Valley that entered as underflow. Groundwater in conceptual zone 3 spans a greater range of deuterium values including depleted values near Goshen Warm Springs, and relatively enriched samples north and west of Genola. Depleted values may represent cool recharge from the Wasatch Range that entered the valley as underflow.

Most water samples in Goshen Valley are old, with some evidence of recent groundwater recharge. Carbon isotopes were analyzed in 23 samples from wells completed in bedrock and basin fill and several springs. Values range from 4 to 76 PMC across Goshen Valley. Tritium concentrations range between 0.05 and 7.8 TU. Fourteen of the 32 samples have tritium less than 0.5 TU. All tritium samples collected in conceptual zone 1 contain less than 0.5 TU. Tritium results indicate most young water and active recharge occurs across the eastern part of Goshen Valley in conceptual zone 3. In conceptual zones 1 and 2, tritium concentrations are low and indicate little recharge to groundwater since 1950.

All samples in conceptual zone 1 and most samples in conceptual zone 2 consist of old groundwater. These waters may be either far traveled or in areas with very low modern recharge. Conceptual zone 3 also contains several old samples located along the valley floor. East of this area, much of the groundwater, including Goshen Warm Springs in conceptual zone 3, is mixed with varying components of young and old groundwater. These samples include both recently recharged water and older, possibly far-traveled groundwater recharged to the east of the study area. Three samples across Goshen Valley represent modern groundwater. Two of these samples are located along the flanks of West Mountain and the East Tintic Mountains, and a third sample is located near Currant Creek west of Goshen.

Dissolved noble gases in groundwater provide an indication of the temperature and pressure conditions at which recharge occurred and a measure of the time since recharge. We collected 20 samples for dissolved gas from springs and wells across the valley floor and several upland locations in Goshen Valley. The data show recharge temperatures ranging from 2.4° to 21.1°C, averaging between 10° and 20°C. The lowest recharge temperatures (less than 10°C) exist at Goshen Warm Springs, an upland spring in the East Tintic Mountains, and a flowing well north of Goshen. Samples at Goshen Warm Springs have average recharge temperatures less than those that would result if recharge occurred upgradient of the spring heads along Long Ridge. However, these temperatures likely result from cool recharge east of Santaquin along or in the Wasatch Range via underflow to Goshen Warm Springs. The temperature for the flowing well north of Goshen is lower than the expected and may also represent groundwater recharged along or in the Wasatch Range. The low average recharge temperatures in the East Tintic Mountains are from an upland spring that contains elevated tritium concentrations and likely represents recent recharge temperatures in the uplands. Samples with average recharge temperatures between 10° and 15°C occur across the floor of Goshen Valley including at sites near Goshen and in the southwestern corner of the valley. Other sites with these same temperatures occur between Genola and Santaquin and near the shore of Utah Lake. Groundwater at all these sites likely recharged within the study area either near or upgradient of the sites, along the floor of Goshen Valley, or near the valley margin. The remaining dissolved gas samples have average recharge temperatures greater than 15°C and up to 21°C. These samples may have equilibrated in areas of elevated water-table temperatures, such as the southwestern part of the valley and the adjoining low-elevation parts of the East Tintic Mountains. Overall, we believe dissolved gas recharge temperatures support localized recharge outside of Goshen. The highly variable nature of groundwater chemistry and large range of groundwater age are a result of the variety of recharge sources and aquifer matrices found in Goshen Valley.

We developed a water budget for each conceptual zone delineated by this study. The water budget is based on estimates of discharge calculated from well withdrawal and evapotranspiration calculated for natural and agricultural plant communities. Recharge is estimated as the sum of interbasin flow, stream and canal seepage, agricultural infiltration, and recharge from precipitation. Total recharge is 32,805 acre-ft/yr and total discharge is 35,750 acre-ft/yr. Most recharge is likely from interbasin flow and minor amounts from precipitation and infiltration of surface water. Most discharge is from well water withdrawal with minor spring discharge and groundwater evapotranspiration. Water-budget components show discharge is greater than recharge by about 3000 acre-ft/yr. This deficit or change in storage is manifested as long-term water-level decline in conceptual zone 2, and to a lesser degree, in conceptual zone 1. The primary driver of discharge in conceptual zone 2 is well withdrawal. Conceptual zone 3 is broadly in balance across the various sources of recharge and discharge, and up to 1830 acre-ft/yr of water may discharge from conceptual zone 3 into Utah Lake. Minimal discharge from groundwater likely flows to Utah Lake from zones 1 or 2.

Groundwater in Goshen Valley resides in either basin-fill or consolidated bedrock aquifers. Most existing wells are completed in the basin-fill aquifer along the valley floor. Recharge to these aquifers may occur from direct infiltration or runoff of precipitation, seepage from perennial streams, seepage from unconsumed irrigation, and subsurface inflow from adjoining mountain blocks and areas of interconnected basin fill—the latter providing fully one-half of the recharge to the basin. More than one-half the discharge from the groundwater system occurs as pumping from wells. The remainder of discharge is from springs, evapotranspiration (ET) from natural vegetation and irrigated agriculture, and subsurface discharge to Utah Lake (minor). Overall, our work shows updated hydrogeologic, geochemical, and potentiometric data in conjunction with refined water-budget techniques to define the hydrogeology and water budget for Goshen Valley.

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APPENDICES

APPENDIX A

Select Well Logs for Goshen Valley

Link to supplemental data:

https://ugspub.nr.utah.gov/publications/special_studies/ss-171/ss-171a.xlsx

APPENDIX B

Water Levels Used to Construct Potentiometric Surface

Link to supplemental data:

https://ugspub.nr.utah.gov/publications/special_studies/ss-171/ss-171b.xlsx