HYDROLOGIC ASSESSMENT OF THE SURFACE WATER AND GROUNDWATER RESOURCES OF CASTLE VALLEY, UTAH: PART 1: HYDROLOGIC AND ENVIRONMENTAL ANALYSIS (HESA) AND PRELIMINARY WATER BUDGET

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1 INTRODUCTION

Under an agreement with Town of Castle Valley, Utah, Hydrologic Systems Analysis LLC (HSA) of Golden, Colorado, in conjunction with Heath Hydrology, Inc. (HHI) of Boulder, Colorado, was tasked: 1) to perform a Hydrologic and Environmental System Analysis (HESA) of the surface water and groundwater resources of the valleys and uplands of the Castle Creek Watershed and Castle Valley Groundwater Basin in the vicinity of the Town of Castle Valley in Grand County, Utah; 2) develop hydrological, hydrogeological and other data bases necessary for constructing a water budget for the Valley; and based on the HESA results and GIS databases developed: 3) develop an as-accurate-as-possible water budget for the Valley in support of watershed management issues including water supply and allocation, water quality and protection, and watershed protection; and 4) determine the siting and protecting of a municipal well and a shallow well(s) near the Castle Valley Ditch Co. diversion to augment surface flows in Castle Creek and irrigation ditches. Each of these tasks constitutes a phase of the project. This report contains the results of phase 1, Hydrologic and Environmental System Analysis (HESA) and includes a preliminary water budget analysis.

The study area is located between the La Sal Mountains to the south, the Colorado River to the north, the Porcupine Rim to the west, and the Castle Spires Rim to the east (Figures 1 and 2). The delineation of the study area is based on the nature and extent of the major hydrogeological systems present, the surface hydrology of the area, and water resources related land use considerations. The area covers the Castle Creek and Placer Creek watersheds as delineated in the GIS files downloaded from the data portal of the Natural Resources Conservation Service (NRCS, 2015). The study distinguishes between 3 hydrologic entities: 1)
the entire Castle Creek Watershed (including Placer Creek drainage); 2) the lower Castle Valley hydrologic system (northwest of roughly a line from the Castleton area to the Porcupine Ranch); and 3) the Castle Valley Groundwater Basin (quaternary and tertiary sand and gravels, and underlying fractured bedrock). The lower Castle Valley hydrologic system will be the setting for the water budget to be developed in a later phase of this study.

The HESA of the surface water and groundwater systems in the Castle Valley (TCV) study area makes extensive use of existing GIS databases and maps of geologic, hydrogeologic and hydrologic characteristics, collected specifically for this study. Additional data layers and evaluations were needed to illustrate the HESA – particularly with respect to the hydrogeological characteristics of the rock types present and the significance of hydrostructures. The results of the HESA of the TCV area are documented in this report, which also contains an introduction to the development of the water budget elements to be evaluated in a later report. The results of the HESA provides support for planning, zoning and other decision-making tasks, including those related to protection of groundwater resources for use as public or communal water supplies, and prepares for the next phase of the study involving water budget quantification and location of the Town of Castle Valley municipal well. The HESA included a few scoping site visits to the study area; no additional fieldwork has been conducted.

![Figure 2. View of the Regional Setting of the Castle Valley Study Area (Google Earth, 2015)](image)

It should be noted that that this report will not obviate the need for additional hydrogeologic analysis on a site-specific/parcel-specific basis by developers and/or the Town, or in any water right, geotechnical, or environmental study requiring due diligence. The information in this report is intended to be used as indicator only, as part of a multi-step land use decision-making process, and to provide a starting point for further study of the Town's surface water and groundwater resources. Additional data bases will be developed as the result of the water budget analysis, and the location of a new municipal well for the Town of Castle Valley.
2 DEVELOPMENT OF A CONCEPTUAL SITE MODEL OF THE HYDROLOGIC SYSTEMS OF THE CASTLE VALLEY (TCV) STUDY AREA

HESA is an approach used to conceptualize and characterize relevant features of hydrologic and environmental systems, integrating relevant considerations of climate, topography, geomorphology, groundwater and surface water hydrology, geology, ecosystem structure and function, and the human activities associated with these systems into a holistic, three-dimensional dynamic conceptual site model (CSM). This watershed-based, hierarchical approach is described by Kolm and others (1996) and codified in ASTM D5979 Standard Guide for Conceptualization and Characterization of Ground Water Systems (ASTM 1996(2008)). The CSM of the TCV study area covers elements of climate, topography, soils and geomorphology, surface water characteristics, hydrogeologic framework, hydrology, and anthropogenic activity as related to the surface water and groundwater systems in the study area.

Based on field surveys and a preliminary HESA, a number of hydrogeologic subsystems were identified within the TCV study area. Each of these subsystems has a unique hydrogeologic setting and groundwater flow system and is described in detail in forthcoming sections of the report. Furthermore, current anthropogenic modifications of the natural hydrologic features in these subsystems are minimal, and are primarily related to domestic water use (wells, lawn watering and septic systems), and irrigation (surface water diversions and irrigation return flow). A brief discussion of potential modification of natural flow patterns and impacts on water budgets and water quality, particularly salts, from agricultural and urbanization activities is included.

2.1 Climate

The climate in the study area has both local and regional components and includes effects of elevation and slope aspect (i.e., steepness and orientation with respect to the prevailing winds and sun exposure). The presence of the Porcupine Rim, Castle Spires Rim, and the La Sal Mountains (uplift) further influences the climate at the lower elevations by orographic precipitation effects, causing enhanced precipitation on the windward side and local and regional rain shadows on the leeward sides. Most of the TCV area is in the rain shadows of these three prominent features, and the precipitation is reduced significantly in comparison to surrounding areas. Relevant weather stations of the National Weather Service (NWS) Cooperative Network (COOP) in the study area, as available from the Western Regional Climate Center (WRCC) at the Desert Research Institute (DRI) for the valley are Castle Valley (COOP 421241), located in the town of Castle Valley and Castleton (COOP 421230). For the watershed in its entirety, La Sal (COOP424946) is also of interest. These stations provide an overlapping period of observations useful for comparative analysis. Active and historic (inactive) stations have also been identified by the Utah Climate Center (UTC) at Utah State University. Those data will be used in the water budget analysis and potential effects of climate change in a later phase of this study. Figure 3 shows the approximate locations of each of these stations.

Tables 1a-c show monthly and annual long-term averages for maximum and minimum temperature, precipitation, snowfall and snow depth.
The NWS data were used to prepare a map of spatially distributed precipitation corrected for elevation (see Figure 4). As these data sources show, there is a gradual precipitation gradient in Castle Valley from about 10 inches annually at the far northwestern boundary of the TCV study area to about 14 inches near Castleton, UT, with a sharp increase in precipitation of about 17 inches on either the northeast and southwest rims of the study area, and up to greater than 40 inches at the higher elevations in the La Sal Mountains.

Table 1a. Average Monthly and Annual Maximum and Minimum Temperature, Precipitation, Snow Fall and Snow Depth for Castle Valley Station (COOP421241 at 4730ft) for Period 08/01/1978 to 04/30/2009. (Source: Western Regional Climate Center (WRCC), Desert Research Institute, Reno, Nevada).
Table 1b. Average Monthly and Annual Maximum and Minimum Temperature, Precipitation, Snow Fall and Snow Depth for Castleton Station (COOP421230 at 5950ft) for Period 11/31/1963 to 05/31/1978. (Source: Western Regional Climate Center (WRCC), Desert Research Institute, Reno, Nevada).

Table 1c. Average Monthly and Annual Maximum and Minimum Temperature, Precipitation, Snow Fall and Snow Depth for La Sal Mountain Station (COOP424946 at 6990ft) for Period 02/02/1901 to 03/31/1978. (Source: Western Regional Climate Center (WRCC), Desert Research Institute, Reno, Nevada).

Precipitation type (rainfall versus snowfall), amount, and temporal and spatial distribution are important for determining the amount of recharge that a groundwater system may receive, particularly when it consists of the thick unconsolidated materials or shallow, permeable bedrock under unconfined conditions. The distribution of average annual precipitation is an important indicator of the climate of a particular area, and in the case of the TCV study area, the climate ranges from semi-arid-to-arid in the valleys and rims, and subhumid to humid in the surrounding mountains. There is a small natural recharge potential, mostly from rain and some snow throughout the late fall, winter, and spring, in the valley floors and on the rims, and a moderate to large natural recharge potential from both rain and snow in the higher elevation areas of the La Sal Mountains. The summer months are characterized by high evaporation rates and are too desiccated for significant groundwater infiltration and recharge in the valley floors and rims, with the exception of some localized intense summer storms, especially on irrigated (high soil moisture content) lands and in the channels of the drainages. Thus, most of the natural
groundwater recharge in the near-surface aquifers occurs during a short period of time in the late fall, winter and early spring (October to April) in the valley floors and rims. By comparison, the topographically higher terrains surrounding the TCV study area near the La Sal Mountains are humid-to-subhumid and cool and have excellent groundwater recharge potential, both from rainfall in the spring, summer, and autumn months, and from the melting of snowpack throughout the winter and early spring, especially where covered by gravels and slope deposits. It should be noted that the entire study area has groundwater recharge potential, with even the driest areas probably receiving approximately 1-2 inches of recharge annually. This is important when considering the ultimate groundwater system flow directions and areas of groundwater recharge, and for calculating water budgets.

![Figure 4. Spatial Distribution of the Average Annual Precipitation in the TCV Study Area (Source: Natural Resources Conservation Service, 2011).](image)

2.2 Topography and Geomorphology

Castle Valley is located in the Colorado Plateau physiographic province, and geomorphically in the Paradox Basin subprovince (Thornbury, 1965). This subprovince is characterized topographically and geologically as a series of northwest trending salt anticlines.
with collapse features called grabens (to be discussed in subsequent chapters of the report) that result in landscapes that seem to be torn apart from the earth with gaping holes (valleys) and sharp serrated surrounding rimlands (Figures 1, 2, and 5). This landscape is characterized as abrupt, angular, and discontinuous, and the result is for surface water and groundwater systems to be localized (non-regional). Castle Valley is a typical feature in this province.

Figure 5. Topography in the TCV Study Area Looking Southeast. (Google Earth, Feb. 2016).

The surface elevation in the TCV study area ranges from about 1,300 m (∼4,000 ft) in the Colorado River Valley to about 3,500 m (∼12,100 ft) in the La Sal Mountains (Figure 1 and 6). The topography of the study area has three distinct terrains: 1) steeply sloping to gently rolling, dissected bedrock foothills and mountains of the La Sal Mountain region to the southeast of Castle Valley, and the dissected bedrock escarpments and plateaus along the northeastern and southwestern flanks of the surrounding rimlands; 2) poorly to moderately dissected, connected and disconnected, continuous and discontinuous hillslope fans and mass wasting features (particularly talus and debris flows along the rimlands), and older alluvial terraces and pediment features in the southeastern part of Castle Valley around Round Mountain; and 3) continuous alluvial valley bottoms associated with the two principal drainages of Castle Creek and Placer Creek (Figure 1, 5, and 6).

In the lower section of the TCV study area --including the Castle Creek and Placer Creek Alluvial Basin and the modern day talus, fans, and alluvial terraces-- are separated topographically from other watersheds regionally by the geologic structures and topography associated with the collapsed anticlines (Porcupine and Castle Spires Rims) and the La Sal Mountain Tertiary intrusives (Ti), and locally by inter-fluvial bedrock uplands associated with features such as Round Mountain (Ti) and the ridges associated with the La Sal Mountains. These bedrock features function as barriers to hydrologic connectivity, and therefore hydrologic
systems in the valley are disconnected from adjacent hydrologic systems. The effects of the bedrock impediments and the stream and valley dissection on the groundwater systems will be discussed in the Groundwater System Conceptual Site Models sections.

The deeper bedrock groundwater systems, if not topographically dissected by the surficial processes or affected by regional geologic structure and uplift activity, will be continuous and regional in nature. However, all of the deeper bedrock groundwater systems are affected by the regional geologic structure, and there is no continuity in the deeper bedrock systems across the region at this location (to be discussed in later sections of the report). Therefore, these deeper bedrock systems in the TCV area do not receive regional groundwater recharge and are recharged by, or are discharging into the local shallow groundwater systems depending on the geomorphic geometry. Most of the alluvial terraces, fans, and river bottoms in the study area are connected, but are isolated topographically from the rest of the region, which results in discrete and localized groundwater systems and can result in discrete and localized springs and connections to surface water systems. This is important in identifying various segments of the water budget.
The topographic gradients in the TCV area can be divided into three types: 1) steep gradient bedrock slopes (greater than 2% slope) mostly in the bedrock regions and flanks of the surrounding rimlands of the collapsed anticlines; 2) steep gradient unconsolidated materials slopes (greater than 2%) including the talus and alluvial fans forming beneath the rimlands of Castle Valley and along the exposed bedrock of the La Sal Mountains to the south east; and 3) low gradient (less than 2% slope) fan, terrace levels, and alluvial valley bottoms associated with Castle and Placer Creeks (Figures 5 and 6). The topographic gradient is useful in estimating the surface of the water table, for estimating the amounts of infiltration versus overland flow and interflow (rapid, shallow subsurface runoff), and for estimating residence times for subsurface water to be in contact with bedrock that may supply salt resulting in declining water quality.

2.3 Surface Water Characteristics and Springs

The TCV study area contains parts of local watersheds draining to the Colorado River via Castle Creek and Placer Creek (Figure 6). Streams can be gaining flow (from groundwater, rapid surface runoff, and interflow), or losing flow (to groundwater, diversions or evaporation through phreatophyte vegetation), dependent on local hydrology, hydrogeology, irrigation practices, and time of year. Both Castle Creek and Placer Creek are mostly dependent on groundwater interactions either as gaining or losing stream reaches.

Castle Creek originates from spring flow and groundwater discharge from the stream bed into the channel in Willow and Bachelor Basins in the La Sal Mountains, and, when not influenced by human diversions, remains perennial throughout its entire length (Ford, 2006). Seepage studies revealed that Castle Creek is a gaining stream from its headwaters to the Day Star Academy’s (DSA) diversion (Ford, 2006) (Figure 7a). Castle Creek, from the DSA diversion to a point just downgradient of the Placer Creek/Castle Creek junction, is losing surface flow to groundwater (groundwater recharge from stream) (Figure 7b). Below the junction of Castle Creek and Placer Creek, Castle Creek becomes a gaining stream as evidenced by springs, increased surface water flow and phreatophytes along its channel, and remains a gaining stream as it leaves the Castle Valley to the northwest (Figure 7c).

Pinhook Creek, the main tributary to Placer Creek, originates from an abandoned mine and is a gaining stream in the La Sal Mountains until it emerges out of the glacial canyons and flows over thick glacial alluvial deposits. This stream recharges the alluvial aquifer and the creek bed goes dry during normal flow. Porcupine Draw, the other main tributary to Placer Creek, originates at Mason Spring and then flows over thick glacial alluvial deposits. This creek recharges the alluvial aquifer and the creek bed goes dry during normal flow. There are places that the bedrock is near the surface, due to faulting, and the alluvial deposits are thin forcing the groundwater to be near or at the surface, and in the case of Porcupine Ranch Spring, allowing the Porcupine Draw channel to briefly flow (Figure 7d). At that point, in the vicinity of Porcupine Ranch, the Placer Creek system has a diversion for irrigation and domestic use (Figure 7d). Below this spring, Placer Creek goes dry and the groundwater reemerges in Castle Creek below the junction (Figure 7c).

The gaining and losing dynamics of these streams are influenced by seasonal events, with bank full conditions occurring during the spring runoff and summer irrigation season, and low
water conditions occurring during the rest of the year. In addition, some storm events of various durations and amounts can affect the yearly and seasonal flows. A graph illustrating these daily, seasonal, and annual events is shown in Figure 8.

Figure 7a. Gaining and Losing Reaches of Castle Creek and Placer Creek in the Upper Part of the TCV Study Area. (Source: Google Earth, Feb. 2016)

Figure 7b. Losing Reaches of Castle Creek and Placer Creek in the Middle Part of the TCV Study Area. (Source: Google Earth, Feb. 2016)
Figure 7c. Gaining Reach of Castle Creek in the Lower Part of the TCV Study Area.
(Source: Google Earth, Feb. 2016)

Figure 7d. Gaining and Losing Sections in the Upper Reaches of Placer Creek in the TCV Study Area,
(Source: Google Earth, Feb. 2016)
In the TCV study area, water is delivered from diversion points to the irrigated fields primarily by means of pipes. In the absence of (unlined) ditches, as often encountered in areas with a long history of agricultural development, water leaking from such ditches into the subsurface is not a major concern in the TCV study area and as such, does not have to be taken into account for the water balance of the groundwater system.
Where water is dispersed onto the crop field area, the excess water delivered to the soil drains down to the groundwater system and thus recharges the groundwater system. This water, called irrigation return flow, may have an altered water quality due to the agricultural chemicals used for the crops. Irrigation return flow is a source of groundwater recharge particularly on the lower part of the Castle Creek gravel and alluvial aquifer subsystem by Day Star Academy. Its significance for the water budget depends on the efficiencies of the agricultural practices applied.

According to the Utah state water right database, there are three areas with diversions in the TCV study area, two of which are affiliated with Castle Creek: 1) the diversions in the lower end of the valley near Day Star Academy and in the Town of Castle Valley (Figure 9a); and 2) diversions near the Castleton area east and southeast of Round Mountain (Figure 9b). The third diversion is located near the Porcupine Ranch in the Placer Creek watershed. The larger diversions are mostly piped and any leakage to the underlying aquifers would be minimal. However, they may a significant reducing effect on the flow in the streams.

![Figure 9a. Location of Selected Surface Water Diversions in the Lower Part of the TCV Study Area; Note the Return Flow Water Right in the Upper Left Corner, and Spring-related Diversions. (Source: Utah Division of Water Rights, February 2016)](image)

As is indicated by wetlands, phreatophytes, and springs/seeps, some of these diversions and affiliated irrigation return flow move water into the groundwater systems of the Castle Creek gravels and alluvium (Qal). These groundwater systems may serve as aquifers used for irrigation and drinking water for landowners located topographically downgradient from the irrigated lands (see sections 2.5 and 2.6).
Springs and seeps indicate places where water flows naturally from a rock or the soil onto the land surface or into a body of surface water. They represent the contact between (saturated) groundwater and the land surface at that location. Springs usually emerge from a single point and result in a visible and measurable flow of water, or contribute measurably to the flow of a stream or the volume of a reservoir or pond. Seeps tend to be smaller than springs, with a more distributed character, and often no visible runoff, especially in this semiarid climate where, in many cases, the water emerging in seeps is lost to evapotranspiration. In semiarid climates such as in the TCV study area, springs and seeps may be identified by the presence of phreatophyte vegetation away from streams. Springs and seeps may be expressions of discharge of shallow groundwater from an unconfined aquifer, or of discharge from deeper aquifers at the contact between (more) permeable and (near) impermeable formations at or near the land surface, in fracture zones, or through karst conduits.

Figure 9b. Location of Surface Water Diversions in the Upper Part of the TCV Area, Grand County, Utah. (Source: Utah Division of Water Rights, February 2016)
The TCV study area contains a number of springs and seeps as identified from Google Earth analysis and field reconnaissance. Most of the springs are found in the upper reaches of Castle Creek and Placer Creek and their tributaries. Of particular interest are the spring/seep areas in the vicinity and upgradient from the Porcupine Ranch, along Castle Creek and its tributaries near Castleton, along Castle Creek northwest of Day Star Academy, and in the far northwest corner of the valley. Also of interest is the presence of seep type of discharges from irrigated parcels in the valley. A detailed discussion of springs and seeps in the TCV area and their relationship with the local groundwater systems is presented in section 2.5.

There are three spatial distributions of springs that are informative for the analysis of the surface water and groundwater systems in the TCV study area. The highest elevation springs in the TCV area are located in the La Sal Mountains: Willow Springs, Bachelor Basin Springs, Cold Spring, Mason Spring, and the springs located in the Miners Basin (Figure 10). These springs emanate from the Tertiary Bedrock systems in the La Sal Mountains, and represent the culmination of the groundwater flow in the Tertiary Intrusive rocks and associated glacial gravels and modern alluvium of the La Sal Mountain hydrologic subsystem. These springs are the beginning of the Castle Creek and Placer Creek surface water systems, which will affect the entire TCV hydrologic systems (Figure 10).

![Fig 10. Location of Spring/Seep Areas in the TCV Study Area.](Source: Google Earth, Feb. 2016)

The springs at Porcupine Ranch on Porcupine Draw and near Castleton represent a window into the middle parts of the Placer and Castle Creek hydrologic subsystems where bedrock faulting at depth has resulted in thinning the unconsolidated materials and therefore the thickness of the near surface aquifer, forcing groundwater to briefly daylight to the surface enhancing the surface water flow regimes. Downgradient of these features, the surface water eventually returns to the groundwater system as recharge or evaporates into the atmosphere. Finally, the springs located below Day Star Academy to the west and northwest, and below the
confluence of Placer and Castle Creek, are the culmination of the Castle Creek and Placer Creek groundwater systems where the groundwater discharges into the surface water systems (Figure 10). The rest of the Castle and Placer Creek groundwater systems discharge into Castle Creek along the main channel in the lower end of the Town, which manifests itself as a gaining stream.

2.4 Hydrogeologic Framework

Bedrock and unconsolidated materials have traditionally been classified as either aquifers or aquitards based upon being able to provide sufficient water for irrigation and industrial and municipal consumption. In this context, an aquifer is a permeable body of rock that is saturated with water and is capable of yielding economically significant quantities of water to wells (human and agricultural use) and springs (human and ecological use). A low-permeability formation overlying an aquifer is often called an aquitard or confining unit. As the terms “aquifer” and “aquitard” are rather ambiguous (e.g., what are economically significant quantities? or how confining is a low-permeability unit with respect to the transport of contaminants?), the use of these terms is replaced by that of the term hydro-stratigraphic unit or hydrogeologic unit, in combination with terms qualifying the permeability and/or saturation of the unit (e.g., saturated, high-permeable hydrogeologic unit). A hydrogeologic unit is a geologic formation, part of a formation, or a group of formations with similar hydrologic characteristics (e.g., similar permeability characteristics and storage capacity). It should be noted that hydrogeologic units may not equate to geological units such as formations, formation members, and formation groups due to the frequently encountered variability of the flow characteristics of such geologic units. The term aquifer in this report is used to indicate a significant source of water supply from hydrogeologic units, and may include the qualifier potential (i.e., potential aquifer) when parameter uncertainty exists, especially with respect to average saturated thickness and water table fluctuations.

From a groundwater flow and water supply perspective, the most important property of rocks is the incorporated pore space and related permeability. The pore space, which defines the amount of water storage within a hydrogeologic unit, may be contemporaneous with the rock formation (primary or matrix porosity), or due to secondary geological processes, such as fracturing, faulting, chemical solution, and weathering (secondary porosity, fracture/karst porosity). The degree of connectivity and the size of the pore openings define the permeability of the rock, that is, the ease with which fluid can move through the rock. As with porosity, permeability may be primarily matrix based (matrix permeability), fracture and/or karst based (fracture/karst permeability), or may be a combination of both (Davis and DeWiest, 1966).

Unconsolidated sediments and clastic materials, as found in the TCV study area, and observed on the mass wasting colluvium and talus, pediment gravels and terraces, and alluvial floodplains in both the Castle Creek and Placer Creek drainages, are geologically very young and consist primarily of silts, sands, and gravels. They are generally very porous and permeable, but can be quite variable in their thickness, continuity, and hydraulic properties. For example, field observations revealed that the thickness of the unconsolidated sediments in the TCV study area ranges from less than 1 ft to greater than 300 ft. Estimates of hydraulic conductivity (K) of these
unconsolidated materials range from 1 to 225 ft per day (Lowe and other, 2004). These hydrogeologic units most likely contain the greatest amount of groundwater.

Consolidated sedimentary rock and extrusive volcanic rock, by comparison, are often quite porous, but variable in permeability. Most fine-grained detrital rocks like shale, claystone, and siltstone may have relatively high matrix porosities, but very low permeabilities (Davis and DeWiest, 1966). These fine-grained bedrock hydrogeologic units are the dominant confining layers of sedimentary groundwater systems, with small hydraulic conductivity values typically less than 0.01 ft per day. Coarser-grained sedimentary rock, such as sandstone, and volcanic basalt, can pair relatively high matrix porosity with significant permeability, and may contain significant amounts of groundwater.

The hydraulic properties of sedimentary and extrusive igneous rock may be largely enhanced when fractures and faults are present (Davis and DeWiest, 1966). As a case in point, most of the sandstones and crystalline extrusive volcanic rocks in and near the TCV study area have enhanced permeability due to fracture and fault density and connectivity. Significant secondary porosity and permeability are developed through faulting, fracturing, and weathering of the sedimentary and extrusive igneous rock, especially in association with active faults, fracture zones, and near-surface stress-release.

### 2.4.1 Regional Hydrogeologic Units

From a regional geologic perspective, Castle Valley is part of the Paradox Subregion Section of the Colorado Plateau Physiographic Province, characterized structurally by northwest-southeast- trending salt anticlines (diapirs) with centrally collapsed areas or graben features due to salt dissolution by groundwater (Doelling and Ross, 1993; Blanchard, 1990) (Figures 11 and 12). Several Quaternary-aged faults related to this dissolution of salt and subsequent collapse structures have been mapped parallel to Porcupine Rim northwest of Round Mountain, and sinkholes along this fault indicate localized dissolution or piping (Mulvey, 1992). As a result, the near-surface sedimentary bedrock stratum ranges from younger rock to the northeast and southwest, to older rock in the core of the anticlines, and the stratum shows a regional dipping trend to the northeast, northwest, and southwest (see Figures 13 and 14). The youngest bedrock units in the TCV area are the Tertiary Geyser Creek Fanglomerate (Tg), and the Tertiary intrusive (granodiorite porphyry) units of the La Sal Mountains and Round Mountain (Ti). These units form mountains and foothills in the southeastern part of the study area, and the older sedimentary rocks form the topographic rimlands and valley bottoms of the main Castle Valley (Figures 13 and 14). It is in these sedimentary and volcanic units that regional and subregional groundwater flow systems are known to occur if the topographic, geomorphic, and geologic structure and continuity are favorable (Freethey and Cordy, 1991; Geldon, 2003).

Given the regional geology of the TCV area, the hydrogeologic framework, including hydrostructures, present in the Castle Valley Hydrologic System is very complex and is studied for the continuity and geometry of possible regional, subregional, and local hydrologic systems. Upon reviewing various groundwater reports for water budgets in the Mill Creek-Pack Creek drainages in Grand County (Sumsion, 1971); bedrock aquifer analysis in San Juan County.
Figure 11. Regional Geographic Features in the Vicinity of the TCV Study Area (From Geldon, 2003).

Figure 12. Generalized Salt Thickness and Major Structural Trends in the Vicinity of the TCV Area, Grand County, Utah (From Weir and Others, 1983).
Figure 13. Generalized Map Showing Regional Geological Features in the Vicinity of the TCV area (Based on GIS Version of Utah Geological Survey Map 180 (Doelling, 2002); Utah, GIS 2015).

Figure 14. Generalized Northeast-Southwest Geological Cross Section Representative for Castle Valley. (Modified from Doelling and Ross, 1988).
(Avery, 1986); ground water conditions in Grand County (Blanchard, 1990; Esinger and Lowe, 1999); regional and subregional groundwater systems of the La Sal Mountains/Spanish Valley area (Geldon, 2003; Basye, 1994); recharge and water quality of the alluvial aquifer in Castle Valley (Snyder, 1996); and Castle Valley water studies and data (Ford and Grandy, 1997; Ford, 2006), the TCV study area hydrological systems consist of multiple distinct hydrogeologic and hydro-structural units, including unconsolidated units consisting of various Quaternary- and Tertiary-aged, highly permeable deposits and weathered bedrock deposits, and several water-bearing bedrock units and significant confining bedrock units, and fault and fracture zones of untested, but very high vertical and lateral transmissivity. The major hydrogeologic unconsolidated and bedrock units are presented in Figure 15 and described in Tables 2a and 2b; the thickness of the unconsolidated valley-fill aquifer and the location of paleo-paleo valleys are presented in figure 16; the major hydro-structural units are presented in Figure 17.

2.4.2 Hydrogeologic Units of the TCV Area

There are two significant groups of hydrogeologic units in the TCV study area: 1) Quaternary and Tertiary unconsolidated clastic materials (Figure 15, Tables 2a and 2b), which are predominantly Stream Alluvium (Qal), Alluvial Fan deposits (Qaf), Glacial Till (Qgt), Slumps andSlides (Qms), Talus and Colluvium (Qmt), Bouldery Colluvium (Qcb), and Older Alluvial Fan Deposits (QTaf), overlying 2) Tertiary, Mesozoic and Paleozoic bedrock units (Figure 15; Tables 2a and 2b), including the following potentially water-bearing units: Geyser Creek Fanglomerate (Tg); fractured Tertiary Intrusive Granodiorite (Ti); and the fractured White Rim and Arkosic members of the Cutler Formation (Pc). Tables 2a and 2b list the hydrologic characteristics of these units, and shows that most of these units have low matrix hydrologic conductivity and have springs with low yields less than 1 gal per minute. By comparison, the Triassic Chinle (Trc) and Moehkopi Formations (Trm), labeled as bedrock undivided on Figure 14, the unfractured Cutler Formation (Pc), and the Paradox Formation (IPpc and labeled “cap rock” on some figures) may act as thick, poorly transmissive confining layers (Blanchard, 1990; Ford, 1997).

From a water supply perspective, the unconsolidated clastic sediments, specifically when composed of larger size particles (>2.5 mm or 0.1 in) and observed to have sufficient saturated thickness and horizontal continuity, provide a significant and accessible water supply. The water supply function of bedrock units is largely dependent on rock type, large-scale structure and degree of fracturing, layer geometry and orientation, and the spatially variable hydrologic inputs and outputs, and may vary significantly dependent on location. The focus of this HESA was on both the shallow groundwater flow systems in the Quaternary and Tertiary unconsolidated clastic materials, which is the source of drinking and irrigation water for most households, the deeper bedrock units that have been tapped for water supplies in areas where the shallow unconsolidated aquifers cannot supply adequate quantities of water for the landowners or Town, and the relations of these hydrologic systems to the surface water systems of Castle and Placer Creeks. Additionally, water quality is also an issue that is addressed, both in discerning the nature of the shallow and deeper groundwater systems, the nature of the interactions between these two types of groundwater systems with Castle and Placer Creeks, and in the placement of future water wells for the Town water supply.
### Table 2a. Correlation of Geological and Hydrogeologic Units in the TCV Study Area: Unconsolidated Sediments

<table>
<thead>
<tr>
<th>Geological Unit</th>
<th>Hydrogeologic Unit</th>
<th>Composition</th>
<th>Hydrogeological Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Permeability/Storativity</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Depth to Water</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Alluvium (Qa1, Qa2)</strong></td>
<td>Stream Alluvium</td>
<td>Qal</td>
<td>Unconsolidated deposits of poorly to moderately sorted riverine silt, sand, and gravel; Qa1 located in active larger channels and floodplains; Qa2 deposits form first surface 6-40 ft. above the active channels. Thickness up to 25 ft.</td>
</tr>
<tr>
<td><strong>Alluvial fan deposits (Qaf3, Qaf4, Qaf5, Qafy, Qafo)</strong></td>
<td>Alluvial Fan Deposits</td>
<td>Qaf</td>
<td>Unconsolidated deposits of poorly sorted, muddy to sandy cobble gravel and boulders; Qaf3 and Qaf4 form dissected surfaces in Castle Valley; younger Qafy and older Qafo deposits form coalesced fans along margins of Castle Valley. Thickness up to 350 ft. as basin fill.</td>
</tr>
<tr>
<td><strong>Glacial till (Qgt)</strong></td>
<td>Glacial Till</td>
<td>Qgt</td>
<td>Very poorly sorted, angular to sub-angular clasts of all sizes. Thickness up to 300 ft.</td>
</tr>
<tr>
<td><strong>Landslide deposits (Qms, Qmsy, Qmso)</strong></td>
<td>Slumps and Slides</td>
<td>Qms</td>
<td>Large coherent blocks to fragmental masses of bedrock and surficial debris transported downslope by mass movement. Thicknesses vary.</td>
</tr>
<tr>
<td><strong>Talus deposits and colluvium (Qmt)</strong></td>
<td>Talus and Colluvium</td>
<td>Qmt</td>
<td>Angular rock-fall blocks, boulders, and small fragments deposited as veneers on slopes below ledges and cliffs; colluvium contains additional slopewash debris in a sandy to muddy matrix. Thickness 0-30 ft.</td>
</tr>
<tr>
<td><strong>Bouldery colluvium deposits (Qc, Qmb)</strong></td>
<td>Bouldery Colluvium</td>
<td>Qc</td>
<td>Qc deposits are poorly to moderately sorted, locally derived gravel, sand, and soil. Thickness 0-25 ft. Qmb rock-slope deposits are poorly sorted angular locally derived debris ranging from block to sand size. Variable thickness.</td>
</tr>
<tr>
<td><strong>Older Alluvial fan deposits (QTaf)</strong></td>
<td>Older Alluvial Fan Deposits</td>
<td>QTaf</td>
<td>Poorly sorted sands, silt, pebbles, cobbles, and boulders deposited at base of La Sal Mtns. Thickness is 200-300 ft.</td>
</tr>
</tbody>
</table>
Table 2B: Correlation of Geologic and Hydrogeologic Units in the TCV Study Area: Bedrock Unit.

<table>
<thead>
<tr>
<th>Geological Unit</th>
<th>Hydrogeologic Unit</th>
<th>Composition</th>
<th>Permeability/ Storativity</th>
<th>Depth to Water</th>
</tr>
</thead>
<tbody>
<tr>
<td>La Sal Mtn. Intrusive Rocks (Th, Ttp, Tpt, Trp, Tn)</td>
<td>Tertiary Intrusions</td>
<td>Alkaline silicic rocks</td>
<td>Fractured crystalline system</td>
<td>moderately low</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>with very low matrix permeability</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>not a regional aquifer</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>may produce locally water in fracture zones and support adjacent unconsolidated aquifers. These characteristics may extend into adjacent rocks, metamorphosed during the Tertiary intrusion.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>mostly low permeability, localized zones with moderate fracture permeability; low to moderate storativity</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>moderate to large fluctuations on ridges and mountain tops; small fluctuations in valley bottoms</td>
<td></td>
</tr>
<tr>
<td>Geyser Creek Fanglomerate (Tg, Tgc)</td>
<td>Geyser Creek</td>
<td>Yellow brown to light grey conglomerate, sandstone and siltstone derived from La Sal Mtns.; Poorly sorted and weakly cemented; thickness up to 1,000 ft., exposures less than 300 ft.</td>
<td>Overbank sandstones form a good aquifer system with moderate to good matrix and fracture based permeability; may be a locally good water producer; siltstones and shales are confining layers; outcrops are recharge areas for a regional flow.</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>layers with very low permeability and layers with moderate matrix and fracture permeability; low to moderate storativity</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>moderate to large fluctuations on ridges and hill tops; small fluctuations in valley bottoms</td>
<td></td>
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<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Older Bedrock (undivided)</td>
<td></td>
<td></td>
<td>Mostly aquitard with very low permeability serving as a confining layer for overlying or embedded aquifers. Responsible for reduced water quality in Castle Valley when wells are placed near the Paradox Formation.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Very low permeability rock; low storativity. High permeability and storage in fault/fracture zones in Castle Valley.</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Entrada (Je), Navajo (Jn), Kayenta (Jk)</td>
<td></td>
<td></td>
<td>Good regional bedrock aquifer system; sandstones and coals have both moderate matrix and fracture based permeability; may locally be a good water producer; shales are confining layers; outcrops are recharge areas for regional flow.</td>
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<tr>
<td>Dakota/Burro Canyon (Kdbc); Morrison (Jm)</td>
<td></td>
<td></td>
<td>Mostly aquitard with very low permeability serving as a confining layer for overlying or embedded aquifers; however, locally moderate aquifer conditions when highly faulted/fractured. Pc High K Zones are observed in Castle Valley. Responsible for reduced water quality in Castle Valley wells.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Very low permeability rock with some moderately permeable beds; low storativity. High permeability and storage in fault/fracture zones in Castle Valley.</td>
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</tbody>
</table>
The Quaternary unconsolidated clastic units (Qal, Qaf, Qgt, Qms, Qmt, Qcb, and QTaf in Table 2a and Figure 15) are locally heterogeneous, with predominantly a mix of coarser materials in the older alluvial deposits, and a mixture of coarser and finer materials in the younger deposits. These deposits, which are moderately to highly permeable, are recharged by infiltration from precipitation that is non-uniformly distributed due to the slope steepness, slope aspect, and to position in the landscape; by the incidental leaky irrigation ditch and irrigation return flow; and by flow in ephemeral stream channels and losing streams in perennial reaches where favorable. The unconsolidated units are variably to fully saturated, based on spatial location and seasonal precipitation events. There is lateral and vertical groundwater flow connection between the unconsolidated materials and the underlying bedrock formations that is critical for understanding the hydrologic systems and water quality of Castle Valley.

The thickness of subsurface distribution of these unconsolidated sediments may be estimated based upon the isopach maps produced in earlier studies (Lowe and others, 2004). The thicknesses range from less than 25 ft in the southeastern part of Castle Creek above Castleton and the southeastern part of Placer Creek above Porcupine Ranch, to greater than 300 ft in the northern part of Castle Valley near Day Star Academy (Figure 16). The greatest thickness of the unconsolidated material is in the collapsed part of Castle Valley northwest of Round Mountain where average thicknesses ranging between 100 – 200 ft. are common (Figure 16).
The subsurface distribution of thickness is indicative of the structural collapse and faulting with subsequent erosion and filling of fault zones with gravels. A linear paleovalley and subsequent groundwater conduit is observed along the northeastern margin of the valley fill beneath the modern day Castle Creek from Castleton extending to near Parriott Mesa (Figures 16). The second linear paleovalley and subsequent groundwater conduit is observed along the southwestern margin of the valley fill beneath the modern day Placer Creek above the Porcupine Ranch extending to beneath the Town of Castle Valley town hall to the northwest (Figure 16). These groundwater conduits approximately overly the bedrock conduits to be discussed in subsequent sections of this report.

![Figure 16. Isopach Map Showing Thickness of Valley Fill Deposits of TCV Study Area. The Valley Fill deposits are the Shallow Unconsolidated Hydrogeologic Units in the TCV Study Area (after Lowe and Others, 2004).]

2.4.3 Hydro-structural Units of the TCV Area

Geologic faults and fracture zones, sometimes expressed at the surface as lineaments or linear drainage segments, may influence the hydrogeology and hydrologic systems of Castle Valley, including Castle and Placer Creek (Figure 17). These hydrostructures underlie the drainages in the bedrock systems (White Rim and Arkosic Members of the Cutler Formation (Pc) and Tertiary Intrusive Granodiorite (Ti), primarily) and are most likely associated with preferential groundwater flow along fault and fracture zones that are observed or hypothesized to transmit groundwater either vertically or laterally along the fault or fracture planes or zones.
These structures may serve as distinct hydrogeologic units, may enhance the permeability of sections of bedrock hydrogeologic units, may connect multiple hydrogeologic units together, or may restrict the thickness and flow of overlying unconsolidated deposits resulting in springs and groundwater discharge areas. These hydrostructures, if “open”, may also result in connectivity between deeper groundwater systems and the streams, which may be a concern if future water well drilling occurs. Each fault and fracture zone should be evaluated for the following characteristics: 1) fault and fracture plane geometry, including the vertical or horizontal nature of the fault/fracture plane and the relations of rock types and geometry on both sides of the structure; and 2) the transmissive nature of the fault/fracture plane or fault/fracture zone, including the nature of fault gouge, if any (clay, gravel) and tectonic setting of fault/fracture plane or zone (extension or compression). The fault/fracture plane geometry is important to evaluate if groundwater can move horizontally across the zone from one transmissive unit to another, or whether the groundwater is forced to move vertically upward to the surface, in many cases, or downward into a different hydrogeologic unit, or laterally parallel to the fault and fracture zone like a geotechnical French drain. The tectonic setting helps determine whether the fault/fracture plane is “open”—able to easily move water (extension), or “closed”—not able to easily move water (compression).

Hydrostructures, which are defined by folds, faults and fracture zones, control the location of Castle Valley, the location of the Castle Creek, Placer Creek, and major tributaries, the location of drainages that are part of the Porcupine and Castle Spires Rims, and the locations of streams draining the La Sal Mountains. These hydrostructures can exist sub-regionally and regionally if structural and topographic continuity exist (Figures 13, 14, and 17). The main subregional fold and fault structure is the Castle Valley Salt Anticline with corresponding graben/collapse structure (Figures 13, 14, and 17). The bounding faults of the collapse, located on the northeast and southwest sides of Castle Valley, dip almost vertically and strike from the southeast to the northwest (Figures 14 and 17). These two fault zones, which are in the White Rim and Arkosic Members of the Cutler Formation are subregional hydrogeologic conduits (high hydraulic conductivity zones or High “K” zones). These conduits are continuous from the southeastern part to the northwestern part of Castle Valley and have high hydraulic conductivity and high yields of groundwater with high TDS water quality (Figure 18). These hydrostructural units pinch out at either end of the valley and with depth keeping the groundwater system subregional and discontinuous beyond the Castle Valley topographic feature. These hydrostructural units also block lateral flow perpendicular to the fault zone. Therefore, no deep regional ground water is laterally entering or exiting Castle Valley from the northeast or the southwest. The termination of these hydrostructural units to the southeast and northwest also blocks lateral flow, so no deep groundwater is laterally entering or exiting Castle Valley from the southeast or the northwest. It is hydrologically important that the entire valley is underlain by a deep “flat lying” caprock of the Paradox Formation, which is a confining unit that, when interacting with groundwater, produces poor water quality due to dissolution of the salt bedrock. Effectively, these hydrogeologic/hydrostructural units ensure that the Castle Valley Bedrock groundwater flow system is entirely contained within the valley, and that the water quality derived from these units is not necessarily favorable (high TDS) (Figures 14, 17 and 18).

The Castle Valley Anticline/Graben also results in the younger bedrock hydrogeologic units being observed on the Porcupine and Castle Spires Rims, in some locations, and dipping away to the northeast, northwest, and southwest (Figures 14 and 17). This results in local and subregional groundwater and surface water systems that flow away from the Castle Valley.
Rimlands into the La Sal Mountain/Spanish Valley Systems, into the Onion Creek or Professor Creek Systems, or towards the Colorado River (Figures 14 and 17).

Figure 17. Map Showing Major Hydro-structures (Faults and Fracture Zones) in the TCV Study Area.

The fault and fracture zones have influenced the location of the main surface water drainages in the TCV study area by providing zones of weakness whereby the streams have downcut into or through the unconsolidated deposits into the underlying Cutler Arkosic and White Rim Members bedrock, the Paradox bedrock, and the Granodiorite Porphyry (Figures 16 and 17). As a result, the TCV study area is dissected into two distinct surface hydrologic subsystems of varying connectivity: Castle Creek and Placer Creek, both of which are separated in the southeastern part of the Valley by Round Mountain and the La Sal Mountain ridges, and become connected in the northwestern part of Castle Valley near the confluence of the drainages (Figures 16 and 17).

Local hydrostructure fracture/fault groups occur in the TCV area: 1) the northeast-southwest trending faults and fractures that are radial to the main Castle Valley Anticline; 2) the northwest-southeast trending faults and fractures that are parallel to the main Castle Valley Anticline collapse structures; and 3) radial and concentric fractures associated with the Tertiary Intrusive (Ti) rocks (Figure 17).

The northwest-southeast trending drainages mirror the underlying faults and fracture zones that include the collapse structures located on the northeast and southwest sides of Castle
Valley, and the underlying faults and fracture zones that are parallel to these bounding structures (Figure 17). These structures are open, and function as groundwater conduits in bedrock, and paleo-valley groundwater conduits in unconsolidated materials (Figure 16).

Figure 18. Total Dissolved Solids (TDS) of the Castle Valley Groundwater System
(From Lowe and Others, 2004)

The northeast-southwest trending drainages/fracture zones (Radial 1 in Figure 17) control most of the steep drainages on the flanks of the Castle Valley rimlands. These drainages are mostly ephemeral, and have the main hydrologic functions of delivering surface water down into the valley floor for groundwater recharge or surface water flooding and sediment transport into Placer and Castle Creeks and associated tributaries (Figure 17).

The radial and concentric fracture pattern surrounding the La Sal Mountain intrusions (Ti) (Radial 2 in Figure 17) control the surface water drainages, and are open, therefore, supporting “French-drain” bedrock groundwater systems in the Tertiary intrusive (Ti) bedrock, and focusing groundwater towards drainages in the Tertiary Geyser Creek fanglomerate (Tg) locally. Examples of this are the minor drainages around Round Mountain, and the drainages in the southeastern part of the study area including the northern flanks of the La Sal Mountain systems where Placer Creek and Castle Creek originate (Figure 17). In the Tertiary intrusive rocks (Ti), groundwater moves laterally down valley and vertically downward along these radial fault and fracture zone planes, and may move vertically up along the fault and fractures plane near the lower reaches of the various drainages as evidenced by gaining reaches in streams,
increased groundwater head with depth in local wells, and by the springs that are the origin of Castle and Placer Creeks. The concentric fracture zones, which function as “French drains”, control the locations and origins of upper Castle Creek and Pinhook Creek (Figure 17).

2.5 Groundwater Flow Systems

Groundwater flow is the movement of water from the earth’s surface into the subsurface (groundwater infiltration and recharge), through the subsurface materials (groundwater flow and storage), and from the subsurface back to the Earth’s surface (groundwater discharge), expressed in terms of flow directions, patterns and velocities. The driving force for groundwater flow is a difference in piezometric “head” or groundwater levels, as expressed, for example, by the slope of the water table. The general Conceptual Site Model (CSM) of the groundwater flow system consists of 1) water inputs (recharge); 2) storage in and movement through subsurface hydrogeologic units (groundwater flow); and 3) water outputs (discharge). The general Conceptual Site Model (CSM) is helpful to determine the water balance of the groundwater flow system, which is the quantitative balance of the water inputs with the water outputs discussed in later sections of the report. Natural recharge is based on climate and soils resulting in infiltration of precipitation and snowmelt. Groundwater interaction with streams, vegetation (evapotranspiration), and human activity (irrigation, urbanization, wells and individual sewage disposal systems, reservoirs and ponds, oil and gas activity, mining, dewatering) will affect groundwater movement to varying degrees. The CSM also incorporates topography (steepness, slope aspect, degree of landscape dissection), geomorphology, and soil and rock properties. Because of the time-space variance of these inputs and outputs, a groundwater system often shows significant variations in water levels, water storage, flow velocities, and flow patterns. Some of the variations are seasonal; others may be related to multi-year periods of above-average or below-average precipitation. This results in variations in the availability of water from these hydrogeologic units.

Based on the HESA approach (Kolm and others, 1996), and previously collected supporting data, the regional, sub-regional, and local scale groundwater flow systems are delineated. The broad hydrologic system inputs include infiltration of precipitation as rain and snowmelt; areas of losing perennial and ephemeral streams (for example, reaches of the Castle Creek and Placer Creek above the Town of Castle Valley, reaches of ephemeral streams on the sides of Porcupine and Castle Spires Rims); infiltration and runoff from water bodies (cattle and house ponds), upland irrigation areas (leaking ditches, irrigation return flow, lawn watering), and inter-aquifer transfer of groundwater between unconsolidated materials and bedrock systems (horizontally and/or vertically). The general hydrologic flow subsystems, including the Mountain, Mesa Top, Hillslope, and Valley Bottom subsystems, consist of the hydrologic processes of surface runoff (channel and/or overland flow) and rapid near-surface runoff (interflow or shallow through-flow); saturated groundwater flow in parts of the bedrock units, landslides, terraces, and valley bottoms; and discharge to springs and seeps, graining streams, by plants as evapotranspiration, and by pumping wells. In general, shallow groundwater flow in these systems is with topography away from the mountain and ridge tops, along the axis of the mesa tops, and/or towards the valley bottoms, perpendicular to the major streams. Where permeable bedrock units underlie the mountains, mesa tops, hill slopes, and valley bottoms, recharge by groundwater moving from unconsolidated hydrogeologic units into the bedrock hydrogeologic units may force the groundwater into a more regional or subregional pattern determined by geological structure, independent from local topography and hydrography.
However, the TCV groundwater subsystems are a complex mix of bedrock aquifers, and predominantly shallow Hillslope and Valley Bottom aquifer systems underlain by either bedrock aquifers, or more confining hydrogeologic units, such as the Pennsylvanian Paradox Formation and the undivided lower Triassic rocks. Locally and sub-regionally, various hydrostructures may influence interconnectivities of the shallow units with deeper bedrock systems, but in general, there are no regional systems due to a lack of hydrogeologic, structural, and geomorphologic (including topographic) connectivity.

The La Sal Mountain Subsystem, located in the southeastern part of the study area, is a complex mix of bedrock (Tertiary Igneous Intrusive rocks or Ti and Tertiary Geyser Creek Fanglomerate or Tg) and unconsolidated deposits (Bouldery Colluvium, Talus and Colluvium, Glacial Till, Alluvial Fan deposits, and Stream Alluvium) which form a robust groundwater system that is directly connected to the surface water systems forming the headwaters of Castle and Placer Creeks (Figures 19 and 20). The top of this subsystem is directly hydraulically connected to Mesa Top subsystems not located in the TCV study area, and to the Castle Creek and Placer Creek Valley Bottom Subsystems in the TCV study area (Figures 19 and 20).
conditions, this subsystem has hydrologic system inputs and outputs similar to the Mountain, Hillslope and Valley Bottom subsystems of Castle Valley. However, the natural topography and geologic setting has blocked this subsystem from attaching to the Castle Valley subsystems, and the groundwater and surface water is part of the La Sal Mountains/Spanish Valley hydrologic system.

![Figure 20. Google Earth View of the Conceptual Site Model of the Hillslope and Valley Bottom Shallow Aquifer Subsystems, and the Bedrock Subsystems with Recharge and Discharge Zones and Groundwater Flow Direction (see Figure 19 for explanation).](image)

The Porcupine Rim and Castle Spires Rim Hillslope Subsystems, located in the steep terrain surrounding the Castle Valley area, are attached/linked to the Valley Bottom subsystems. These Hillslope subsystems have hydrologic system inputs and outputs, similar to the Valley Bottom subsystems. However, natural influences have created unique hydrogeologic units (Quaternary debris flows and fans, talus, weathered bedrock) that frequently attach these subsystems hydrologically to adjacent Valley Bottom subsystems, and there is minor bedrock support for significant groundwater contribution.

The Castle Creek and Placer Creek Subsystems, where stream-aquifer-wetland interactions occur, are areas of both groundwater recharge and discharge, and groundwater flow can have a rather diffuse character and often flows towards or aligns more or less with the streams and rivers. These subsystems depend primarily on interactions with their main tributaries and associated alluvial groundwater systems such as Castle Creek and Placer Creek; discharge from the Porcupine Rim and Castle Spires Rim subsystems; discharge from the bedrock subsystems such as the Geyser Creek fanglomerates, the fractured arkoses and White Rim sandstones of the Cutler Formation, and the Tertiary intrusive rocks of the La Sal Mountains foothills; and the management of subsurface return flow from irrigation lands. The wetlands associated with the local hydrogeologic conditions in the Castle Creek and Placer Creek drainages, and in the adjoining tributaries, are a mix of slope-type and riverine-type classifications given the groundwater support of various irrigation schemes, unconsolidated hydrogeologic unit groundwater systems, bedrock hydrogeologic unit groundwater systems, and hydrostructures.
As springs are discharge points of groundwater flow systems, their presence in the TCV study area provide clues about these groundwater flow systems, including the role of the hydrogeological units, hydrostructures, and the effects of natural and anthropogenic recharge on flow and water quality. To identify the location and discharge rates of springs and seeps in the TCV area the State water rights database was searched in Jan 2016 (UDWR 2016).

There are three general categories of springs, based on spring location with respect to hydrogeologic location, that are identified on topographic maps, field excursions, and in the State water rights records (Figure 10): 1) Unconsolidated Unit/Faulted Shallow Bedrock springs; 2) Unconsolidated Unit springs controlled by topography, geomorphology, and upward gradient groundwater flow; and 3) bedrock associated springs. The Unconsolidated Unit/Faulted Shallow Bedrock (Qal/Pc) springs are located at areas where the deeper bedrock aquifers are faulted and pinched out, and the groundwater is forced to the surface as surface water, such as the springs located north and west of the Day Star Academy, or where a cross-valley fault system or resistant bedrock unit has caused the shallow unconsolidated units to thin resulting in groundwater being forced to the surface, such as the springs above the Porcupine Ranch Spring in upper Placer Creek (Figure 10). The unconsolidated unit (Qal, Qaf) springs, which indicate discharge of local or subregional groundwater to Castle Creek are located above the hamlet of Castleton on tributaries of Castle Creek in the Tertiary Geyser Creek Fanglomerates (Tg), and below the confluence of Castle and Placer Creeks in the Town of Castle Valley (Figure 10). The bedrock-controlled springs are located mostly in the La Sal Mountain foothills in the southeastern part of the watershed, and the discharge of groundwater is from the Tertiary intrusive granodiorite (Ti) through the Quaternary hydrogeologic units (Qgt, Qcb, and QTaf) to the streams where Castle Creek and Placer Creek tributaries originate (Figure 10).

2.6 Groundwater System Conceptual Site Models by Subsystem

Based on the presence and orientation of various hydrogeologic and hydro-structural units, hydrography and topography, two categories of CSMs will be discussed in the TCV study area:

1. La Sal Mountain Subsystem, which include the Tertiary Intrusive Granodiorite and Tertiary Geyser Creek Fanglomerate bedrock hydrogeologic units and associated high K zone hydrostructures; and
2. Castle Creek and Placer Creek Hillslope and Valley Bottom Shallow Aquifer Subsystems, which include the Castle Spires Rim and Porcupine Rim Subsystems, and the fractured arkose and White Rim members of the Permian Cutler formation bedrock hydrogeologic unit and the associated high K zone hydrostructures.

The La Sal Mountain Subsystem will be discussed first since it is located at the highest topographic level, and is the headwaters of the overall Castle Valley surface and groundwater hydrologic system (Figures 19 and 20). In addition, a discussion of the interface between the three subsystems will be presented. The conceptual models are discussed in forthcoming sections and illustrated by cross-sectional and plan view figures. The locations of representative cross-sections are shown in Figure 21. Note that all of the subsystems have some interconnectedness with the surrounding subsystems, whether by subsurface groundwater flow, or by tributary stream flow (Figures 19).
2.6.1 La Sal Mountain Subsystem

As stated in Section 2.4.2, there are two significant hydrogeologic groups in the La Sal Mountain Subsystems:

1. Quaternary and Tertiary unconsolidated clastic materials (Figures 15, and 16; Table 2a), which are predominantly Alluvial Fan deposits (Qaf), Glacial Till (Qgt), Slumps and Slides (Qms), Talus and Colluvium (Qmt), Bouldery Colluvium (Qcb), and Older Alluvial Fan Deposits (QTaf); overlying

2. Tertiary bedrock units (Figures 14, and 15; Table 2b), including the following potentially water-bearing units: Tertiary Geyser Creek Fanglomerate (Tg) and Tertiary Intrusive Granodiorite (Ti).

![Figure 21. Map Showing the Locations of the Cross-sections Representative for the Conceptual Site Models in the TCV Study Area on Top of the Hydrogeologic Units.](image)

In addition, there are two types of geological structures of significance to the hydrogeology in the La Sal Mountain Aquifer Subsystems:

1. Northwest-southeast trending fault/fracture zone hydrostructures (southeastern extent of the high K zones extending to the northwest part of Castle Valley) that are observed on both the northeastern and southwestern sides of Castle Valley dipping vertically (Figures 14, 17, 19, and 22); and
2. Radial and concentric fault/fracture zone hydrostructures that are observed radiating out from and surrounding the Tertiary intrusions and dissecting the Tertiary Geyser Creek unit (Figures 14, and 19).

The shallow Quaternary and Tertiary unconsolidated materials in the La Sal Mountain Subsystem are ubiquitous, and include alluvial, glacial-alluvial, glacial, mass wasting, and paleo-alluvial (terrace) deposits mostly derived from the Tertiary Intrusive rocks (Figures 15, and 16; and Table 2a). These highly-permeable deposits are locally heterogeneous, with a mix of coarser and finer materials in all of the deposits. These deposits are underlain by a paleo-topographic surface carved out by paleo mass wasting and fluvial systems that originally deposited the Tertiary Geyser Creek unit. The glacial, fluvial, and mass wasting processes continued to eventually deposit the Quaternary unconsolidated materials that are the shallow aquifers in continuity with the Castle Creek and Placer Creek subsystems (Figure 19). It should be noted that the paleo-alluvial and modern alluvial systems followed structural fault zone controlled valleys and account for increased aquifer thicknesses in these valleys (Figure 17, 22, and 23).

Figure 22. Schematic Northeast-Southwest Cross-sectional View of the Conceptual Site Models of the Hillslope and Valley Bottom Shallow Aquifer Subsystems in the Vicinity of the Town of Castle Valley (A-A' in Figure 21).
Figure 23. Schematic Northeast-Southwest Cross-sectional View of the Conceptual Site Models of the Hillslope and Valley Bottom Shallow Aquifer Subsystems Southeast of Round Mountain (B-B’ in Figure 21).

Figure 24. Schematic Northwest-Southeast Cross-sectional View of the Conceptual Site Models of the Hillslope and Valley Bottom Shallow Aquifer Subsystems along the Northeast Side of Castle Valley (C-C’ in Figure 21).
Figure 25. Schematic Northwest-Southwest Cross-sectional View of the Conceptual Site Models of the Hillslope and Valley Bottom Shallow Aquifer Subsystems along the Southwest Side of Castle Valley (D-D’ in Figure 21).

Figure 26. Schematic Northwest-Southwest Cross-sectional View of the Conceptual Site Models of the Hillslope and Valley Bottom Shallow Aquifer Subsystems along the Placer Creek and Lower Castle Creek Drainages (E-E’’’ in Figure 21).
The general aspects of groundwater flow in the Quaternary unconsolidated materials have been discussed in Section 2.5. Specifically, the shallow groundwater in the La Sal Mountain Subsystem is dominated by the Quaternary alluvium (Qal); Quaternary Alluvial Fan Deposits (Qaf), Glacial Till (Qgt); Slumps and Slides (Qms); Talus and Colluvium (Qmt); Bouldery Colluvium (Qcb); and Older alluvial Fan deposits (QTaf), which receive natural recharge ($R_Q$) by infiltration of precipitation (snow and rain); input from hillside (slope) deposits located upgradient from a given location; and input from the two bedrock aquifers: the Geyser Creek Fanglomerate (Tg), and the Tertiary Intrusive units (Figures 19, 20, 22, 23, 24, 25, and 26).

Groundwater flow in the La Sal Mountains unconsolidated materials is with topography from hilltop and ridgetop down the hillslope to the valley bottom, and then parallel with the valley bottom steams (Figure 19). Groundwater in the valley bottom stream unit moves in the same direction as the stream with various stream reaches being gaining ($D_Q$) or losing ($R_Q$) depending on subsurface topography, saturated thickness of the alluvium, or the seasonal variations caused by snowpack runoff or storm events (Figure 19). These streams and tributaries are the headwaters of Castle Creek and Placer Creek, and most reaches are gaining from the

Figure 27. Potentiometric Surface of the Castle Valley Unconfined Aquifer (from Snyder, 1996).
alluvial and bedrock aquifers (Figure 19). There is also groundwater discharge (D_Q) from the alluvium locally by groundwater wells and by phreatophytes.

The shallow groundwater in the La Sal Mountain Subsystem is sustained by and connected directly to the underlying bedrock groundwater systems: the Tertiary Intrusive hydrogeologic unit (Ti), and the Tertiary Geyser Creek Fanglomerate hydrogeologic unit (Tg) (Figure 19). The connection of these two units is further enhanced by the radial and concentric faults/fracture zones where preferential (high K zones) groundwater flow occurs in the bedrock (Figures 17 and 19).

Groundwater recharge (R_I) occurs on the mountain tops and ridges where the Tertiary Intrusive units are frequently exposed (Figure 19). Groundwater then flows downgradient with topography along the radial faults and fractures to the radial and concentric valley bottoms, also preferred high K fault and fracture zones that serve as groundwater “French drains”, where the groundwater discharges (D_Q) into the unconsolidated materials and streams (gaining streams) (Figure 19). These valley bottoms, with combined bedrock and unconsolidated deposits, have increased groundwater flow and storage, and connectivity between the two hydrologic systems (Figure 19). Given the granodiorite composition of bedrock, the natural water quality is good except where mining activity has been undertaken.

Groundwater recharge (R_I) also occurs on the hills and ridges where the Tertiary Geyser Creek Fanglomerate units are exposed (Figure 19). Groundwater then flows downgradient with topography to the northwest-southeast linear valley bottoms, also preferred northwest-southeast trending high K fault and fracture zones that serve as groundwater “French drains”, where the groundwater discharges (D_Q) into the unconsolidated materials and streams (gaining streams) (Figure 19). These valley bottoms, with combined bedrock and unconsolidated deposits, have increased groundwater flow and storage, and connectivity between the two hydrologic systems (Figure 19). Given the fanglomerate composition of bedrock, the natural water quality is good unless nearby human activity (cattle grazing) has locally had an effect.

2.6.2 Hillslope and Valley Bottom Shallow Aquifer Subsystems

As stated in Section 2.4.2, there are two significant hydrogeologic groups in the Hillslope and Valley Bottom Shallow Aquifer Subsystems, which include the Castle Creek Subsystem, and the Placer Creek Subsystem:

1. Quaternary unconsolidated clastic materials (Figures 15, and 16; Table 2a), which are predominantly Stream Alluvium (Qal), Alluvial Fan deposits (Qaf), Slumps and Slides (Qms), and Talus and Colluvium (Qmt); overlying
2. Tertiary and Paleozoic bedrock units (Figures 14, and 15; Table 2b), including the following potentially water-bearing units: Tertiary Intrusive Granodiorite (Ti) (Round Mountain); and the White Rim and Arkosic members of the Cutler Formation (Pc).

In addition, there are two types of geological structures of significance to the hydrogeology in the Hillslope and Valley Bottom Shallow Aquifer Subsystems:

1. Northeast-southwest trending fault/fracture zone hydrostructures (Figure 17); and
2. Northwest-southeast trending faults, and fault/fracture zone hydrostructures (bedrock high K units) that are observed on both the northeastern and southwestern sides of Castle Valley dipping vertically (Figures 14, 17, 22, and 23).
The shallow Quaternary unconsolidated materials in these two subsystems are ubiquitous, and include alluvial, mass wasting, and paleo-alluvial terrace and fan deposits (Figures 15, 16; and Table 2a). These highly-permeable deposits are locally heterogeneous, with a mix of coarser and finer materials in all of the deposits. These deposits are underlain by a paleo-topographic surface carved out by paleo mass wasting and fluvial systems that eventually deposited the Quaternary unconsolidated materials that are the aquifers being evaluated. It is noted that the paleo-alluvial and modern alluvial systems followed structural fault zone controlled valleys and account for increased aquifer thicknesses in these paleo-valleys (Figure 16). The general aspects of groundwater flow in the Quaternary unconsolidated materials have been discussed in Section 2.5. Specifically, the shallow groundwater in the Castle Creek subsystem is dominated by the Quaternary alluvium (Qal) and Quaternary alluvial fan deposits (Qaf), which receive natural recharge (RQ) by infiltration of precipitation (snow and rain; losing streams; input from hillside (slope) deposits (Qms and Qmt) derived from the mass wasting gravels and northeast-southwest trending fracture-controlled ephemeral stream channels and deposits (Qms and Qmt); and additional recharge from return flow from irrigation locally (Figures 19, 20, 22, 23, and 24). Water leaking from the irrigated areas enters into the (connected) gravels underneath and flows downgradient towards the discharge zones (DQ) (gaining streams, springs and seeps, and wetlands) (Figures 19, 20, 22, 23, and 24).

Groundwater flow in the Castle Creek alluvium moves in the same direction as the stream with various stream reaches being gaining (DQ) or losing (RQ) depending on subsurface topography, bedrock hydrogeology, hydrostructures, and saturated thickness of the alluvium, or the seasonal variations caused by snowpack runoff or storm events (Figures 19, 20, 22, 23, and 24). There is also groundwater discharge from the alluvium (DQ) locally by groundwater wells and by phreatophytes.

The shallow groundwater in the Castle Creek alluvial subsystem would normally have little connection to the local bedrock or the regional groundwater systems, given the very low permeability Pennsylvanian Paradox Formation (IPPC), unfractured Permian Cutler Formation (Pc), and other unfractured younger bedrock (Figures 22 and 23). However, underlying the northeastern side of Castle Valley is the northwestern-southeastern trending Castle Creek fault/fracture zone that formed with the collapse of the Castle Valley salt anticline (Figure 18). This area of hydrostructures is an open vertical and horizontal conduit (High K zone), where the faulted and fractured Permian Cutler (Pc) bedrock combines with the alluvium (Qal) to form a French Drain affect resulting in increased groundwater flow and storage, and connectivity between the two hydrologic systems (Figures 22, 23, and 24).

The fractured and faulted Permian Cutler bedrock aquifer is variably to fully saturated based on location and proximity to recharge area. In the Castle Creek Subsystem, groundwater recharge (RC) by losing stream reaches and infiltration of precipitation is possible only by connection to the Castle Creek fault and fracture zone, and by the northeast-southwest fault and fractures that control drainages below the Castle Spires Rim (Figures 19 and 20). The subregional groundwater flow direction is from southeast to northwest parallel to the Castle Valley salt anticline collapse structures and Castle Creek (Figures 22, 23, and 24). This High K Zone flow system ends at the northwest end of Castle Valley, and the groundwater moves vertically upward into the Qal and ultimately into springs as discharge (DC) and into Castle Creek (DC) (Figures 19, 22, 23, and 24). This results in decreased water quality either naturally (Permian Cutler hydrogeologic unit water has higher TDS) or due to human activities, such as
agriculture or human waste disposal activities (Figure 18). A Google Earth view of the Hillslope and Valley Bottom subsystem in the Castle Creek drainage is shown in Figure 20.

The second Hillslope and Valley Bottom Subsystem in the TCV study area is the shallow groundwater in the Placer Creek Subsystem. This subsystem is dominated by the Quaternary alluvium (Qal) and Quaternary alluvial fan deposits (Qaf), which receive natural recharge ($R_Q$) by infiltration of precipitation (snow and rain; losing ephemeral streams from the southeast (Cain Hollow and Placer Creek, for example); input from hillside (slope) deposits (Qms and Qmt) derived from the mass wasting gravels and northeast-southwest trending fracture-controlled ephemeral stream channels and deposits (Qms and Qmt); and additional recharge from leaky irrigation ditches originating from the Porcupine Ranch Spring area, and return flow from irrigation locally ($R_O$) (Figures 19, 20, 22, 23, 25 and 26). Water leaking from the unlined ditches and irrigated areas enter into the (connected) gravels underneath and flows downgradient into the main Placer Creek groundwater flow system (Figures 19, 20, 22, 23, 25, and 26).

Groundwater flow in the Placer Creek alluvium moves in the same direction as the stream with most of the stream reaches being losing ($R_Q$) when surface water flow occurs due to the seasonal variations caused by snowpack runoff or storm events (Figures 19, 20, 22, 23, 25, and 26). There is also groundwater discharge ($D_Q$) from the alluvium locally by groundwater wells and by phreatophytes.

The shallow groundwater in the Placer Creek alluvial subsystem would normally have little connection to the local bedrock or the regional groundwater systems, given the very low permeability Pennsylvanian Paradox Formation (IPpc), unfractured Permian Cutler Formation (Pc), and other unfractured younger bedrock (Figures 22 and 23). However, underlying the southwestern side of Castle Valley is the northwestern-southeastern trending Placer Creek fault/fracture zone that formed with the collapse of the Castle Valley salt anticline (Figure 17). This area of hydrostructures is an open vertical and horizontal conduit (High K zone), where the faulted and fractured Permian Cutler (Pc) bedrock combines with the alluvium (Qal) and Alluvial Fan Deposits (Qaf) to form a French Drain affect resulting in increased groundwater flow and storage, and connectivity between the two hydrologic systems (Figure 22, 23, 25, and 26).

The fractured and faulted Permian Cutler bedrock aquifer is variably to fully saturated based on location and proximity to recharge area. In the Placer Creek Subsystem, groundwater recharge ($R_C$) by losing stream reaches and infiltration of precipitation is possible only by connection to the Placer Creek fault and fracture zone, and by the northeast-southwest fault and fractures that control drainages below the Porcupine Rim (Figure 17). The subregional groundwater flow direction is from southeast to northwest parallel to the Castle Valley salt anticline collapse structures and Placer Creek (Figures 19, 20, 25, and 26). This High K Zone flow system ends at the northwest end of Castle Valley, and the groundwater moves vertically upward into the Qal and ultimately into springs as discharge ($D_C$) and into Castle Creek ($D_C$) (Figures 19, 20, 24, 25, and 26). This results in decreased water quality either naturally (Permian Cutler hydrogeologic unit water has higher TDS) or due to human activities, such as agriculture or human waste disposal activities (Figure 18). A Google Earth view of the Hillslope and Valley Bottom subsystem in the Castle Creek drainage is shown in Figure 20.

A potentiometric surface map of northwestern Castle Valley showing discharge area and water table elevations is presented in Snyder (1996) (Figure 27). This potentiometric surface
map, a more simplified representation of the northwestern end of the Combined Castle Creek and Placer Creek subsystems presented in this Section, shows that the groundwater flow in the Valley is generally from southeast-to-northwest and has a somewhat uniform gradient throughout, but a flatter gradient where the unconsolidated sediments thicken (Figure 27). Given the conceptual model that is presented in this section and throughout the report, Figure 27 does not show the presence of the two Permian Cutler (Pc) high K bedrock zones on the northeastern and southwestern sides of the Valley that connect with the groundwater system in the unconsolidated units. Figure 27 also does not show the very pronounced connections of Castle Creek with the groundwater system (losing in the up valley reaches, gaining in the down valley reaches indicated by springs), the groundwater discharge represented by springs along the northwestern margin of the Valley, and the effects of irrigation on the water table or the potentiometric surface. Figure 27 does indicate that regional groundwater flows into the system on the western side of the Valley, whereas the conceptual model presented in this Section indicates that the western side of the system has a no flow boundary, and that no regional groundwater system connects to the Castle Valley.

2.7 Anthropogenic Influences

Human activity in the TCV study area has affected both the surface and subsurface parts of the hydrologic systems. Past land use and human activity was mostly associated with cattle grazing, irrigation, and small reservoir construction and operation, or subdivision of lands for domestic use. These activities have been accompanied by removal or selective reduction of native vegetation, introduction of irrigation and high-ET (evapotranspiration) crops or vegetation associated with homes, construction of (often leaking) irrigation ditches (now mostly piped), and the drilling of primarily domestic wells. This activity has resulted in localized changes of groundwater water levels and flow directions that are affected due to changes of recharge (return flow from primarily irrigation and, to a lesser extent, leaky irrigation ditches); and to changes in discharge (new domestic wells, reduction of groundwater flow due to reduction of surface water flow that has been diverted in local, shallow aquifers of the Quaternary materials in the alluvium (Qal) of the Castle Creek and Placer Creek Subsystems. In addition, this activity may result in increased mobility of various salts in the groundwater and surface water systems, particularly in the Castle Creek watershed below Castleton, and the Placer Creek groundwater system in and around the fractured High K Zone in the Permian Cutler hydrogeologic unit in the northwestern part of Castle Valley.

Current land use and human activity changes are mostly associated with minor subdivision of natural or agricultural lands, such as the expansion of the Town of Castle Valley in the northwestern part of Castle Valley, and the potential changes of land use at Day Star Academy. These changes result in changes to surface water throughflow/interflow, overland flow, and channel flow, as well as changes in groundwater recharge, flow directions, and discharge. Water quality changes may result as well.

2.7.1 Effects of Land Use Changes on Groundwater Systems

The main irrigation activities in Castle valley take place upgradient of the bottomlands (Qal) on the alluvial fans (Qaf) of the Hillslope and Valley Bottom Subsystems, while most grazing activities are scattered about the Hillslope and Valley Bottom Subsystems. Agricultural
production of animal feed is supported by surface water irrigation, often delivered through pipes or a center pivot conveyance system (Figure 28). The main irrigation method in use is flood irrigation, which tends to provide more water to the fields than can be consumed by vegetation. Excess water from irrigation results in infiltration to the water table and recharge of the groundwater system at the location of these fields (i.e., \( R_Q \), irrigation return flow), or direct runoff of surface water to Castle Creek (Figure 28). At this time, Castle Valley is not experiencing a major shift from agricultural to nonagricultural land use, and the return flow from irrigation and subsequent groundwater recharge is stable. However, changes in groundwater quality due to fertilization practices of home owners and ranches with irrigation should be monitored.

The TCV study area consists primarily of the combined Hillslope and Valley Bottom Castle Creek and Placer Creek Subsystems, limiting the irrigated areas to the lower (Qal: alluvium and Qaf: alluvial fans) portions of the subsystems (Figures 28). Here, there are some unlined irrigation ditches and canals that are excavated primarily in unconsolidated Quaternary (Qal) deposits (Figure 28). When carrying water, the ditches may leak into the underlying and surrounding unconsolidated materials as evidenced by the phreatophytes (such as Cottonwoods) often found alongside. The water leaking from the ditches may be used by vegetation and discharged as evapotranspiration, or may recharge the underlying groundwater system, forming a local groundwater mound. As most of the groundwater systems in the study area are local in nature, ditch and canal leakage may contribute significantly to the local water balance, increase the water table elevation, and influence groundwater flow patterns.

As discussed previously, irrigation return flow can be a significant recharge element in the local groundwater balance, and in the surface water balance within the lower part of the Castle Creek watershed. Taking irrigated fields out of production and re-allocating pipe-conveyed water reduces recharge of groundwater resulting in lowered water tables, reduced groundwater discharges to nearby wetlands and streams, and decreased water supplies.
Water wells are found throughout the TCV study area, primarily in the unconsolidated Quaternary deposits (Qal) at valley bottoms and in the High K Zone of the Permian Cutler (Pc) Hydrogeologic Unit (Figure 29). Most of these wells serve domestic water supply or irrigation needs, and the effect on the groundwater system locally may be significant. However, if additional water is needed by urban or agricultural development, or water is displaced by urban and recreational activities, for example, the compound effect on the groundwater system could be more significant in the future, resulting in a possible lowering of the water table, changes in flow direction, decreasing discharge to streams or increasing stream loss to groundwater, draining of wetlands, or even depletion of local aquifers. It should be noted that areas with higher density of wells, such as the Town of Castle Valley, the community of Castleton, and the area west of Round Mountain, also have a higher density of septic tanks.

![Figure 29. Anthropogenic Influences: Constructed Wells in the TCV Study Area.](image)

(From Utah Division of Water Right Data Base with Filter Setting: Perfected, Underground, Water Right, All Uses; Accessed March 2016).

### 2.7.2 Potential Effects of Groundwater Use on Water Quality

The HESA evaluation of the TCV hydrologic systems can also be used for assessing the vulnerability of groundwater and surface water to contaminants in both the natural and anthropogenic environment. Regionally, salt concentrations (Total Dissolved Solids or TDS) are known to frequently exceed drinking water and ecosystem standards, whether naturally or human-induced. Salts are very soluble and mobile in surface and groundwater environments, and tend to concentrate in surface water environments in arid and semi-arid climates. The Permian
Cutler Group (Pc) and Pennsylvanian Paradox Formation (IPpc) hydrogeologic units, usually considered groundwater flow system confining layers, are the main source in Castle Valley for naturally occurring salt in a chemically soluble form. The faulted and fractured Cutler Group (Pc), referred to as two High K Zones located under Castle Creek and Placer Creek (Figures 17, 19, and 20), allow large quantities of groundwater to flow through these conduits where large quantities of soluble salt are incorporated into the groundwater flow system. These salts are then transported in the groundwater and/or surface water to exposure sites such as wells, lakes, and surface water bodies like Castle Creek where they may be measured in quantities unacceptable by drinking water and/or ecosystem regulatory standards. Many spatial (3-dimensional) and temporal (past, present, and future time frames) factors affect how the salt is being mobilized and transported including: 1) Salt source location with respect to hydrogeologic framework, specifically the hydrogeology of unweathered and weathered Cutler and Paradox Formation bedrock and the hydro-geomorphology of overlying unconsolidated Quaternary deposits, such as landslides, glacial and alluvial gravels, soils and weathering profiles; 2) Groundwater flow pathways including exposure sites such as groundwater discharge zones to the surface water systems; and 3) Past, present, and future hydrologic “stresses” to the system, for example irrigation of weathered Cutler or Paradox Formation bedrock, and irrigation on geomorphologic deposits on weathered Cutler and Paradox Formation bedrock.

2.7.2.1 Hillslope Subsystems Water Quality

The hydrogeology of the Porcupine Rim and Castle Spires Rim Hillslope Subsystems, as previously described in Section 2.6, is primarily Quaternary and Tertiary unconsolidated clastic materials, which are predominantly Stream Alluvium (Qal), Alluvial Fan deposits (Qaf), Glacial Till (Qgt), Slumps and Slides (Qms), Talus and Colluvium (Qmt), Bouldery Colluvium (Qcb), and Older Alluvial Fan Deposits (QTaf); overlying Tertiary and Paleozoic bedrock units, including the following potentially water-bearing units: the Tertiary Geyser Creek Fanglomerate (Tg); Tertiary Intrusive Granodiorite (Ti); and the White Rim and Arkosic members of the Cutler Formation (Pc), and the following confining hydrogeologic units: Paradox Formation (IPpc), unfractured Permian Cutler (Pc), and undivided bedrock (mostly Triassic) units. A small weathered zone exists as the interface between the Quaternary unconsolidated hydrogeologic units and the Bedrock hydrogeologic units. The hydrologic system of these steep Hillslope Subsystems, as previously described in Section 2.6, is that surface water in fracture-controlled channels, and overland and interflow from precipitation rapidly runs off the steep hillslopes until flowing across or through the Quaternary and/or Tertiary unconsolidated hydrogeologic units, where the water quickly disappears into the aquifer as groundwater recharge (R$_Q$ and R$_C$, Figure 18). In the process of channeled surface water, or overland and interflow, soluble salts in the bedrock are incorporated into the surface and near surface water to be transported into the unconsolidated deposits aquifers. The fringes of these aquifers would have higher TDS than the central parts of these aquifers in the main valley (Figure 18).

The natural pollutants that are most likely occurring include salts (carbonates and sulfates), and the most likely source of these pollutants is the weathered zone of the older bedrock upgradient. It is hypothesized that the natural system has been flushing salt through this system since the erosion of the landscape commences resulting in the deposition of the Quaternary and Tertiary unconsolidated material in the various drainages and Castle Valley.

The anthropogenic pollutant sources to these subsystems are from the homes that are located on the unconsolidated materials and would include mostly fertilizers for grass (urban) or
crops, or rural septic tank waste. Most of these are organics and nutrients, and would need to be monitored accordingly.

2.7.2.2 Valley Bottom Subsystems Water Quality

The hydrogeology of the two Valley Bottom Subsystems, as previously described in Section 2.6, is primarily Quaternary and Tertiary unconsolidated clastic materials, which are predominantly Stream Alluvium (Qal), Alluvial Fan deposits (Qaf), Glacial Till (Qgt), Slumps and Slides (Qms), Talus and Colluvium (Qmt), Bouldery Colluvium (Qcb), and Older Alluvial Fan Deposits (QTaf); overlying Tertiary and Paleozoic bedrock units, including the following potentially water-bearing units: Geyser Creek Fanglomerate (Tg); Tertiary Intrusive Granodiorite (Ti); and the White Rim and Arkosic members of the Cutler Formation (Pc), and predominantly the following confining hydrogeologic unit: Paradox Formation (IPpc). A major rubbly weathered zone called the “cap rock” exists as the interface between the Quaternary and Tertiary unconsolidated units, and the Bedrock hydrogeologic units. A weathered zone most likely exists as the interface between the two groups of hydrogeologic units. The hydrologic system of the two Valley Bottom Subsystems is described previously in Section 2.6.

The natural pollutants that are most likely occurring includes salts (high TDS), and the most likely source of these pollutants is the weathered zone at the interface between the two main hydrogeologic bedrock units: The Permian Cutler Formation (Pc) and the Pennsylvanian Paradox Formation Cap Rock (IPpc) and the Quaternary and Tertiary unconsolidated materials. It is hypothesized that the natural system has been flushing salts through this system since the deposition of first the Tertiary Gravels, then the Quaternary glacial, mass wasting, and alluvial gravels (Qal). Given the large water quantities being circulated, and long period of time of flushing, it is unlikely that large amounts of salts are being leached and transported directly from the bottom of these subsystems. However, it is hypothesized that a substantial amount of these natural pollutants enters the wells of Placer Creek and the Castle Creek Subsystems through the High K Zones of the fractured Permian Cutler Units (Pc) groundwater systems to eventually daylight into the Castle Creek surface water system (See Figure 18).

The anthropogenic pollutant sources to these Valley Bottom subsystems are mostly fertilizers for grass (urban) or crops, industrial pollutants (local garages, for example), or rural septic tank waste. Most of these are organics and nutrients, and would need to be monitored accordingly.
3 PRELIMINARY WATER BALANCE

The components of the Castle Valley (TCV) area hydrologic system have been determined and the surface water and groundwater flow systems analyzed, using the HESA approach, and discussed in Section 2. Three Subsystems have been identified and characterized: the La Sal Mountain Subsystem; Castle Creek Hillslope and Valley Bottom Subsystem; and the Placer Creek Hillslope and Valley Bottom Subsystem (Section 2.6 and Figure 18). Each of these hydrologic systems have been analyzed for their surface water dynamics (stream input or stream flux in, stream flow through the given area, stream output or stream flux out) and measurements of stream dynamics (discharge and velocity over time) have been collected at various stations (Section 2.3). In addition, precipitation measurements have been collected at various locations as input into the watershed (Section 2.1). Likewise, each of the Subsystems has been analyzed for groundwater systems (Section 2.4-2.6), and the groundwater input or recharge areas, groundwater flow system, and groundwater output or discharge areas been determined (Section 2.6). Well measurements have been collected at well locations to quantify groundwater output, and spring measurements, which are also groundwater output, have been collected (Ford, 2006). In addition, groundwater level data have been collected at wells, which enable the determination of groundwater flow direction and amount of water storage and well yield at a given point in the groundwater system, and calculations of groundwater flux and storage over time can be done (Snyder, 1996).

In order to further understand how the hydrologic systems in the TCV area work, and to determine quantitatively if the hydrologic system is properly analyzed, a water balance can be calculated for a given part of, or the entirety of the TCV study area. The hydrologic system water balance, or water budget, is the quantitative listing of the surface water and groundwater inputs and outputs, and changes in internal storage over a particular period of time. In its most simple form, the period of time is chosen such that the internal storage is so small that it does not have to be taken into account. Considering climatic variability, often a multi-year period with averaged inputs and outputs is selected to determine the water budget for a particular hydrologic system. Without a storage term, the water budget inputs should be equal to or "balance" the water budget outputs. The selection of the time period for which to calculate the water budget depends, among others, on the nature of the climatic variability, and the availability of climatic and hydrologic records. Frequently this is done for a one- or multi-year period to capture a full cycle of seasons, or multi-year trends. For shorter periods of time, such as the growing season, water budget calculations may involve estimating the release from or addition to internal storage. This change in storage could be seasonal changes in measured water tables, or changes in reservoir water levels.

The first step in determining an accurate water balance for the Castle Valley hydrologic system is to determine the correct Hydrologic System Conceptual Model using HESA. With HESA individual components of the hydrologic system are analyzed, followed by evaluating the aggregate of components and their interactions, to locate and quantify relevant hydrologic subsystems. The results of the HESA for the TCV study area are given in Section 2. Step 2 in determining the water balance is setting up a logic diagram based on the conceptual models to show all the significant hydrologic units and processes, including the external hydrologic system inputs, outputs, and internal storage areas, and internal exchanges. Step 3 is to subset the overall conceptual model area to a manageable area where quantification of the hydrologic system will be most practical and accurate given the available data and the landscape terrain measurability...
(estimates of inputs and outputs where engineering data is not available or not practical/cost-effective at this time).

3.1 Water Balance Logic Diagram

The generalized hydrologic system components and processes diagram for the study area (TCV), based on the HESA-derived conceptual models, shows all the significant hydrologic and hydrogeologic units or storage components (boxes), and the hydrologic exchange processes or fluxes (arrows) (Figure 30). The main hydrologic units are: atmosphere; unsaturated zone (between ground surface and water table), shallow groundwater zone (saturated valley-fill unconsolidated sediments); and deep groundwater zone (bedrock hydrogeologic units and hydrostructures). Figure 30 also shows the process-type interactions between these hydrologic units as present in the TCV study area. Not included are the processes internal to the hydrologic units, such as atmospheric flow, stream flow, and groundwater flow. These processes can be quantified as fluxes or flow rates such as precipitation rates (in/hr, in/yr), groundwater recharge

![Figure 30. Generalized Hydrologic System Components and Processes.](image-url)
(in/yr), spring discharge (gpm), groundwater discharge to/recharge from streams (ft³/d/ft'), and well discharge (gpm). It should be noted that many of the processes are difficult to measure or estimate and introduce significant uncertainty in water budget calculations when used.

Often, to get a better understanding of the water budget components and reduce uncertainty, the complex set of hydrologic units and processes shown in Figure 30 is replaced a subset of units and processes by a single inflow/outflow flux. For example, a water budget may focus on surface water and its interaction with the atmosphere. In that case, the subsurface units and processes, depicted in Figure 30 as the unsaturated zone, the shallow groundwater (saturated zone), and deep groundwater zone (bedrock) and related processes, would be represented by a single gain or loss flux. In the same fashion, a focus on the groundwater system may replace the atmosphere, streams, and unsaturated zone by inputs and outputs only, and any change in storage would be limited the shallow and deep aquifers.

The Conceptual Site Models resulting from the HESA of the TCV study area, together with the location of the Castle Creek stream flow gages, provided guidance on how to simplify the complex hydrologic system components and process illustrated in Figure 30 to develop a preliminary water budget for Castle Valley.

3.2 Preliminary Water Balance for the TCV Project Area

A preliminary water balance (PWB) for the (TCV) project area has been calculated based upon the information previously collected and analyzed by Ford (2006), and the HESA-based conceptual model determined as part of this study. The area in Castle Valley of the water balance is determined in part based upon the locations of two USGS stream gages on Castle Creek, the location of most anthropogenic activities (domestic and agricultural), and the natural boundaries of the TCV hydrologic systems (lower Castle Creek and Placer Creek Hillslope and Valley Bottom Subsystems which merge in the northwestern part of Castle Valley under the Town of Castle Valley) (Figure 31). The water balance area is from Cross-section B-B' in the southeastern part of Castle Valley, to the Castle Creek exit in the northwestern part of Castle Valley, and extends to the Porcupine Rim to the southwest and to the Castle Spires Rim to the northeast (Figure 31).

The inputs of the PWB are: Castle Creek surface water at Castleton, UT; Castle Creek Subsystem groundwater flux flowing in the unconsolidated hydrogeologic units (Qaf) from the southeast; Placer Creek subsystem groundwater flux flowing in the unconsolidated hydrogeologic units (Qaf) and Tertiary Geyser Creek hydrogeologic unit (Tg); and recharge by infiltration of precipitation (rain and snow) across the entire Castle Valley area. The outputs of the PWB are: Castle Creek at the northwestern end of Castle Valley; Evapotranspiration by native Phreatophytes (Cottonwoods and Willows); and Consumptive Use by irrigation and domestic wells. Figure 32 shows a diagrammatic representation of the water budget components. It should be noted that the groundwater inflow components "irrigation return flow" and "septic tank leach field infiltration" shown in Figure 32 are considered small enough not to be taken into consideration for the PWB; all terms on the left side except "stream flow" are considered consumptive use.
Figure 31. Map Showing the Location of Preliminary Water Balance (PWB) Area with Inputs and Outputs. Based on the Conceptual Site Models in the TCV Area and locations of Stream Gages.

Fig 32. Inflows and Outflows of the Simplified Water Balance Calculation for the TCV Study Area.
A starting point for determining the PWB is the report by Ford (2006) which includes a section on the water budget for the valley. Ford (2006) specifically addresses stream flows and quantification of consumptive use, including domestic (wells) and irrigation (stream diversions) water use, and water loss through riparian vegetation (evapotranspiration – ET). For stream inflow and outflow Ford (2006) uses USGS Station 09182200 below Castleton (upper gage; inflow) and USGS Station 09182400 between Red Cliffs Ranch and the Colorado River (lower gage; outflow). The stage and discharge records for Station 09182200 cover the period 1992 - 2001, and the records for Station 09182400 cover the period 1992-present. For calculation of a multi-year average for both stations, Ford (2006) selected the period 1992-1998, resulting in an average discharge at Station 09182200 of 3.48 cfs or 2,521 ac-ft/yr, and at Station 09182400 of 7.00 cfs or 5,071 ac-ft/yr. Ford (2006) reported a total consumptive use in the valley (irrigated crops, ET from riparian vegetation, and domestic wells) of 1,748 ac-ft/yr. Balancing these inflows (2,521 ac-ft/yr) and outflows (6,819 ac-ft/yr) indicates that 4,298 ac-ft/yr enters the valley as groundwater and effective precipitation (primarily groundwater recharge).

To further analyze the groundwater inflow and groundwater recharge components, several PWB scenarios were calculated for the in Figure 31 shown water budget area, varying the saturated thickness and water table levels of the Placer Creek and Castle Creek groundwater boundary conditions. In addition, groundwater recharge due to infiltration of precipitation was varied. The PWB used calculations by Ford (2006) for consumptive use, and the data for Castle Creek surface water in, and Castle Creek surface water out.

The basis for the calculation of groundwater recharge due to infiltration of precipitation (rain and snow), and infiltration along ephemeral stream channels during flooding events was generalized as to spatial location, and spatially distributed across the entire 16,000 acres of the Qal/Qaf surface area between B-B’ in the southeast and the valley exit of Castle Creek in the northwest. Three calculations were completed: Recharge of 1.4 in/yr (roughly 10% of precipitation, a common estimate in groundwater modeling for these environments) or a total of 1,867 ac-ft/yr; 2.0 in/yr or a total of 2,667 ace-ft/yr; and 3.0 in/yr or a total of 4,000ac-ft/yr. This would leave the remaining groundwater input as flux across the cross-sectional area of B-B’ as: 2,368 ac-ft/yr; 1,568 ac-ft/yr; and 235 ac-ft/yr, respectively. Given these calculations, the range of recharge rates of 1-2 in/yr is most likely and commonly observed in other areas of similar climates and hydrogeologic materials.

The basis for the calculation of groundwater flux across the southeast part of the PWB area (B-B’ in Figure 31) is Darcy’s Law:

\[ Q = KIA; \]

where Q is discharge per unit time; K is hydraulic conductivity of the Hydrogeologic Unit; I is \( \frac{dH}{dL} \) or hydraulic gradient (change in head H over a distance L); and A is cross-sectional area. Q will be the groundwater input/inflow into the water budget that is derived from the La Sal Mountain subsystem (Section 2.6.1). K is determined by aquifer tests, which reveal a range of values from approximately 1 – 10 ft/day (Lowe and others, 2004). Hydraulic gradient was determined using the potentiometric surface map of Snyder (1996) to be 0.0322 (Figure 27).

The cross-sectional area used to calculate flux was estimated from cross-section B –B’ (modified from Lowe and others, 2004), and primarily focused on the Qal/Qaf hydrogeologic unit (Figure 33). The cross-sectional area of the Placer Creek subsystem was the sum of the total.
cross-sectional area (total depth times surface length of two distinct areas) minus the shallow unsaturated cross-sectional area (top 100 ft times surface length based on depth to water table). The well logs (available from the Utah Division of Water Rights web site) show that the water table at cross-section B-B' is approximately 100 ft below the land surface. The Placer Creek Qa/Qaf saturated cross-sectional area was calculated to be 1,399,617 sq.ft.

The cross-sectional area of the Castle Creek subsystem was the sum of the total cross-sectional area (total depth times surface length of one distinct area) minus the shallow unsaturated cross-sectional area (top 20 ft times surface length based on depth to water table). Well logs in this area show that the water table is approximately 20 ft below the land surface. The Castle Creek Qa/Qaf saturated cross-sectional area was calculated to be 475,200 sq.ft.

Several PWB scenarios were calculated, first varying the K values between 1 and 10 ft per day; then varying the cross-sectional area values by 10%. The closest fit was using K values between 5 and 7 ft/day, which fit the aquifer test data closely, and cross-sectional areas about 10% less that estimated yielding 2,276 – 2,833 ac-ft/yr which centered on the 2,431 ac-ft/yr needed to balance the recharge value 1.4 in/yr (1,867 ac-ft/yr) across the project acreage. The Preliminary Water Budget results summarized: Surface water in (2,521 ac-ft/yr) + Recharge in (1,867 ac-ft/yr) + Groundwater in (2,431 ac-ft/yr) = Surface water out (5,071 ac-ft/yr) + Consumptive use out (1,748 ac-ft/yr) = Total Water Budget (6,819 ac-ft/yr).

![Figure 33. Detail of Cross-section B-B' Showing the Location of the Cross-sectional Southern Boundary Areas Used for Calculation of the Groundwater Inflow Component of the Preliminary Water Balance (PWB).](image)

There are many uncertainties in these preliminary calculations, so further analysis is planned and needed. The primary significance of the PWB is that there is a significant amount of groundwater contributed to the Castle Creek and Placer Creek subsystems from the La Sal
Mountain subsystem, or in percentages of input into the Castle Valley system: surface water (Castle Creek) counts for 37%; local recharge from precipitation or ephemeral channel loss counts for 27%; and groundwater counts for 36%. This means that the La Sal Mountain subsystem contributes 72% of the total inflow in the PWB area.

The reduction of water contributions originating from the La Sal Mountain subsystem in amounts and timing of precipitation (rain and snowfall) and snowmelt resulting from climate change may have a significant impact on streamflows, groundwater recharge and subsurface inflow into the valley. In addition, water diversion projects to other watersheds, especially up-valley, will result in decreased surface water flows and groundwater recharge from losing streams. Impacts on the valley's water budget may also result from deforestation due to lumbering or fire (increased surface runoff and stream flows); increased forestation (increased ET; decrease of runoff and stream flows); and mining (increased or decreased stream flows and groundwater fluxes). Land use conversions/changes resulting in more or less consumptive uses need to be evaluated regarding the surface water output to Castle Creek at the northwest end of Castle Valley. Increased consumptive use would result from increased urbanization (more wells, non-native vegetation), or increased irrigation.
SUMMARY AND CONCLUSIONS

Under an agreement with Town of Castle Valley, Utah, Hydrologic Systems Analysis LLC (HSA) of Golden, Colorado, in conjunction with Heath Hydrology, Inc. (HHI) of Boulder, Colorado, was tasked: 1) to perform a Hydrologic and Environmental System Analysis (HESA) of the surface water and groundwater resources of the valleys and uplands of the Castle Creek Watershed and Castle Valley Groundwater Basin in the vicinity of the Town of Castle Valley in Grand County, Utah; 2) develop hydrological, hydrogeological and other data bases necessary for constructing a water budget for the Valley; and based on the HESA results and GIS databases developed: 3) develop an as-accurate-as-possible water budget for the Valley in support of watershed management issues including water supply and allocation, water quality and protection, and watershed protection; and 4) determine the siting and protecting of a municipal well and a shallow well(s) near the Castle Valley Ditch Co. diversion to augment surface flows in Castle Creek and irrigation ditches. Each of these tasks constitutes a phase of the project. This report contains the results of phase 1, Hydrologic and Environmental System Analysis (HESA) and includes a preliminary water budget analysis.

The HESA showed that there are two significant groups of hydrogeologic units in the TCV study area: 1) Quaternary and Tertiary unconsolidated clastic materials, overlying 2) Tertiary, Mesozoic and Paleozoic bedrock units. Potentially water-bearing units include: 1) unconsolidated clastic materials; 2) weakly-cemented Tertiary Geyser Creek Fanglomerate; 3) faulted and fractured Tertiary Intrusive Granodiorite; and 4) White Rim and Arkosic Members of the Cutler Formation. The significant non-water bearing units or confining units, which may be a source of salts in the groundwater system and wells, are: 1) Triassic Chinle and Moenkopi Formations; 2) unfractured Permian Cutler Formation; and 3) Permian Paradox Formation including Caprock.

The Quaternary unconsolidated clastic units are locally heterogeneous, with predominantly coarser materials in the older alluvial deposits, and a mixture of coarser and finer materials in the younger deposits. These deposits, which are moderately to highly permeable, are recharged by infiltration from precipitation that is non-uniformly distributed due to the slope steepness, slope aspect, and to position in the landscape, by the incidental leaky irrigation ditch and irrigation return flow, and by flow in ephemeral stream channels and losing reaches in perennial streams where favorable. The unconsolidated units are variably to fully saturated, based on spatial location and seasonal precipitation events. There is lateral and vertical groundwater flow connection between the unconsolidated materials and the underlying bedrock formations that is critical for understanding the hydrologic systems and water quality of Castle Valley.

The thicknesses and subsurface distribution of these unconsolidated sediments range from less than 25 ft in the southeastern part of Castle Creek above Castleton and the southeastern part of Placer Creek above Porcupine Springs ranch to greater than 300 ft in the northern part of Castle Valley near Day Star Academy. The greatest thickness of the unconsolidated material is in the collapsed part of Castle Valley northwest of Round Mountain where average thicknesses ranging from 100 to 200 ft are common. The subsurface distribution of thickness is indicative of the structural collapse and faulting with subsequent erosion and filling of fault zones with gravels. Linear paleo-valleys and subsequent groundwater conduits are observed along: 1) the
northeastern margin of the valley fill beneath the modern day Castle Creek from Castleton extending to Day Star Academy; and 2) the southwestern margin of the valley fill beneath the modern day Placer Creek from above the Porcupine Springs Ranch extending to beneath the Town of Castle Valley town hall to the northwest.

Geologic faults and fracture zones, sometimes expressed at the surface as lineaments or linear drainage segments, may influence the hydrogeology and hydrologic systems of Castle Valley, including the location of Castle Creek and Placer Creek. These hydrostructures underlie the drainages in the three bedrock hydrogeologic systems, and are most likely associated with preferential highly transmissive groundwater flow along fault and fracture zones that are observed or hypothesized to transmit groundwater either vertically or laterally along the fault or fracture planes or zones.

The main subregional fold and fault structure is the Castle Valley Salt Anticline with corresponding graben/collapse structure. The bounding faults of the collapse, located on the northeast and southwest sides of Castle Valley, dip almost vertically and strike from the southeast to the northwest. These two fault zones, when located in the White Rim and Arkosic Members of the Cutler Formation, are subregional hydrogeologic conduits or high hydraulic conductivity zones or High “K” zones. These conduits are continuous from the southeastern part to the northwestern part of Castle Valley and have high yields of groundwater with elevated TDS water quality. These hydrostructural units pinch out at either end of the valley and with depth, keeping the groundwater system local and discontinuous beyond the Castle Valley topographic feature. These hydrostructural units also block lateral flow perpendicular to the fault zone. Therefore, no deep regional groundwater is laterally entering or exiting Castle Valley from the northeast or the southwest. The termination of these hydrostructural units to the southeast and northwest also blocks lateral flow, so no deep groundwater is laterally entering or exiting Castle Valley from the southeast or the northwest. The entire valley is underlain by a deep “flat lying” caprock of the Paradox Formation, which is a confining unit that, when interacting with groundwater, produces poor water quality due to dissolution of the salt bedrock. Effectively, these hydrogeologic/hydrostructural units insure that the Castle Valley Bedrock groundwater flow system is entirely contained within the valley.

The Castle Valley Anticline/Graben also caused the younger bedrock hydrogeologic units being observed on the Porcupine and Castle Spires Rims, to dip away to the northeast, northwest, and southwest. This results in local and subregional groundwater and surface water systems that flow away from the Castle Valley rimlands into the La Sal Mountain/Spanish Valley systems, the Onion Creek/Professor Creek systems, or towards the Colorado River. The fault and fracture zones have influenced the location of the main surface water drainages in the TCV study area by providing zones of weakness whereby the streams have downcut into or through the unconsolidated deposits into the underlying bedrock. As a result, the TCV study area is dissected into two distinct surface water and groundwater hydrologic subsystems of varying connectivity: 1) Castle Creek; and 2) Placer Creek. Both subsystems are separated in the southeastern part of the Valley by a third subsystem, the La Sal Mountain subsystem, and become connected in the northwestern part of Castle Valley near the confluence of the two drainages.

In addition to the bounding faults of the Castle Valley Anticline/Graben, three groups of local hydrostructures occur in the TCV area: 1) the northeast-southwest trending faults and
fractures that are radial to the main Castle Valley Anticline; 2) the northwest-southeast trending faults and fractures that are parallel to the main Castle Valley Anticline collapse structures; and 3) radial and concentric fractures associated with the Tertiary Intrusive rocks. The northwest-southeast trending drainages mirror the underlying faults and fracture zones that include the collapse structures located on the northeast and southwest sides of Castle Valley, and the underlying faults and fracture zones that are parallel to these bounding structures. These structures are open, and function as groundwater conduits in bedrock, and paleo-valley groundwater conduits in unconsolidated materials. By comparison, the northeast-southwest trending drainages/fracture zones control most of the steep drainages on the flanks of the Castle Valley rimlands. These drainages are mostly ephemeral, and their main hydrologic function is delivering surface water down into the valley floor drainages.

The radial and concentric fracture pattern surrounding the La Sal Mountain intrusions control the surface water drainages, and are open, therefore, supporting “French-drain” bedrock groundwater systems in the Tertiary Intrusive bedrock, and focusing groundwater towards drainages in the Tertiary Geyser Creek fanglomerate locally. This includes the minor drainages around Round Mountain, and the drainages in the southeastern part of the study area including the northern flanks of the La Sal Mountain systems where Placer Creek and Castle Creek originate. In the Tertiary intrusive rocks, groundwater moves laterally down valley and vertically downward along these radial fault and fracture zone planes, and may move vertically up along the fault and fractures plane near the lower reaches of the various drainages as evidenced by gaining reaches in streams, and by the springs that are the origin of Castle Creek and Placer Creek tributaries.

Based on the HESA approach, and on the presence and orientation of various hydrogeologic and hydro-structural units, hydrography and topography, two types of Conceptual Site Models (CSMs) are delineated in the TCV study area: 1) La Sal Mountain Subsystem; and 2) Castle Creek and Placer Creek Hillslope and Valley Bottom Shallow Aquifer Subsystems. The La Sal Mountain Subsystem, which includes the Tertiary Intrusive Granodiorite and Tertiary Geyser Creek Fanglomerate bedrock hydrogeologic units and is located in the southeastern part of the study area, is a complex mix of bedrock and unconsolidated deposits, which form a robust groundwater system that is directly connected to the surface water systems forming the headwaters of Castle and Placer Creeks. The top of this subsystem is directly hydraulically connected to Mesa Top subsystems not located in the TCV study area, and the bottom of this subsystem is directly hydraulically connected to the Castle Creek and Placer Creek Hillslope and Valley Bottom Subsystems in the TCV study area. In addition to the hydrogeological units, there are two types of geological structures of significance to the hydrogeology in the La Sal Mountain Subsystem: 1) Northwest-southeast trending fault/fracture zone hydrostructures (southeastern extent of the high K zones of Castle Valley) dipping vertically; and 2) Radial and concentric fault/fracture zone hydrostructures that are observed radiating out from and surrounding the Tertiary intrusions and dissecting the Tertiary Geyser Creek unit.

The shallow groundwater in the La Sal Mountain Subsystem is dominated by the Quaternary deposits, which receive natural recharge by infiltration of precipitation (snow and rain); input from hillside (slope) deposits located upgradient from a given location; and input from the two bedrock aquifers: 1) the Geyser Creek Fanglomerate, and the Tertiary Intrusive units. Groundwater flow in the La Sal Mountains unconsolidated materials is with topography
from hilltop and ridgetop down the hillslope to the valley bottom, and then parallel with the valley bottom stream. Groundwater in the valley bottom stream units moves in the same direction as the stream with various stream reaches being gaining or losing depending on subsurface topography, saturated thickness of the alluvium, or the seasonal variations caused by snowpack runoff or storm events. These streams are the headwaters of Castle Creek and Placer Creek tributaries, and most reaches are gaining from the alluvial and bedrock aquifers. There is also groundwater discharge from the alluvium locally by groundwater wells and by phreatophytes. Given the granodiorite composition of bedrock, the natural water quality is good except where mining activity has been undertaken. Groundwater recharge also occurs on the hills and ridges where the Tertiary Geyser Creek Fanglomerate units are exposed. Groundwater then flows downgradient with topography towards the Castle Creek and Placer Creek Hillslope and Valley Bottom Subsystems.

The two dominant hydrogeologic features of the Castle Creek and Placer Creek Hillslope and Valley Bottom Subsystems are the highly-permeable unconsolidated hydro-units in the center of the valley, and the northwest-southeast trending high K hydrostructures that are observed on both the northeastern and southwestern sides of Castle Valley. The Castle and Placer Creek Subsystems receive natural recharge by infiltration of precipitation (snow and rain); losing perennial streams; input from hillside (slope) deposits and fracture-controlled ephemeral stream channels and deposits. Additional recharge occurs locally from irrigation practices and septic sewer system infiltration. Discharge from the groundwater system occurs downgradient towards gaining streams, springs, seeps, wetlands, phreatophytes, and by wells.

Groundwater flow in the Castle Creek alluvium moves in the same direction as the stream with various stream reaches being gaining or losing depending on subsurface topography, bedrock hydrogeology, hydrostructures, and saturated thickness of the alluvium, or the seasonal variations caused by snowpack runoff or storm events. Groundwater flow in the Placer Creek alluvium also moves in the same direction as the stream, but with most of the stream reaches being losing when surface water flow occurs. There is also groundwater discharge from the alluvium locally by groundwater wells and by phreatophytes in both subsystems.

Underlying both the northeastern and the southwestern sides of Castle Valley are northwestern-southeastern hydrostructures that act as open vertical and horizontal conduits (high K zones). At the northeastern side the faulted and fractured Permian Cutler bedrock combines with the alluvium to form a French Drain effect resulting in increased groundwater flow parallel to the fault and fracture zone, storage, and connectivity between the two hydrologic systems. At the southeastern side the faulted and fractured Permian Cutler bedrock combines with both the alluvium and the alluvial fans to form the same type of French Drain effect as on the Castle Creek side. The fractured and faulted Permian Cutler bedrock aquifers are variably to fully saturated, based on location and proximity to recharge area. In the Castle Creek Subsystem, groundwater recharge by losing stream reaches and infiltration of precipitation is possible only by connection to the Castle Creek fault and fracture zone, and by the northeast-southwest fault and fractures that control drainages below the Castle Spires Rim. In the Placer Creek Subsystem, groundwater recharge is by losing stream reaches when flowing, and infiltration of precipitation is possible only by connection to the Placer Creek fault and fracture zone, and by the northeast-southwest fault and fractures that control drainages below the Porcupine Rim. In both systems groundwater flow direction is from southeast to northwest parallel to the Castle Valley salt.
anticline collapse structures and Placer Creek. These high K zone flow systems end at the northwest end of Castle Valley, where the groundwater moves vertically upward into the alluvium and ultimately discharges into springs and seeps and into Castle Creek, or is transpired by phreatophytes.

The HESA evaluation of the TCV hydrologic systems was used for assessing the vulnerability of groundwater and surface water to contaminants in both the natural and anthropogenic environment. The Permian Cutler Group and Pennsylvanian Paradox Formation hydrogeologic units are the main source in Castle Valley for naturally occurring salt in a chemically soluble form. The faulted and fractured Cutler Group, referred to as the high K zones located under Castle Creek and Placer Creek, allow large quantities of groundwater to flow through these conduits where large quantities of soluble salt are incorporated into the groundwater flow system. These salts are then transported in the groundwater and/or surface water to exposure sites such as wells, ponds, and surface water bodies like Castle Creek.

The hydrologic system of the steep Porcupine Rim and Castle Spires Rim Hillslope Subsystems is surface water in fracture-controlled channels, and overland and interflow from precipitation that rapidly runs off the steep hillslopes until flowing across or through the Quaternary and/or Tertiary unconsolidated hydrogeologic units, where the water quickly disappears into the aquifer as groundwater recharge. In the process of channeled surface water, or overland and interflow, soluble salts in the bedrock are incorporated into the surface water and near surface water to be transported into the unconsolidated deposits aquifers. The fringes of these aquifers would have higher TDS than the central parts of these aquifers in the main valley. The natural pollutants that are most likely occurring include salts (carbonates and sulfates), and the most likely source of these pollutants is the weathered zone of the older bedrock upgradient. The anthropogenic pollutant sources to the Hillslope and Valley Bottom subsystems are mostly fertilizers for grass (urban) or crops, industrial pollutants (local garages, for example), or rural septic tank waste. Most of these are organics and nutrients, and would need to be monitored accordingly.

A preliminary water balance (PWB) for the (TCV) project area has been calculated based upon the calculations previously published by various authors and the HESA-based conceptual model determined as part of this study. The area in Castle Valley of the water balance is determined in part based upon the locations of two stream gages on Castle Creek, the location of most anthropogenic activities (domestic and agricultural), and the natural boundaries of the TCV hydrologic systems, specifically the lower Castle Creek and Placer Creek Hillslope and Valley Bottom Subsystems that merge in the northwestern part of Castle Valley. The water balance area is from a cross-sectional boundary in the southeastern part of Castle Valley linking Castleton to the Porcupine Ranch, to the Castle Creek exit in the northwestern part of Castle Valley, and extends to the Porcupine Rim to the southwest and to the Castle Spires Rim to the northeast. The inputs of the PWB are: Castle Creek surface water at Castleton, UT; Castle Creek Subsystem groundwater flux flowing in the unconsolidated hydrogeologic units from the southeast; Placer Creek subsystem groundwater flux flowing in the unconsolidated hydrogeologic units and Tertiary Geyser Creek hydrogeologic unit; and recharge by infiltration of precipitation (rain and snow) across the entire Castle Valley area. The outputs of the PWB are: Castle Creek at the northwestern end of Castle Valley; Evapotranspiration by native Phreatophytes (Cottonwoods and Willows); and Consumptive Use by irrigation and domestic wells.
Balancing the published inflows (2,521 ac-ft/yr) and outflows (6,819 ac-ft/yr) indicates that 4,298 ac-ft/yr enters the valley as groundwater and effective precipitation (primarily groundwater recharge). A first approximation of the recharge from precipitation in the water balance area using 1.4 in/yr (roughly 10% of precipitation, a common estimate in groundwater modeling for these environments) over 16,000 acres of surface area results in a total of 1,867 ac-ft/yr. This would leave the remaining groundwater input at 2,432 ac-ft/yr. Calculation of groundwater flux across the southeast part of the water balance area using Darcy’s Law yields 2,276 to 2,833 ac-ft/yr, which centered on the 2,431 ac-ft/yr. The Preliminary Water Budget results summarized: Surface water in (2,521 ac-ft/yr) + Recharge in (1,867 ac-ft/yr) + Groundwater in (2,431 ac-ft/yr) = Surface water out (5,071 ac-ft/yr) + Consumptive use out (1,748 ac-ft/yr) = Total Water Budget (6,819 ac-ft/yr).

The reduction of water contributions originating from the La Sal Mountain subsystem in amounts and timing of precipitation (rain and snowfall) and snowmelt resulting from climate change may have a significant impact on streamflows, groundwater recharge and subsurface inflow into the valley. In addition, water diversion projects to other watersheds, especially up-valley, will result in decreased surface water flows and groundwater recharge from losing streams. Impacts on the valley's water budget may also result from deforestation due to lumbering or fire (increased surface runoff and stream flows); increased forestation (increased ET; decrease of runoff and stream flows); and mining (increased or decreased stream flows and groundwater fluxes). Land use conversions/changes resulting in more or less consumptive uses need to be evaluated regarding the surface water output to Castle Creek at the northwest end of Castle Valley. Increased consumptive use would result from increased urbanization (more wells, non-native vegetation), or increased irrigation.
5 REFERENCES


