GROUNDWATER SYSTEMS IN DELTA COUNTY, COLORADO: UNCOMPAHGRE VALLEY AND TOWN OF DELTA (UVTD)

GIS-Based Hydrological and Environmental Systems Analysis and Formulation of Conceptual Site Models

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1 INTRODUCTION

Under an agreement with Delta County, Colorado, Hydrologic Systems Analysis LLC (HSA) of Golden, Colorado, in conjunction with Heath Hydrology, Inc. (HHI) of Boulder, Colorado, was tasked to perform a Hydrologic and Environmental System Analysis (HESA) of the groundwater resources of the valleys and uplands of the Uncompahgre and Gunnison Rivers in the vicinity of the Town of Delta in Delta County, Colorado between the Uncompahgre Uplift to the west, the Black Canyon uplift to the east, the county line to the south and the border of the public lands north of the Gunnison River (Figure 1). The delineation of the study area is based on the nature and extent of the major hydrogeological systems present, the hydrology of the area, and water resources related land use considerations. The study area is located in the Uncompahgre and Lower Gunnison watersheds and roughly covered by Delta County water planning areas 1d, 1e, and 2a and parts of planning areas 4a, 4b and 8 (Figure 2). The study area is to the west of the previously conducted Oak Mesa and North Fork Valley groundwater studies (*Kolm and van der Heijde, 2012, 2013*; Figure 3),and directly southwest of the Surface Creek Valley study (*Kolm and van der Heijde, 2014*; Figure 3). It should be noted that for display purposes in this report a rectangular area is used, referred to as *Clipping or Display Area*, which include the entire Uncompahgre Valley and Town of Delta (UVTD) study area (Figure 2). However, all analyses regarding the groundwater systems in this report are focused on the irregular shaped *UVTD Study Area*.

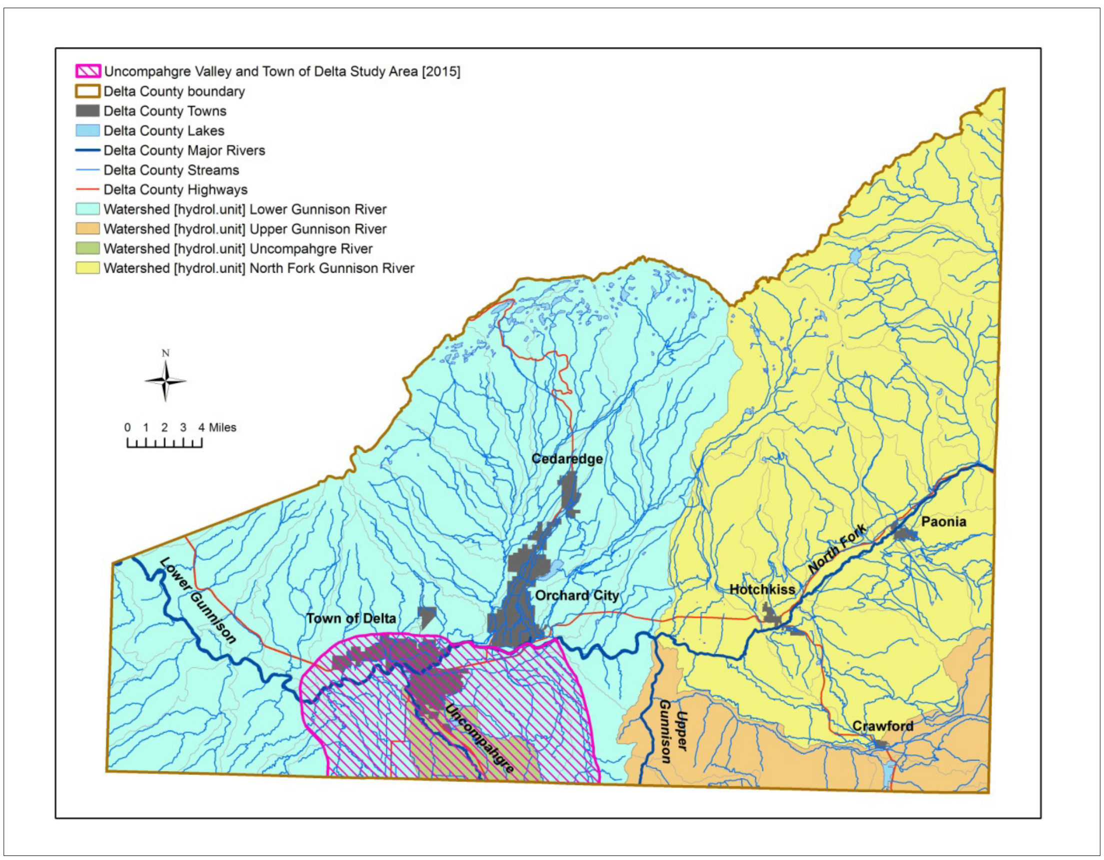

Figure 1. Location of the Uncompahgre Valley and Town of Delta (UVTD) Study Area and the Major Regional Watersheds in Delta County, Colorado.

In addition to performing a HESA of the groundwater systems in the UVTD study area, this project extends the GIS databases and maps of hydrogeologic and hydrologic characteristics of the groundwater systems developed in earlier studies by Kolm and van der Heijde (*2012, 2013, 2014*) to the entire county. The HESA of the UVTD area is documented in this report, which also contains a description of the GIS databases and maps developed as part of this project, as well as a discussion of the hydrogeological aspects of selenium mobility in groundwater and resulting vulnerability of groundwater resources. The report and GIS databases provide support for planning, zoning and other decision-making tasks of county staff, including those related to protection of groundwater resources for use as public or communal water supplies.

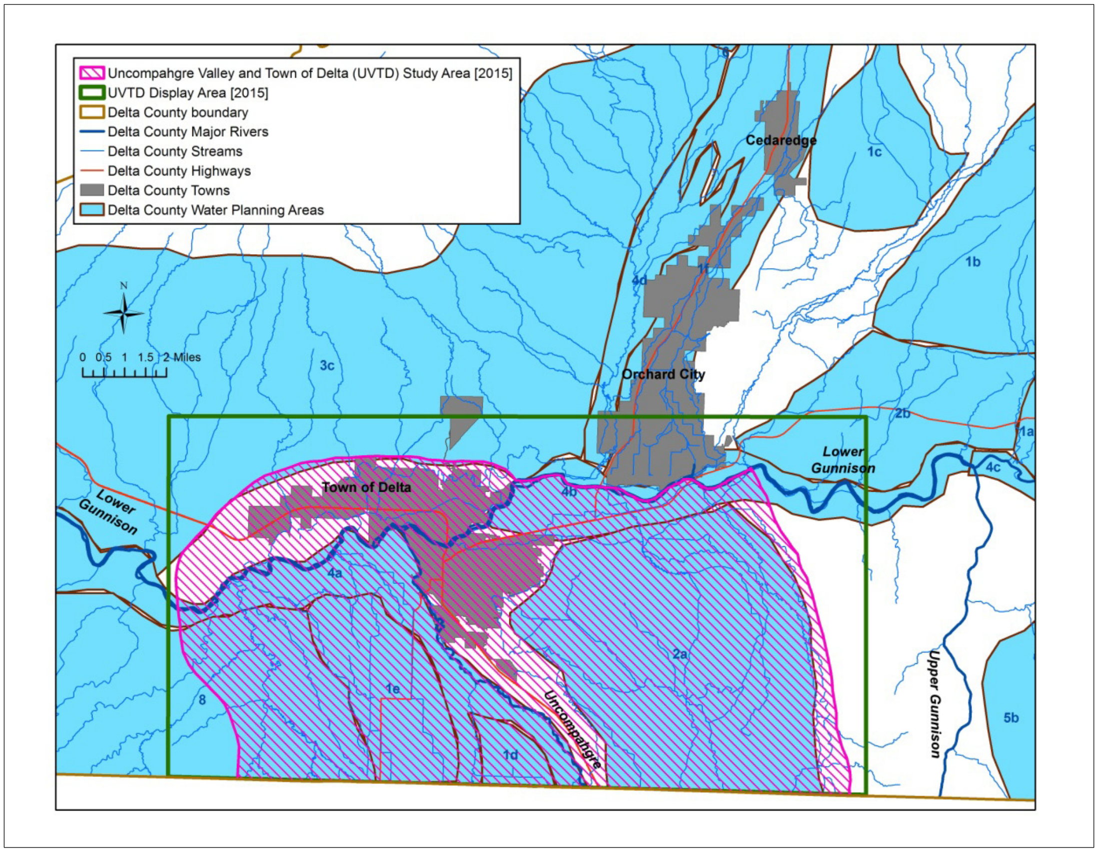

Figure 2. UVTD Study Area and Delta County Water Planning Areas.

The GIS maps have been created, in part, from previously published, or otherwise available public information, as well as the results of the HESA. Additional data layers and evaluation were needed to construct the GIS database – particularly with respect to the hydrogeological characteristics of the rock types present. The HESA included a few scoping site visits to the study area; no additional fieldwork has been conducted. The maps (and underlying databases) have been produced using the ARCGIS/ARCMAP GIS software system.

The UVTD groundwater study included the following tasks:

1. Conduct a comprehensive HESA, focused primarily on the irrigated areas in and surrounding the Town of Delta, and formulate relevant conceptual hydrologic site

models to provide the physical framework for the availability, sustainability and vulnerability assessments;
2. Continue refining a consistent and practical hydrogeologic nomenclature for county-wide use;
3. Continue digitizing existing geologic maps – to the extent and detail necessary for the project – and converting them to hydrogeologic system layers in the GIS, including layers showing hydrogeologic units and characteristic stacks of such units, hydrostructures; and hydro-chemical units that may be prone to selenium related water quality issues
4. Adapt additional hydrological and other GIS maps and databases needed to evaluate the groundwater resources in the county; these databases will contain data from various public domain sources; and
5. Provide a set of consistent and continuous county-wide GIS maps of various hydrologic and hydrogeologic characteristics to complete the study.

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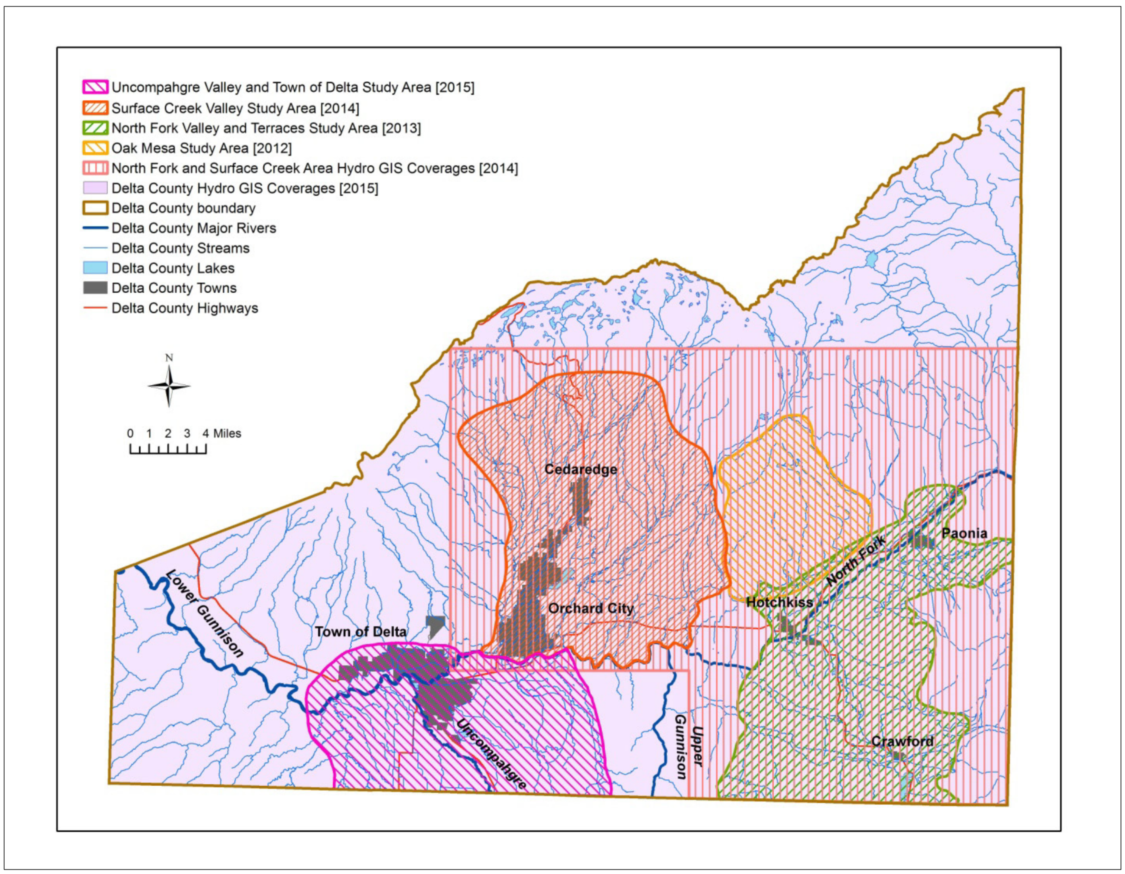

Figure 3. UVTD Study Area in Relationship to Phase 1, 2, and 3 Study Areas; Database Coverage of the Previous Studies (Vertical Hachured Area); and Database Coverage of the Current Study (Entire County).

The hydrogeological databases for the UVTD study area are a continuation and extension of the hydrogeologic databases prepared during the earlier studies, and include the results of the earlier studies. They provide coverages for the entire county as shown in Figure 3 (see chapter 3 for details).

It should be noted that that these maps and databases will not obviate the need for additional hydrogeologic analysis on a site-specific/parcel-specific basis by developers and/or the County, or in any water right, geotechnical, or environmental study requiring due diligence. These maps and the associated groundwater evaluation procedure are intended to be used as indicators only, as part of a multi-step land use decision-making process, and to provide a starting point for further study of the County's groundwater resources.

2 DEVELOPMENT OF CONCEPTUAL SITE MODELS OF THE UNCOMPAHGRE VALLEY AND TOWN OF DELTA (UVTD) 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 UVTD study area covers elements of climate, topography, soils and geomorphology, surface water characteristics, hydrogeologic framework, hydrology, and anthropogenic activity as related to the shallow groundwater systems in the study area.

Based on field surveys and a preliminary HESA, a number of hydrogeologic subsystems were identified within the UVTD 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 were identified, including groundwater recharge from large scale irrigation ditches and reservoirs, groundwater recharge from irrigated acreage subsurface return flow, and increased or decreased groundwater discharge from existing or newly created springs and seeps. A brief discussion of potential modification of natural flow patterns and impacts on water budgets and water quality, particularly selenium, from 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 Uncompahgre Plateau, Grand Mesa, and the Black Canyon of the Gunnison Plateau (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 UVTD area is in the rain shadows of these three prominent features, and the precipitation is reduced significantly in comparison to surrounding areas. From the relevant weather stations of the National Weather Service (NWS) Cooperative Network (COOP) near the study area Delta (COOP 052192), located in the town of Delta, has been selected as representative for the study area (Figure 4). Table 1 shows monthly and annual long-term averages for temperature, precipitation, snowfall and snow depth (*WRCC, 2013*); Figure 5 summarizes the average total monthly precipitation (*i.e.*, rain and snowfall SWE - Snow Water Equivalent), snowfall (*i.e.*, thickness of freshly fallen snow), and snow depth (*i.e.*, snow pack) for the Delta station.

The NWS data were used by the Natural Resources Conservation Service (NRCS) to prepare a map of spatially distributed precipitation corrected for elevation (see Figure 6). As these data sources show, there is a small precipitation gradient in the area from about 11 inches annually at the far western and eastern boundaries of the UVTD study area on the eastern slopes of the Uncompahgre Plateau and on the western slopes of the Black Canyon of the Gunnison River Uplift to about 8 inches near the Uncompahgre and Gunnison Rivers in the center of the study area.

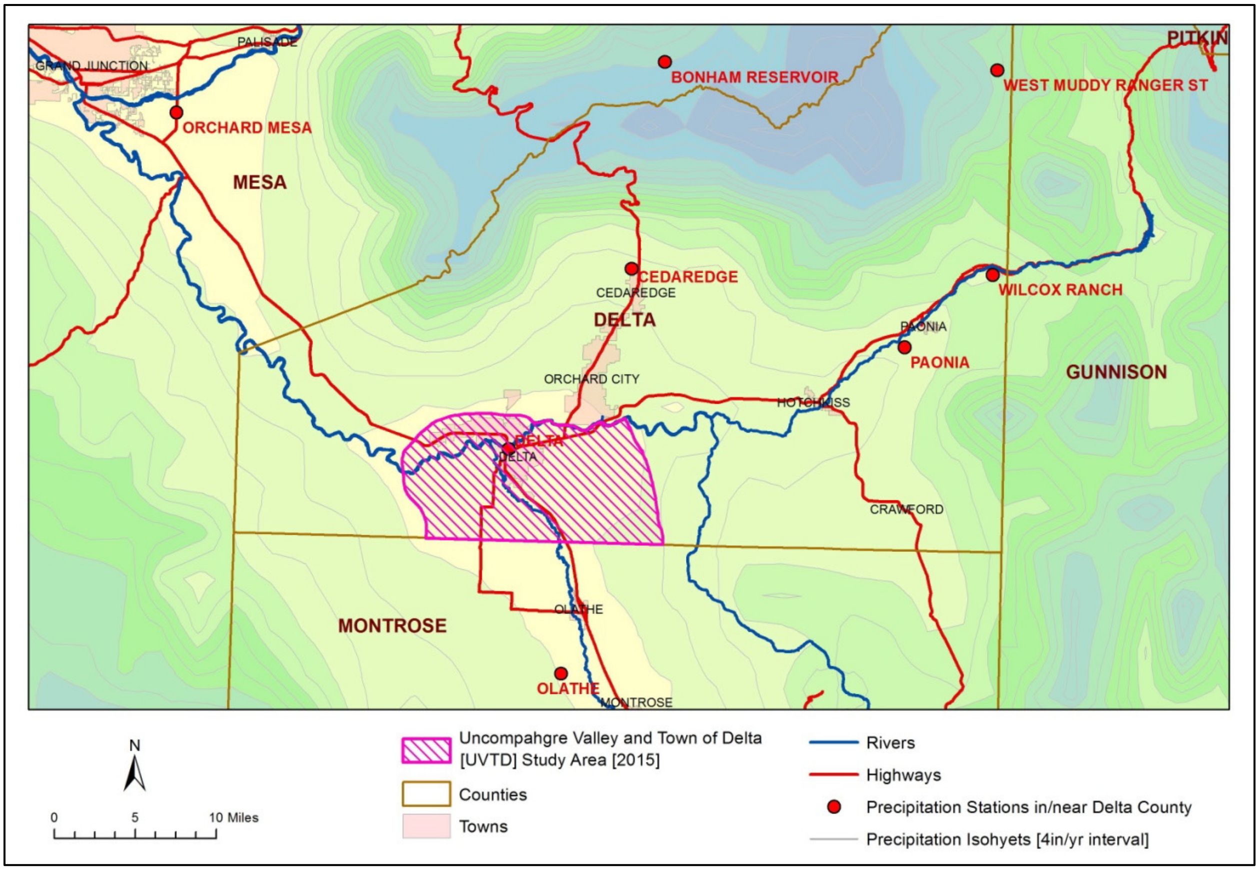

Figure 4. Location of NWS/COOP Weather Stations in and near Delta County and the UVTD Study Area.

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 as infiltration from precipitation to the shallow bedrock groundwater systems. Average annual precipitation determines the climate of the project area, and in the case of the UVTD study area, the climate is mostly semi-arid-to-arid and there is a small natural recharge potential, mostly from rain and some snow throughout the winter and spring. The summer months are characterized by high evaporation rates and are too desiccated for significant groundwater infiltration and recharge, barring some localized intense summer storms, especially on irrigated (high soil moisture content) lands. Thus, most of the natural groundwater recharge in the near-surface aquifers occurs during a very short period of time in the winter and early spring (December to March). By comparison, the topographically higher terrains surrounding the UVTD study area near Uncompahgre Plateau, Grand Mesa, and Black Canyon of the Gunnison Plateau 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 about approximately 1 inch of recharge annually. This is important when considering the ultimate groundwater system flow directions and areas of groundwater recharge.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Average Max. Temperature (F)	38.7	47.0	57.4	67.6	77.5	87.9	93.1	90.1	82.4	69.9	53.4	40.6	67.1
Average Min. Temperature (F)	12.2	19.0	26.1	33.8	41.9	48.5	54.8	53.1	44.1	33.4	22.8	14.6	33.7
Average (Mean) Temperature (F)	25.5	33.0	41.8	50.7	59.7	68.3	73.9	71.6	63.2	51.6	38.1	27.6	50.4
Average Total Precipitation (in.)	0.48	0.43	0.56	0.61	0.75	0.48	0.72	1.12	0.94	0.93	0.53	0.44	8.01
Average Total Snow Fall (in.)	4.6	2.7	2.0	0.5	0.0	0.0	0.0	0.0	0.0	0.2	1.5	3.7	15.2
Average Snow Depth (in.)	1	0	0	0	0	0	0	0	0	0	0	0	0

Table 1. Average Maximum, Minimum and Mean Monthly and Annual Temperature, and Average Monthly and Annual Precipitation, Snow Fall and Snow Depth for Delta (052192) for period 1/1/1893 to 12/31/1999. (Source: Western Regional Climate Center (WRCC), Desert Research Institute, Reno, Nevada).

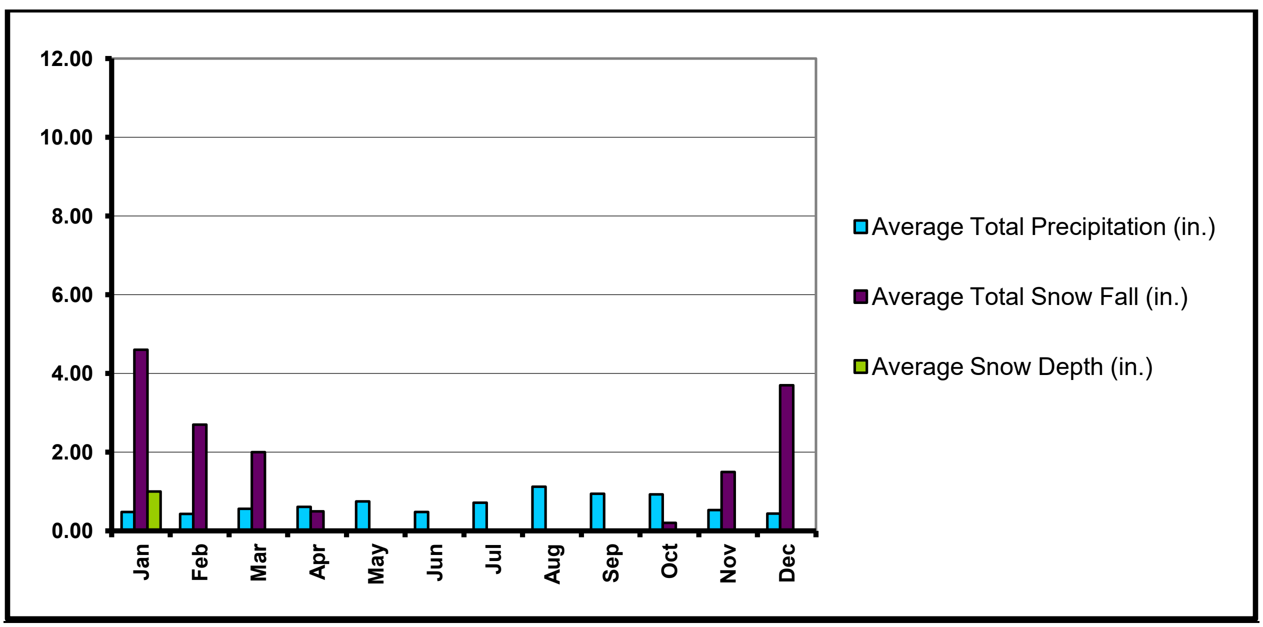

Figure 5. Average Monthly Precipitation, Snow Fall and Snow Depth for Delta (052192) for period 1/1/1893 to 12/31/1999. (Source: Western Regional Climate Center, Desert Research Institute, Reno, Nevada).

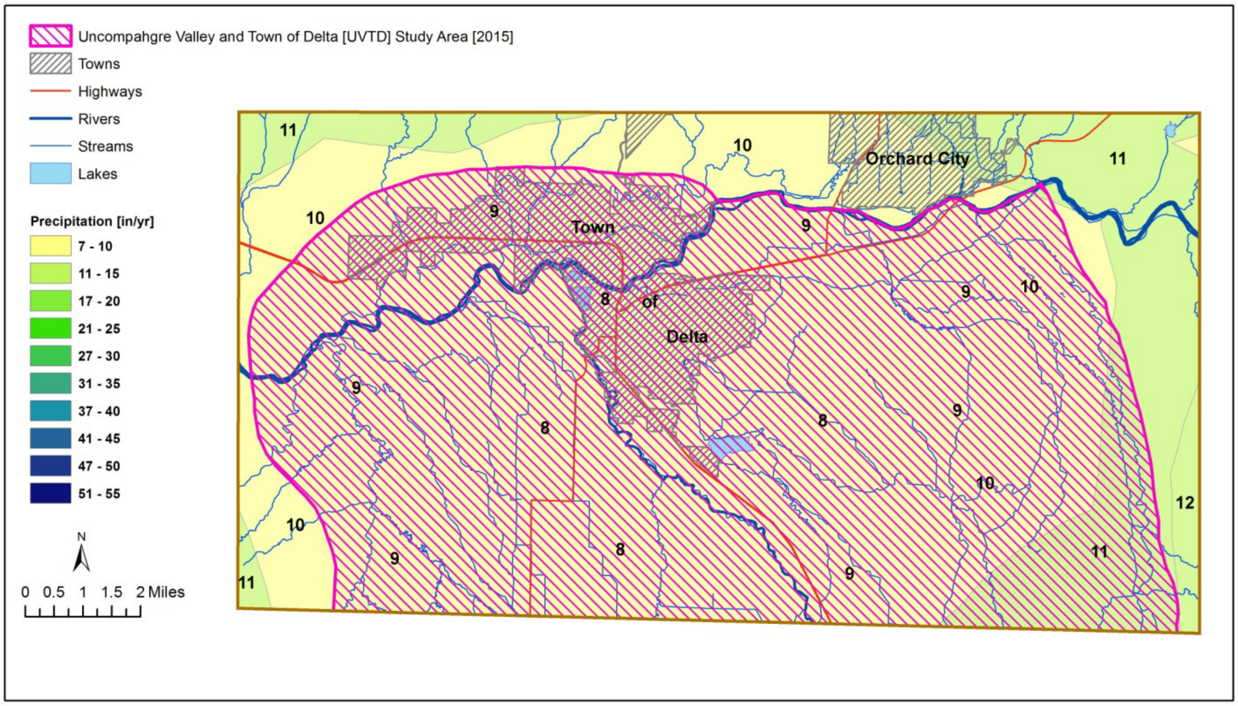

Figure 6. Spatial Distribution of the Average Annual Precipitation in the UVTD Area, Delta County, Colorado (Source: Natural Resources Conservation Service 2011).

2.2 Topography and Geomorphology

The surface elevation in the UVTD study area ranges from about 1,500 m (≈5,000 ft) in the Uncompahgre and Gunnison River Valleys near Delta to about 1,700 m (≈5,600 ft) on the bedrock above both sides of the Uncompahgre River Valley along the flanks of the Uncompahgre Plateau and Black Canyon of the Gunnison River Uplift (Figures 7 and 8). The topography of the study area has three distinct terrains: 1) steeply sloping to gently rolling, gullied bedrock uplands mostly along the eastern and western flanks of the surrounding uplifts; 2) poorly to moderately dissected, connected and disconnected, continuous and discontinuous hillslope fans and mass wasting features (particularly earth and mudflows in the Mancos Shale terrain), and alluvial terraces; and 3) continuous alluvial valley bottoms.

In the core of the UVTD study area --including Garnet Mesa, Mancos Uplands, and the modern day Uncompahgre and Gunnison River terraces-- the fans, mass wasting features, and alluvial terraces are separated topographically by Mancos Shale Bedrock features, such as inter-fluvial uplands/badlands and river and terrace escarpments. These shale features frequently function as barriers to connectivity, and hydrologic systems frequently are not connected across the drainages to nearby systems. The effects of the escarpments 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. The best example of these regional systems are observed in sedimentary bedrock underlying the main Uncompahgre River Valley syncline located in the central region of the UVTD study area. These deeper bedrock systems can be a source of regional groundwater and are recharged by, or are discharging into, the shallow groundwater systems depending on the geomorphic geometry. Most of the alluvial terraces, fans, and river bottoms in the study area are isolated topographically, which results in discrete and localized groundwater systems and can result in discrete and localized springs and connections to surface water systems.

The topographic gradients in the UVTD area can be divided into two types: 1) steep gradient bedrock slopes (greater than 2% slope) mostly in the Mancos Shale regions and flanks of the surrounding uplifts; and 2) low gradient (less than 2% slope) fan and terrace levels and alluvial valley bottoms. The topographic gradient is useful in estimating the surface of the water table and for estimating the amounts of infiltration versus overland flow and interflow.

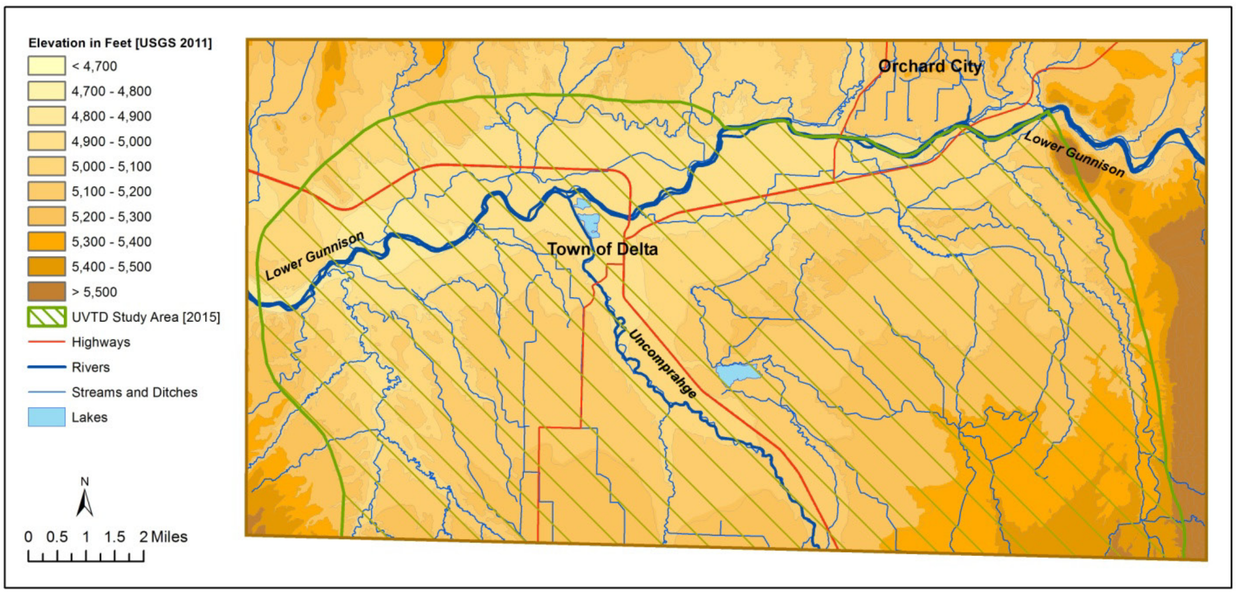

Figure 7. Topography in the UVTD Area.
(Sources: Natural Resources Conservation Service 2011; Delta County 2011).

2.3 Surface Water Characteristics and Springs

The UVTD study area contains parts of local watersheds draining to the Gunnison River directly, or to the Gunnison River via the Uncompahgre River; Stirrup Creek and Peach Valley streams in the southeast Mancos Shale sections of the study area; Garnet Mesa streams near the Town of Delta; Dry Creek; Seep Creek; Buttermilk Creek; Wise Creek; Cummings Creek; Bixley Gulch; and Roubideau Creek in the southern and western parts of the study area (Figure 9). Streams can be gaining flow (from groundwater, irrigation ditches, and return flow from irrigation) or losing flow (to groundwater, diversions or evaporation), dependent on local hydrology, hydrogeology, irrigation practices, and time of year. Seep Creek, Buttermilk Creek, Wise Creek, Bixley Gulch, and Cummings Creek are mostly dependent on groundwater

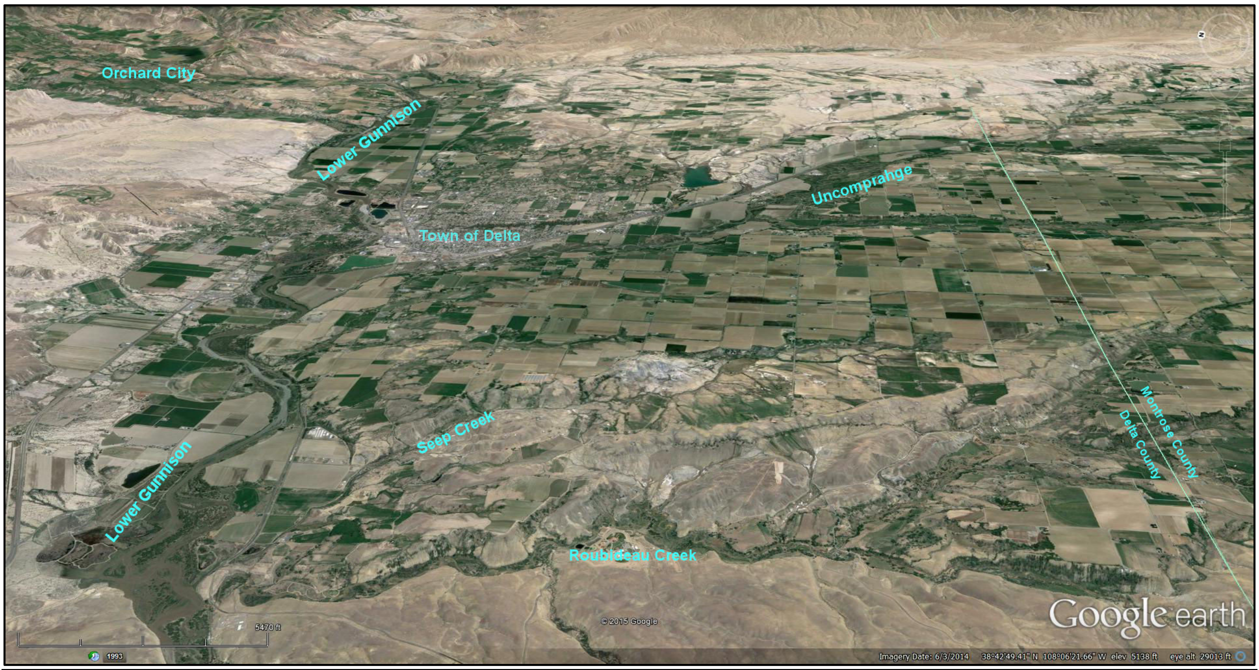

Figure 8a. Google Earth View of Topography in the UVTD Area looking East (2015).

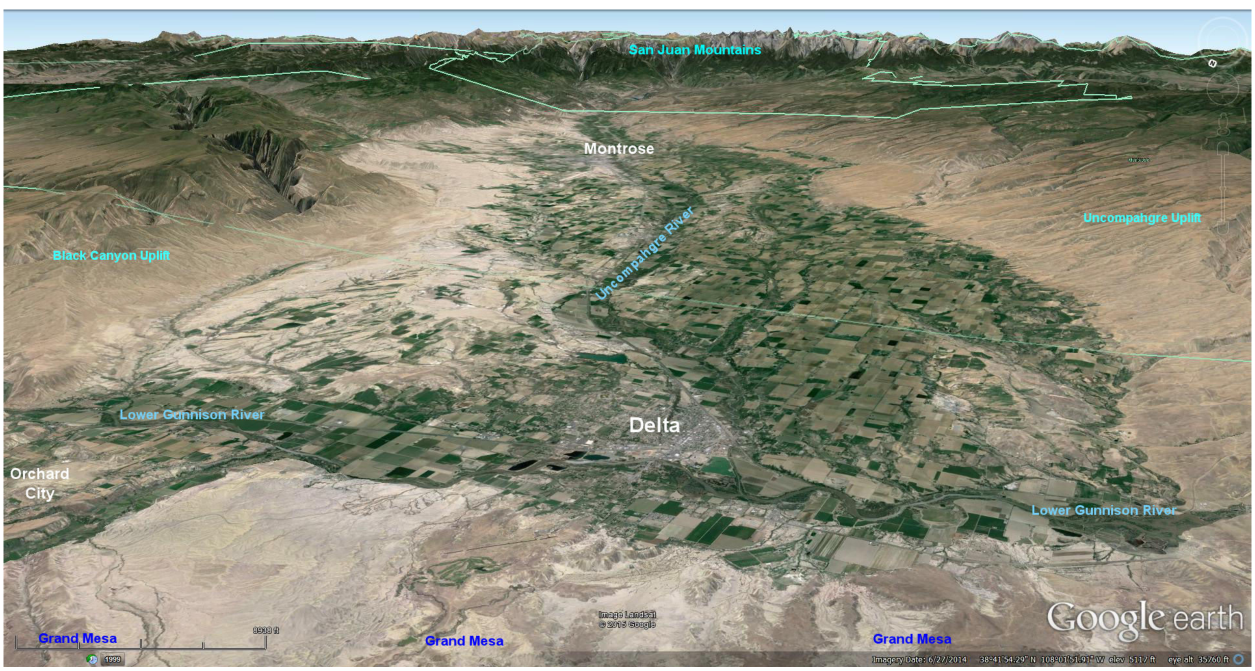

Figure 8b. Google Earth View of Topography in the UVTD Area looking South (2015).

discharge from the Quaternary gravels due to intensive irrigation upgradient. Roubideau and Dry Creeks rely on most of their water from events occurring upgradient on the Uncompahgre Plateau although there is groundwater exchange between the streams and the underlying Quaternary Alluvium (Qal). Dry Creek in particular receives some water as groundwater leakage from the surrounding gravel capped mesas. Garnet Mesa drainages receive most of their water from leaky gravels due to irrigation ditches and irrigation practices. The gaining and losing dynamics of these streams are seasonal, with bank full conditions occurring during the spring and summer irrigation season, and low water conditions occurring during the rest of the year.

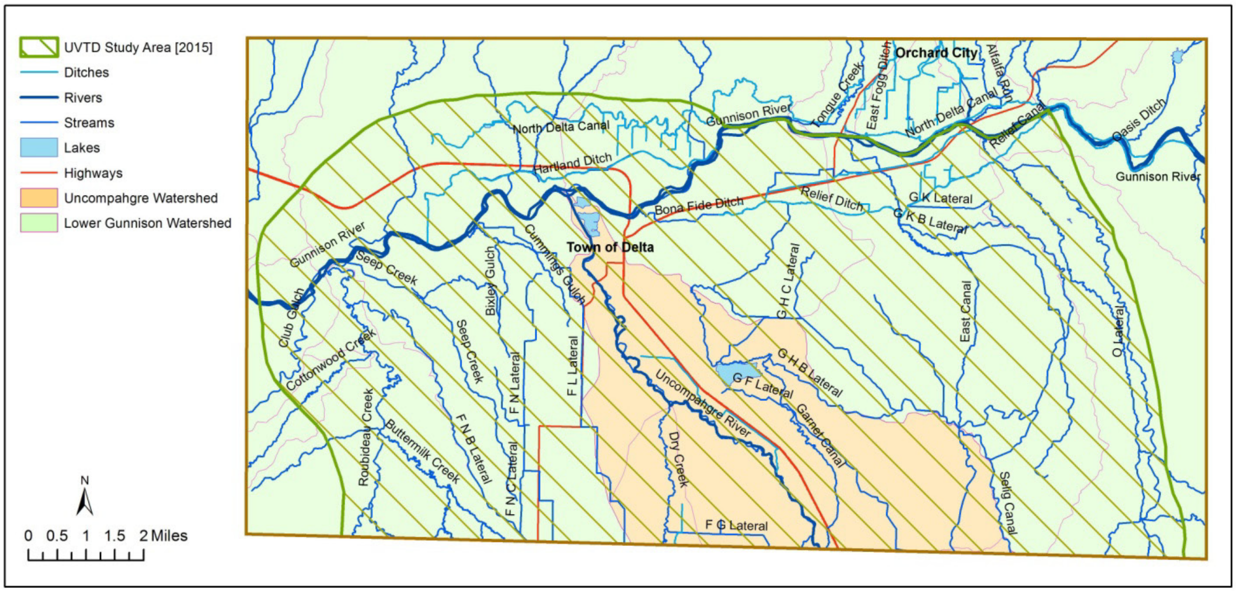

Figure 9. Major Watersheds, Streams, Reservoirs and Ditches in the UVTD Area.
(Sources: NRCS 2011; Delta County 2011).

The surface water conditions of the Mancos Shale region, the eastern and southeastern part of the study area, are unique to the UVTD hydrology. Originally, the drainages in Peach Valley and in the vicinity of Stirrup Creek were mostly ephemeral, and responded to climatic, seasonal, and rainstorm events with much of the precipitation gathered as runoff and sediment (including selenium) to be transported quickly to the Gunnison River in the northern part of the study area. Parts of the watershed did develop naturally a mass wasting based (mud and earthflow process) alluvial material (Qal) that locally served as a shallow groundwater system, which had high TDS water (Sarcobatus vegetation). With the advent of Project 7 water delivery through ditches and canals, the dynamics of these watersheds changed, much of the available mass wasting/alluvial material was irrigated and became shallow aquifers (like the river gravels in the valleys below), and perennial streams resulted with the movement of additional sediment and selenium. Essentially, the watershed and streams contained in the Mancos Shale region are completely controlled by the rhythms of the Project 7 water and the related ditch and canal delivery.

The Uncompahgre River is likely a gaining river along the reach from the Dry Creek confluence to the Gunnison River confluence in the UVTD study area due to the added groundwater and surface water from Dry Creek, Ash Mesa springs, Lower California Mesa groundwater from leaky gravels, Western Garnet Mesa drainages and groundwater, releases from Sweitzer Lake, and runoff from the Town of Delta. The gaining and losing dynamics of the Uncompahgre River is seasonal, with bank full conditions occurring during the spring and summer irrigation season favoring less groundwater discharge from the Qal to the River, and low water conditions occurring during the rest of the year favoring greater groundwater discharge to the River.

The Gunnison River would be generally a gaining river along the northeastern boundary of the UVTD study area due to the added groundwater and surface water from the Currant Creek, Surface Creek, and Tongue Creek hydrologic systems, and from the lower Surface Creek and Cedar Mesa/Fruitgrowers Reservoir/Harts Basin groundwater systems. However, the River is located on the northern side of the valley with Qal gravels to the south and southwest. Therefore this reach of the Gunnison River is most likely recharging the alluvial gravels with the net effect of becoming a losing river recharging the groundwater system underneath. Groundwater flow back to the Gunnison River is driven by groundwater recharge in nearby alluvium (Qal) and younger river terraces (Qat) from infiltration of precipitation, leaky irrigation ditches, and flood irrigation water, and loosing stretches of tributaries, such as Stirrup Creek and Peach Valley drainages, along the edges of the modern alluvial valley. The reaches of the Gunnison River downstream from the Town of Delta and the confluence of the Uncompahgre River are likely to be locally gaining due to local irrigation dynamics, and inflow of groundwater and surface water from the Cummings Gulch, Seep Creek, Bixley Creek, and Uncompahgre River areas. There will be seasonality of river stage (spring flooding and monsoon storm runoff verses autumn low stream flow) due to upriver events.

The UVTD area has Sweitzer Lake and some smaller reservoirs, as well as many ponds (primarily related to farmland modifications and sub-urban development requirements), and an extensive network of irrigation and water diversion and collection ditches (Figure 9; see also Section 2.7). Sweitzer Lake is located between Garnet Canal and East Canal, and affects the nearby surface water and groundwater system of the Uncompahgre River Valley from south of Delta to the Uncompahgre River/Gunnison River confluence. Most of the smaller reservoirs and ponds, by comparison, are affiliated with local landowners, and affect only the local surrounding surface water and groundwater system. These ponds are filled with groundwater by direct discharge, or by wells or springs supplying local groundwater –most of which is sustained by irrigation, leaky ditches, or to a lesser extent, direct precipitation. These ponds leak into the local aquifer system depending upon location, and tend to concentrate nutrients or release selenium if located in the Mancos Shale subsystem.

The extensive network of ditches has been inventoried by Delta County (Figure 9; see Section 3 for details). Generally, some ditches flow more or less continuously, at least during part of the year, others are only used when fields are being irrigated. Some ditch alignments coincide with stream sections, resulting in so-called “enhanced stream flows” or “enhanced streams.” Other ditch alignments contour throughout the landscape, and affect the various streams and mesas that are traversed. Most ditches were originally unlined, and leaked water into the subsurface. More modern practices of piping, due to the various programs of selenium reduction, have reduced this water loss. Wetlands and phreatophyte vegetation are indicators of groundwater discharge to the land surface. The irrigation ditches located on the fans and terraces and along stream valleys often have wetlands, phreatophytes and seeps, indicative of leaky, unlined ditch perimeters, which can be a source of significant groundwater recharge to a hydrogeologic unit that may naturally be dry in normal conditions, but may be an aquifer due to long time ditch leakance into the hydrologic system. Given this situation, there may be an effect of increased surface water flow in springs and drainages due to reservoir and ditch releases that ultimately can affect groundwater recharge to shallow and bedrock systems in various areas. These diversions and anthropogenic changes to the surface water system must be accounted for in the water balance calculations, including springs, for the overall hydrologic system of the UVTD area.

Each hydrologic subsystem in the UVTD area has ditches that primarily deliver water from the nearby parent stream to the irrigated lands located topographically down gradient from the highpoint of the ditch entry into the subsystem, or from the Project 7 canals that dominate the UVTD area that originate out of Delta County to the south. These ditches typically are responsible for two forms of groundwater recharge to the hydrologic subsystem: 1) If unlined, as linear groundwater recharge sources underneath and beside the ditch in areas indicated by the light blue lines showing ditch location (Figures 9 and 10); and 2) Where water is dispersed onto the crop field area, as areal groundwater recharge sources due to irrigation return flow in areas indicated by the green irrigated fields (Figure 10). Given the major programs to reduce unlined ditches to reduce selenium runoff, the irrigation return flow mechanism is the major source of groundwater recharge on most of the gravel and alluvial aquifer systems.

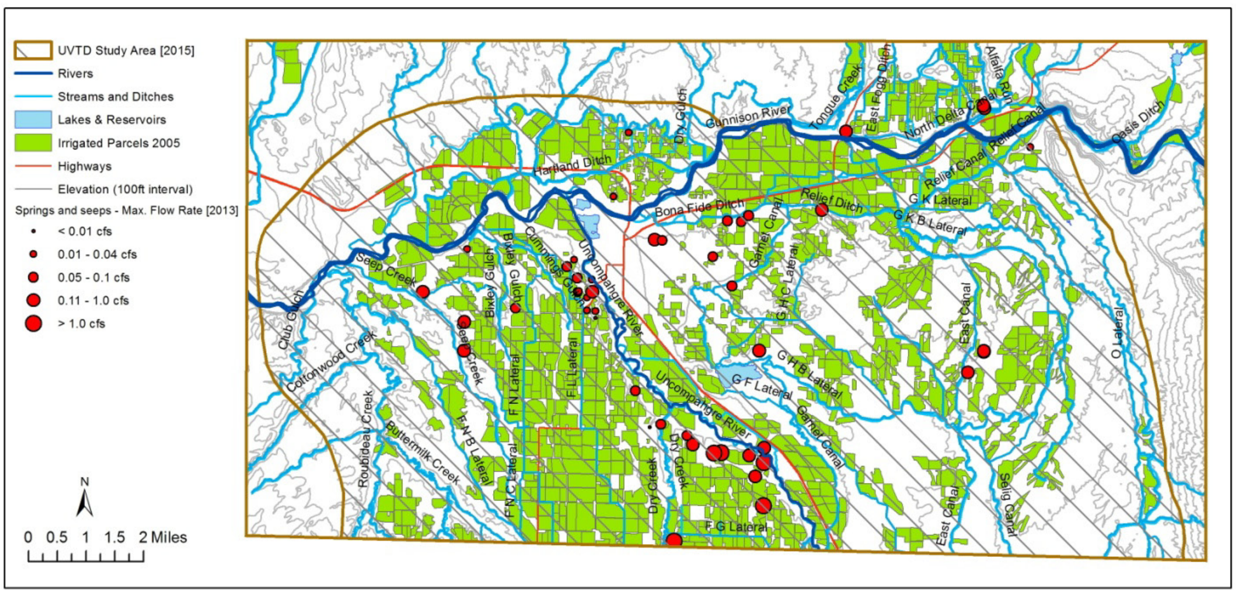

Figure 10. Springs and Seeps in Relationship to Irrigated Areas and Surface Water in the UVTD Area. (Sources: CDSS 2014, NRCS 2011, Delta County 2012).

There are two major ditch groups affiliated with the Mancos Shale/Peach Valley/Stirrup Creek area: 1) the Selig Canal and associated ditches on the east side; and 2) the East Canal and associated ditches in the central region (Figure 8). These ditches, which originate from Project 7 water, traverse the Mancos Shale region and related earthflows, mudflows and alluvium (Qal) and would significantly affect the localized aquifers, and the water quality (primarily selenium and other salts) in the Peach Valley drainage and Stirrup Creek springs, which is ultimately delivered to the Gunnison River and the Gunnison River aquifers (Qal) (Figures 9 and 10).

There is one major canal affiliated with the Garnet Mesa area: 1) the Garnet Canal. The Canal, which originates at the Uncompahgre River, traverses the alluvial sediments (Qal) of the

Uncompahgre River, flows around Sweitzer Lake, and traverses the central part of Garnet Mesa to ultimately end up in the Gunnison River alluvium east of the Town of Delta. This canal delivers water that ultimately affects Garnet Mesa (leaky ditch) (Qat) and parts of the Gunnison River alluvial systems (Qal) (Figure 9).

There are a multitude of ditches affiliated with the Ash Mesa area (Figures 9 and 10). These ditches, which originate primarily from Project 7 water south of the study area, traverse the axis of the Uncompahgre River gravels (Qat) and would significantly affect the springs and groundwater that flows into the Uncompahgre River alluvium and the springs at the end of Ash Mesa (Figures 9 and 10).

There are a multitude of ditches affiliated with the California Mesa area originating from Project 7 water south of the County line. These ditches traverse the axis of the Uncompahgre River Valley gravels (Qat) sub-parallel to the Uncompahgre River, and would significantly affect the springs, seeps, and surface water flow of Cummings Gulch, Bixley Gulch, Seep Creek, Buttermilk Creek, and Wise Creek (Figures 9 and 10).

Finally, there are ditches affiliated with the Gunnison River alluvial system, which include: 1) the Relief Ditch system; 2) the North Delta Canal; 3) the Bonafide Ditch; and 4) the Heartland Ditch. These canals and the associate ditches traverse the Gunnison River alluvium (Qal) and would significantly affect the groundwater flow and water table elevations in the entire lower Gunnison River aquifer (Figures 9 and 10).

As is indicated by wetlands, phreatophytes, and springs/seeps, some of these canals and ditches are unlined and leak water into the groundwater systems of the Uncompahgre River and Gunnison River terrace gravels and alluvium (Qal). These groundwater systems may serve as aquifers used for irrigation and drinking water for landowners located topographically downgradient from the canals or ditches (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 the (semi) arid West where, in many cases, the water emerging in seeps is lost to evapotranspiration. Springs may be an expression 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.

The UVTD study area contains a number of springs and seeps as identified in the Water Rights data base of the State of Colorado [CDWR 2015]. Plotting the location of springs and seeps is very helpful in analyzing the characteristics of localized groundwater systems, and in determining where regional groundwater systems may interact with shallow groundwater systems and streams (Figure 10). Of particular interest is the relationship found between (leaking) irrigation ditches and irrigated areas and spring discharges from shallow groundwater in the UVTD area. A detailed discussion of springs and seeps in the UVTD area and their relationship with the local groundwater systems is presented in section 2.5.

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 UVTD study area, and observed on the terraces and floodplains in both the Uncompahgre and Gunnison River Valleys, and in the floodplains of various tributaries such as the Peach Valley and Seep Creek 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 UVTD study area ranges from less than 1 ft to greater than 100 ft. Estimates of hydraulic conductivity (K) of these unconsolidated materials range from 0.1 to 500 ft per day (*Watts, 2008*). 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 UVTD 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, Delta County is part of the southern edge of the Piceance Basin (Figure 11), the northern and western edge of the Black Canyon of the Gunnison uplift, and the eastern edge of the Uncompahgre uplift. As a result, the near-surface sedimentary bedrock stratum ranges from younger rock to the north and east, to older rock in the south and west, and the stratum shows a regional dipping trend to the north and east (see Figures 12 and 13). The youngest bedrock units in the county are the Tertiary intrusive (quartz monzonite) and extrusive (basalt) units of the West Elk Mountains and Grand Mesa volcanic field. These units form mountains and high plateaus in the northern and eastern part of the county. It is in these sedimentary and volcanic units that regional groundwater flow systems are known to occur (*Freethey and Cordy, 1991; Geldon, 2003*).

Given the regional geology of the UVTD area, the hydrogeologic framework present in the lower Uncompahgre and Gunnison watersheds is less complex then the hydrogeologic framework of the Surface Creek and Oak Mesa region subsystems studied previously (Kolm and van der Heijde, 2012; 2014). Upon reviewing various groundwater reports (*Ackerman and Brooks, 1986; Brooks, 1983; Brooks and Ackerman, 1985;* and *Cordilleran Compliance Services, Inc., 2002,* among others) and (hydro-)geologic maps (*Ellis and others, 1987; Hail, 1972a, 1972b; Morgan and Others, 2008; Noe and Zawaski,2013; Tweto and others, 1976, 1978; Williams, 1976*), the UVTD study area hydrological systems consist of multiple distinct hydrogeologic and hydro-structural units, including unconsolidated units consisting of various Quaternary-aged, highly permeable deposits and weathered bedrock deposits, but very few water-bearing bedrock units and one significant confining bedrock unit, and fault and fracture zones of untested transmissivity. The major hydrogeologic unconsolidated and bedrock units are presented in Figures 14 and 15 and described in Tables 2a and 2b; the major hydro-structural units are presented in Figure 16.

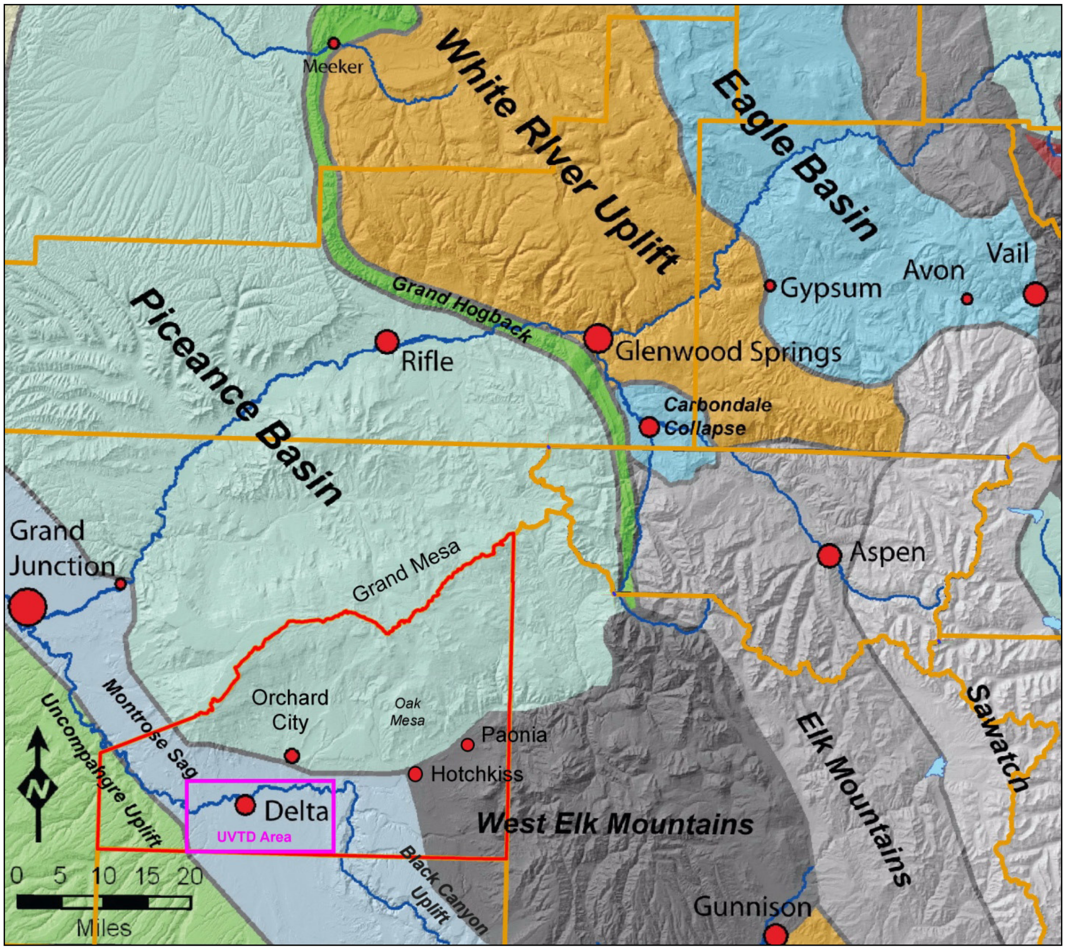

Figure 11. Generalized Map Showing Regional Geographic and Geological Features (*After Topper and others, 2003; Tweto and others, 1978*).

2.4.2 Hydrogeologic Units of the UVTD Area

There are two significant groups of hydrogeologic units in the UVTD study area: 1) Quaternary unconsolidated clastic materials (Figure 14; Table 2a), which are predominantly glacial-fluvial river terrace gravels (Qat) and alluvial valley bottom deposits Qal), with some hillside deposits (Qs), and fans and lower mesa gravels (Qgf); overlying 2) Cretaceous bedrock units (Figure 15; Table 2b), including the following potentially water-bearing unit: Cretaceous Dakota Sandstone and Burro Canyon Formation (Kdb). The Dakota/Burro Canyon hydrogeologic units have porosity values ranging from 0.7 – 12% and transmissivities in the range 10-100ft^2/day (*Robson and Banta, 1995*). By comparison, the Mancos Shale unit (Km) may act as a thick, poorly transmissive confining layer *(Robson and Banta, 1995*).

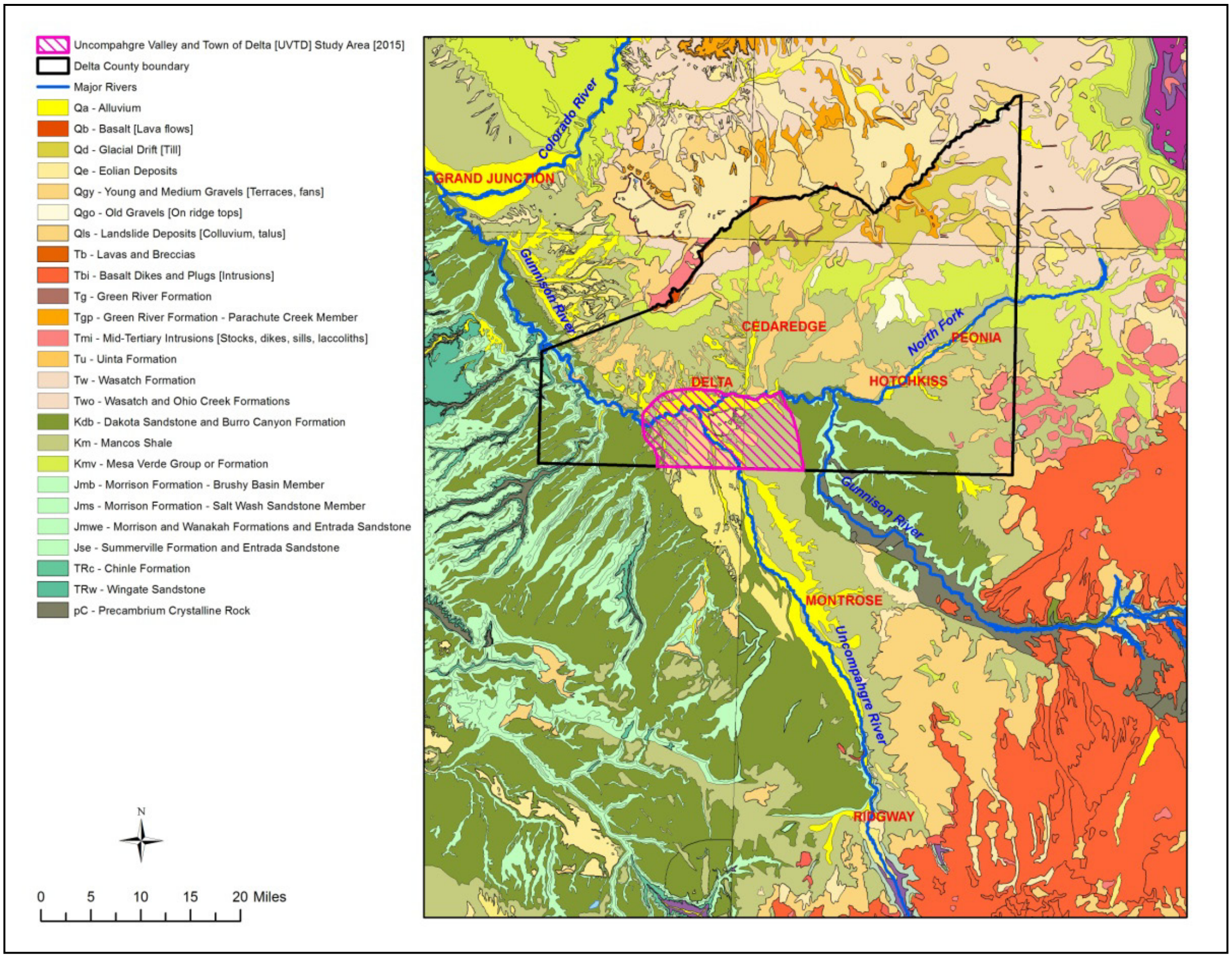

Figure 12. Composite Large Scale Map of the Geology in the Vicinity of the UVTD Study Area. **(*Based on Tweto and others, 1976; Tweto and others, 1978; Whitney, 1981; Williams, 1976*).**

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, may 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 project was on both the shallow groundwater flow systems in the Quaternary unconsolidated clastic materials, which is a source of drinking and irrigation water for several municipalities and households, and the Cretaceous Mancos Shale bedrock confining unit that may protect the integrity and water quality of the shallow drinking water systems, particularly from nearby energy development activities, or may serve to be a source of unwanted salts and selenium. In addition, the Cretaceous Dakota-Burro Canyon hydrogeologic unit is considered as a source for water supply.

The Quaternary unconsolidated clastic units (Qal, Qat, Qs, and Qgf in Table 2a and Figure 14) are locally heterogeneous, with predominantly a mix of coarser and finer materials in the older alluvial deposits, 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, and by the incidental leaky irrigation ditch and irrigation return flow. The unconsolidated units are variably to fully saturated, based on spatial location and seasonal precipitation events. There may be lateral and vertical groundwater flow connection between the unconsolidated materials and the Cretaceous sedimentary unit in the underlying bedrock formations.

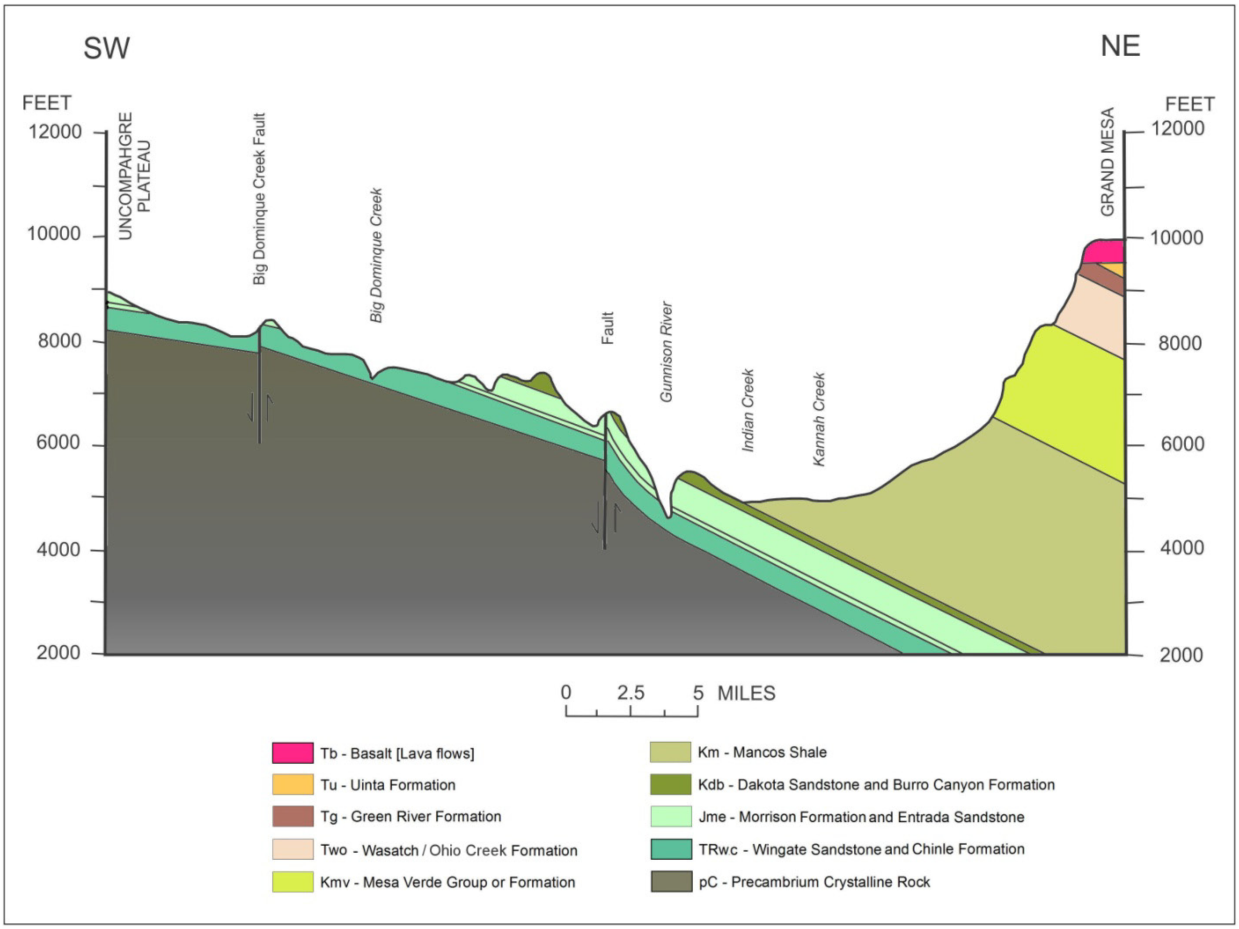

Figure 13. Generalized Northeast-Southwest Geological Cross Section Representative for Delta County.
(Modified from Brooks and Ackerman, 1985).

Of special hydrological interest is the possible occurrence of a weathered zone and mass wasting (earthflows and mudflows) on the surface of the Mancos Shale (Km). This occurs in the Peach Valley and Stirrup drainage in the southeastern and eastern areas of the study area, near the topographic surface of exposed or shallow weathered Mancos Shale bedrock (Km(w)) on the top of and along the hills and escarpments on California Mesa, and in the exposed hills west of California Mesa by Seep Creek, Bixley Gulch, Buttermilk Creek, Wise Creek, and. Cummings Gulch. This weathered surface is due to natural rebound of the land surface combined with the physical and chemical weathering processes. As a result, this weathered zone may transmit water of variable water quality along the topographic gradient of occurrence, and as a result, Qgf and Qat deposits can be connected to the hillslope deposits (Qs) as one system. Indeed, the weathered Mancos Shale will tend to fail in slump failures and mudflows and may become the hillslope (Qs) aquifer. This will become apparent in the discussions of the Peach Valley/Stirrup Creek Subsystem (Km(w)-Qal) hydrologic connectivity, and the Seep Creek/Cummings Gulch Subsystem (Km(w)-Qs-Qal) hydrologic connectivity.

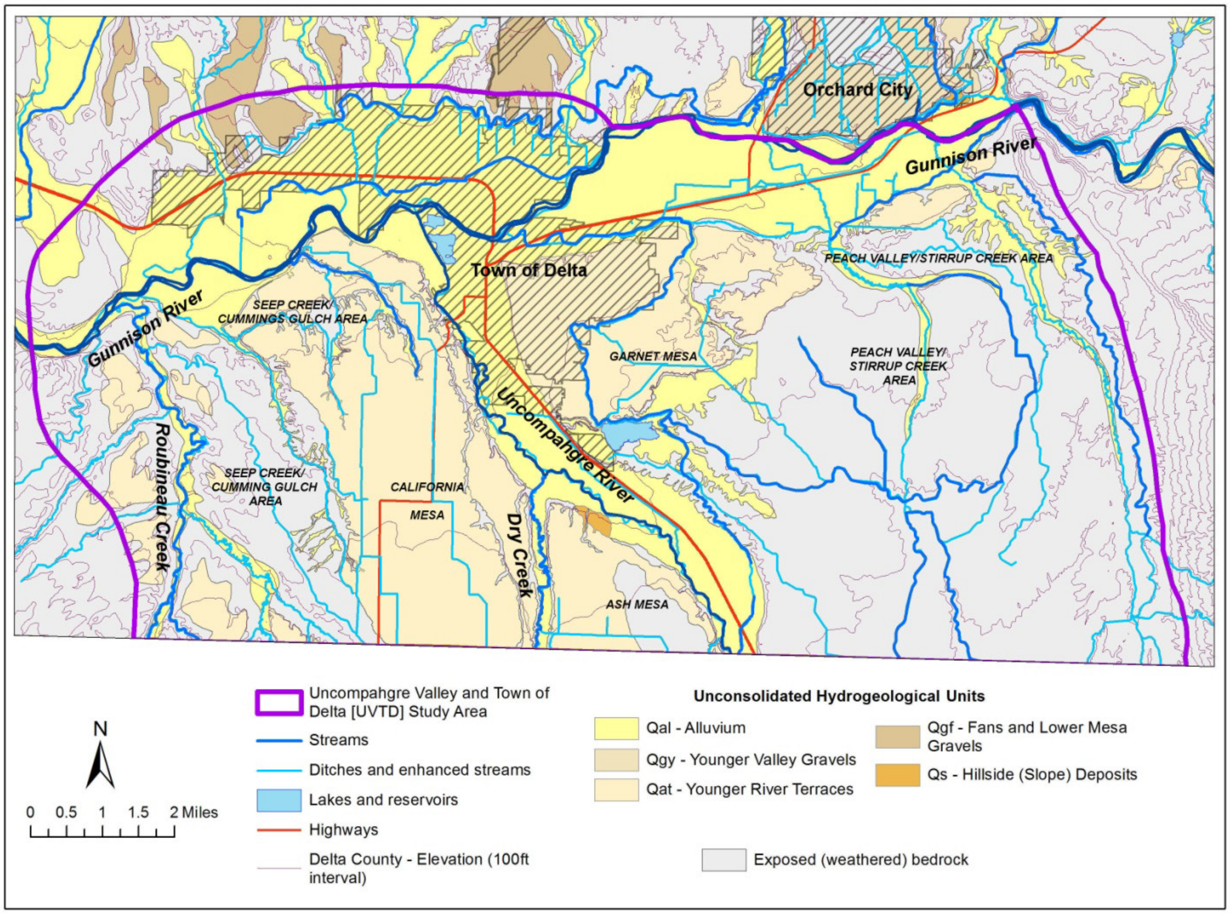

Figure 14. Map Showing the Shallow Unconsolidated Hydrogeologic Units in the UVTD Area.

2.4.3 Hydro-structural Units of the UVTD Area

Hydrostructures, which are defined by folds, faults and fracture zones, control the location of the major valleys (Uncompahgre and Gunnison River Valleys) and of most of the main drainages, and exist sub-regionally and regionally (Figure 16). The main regional fold structure, the Uncompahgre Valley Syncline, is hydrologically important in that the entire valley is underlain by flat lying Mancos Shale dipping gently to the north. The Mancos shale is tilted on the eastern and western margins of the study area, with beds dipping east off of the Uncompahgre Plateau and west off of the Black Canyon of the Gunnison uplift. The Uncompahgre Valley Syncline controls the bedrock regional groundwater systems. Deeper bedrock systems, like the Cretaceous Dakota Sandstone/Burro Canyon Formation, would have groundwater flow from south to north parallel to the Uncompahgre River Valley with the regional dip of the bedrock.

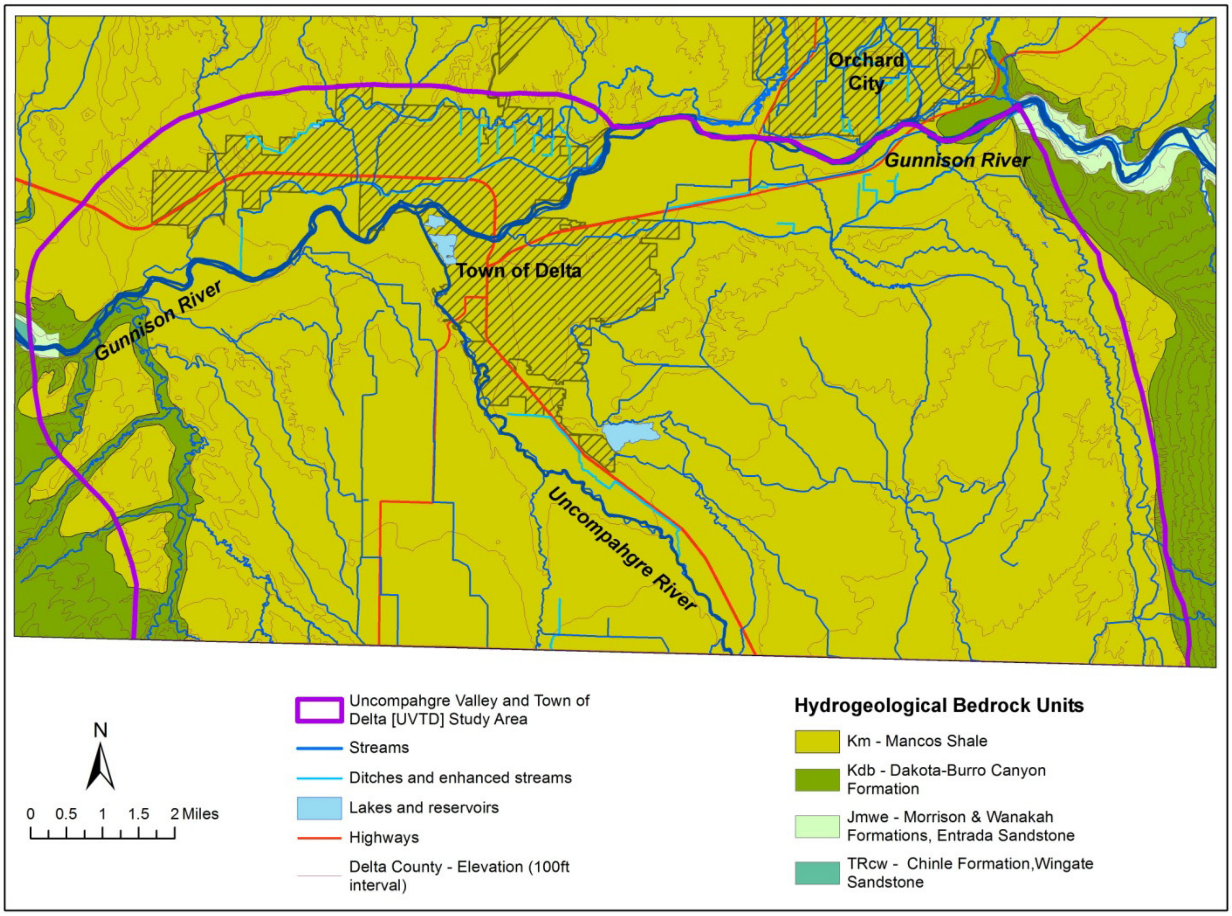

Figure 15. Map Showing Top of Bedrock Hydrogeologic Units in UVTD Area.

The fault and fracture zones have influenced the location of the main surface water drainages in the UVTD study area by providing zones of weakness whereby the streams have downcut through the unconsolidated deposits into the underlying Mancos Shale bedrock. As a result, the UVTD study area is dissected into seven distinct hydrologic subsystems of varying connectivity: California Mesa; Ash Mesa; Garnet Mesa; Seep Creek/Cummings Gulch; Peach Valley/Stirrup Creek; Uncompahgre River Valley; and Gunnison River Valley (Figure 16).

The faults and fracture zones, sometimes expressed at the surface as lineaments, may influence the hydrogeology and hydrologic systems of Peach Valley, Stirrup drainage, Garnet Mesa drainages, Dry Creek, Cummings Gulch, Bixley Gulch, Seep Creek, Buttermilk Creek, and Roubideau, Creek, and the main Gunnison and Uncompahgre Rivers as hydrostructures (Figure 15). These hydrostructures underlie these drainages in the bedrock systems (Mancos Shale 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 oil and gas activity is progressing at depth (fracking, horizontal drilling).

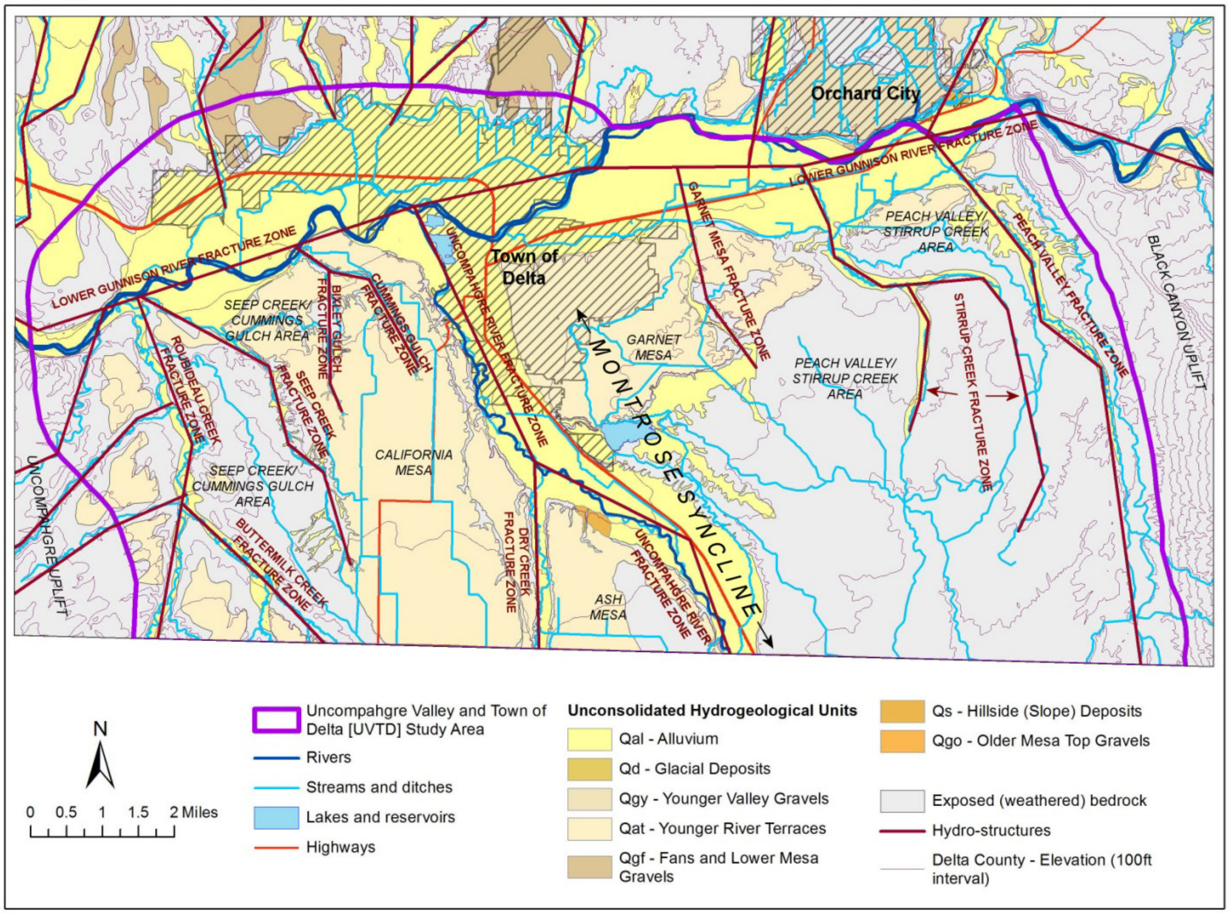

Figure 16. Map Showing Major Hydrostructures (Faults and Fracture Zones) in the UVTD Area.

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).

Three broad hydrostructure sets occur in the UVTD area: 1) the northwest-southeast trending faults and fractures that parallel the Uncompahgre River fracture zone which in turn is parallel to the bounding faults of the Uncompahgre Plateau uplift and the Black Canyon of the Gunnison River uplift structures and associated en-echelon faults and fracture zones (for example, the lower Peach Valley fracture zone, lower Stirrup Creek fracture zone, Garnet Mesa drainages fracture zones, Cummings Gulch fracture zone, Bixley Gulch fracture zone, and the Buttermilk Creek fracture zone); 2) the north-south-trending Dry Creek fracture zone and Roubideau Creek fracture zone; and 3) the east-west trending Gunnison River fracture zone (Figure 16).

The northwest-trending faults and fractures are relatively young, as the geomorphic systems of the Uncompahgre River and lower Roubideau Creek are responding with considerable downcutting, allowing for partial to full penetration of the unconsolidated hydrogeologic unit aquifers. It is hypothesized that the northwest-trending fracture zones are “open” and function like French drains. Groundwater moves laterally down valley and vertically downward along the northwest-trending fault and fracture zone planes, and may move vertically up along the fault and fractures plane near the lower reaches of the various drainages (this would be evidenced by gaining reaches in streams or increased groundwater head with depth in local wells).

The north-south-trending Roubideau and Dry Creek fracture zones and associated en-echelon fault and fracture zones, are also hypothesized to be “open” and function like French drains. Groundwater moves laterally down valley and vertically downward along the north-south-trending fault and fracture zone planes, and may move vertically up along the fault and fractures plane near the lower reaches of the various drainages (this would be evidenced by gaining reaches in streams or increased groundwater head with depth in local wells).

In the east-west trending Gunnison River fracture zone, groundwater in alluvium and the underlying bedrock systems moves horizontally along the fault plane from east to west, and vertically downward from unconsolidated materials into bedrock systems in the lower reaches below the Town of Delta, where it potentially recharges the regional aquifer systems below. Therefore, the effects of anthropogenic activities, such as irrigation or oil and gas activity, may propagate to the regional groundwater system (Figure 16).

Geological Unit	***Geological Subunit***	***Hydrogeological Unit***	***Hydro-geological Unit Symbol***	***Composition***	***Hydrogeological Characteristics***	***Permeability/Storativity***	***Depth to Water*** (small/ moderate/ large/ highly fluctuating)	***Extent*** (local/ sub-regional/ regional)	***Recharge Type*** (natural/ anthropogenic)
Alluvium (Qa); alluvium and eolian deposits (Qae); Alluvial mudflows (Qam, Qamf)		Alluvium and recent mudflows	Qal	Poorly sorted riverine gravel, sand and silt deposited mainly in stream channels and floodplains in major stream valley bottoms; moderately to well bedded deposits. In exposed Mancos shale areas finely graded, clayey mudflow/ eartflow deposits included.	Generally good local phreatic aquifer with matrix based permeability; limited variations in groundwater levels; often sustained by local and sub-regional discharge to adjacent stream or recharge directly from stream. Areas of mudflow deposits provide connectivity between adjacent aquifers but do not provide a sustainable source of water.	stream deposits have high matrix-permeability and high storativity; mudflow areas have low to moderate permeability and low storativity.	small to highly fluctuating	local	natural and anthropogenic
Younger gravel (Qg, Qgy) (stream valleys on Grand Mesa slopes)		Younger glacial stream gravels	Qgy	Poorly sorted sands and gravels; pebbles and cobbles in sand to silt matrix.	Potentially good, spatially continuous phreatic aquifer with high matrix based permeability; may be supported by underlying bedrock.	high matrix-permeability; high storativity	highly fluctuating	local	natural and anthropogenic
Glacial drift, till, moraine (Qd, Qm, Qpt) (top of Grand Mesa)		Glacial deposits	Qd	Heterogeneous, poorly sorted deposits of boulders, gravel, sand, silt and clay	Potentially good local phreatic aquifer with variable matrix based permeability and high water table gradients.	high matrix-permeability; high storativity	highly fluctuating	local	natural and anthropogenic
Landslide deposits, colluvium, talus (Ql, Qcl, Qs, Qls, Qta, Quw)		Hillside (slope) deposits	Qs	Loose gravels and rock debris with mixed matrix composition (sand-clay) on valley sides, valley floors and hillslopes; deposited by gravitational processes.	Potentially good, highly localized phreatic aquifer with high matrix based permeability and high water table gradients.	high matrix-permeability; high storativity	highly fluctuating	local	natural and anthropogenic
Old/older gravels (Qgo, Qgd)		Older mesa top gravels	Qgo	Poorly sorted sands and gravels; pebbles and cobbles in sand to silt matrix	Potentially good, spatially continuous phreatic aquifer with high matrix based permeability; may be prone to significant (seasonal) water table fluctuations; tends to recharge bedrock systems.	high matrix-permeability; high storativity	moderate	local	natural and anthropogenic
Middle gravel (Qgm) and fans (Qf)		Fans and lower mesa gravels	Qgf	Poorly sorted sands and gravels; pebbles and cobbles in sand to silt matrix.	Having high matrix based permeability, presence of groundwater depends on location in topography and on landuse.	high matrix-permeability; high storativity	highly fluctuating	local	natural and anthropogenic
High level alluvium (Qat); younger terraces (Qad); alluvial gravels (Qga)		Younger terrace gravels	Qat	Poorly sorted sands and gravels; pebbles and cobbles in sand to silt matrix; terraces above current North Fork, Gunnison and Uncompahgre river levels.	Potentially good, spatially continuous phreatic aquifer with high matrix based permeability.	high matrix-permeability; high storativity	highly fluctuating	local	natural and anthropogenic

Table 2a. Correlation of Geological and Hydrogeologic Units in Delta County: Unconsolidated Sediments.

Geological Unit	Geological Subunit	Hydrogeo-logical Unit	Hydro-Unit Symbol	Composition	Hydrogeological Characteristics	Permeability/Storativity	Depth to Water (small/ moderate/ large/ highly fluctuating)	Extent (local/ sub-regional/ regional)	Recharge Type (natural/ anthropogenic)
Tertiary Intrusive Rocks		Tertiary Intrusive Rocks	Tmi	Granodiorite and quartz monzonite; may occur as dikes and sills	Fractured crystalline system with very low matrix permeability; not a (sub-)regionale aquifer; may produce locally water in fracture zones and support adjacent unconsolidated aquifers. These characteristics may extend into adjacent rocks,methamorphosed during the Tertiary intrusion.	mostly low permeability, localized zones with moderate fracture permeability; low storativity	large	local	natural
Wasatch Formation (Tw) - including Ohio Creek Member		Wasatch Formation	Two	Channel sandstones and overbank siltstones and shales; conglomerate; carbonaceous shales and lignite near base	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.	layers with very low permeability and layers with moderate matrix and fracture permeability; low to moderate storativity	large	regional	natural
Mesa Verde Group (Kmv)	Undivided Barren Member Upper Coal-bearing Layer Lower Coal-bearing Layer Rollins Sandstone Member	Mesa Verde Group (undivided)	Kmv	Interbedded sandstones and siltstones, shales and carbonaceous shales and coals.	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.	layers with very low permeability and layers with moderate matrix and fracture permeability; low to moderate storativity	large	regional	natural
Mancos Shale (Km)	Undivided Upper and Lower Sandstone Members of Mancos Shale (Kms, Kmsl) Fort Hays Limestone Member of Mancos Shale (Kmf) Lower Mancos Shale, including Frontier Sandstone and Mowry Shale members (Kml)	Mancos Shale (undivided)	Km	Silty to sandy shale with bentonites with minor limestone- and sandstone beds; when undivided, lower section includes Ft Hays limestone	Mostly aquitard with very low permeability serving as a confining layer for underlying or embedded aquifers; however, locally moderate aquifer conditions when highly fractured or in areas with sand lenses and sandy beds.	very low permeability rock with some moderately permeable beds; low storativity	highly fluctuating	n.a.	natural
		Weathered Top of Mancos Shale	Km(w)	Weathered shale, shale-derived soils	Provide pathways for irrigation return flow towards discharge zones and between terrace aquifers and stream valleys; not an aquifer.	low to moderate permeability	depends on location	highly local	anthropgenic
Dakota Sandstone and Burro Canyon Formation (Kdb)		Dakota Sandstone and Burro Canyon Formation	Kdb	Well indurated, medium to coarse grained quartzose sandstones in well-cemented thick beds and conglomerate with occasional siltstones and carbonaceous shale	Good regional bedrock aquifer system; sandstones have both moderate matrix and fracture based permeability; sub-regionally aquifer with recharge in outcrop areas.	moderate matrix and fracture permeability; moderate storativity	large	regional	natural
Morrison Formation (Jm, Jmb, Jms); Morrison, Wanakah and Entrada Formations undivided (Jmwe)		Morrison and Entrada Formations	Jmwe	Morrison Form. (Jm): Siltstones and claystones throughout with sandstones becoming more common in lower sections, and limestone near base; Entrada Form. (Je): fine-grained, well-sorted sandstones; Je is overlain by Jm	Entrada is a very good, regionally sustainable aquifer with moderate to good matrix and fracture based permeability. Morrison shales are confining layers while the lower Morrison sandstones and limestone may serve as local to sub-regional aquifers.	layers with very low permeability and layers with moderate matrix and fracture permeability; low to moderate storativity	large	regional	natural

Table 2b. Correlation of Geological and Hydrogeologic Units in Delta County: Bedrock Units.

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) outputs (discharge). 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 subregional and local scale (typically less than 100 square miles) shallow groundwater flow systems are delineated. The broad hydrologic system inputs include infiltration of precipitation as rain and snowmelt; areas of losing streams and rivers (for example, reaches of the Gunnison River above the Town of Delta near the confluence of the Surface Creek); infiltration and runoff from water bodies (cattle and house ponds, Sweitzer Lake), upland irrigation areas (leaking ditches, irrigation return flow), and inter-aquifer transfer of groundwater between unconsolidated materials and bedrock systems. Mesa Top and Hillslope subsystems consist of the hydrologic processes of surface runoff (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 along the axis of the terraces, and/or towards the valley bottoms, perpendicular to the major streams. Where permeable bedrock units intersect 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 pattern determined by geological structure, independent from local topography and hydrography. However, the UVTD groundwater systems are a complex mix of predominantly shallow aquifer systems underlain by a more confining hydrogeologic unit: the Cretaceous Mancos shale. Locally and sub-regionally, various hydrostructures may influence interconnectivities of the shallow units with deeper bedrock systems, but in general, the regional systems are at depth with only minimal connectivity.

The Mesa Top (Garnet Mesa; California Mesa; Ash Mesa) subsystems, located in close proximity to the Hillslope and Valley Bottom subsystems, have a unique, sometimes complex groundwater story, often resulting from human interference. Under natural conditions, these subsystems have hydrologic system inputs and outputs, similar to Hillslope and Valley Bottom subsystems. However, natural and anthropogenic influences have frequently attached these subsystems hydrologically to adjacent Hillslope and Valley Bottom subsystems.

The Hillslope (Peach Valley/Stirrup Creek; Seep Creek/Cummings Gulch Group) subsystems, located as stand-alone subsystems, or in close proximity to and below the Mesa Top subsystems, have a unique and complex groundwater story, often resulting from human interference. Under natural conditions, these subsystems have hydrologic system inputs and outputs, similar to Hillslope and Valley Bottom subsystems. However, natural and anthropogenic influences have created unique hydrogeologic units (earthflows, mudflows, weathered Mancos Shale) that frequently attach these subsystems hydrologically to adjacent Mesa Top and Valley Bottom subsystems.

The Valley Bottom (Gunnison River Alluvium; Uncompahgre River Alluvium (including Dry Creek Alluvium) 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 Surface Creek, Alfalfa Run, Peach Valley drainage, Stirrup Creek, Garnet Mesa drainages, Sweitzer Lake and drainage, Cummings Gulch drainage, Bixley Gulch drainage, Wise Creek, Seep Creek, and Roubideau Creek; discharge from the Hillslope and Mesa Top subsystems such as California Mesa, Garnet Mesa, and Ash Mesa, and the management of sub-regional ditches and subsurface return flow from irrigation lands and corresponding spring storage.

The wetlands associated with the local hydrogeologic subsystems in the Gunnison River Valley and the Uncompahgre River Valley, and in the adjoining tributaries are a mix of slope-type and riverine-type classifications given the groundwater support of various ditches and irrigation schemes, unconsolidated hydrogeologic unit groundwater systems, and hydrostructures.

As springs are discharge points of groundwater flow systems, their presence in the UVTD study area provide clues about these groundwater flow systems, including the role of the hydrogeological units, 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 UVTD area the State water rights database was searched in June 2015 (*CDWR 2015*).

There are two general categories of springs, based on spring location with respect to hydrogeologic location, that are identified on topographic maps and in the State water rights records for Delta County (Figure 10): 1) Unconsolidated Unit/Cretaceous Mancos Shale interface springs; and 2) Unconsolidated Unit or non-interface springs controlled by topography and geomorphology. The interface springs are located at the Qal/Km interfaces along drainages or at the Qat/Qs/Km interfaces along the edges of mesas where the terrace gravels (Qat) and mass wasting slope materials (Qs), which are the potential unconsolidated aquifers, abut against the Cretaceous Mancos Shale (Km), which is a confining unit, forcing groundwater to the surface. The non-interface springs are located primarily in the modern alluvium (Qal).

Springs can also be categorized with respect to recharge dynamics: 1) Springs recharged primarily by natural precipitation and infiltration; 2) Springs recharged primarily by leaky irrigation ditches, with secondary recharge by return flow from irrigation and infiltration of natural precipitation; and 3) Springs recharged primarily by return flow from irrigation, and secondary recharge by precipitation and/or leaky irrigation ditches. In the UVTD study area, most of the springs are recharged primarily from return flow from irrigation, and secondary recharge by precipitation and/or leaky irrigation ditches, and are observed in the lower discharge areas of Mesa Top or Hillslope subsystems into the Valley Bottom subsystems (for example, the Ash Mesa springs located south of Sweitzer Lake on the opposite site of the Uncompahgre river).

Finally, springs can also be categorized with respect to age based on information from the State water rights data base for springs/seeps and ditches (*CDWR 2015*): 1) Pre-irrigation springs that most likely were the result of infiltration of natural precipitation; and 2) Post-irrigation development springs that most likely were the result of either irrigation return flow to the groundwater or infiltration of water due to leaky irrigation ditches. This latter category of springs and nearby wells is most vulnerable to changes in water use and water rights decisions. Most of the springs in the UVTD area and affiliated water rights will be associated with the effects of the various leaky irrigation ditches and the return flow of irrigated water.

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, four categories of CSMs will be discussed in the UVTD study area:

1. Mesa Top Shallow Aquifer Subsystems, which include the California Mesa, Ash Mesa, and Garnet Mesa Subsystems;
2. Hillslope Shallow Aquifer Subsystems, which include the Peach Valley/Stirrup Creek and Seep Creek/Cummings Gulch Group;
3. Valley Bottom Shallow Aquifer Subsystems, which include the Uncompahgre River (including Dry Creek) and Gunnison River Alluvial Subsystems; and
4. Regional Bedrock Aquifer Subsystems.

In addition, a brief discussion of the interface of the Mesa Top and Hillslope Shallow Aquifer Subsystems, and the interface of the Hillslope and Valley Bottom Shallow Aquifer Subsystems particularly with respect to the Gunnison River Subsystem will be presented. The conceptual models are discussed in forthcoming sections and illustrated by cross-sectional and plan view figures, and by Google Earth screen shots. The locations of representative cross-sections are shown in Figure 17. A landscape view of the area is shown in Figures 8a and 8b. Note that most of the subsystems have some interconnectedness with the surrounding subsystems, whether by subsurface groundwater flow, or by tributary stream flow.

2.6.1 Mesa Top Shallow Aquifer Subsystems

As stated in Section 2.4.2, there are two significant hydrogeologic groups in the Mesa Top Shallow Aquifer Subsystems, which include the California Mesa Subsystem, the Ash Mesa Subsystem, and the Garnet Mesa Subsystem:

1. Quaternary unconsolidated clastic units (Qs, Qat in Table 2a and Figure 14), which are predominantly hillside (slope) deposits and terrace gravels; and
2. Cretaceous bedrock unit of the Mancos Shale (Km) (Table 2b and Figure 15).

The shallow Quaternary unconsolidated materials in these two subsystems are ubiquitous, and include glacial-alluvial, mass wasting, and paleo-alluvial (terrace) deposits (Figure 14 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 fluvial systems that eventually deposited the Quaternary unconsolidated materials that are the aquifers being evaluated.

The general aspects of groundwater flow in the Quaternary unconsolidated materials have been discussed in Section 2.5. Specifically, the shallow groundwater on California Mesa is dominated by two levels of Quaternary unconsolidated materials (Qat and Qs), which receive natural recharge by infiltration of precipitation (snow and rain; Rp), and major recharge from leaky irrigation ditches originating from Project 7 water (Rd) and return flow from area irrigation locally (Ri) (Figures 18, 19, and 20). Any unlined ditches are "line" sources of groundwater recharge (Rd) leading to and at the top of the irrigated field areas; the return flow from irrigation is considered an "area" source of groundwater recharge (Ri). Water leaking from the unlined ditches and irrigated areas enter into the (connected) gravels underneath and flows downgradient towards the discharge zones (streams, collection ditches, springs and seeps, and wetlands) (Figures 18, 19, and 20). Note that the collection ditches may be leaking too (Rd).

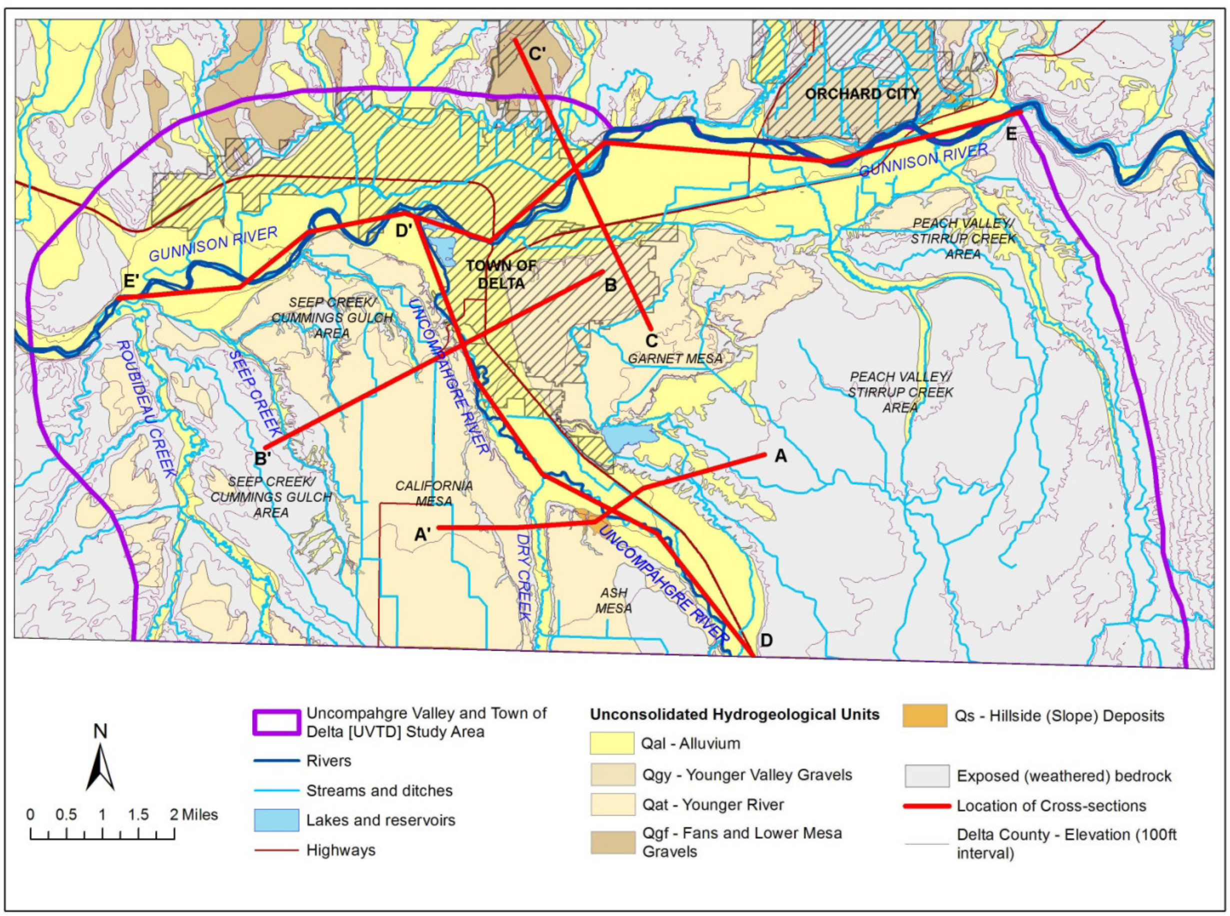

Figure 17. Map Showing the Locations of the Cross-sections Representative for the Conceptual Site Models in the UVTD Area on Top of the Hydrogeologic Units.

Groundwater flow on top of the gravel-capped California Mesa then moves with topography or subsurface paleo-topography to discharge into springs at the gravel/Mancos Shale interface along the incised drainages that bound (Buttermilk Creek, Wise Creek, Seep Creek) or incise (Cummings Gulch, Bixley Gulch) the mesa (Dsp), discharge directly out the north or east side of the mesa as seeps or springs (Dsp) at the gravel/Mancos Shale interface, or discharge into the hillslope slope and mudslide deposits (Qs) causing further mass wasting activity (Figures 18, 19, 20, and 26). Given the "new" water that has recharged the aquifer, springs may have been developed after the initiation of irrigation on the mesa and claimed as being "new" springs. There is also groundwater discharge from the gravels locally by groundwater wells (Dw) and by phreatophytes (Dp). The shallow groundwater subsystems in California Mesa have little connection to the local bedrock or the regional groundwater systems, but do have connection to nearby hillslope and alluvial systems, such as Seep, Buttermilk, and Wise Creeks, and Cummings and Bixley Gulches; and to both the lower Gunnison River alluvium and the lower Uncompahgre River alluvium. Google Earth can be used to visualize these relationships (for example, Figures 21 and 22).

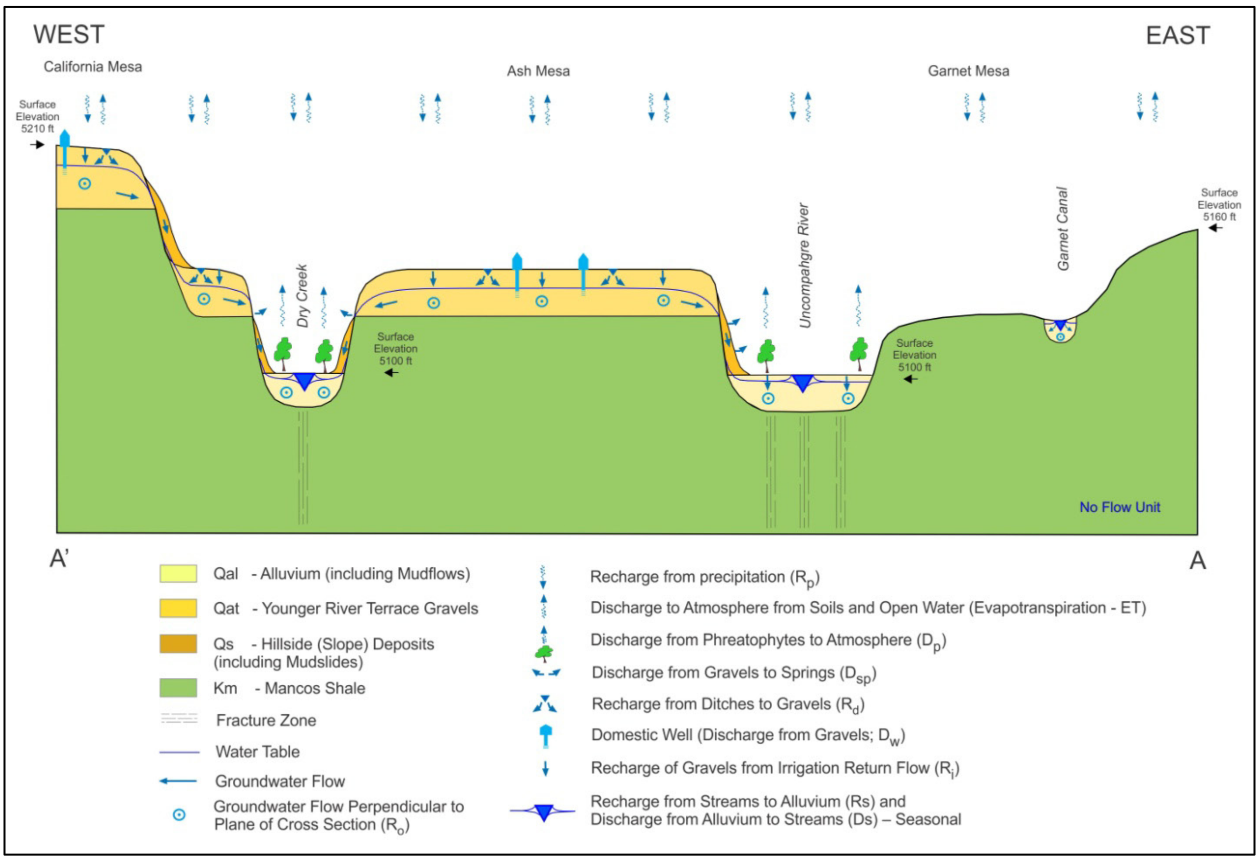

Figure 18. Schematic East-west Cross-sectional View of the Conceptual Site Models of the Mesa Top and Hillslope, and Valley Bottom Shallow Aquifer Subsystems in the Vicinity of Ash Mesa (A-A' in Figure 17).

A similar hydrologic system exists on Ash Mesa, a subsystem that extends from south of the southern Delta County line to the confluence of Dry Creek and the Uncompahgre River (Figures 18 and 20). The Ash Mesa Subsystem is dominated by the Quaternary unconsolidated materials (Qat), which receive natural recharge by infiltration of precipitation (snow and rain; Rp), and major recharge from leaky irrigation ditches originating from Project 7 water, and return flow from flood irrigation locally (Ri) (Figures 18 and 20). Water leaking from the unlined ditches and irrigated areas enter into the (connected) gravels underneath and flows downgradient towards the discharge zones (streams, springs and seeps, and wetlands) (Figures 18 and 20).

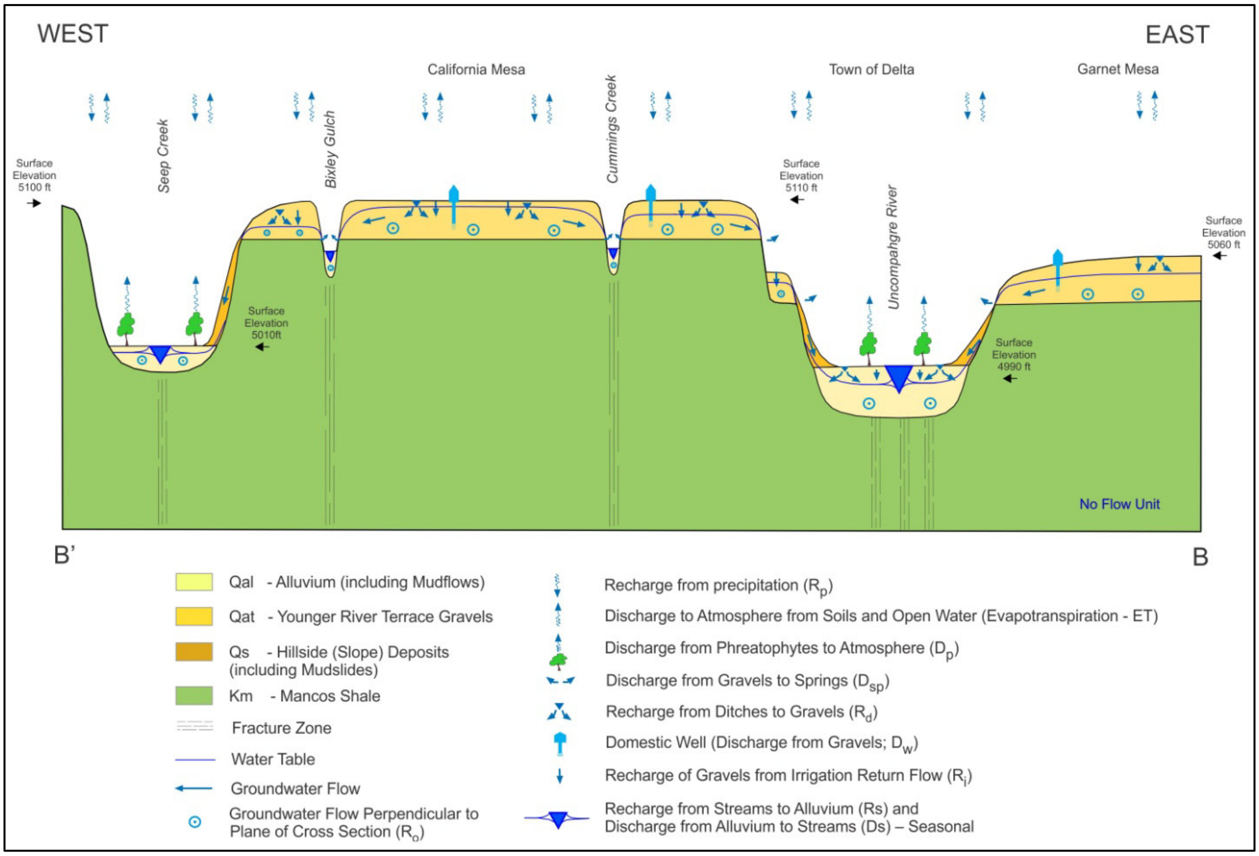

Figure 19. Schematic East-west Cross-sectional View of the Conceptual Site Models of the Mesa Top and Hillslope, and Valley Bottom Shallow Aquifer Subsystems in the Vicinity of California Mesa and Garnet Mesa (B-B' in Figure 17).

Groundwater flow on top of the gravel-capped Ash Mesa then moves with topography or subsurface paleo-topography to discharge into springs at the gravel/Mancos Shale interface along the incised drainages that bound (Dry Creek; Uncompahgre River) the mesa (Dsp), discharge directly out the north or west side of the mesa as seeps or springs (Dsp) at the gravel/Mancos Shale interface, or discharge into the hillslope slope and mudslide deposits (Qs) causing further mass wasting activity (Figures 18 and 20). Given the "new" water that has recharged the aquifer, springs may have been developed after the initiation of irrigation on the mesa and claimed as being "new" springs. There is also groundwater discharge from the gravels locally by groundwater wells (Dw) and by phreatophytes (Dp). The shallow groundwater subsystems in Ash Mesa have little connection to the local bedrock or the regional groundwater systems, but do have connection to nearby hillslope and alluvial systems, such as Dry Creek alluvium and Uncompahgre River alluvium. Google Earth can be used to visualize these relationships (for example, Figures 21 and 22).

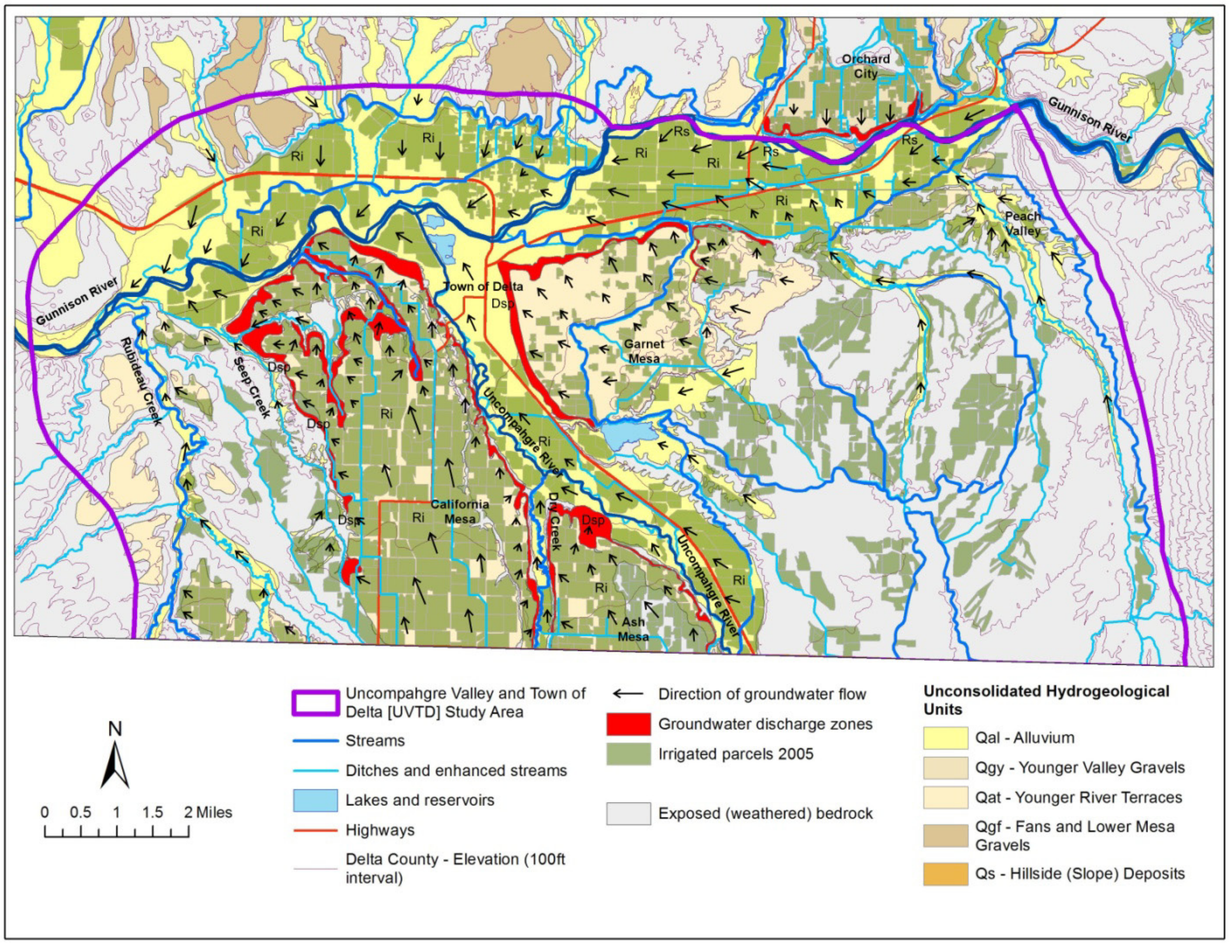

Figure 20. Plan View of the Conceptual Site Model of the Mesa Top and Hillslope, and Valley Bottom Shallow Aquifer Subsystems with Discharge Zones and Groundwater Flow Direction.

The third Mesa Top subsystem is observed on Garnet Mesa, a subsystem that extends from Sweitzer Lake on the south to the Gunnison Valley alluvial subsystem to the north, and encompasses most of the eastern part of the Town of Delta (Figures 18, 19, 20, and 23). The Garnet Mesa Subsystem is dominated by the Quaternary unconsolidated materials (Qat) derived from the paleo Gunnison River, which receive natural recharge by infiltration of precipitation (snow and rain; Rp), and major recharge from leaky irrigation ditches and canals originating from Project 7 water, and return flow from flood irrigation locally(Ri) (Figures 18, 19, 20, and 23). Water leaking from the unlined ditches and irrigated areas enter into the (connected) gravels underneath and flows downgradient towards the discharge zones (drainages, springs and seeps, and wetlands) .

Unlike California and Ash Mesas, Garnet Mesa is well dissected by drainages that fully penetrate the bottom of the gravels into the Mancos shale. In addition, the northwestern part of Mesa has been urbanized, which significantly alters the amount of water and flow characteristics of that part of the groundwater system. Groundwater flow on top of the gravel-capped Garnet Mesa moves with topography or subsurface paleo-topography to discharge into springs at the gravel/Mancos Shale interface along the incised drainages that incises and dissect the mesa (Dsp), discharge directly out the north or west side of the mesa as seeps or springs (Dsp) at the

Figure 21. Google Earth View of the Mesa Top Subsystem at California Mesa, Looking Southwest. Note Seepage Line along the Edge of the Mesa (dark green areas).

Figure 22. Google Earth View of the Mesa Top and Hillslope Subsystem at Ash Mesa, Looking Southeast. Note Slumped Area in Northeast Corner (Qs) Providing Groundwater Flow Connectivity between the Gravels on the Mesa Top (Qat) and the Valley Bottom Aquifer(Qal); Also Note the Seepage Line at the Bottom of the Mesa Gravels (Qat) along the Western Edge of the Mesa (dark green areas).

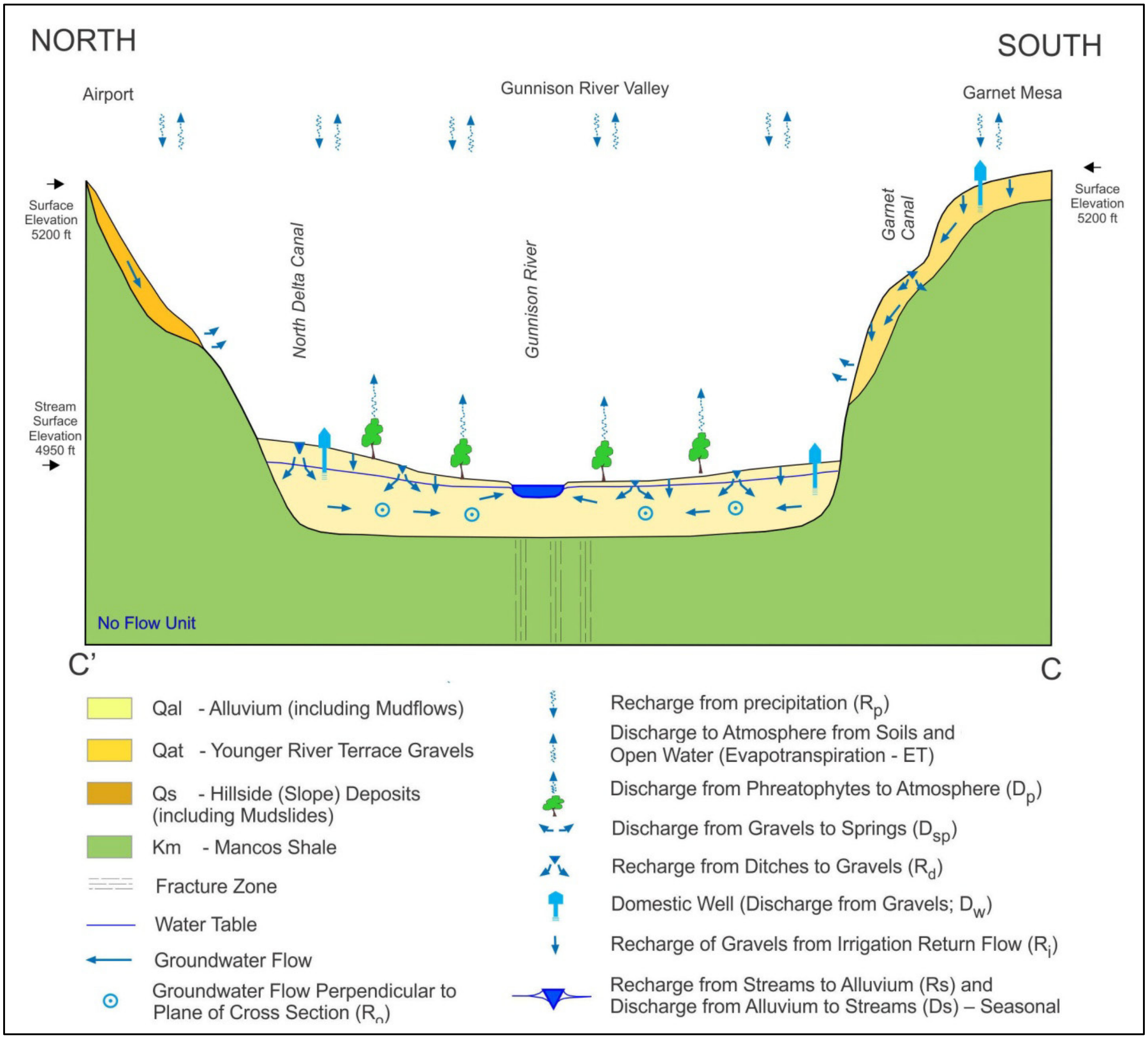

Figure 23. Schematic South-north Cross-sectional View of the Conceptual Site Models of the Mesa Top and Valley Bottom Subsystem in the Garnet Mesa/Gunnison River Area (C-C' in Figure 17).

gravel/Mancos Shale interface, or discharge into the hillslope slope and mudslide deposits (Qs) causing further mass wasting activity (Figures 18, 19, 20, and 23). Given the "new" water that has recharged the aquifer, springs may have been developed after the initiation of irrigation on the mesa and claimed as being "new" springs. There is also groundwater discharge from the gravels locally by groundwater wells (Dw) and by phreatophytes (Dp). The shallow groundwater subsystems in Garnet Mesa have little connection to the local bedrock or the regional groundwater systems, but do have connection to both the Gunnison River alluvium and the lower Uncompahgre River alluvium. Google Earth can be used to visualize these relationships (for example, Figures 24 and 25).

Figure 24. Google Earth View of the Mesa Top Subsystem at Garnet Mesa, Looking Southeast. Note Seepage Line along the Edge of the Mesa (dark green areas).

Figure 25. Google Earth View of the Mesa Top Subsystem at Garnet Mesa, Looking Northeast. Note Seepage Line along the Edge of the Mesa (dark green areas).

2.6.2 Hillslope Shallow Aquifer Subsystems

As stated in Section 2.4.2, there are two significant hydrogeologic groups in the Hillslope Shallow Aquifer Subsystems, which include the Peach Valley/Stirrup Creek Subsystem, and the Seep Creek/Cummings Gulch Group Subsystem:

1. Quaternary unconsolidated clastic units (Qs and Qal in Table 2a and Figure 14), which are predominantly hillside (slope) deposits and modern day alluvium; and
2. Cretaceous bedrock unit of the Mancos Shale (Km) including weathered Mancos Shale (Km(w)) (Table 2b and Figure 15).

The shallow Quaternary unconsolidated materials in these two subsystems are ubiquitous, but not necessarily continuous, and consist of modern day weathering (weathered bedrock), mass wasting (slumps, earthflow, mudflow), and alluvial deposits (Figure 14 and Table 2a). These moderately-permeable deposits are locally heterogeneous, with a mix of mostly finer materials in all of the deposits. These deposits are underlain by a modern topographic surface carved out by modern weathering, mass wasting and fluvial systems that deposited the Quaternary unconsolidated materials that are the hydrogeologic units and aquifers being evaluated.

The general aspects of groundwater flow in the Quaternary unconsolidated materials have been discussed in Section 2.5. Specifically, the shallow groundwater in the Peach Valley/Stirrup Creek Watershed and subsystem is dominated by the Quaternary unconsolidated materials (Km(w), Qal, and Qs), which receive less than an inch annually of natural recharge by infiltration of precipitation (snow and rain; Rp), and major recharge from leaky irrigation ditches originating from the East and Selig canals (Project 7 water) (Rd) and small reservoirs locally, and return flow from area irrigation locally (Ri) (Figures 20 and 26). The unlined ditches are "line" sources of groundwater recharge (Rd) leading to and at the top of the irrigated field areas; the return flow from irrigation is considered an "area" source of groundwater recharge (Ri). Water leaking from the unlined ditches and irrigated areas enter into the (connected) weathered bedrock, earthflow and mudflow deposits, and alluvium in the drainages underneath and flows downgradient towards the discharge zones (gaining streams, springs and seeps, and wetlands) (Figures 20 and 26).

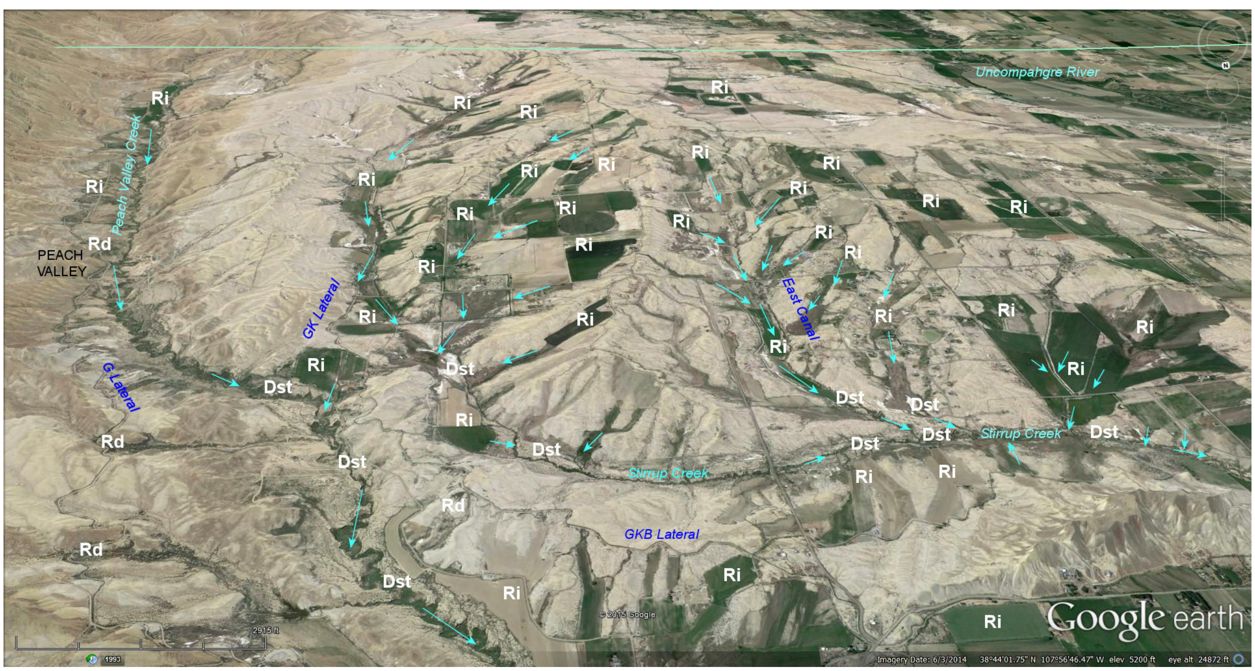

Figure 26. Google Earth View of the Conceptual Site Model of the Hillslope Shallow Aquifer Subsystem in the Peach Valley/Stirrup Creek Area with Groundwater Flow Direction.

(Rd = Recharge from leaky ditch; Ri = Recharge from irrigation return flow; Dst = Discharge to stream)

Groundwater flow is extremely localized and within the fine-grained weathering, mass wasting and fluvial deposits on top of the Mancos Shale, which moves with topography or subsurface paleo-topography to discharge into springs and seeps, gullies, or drainages at the alluvium/Mancos Shale interface along the incised drainages that dissect the Peach Valley/Stirrup Creek watershed (Dst) (Figures 20 and 26). Given the “new” water that has recharged these highly localized aquifers, springs may have been developed after the initiation of irrigation on the landscape and claimed as being “new” springs. There is also groundwater discharge from the weathered shale, mudflow and earth flow deposits, and alluvium locally by groundwater wells (Dw) and by phreatophytes (Dp). The shallow groundwater subsystems in this Hillslope area have little connection to the local bedrock or the regional groundwater systems, or to nearby alluvial systems until the very end of the surface water system where Peach Valley and Stirrup Creek discharge into the alluvium of the Gunnison River. This is a critical juncture as any selenium derived in these upper basins due to irrigation or flooding would be delivered to the Gunnison river system at these locations. Google Earth can be used to visualize these relationships (Figures 8 and 26).

The Seep Creek/Cummings Gulch Group Hillslope Subsystem, located to the west and northwest of California Mesa, is very different from the shallow groundwater subsystem in the Peach Valley/Stirrup Creek Watershed. Both subsystems are dominated by the Quaternary unconsolidated materials (Km(w), Qal, and Qs), and receive less than an inch annually of natural recharge by infiltration of precipitation (snow and rain; Rp). However, the recharge of the Seep Creek/Cummings Gulch Group Subsystem is from leaky irrigation ditches originating from the Project 7 water (Rd), return flow from area irrigation locally (Ri), and major leakage of irrigation return flow water from the California Mesa subsystem located topographically above these systems (Figures 20 and 27). Essentially the groundwater discharge from the California Mesa Subsystem becomes the recharge for much of the Seep Creek/Cummings Gulch Group Subsystem. The unlined ditches are "line" sources of groundwater recharge (Rd) leading to or from, and at the top of the irrigated field areas; the return flow from irrigation is considered an "area" source of groundwater recharge (Ri). Water leaking from the unlined ditches and irrigated areas enter into the (connected) weathered bedrock, earthflow and mudflow deposits, and alluvium in the drainages underneath and flows downgradient towards the discharge zones (gaining streams, springs and seeps, and wetlands) (Figures 20 and 27).

Groundwater flow is extremely localized and within the fine-grained weathering, mass wasting and fluvial deposits on top of the Mancos Shale, which moves with topography to discharge into springs, gullies, or drainages at the alluvium/Mancos Shale interface along the incised drainages that dissect the landscape: Buttermilk, Seeps, and Wise Creeks, and Bixley and Cummings Gulches – each with their own unique watershed (Dst) (Figures 20 and 27). Given the “new” water that has recharged these highly localized aquifers, springs may have been developed after the initiation of irrigation at California Mesa and on the Mancos landscape and claimed as being “new” springs. There is also groundwater discharge from the weathered shale, mudflow and earthflow deposits, and alluvium locally by groundwater wells (Dw) and by phreatophytes (Dp). The shallow groundwater subsystems in this Hillslope area have little connection to the local bedrock or the regional groundwater systems, or to nearby alluvial systems until the termination of the surface water system where Seep Creek, Bixley and Cummings Gulches discharge into the alluvium of the Gunnison River. This is a critical juncture as any selenium derived in these lower Mancos Shale basins due to irrigation or flooding would be delivered to the lower Gunnison river system at these locations. Google Earth can be used to visualize these relationships (Figures 8 and 27).

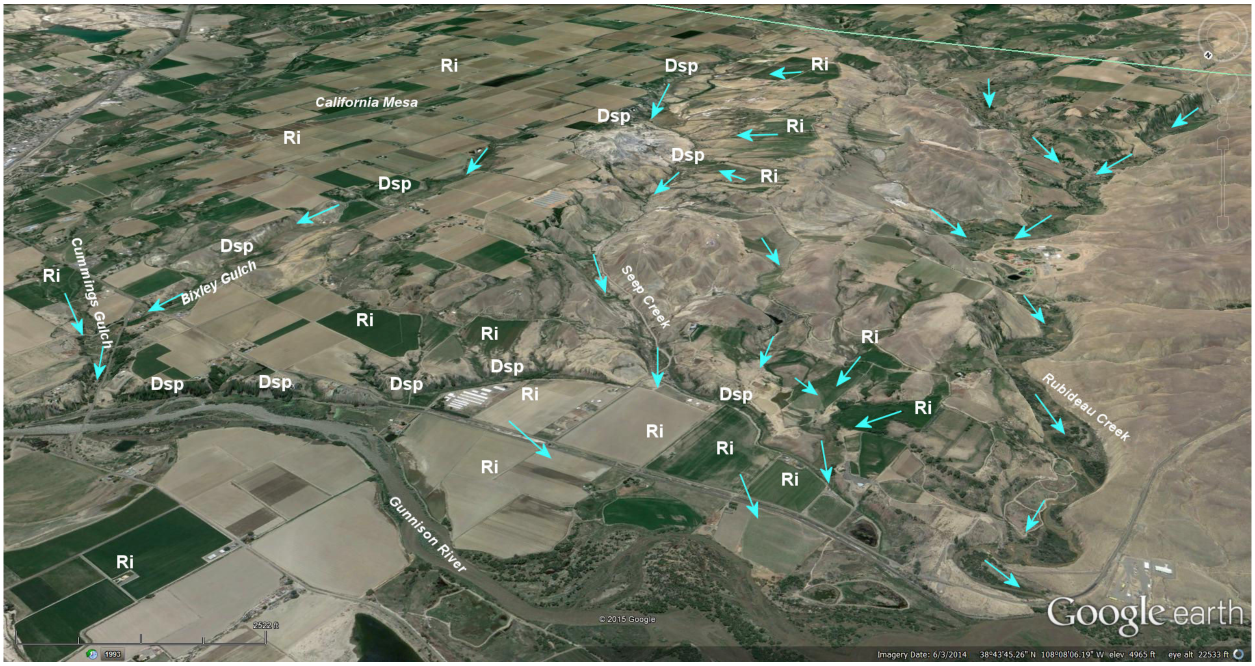

Figure 27. Google Earth View of the Conceptual Site Model of the Hillslope Shallow Aquifer Subsystem in the Seep Creek/Cummings Creek Area with Groundwater Flow Direction

(Ri = Recharge from irrigation return flow; Dsp = Discharge to springs and seeps).

2.6.3 Valley Bottom Shallow Aquifer Subsystems

As stated in Section 2.4.2, there are two significant hydrogeologic groups in the Valley Bottom Shallow Aquifer Subsystems, which include the Gunnison River Alluvial Subsystem and the Uncompahgre River Alluvial Subsystem (and Dry Creek alluvial subsystem):

1. Quaternary unconsolidated clastic materials (Qal and Qat) in Table 2a and Figure 14), which are predominantly alluvial valley bottom and terrace deposits; and
2. Cretaceous Mancos Shale bedrock unit (Km in Table 2b and Figure 15); and Cretaceous Dakota Sandstone and Burro Canyon Formation (Kdb in Table 2b and Figure 15).

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

1. Northeast-southwest trending, north-south trending, and east-west trending fault/fracture zone hydrostructures (Figure 16); and
2. Uncompahgre Valley or Montrose Syncline with synclinal axis trending north- south dipping gently to the north.

The shallow Quaternary unconsolidated materials in these subsystems are thick and ubiquitous, and include modern alluvium (Qal) and younger terrace gravels (Qat) (Figure 14 and Table 2a). These highly-permeable deposits are locally heterogeneous, with a mix of coarser and finer materials in the alluvial deposits (usually coarser sediments on the bottom grading to finer sediments on top). These deposits are underlain by a paleo-topographic surface carved out by paleo-fluvial systems that eventually deposited the Quaternary unconsolidated materials that are the aquifers being evaluated.

The general aspects of groundwater flow in the Quaternary unconsolidated materials have been discussed in Section 2.5. Specifically, the shallow groundwater in the Uncompahgre River Valley (and Dry Creek tributary valley) subsystem is dominated by the Quaternary alluvium (Qal), which receives natural recharge by infiltration of precipitation (snow and rain; Rp) and losing streams (Rs); input from hillside (slope) deposits derived from the terrace gravels (Rsd); and additional recharge from leaky irrigation ditches originating from both the Garnet Canal and local ditches sourced to both the Uncompahgre River and Dry Creek (Rd); and return flow from irrigation locally (Ri) (Figures 20, 28 and 29). Water leaking from the unlined ditches and irrigated areas enter into the (connected) gravels underneath and flows downgradient towards the discharge zones (gaining streams, springs and seeps, and wetlands) (Figures 20, 28 and 29).

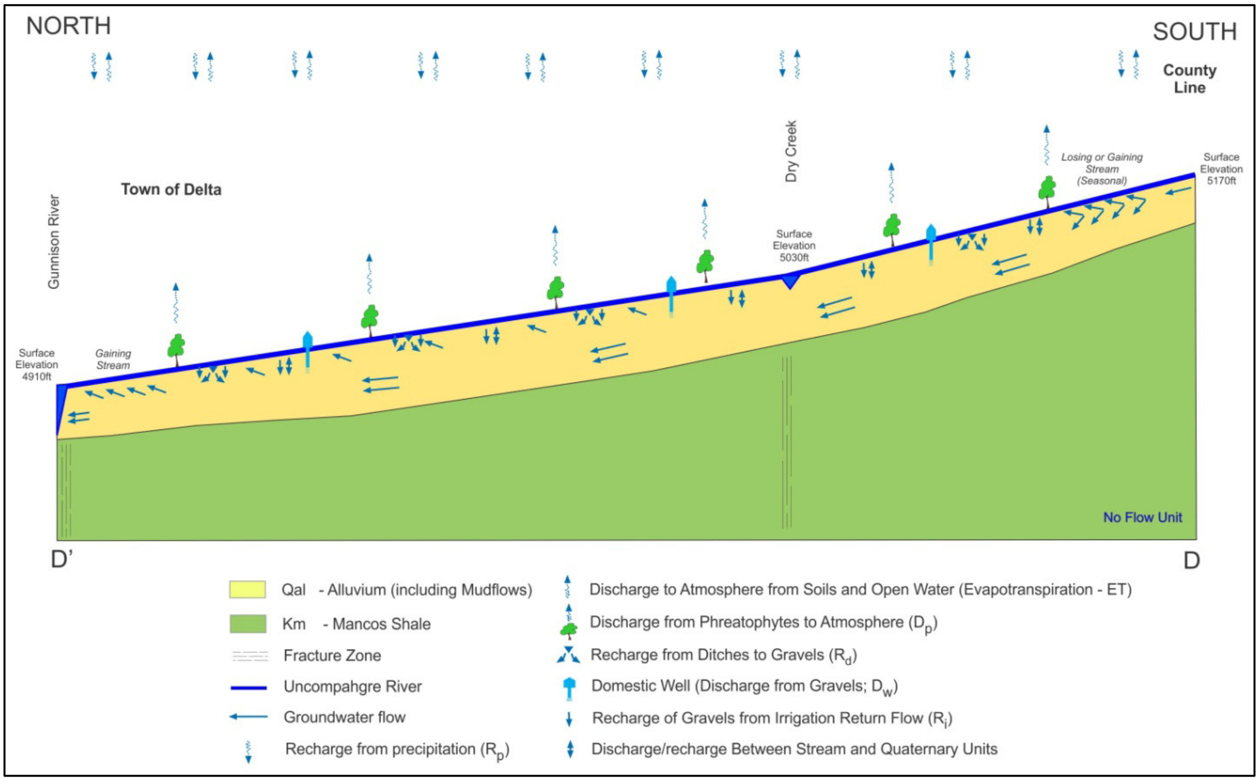

Figure 28.Schematic Cross-sectional View of the Conceptual Site Models of the Valley Bottom Shallow Aquifer Subsystem along the Uncompahgre River Valley (D-D' in Figure 17).

Groundwater flow in the Dry Creek and Uncompahgre River alluvium moves in the same direction as the stream with various stream reaches being gaining (Ds) or losing (Rs) depending on subsurface topography, saturated thickness of the alluvium, or the seasonal variations caused by snowpack runoff or storm events (Figures 20, 28 and 29). There is also groundwater discharge from the alluvium locally by groundwater wells (Dw) and by phreatophytes (Dp). The shallow groundwater in the Dry Creek and Uncompahgre River alluvial subsystems would normally have little connection to the local bedrock or the regional groundwater systems, given the Mancos Shale bedrock. However, underlying Dry Creek is the north-south trending Dry Creek fracture zone, and underlying the Uncompahgre River is the northwest-southeast trending Uncompahgre River fracture zone (Figure 16). These areas of hydrostructures that may be open vertical conduits, where the faulted and fractured bedrock may combine with the alluvium (Qal) to form a French Drain affect resulting in increased groundwater flow and storage, and connectivity to deeper hydrologic systems notably the Cretaceous Dakota Sandstone/Burro Canyon Formation hydrogeologic unit. This could result in decreased water quality either naturally (Mancos Shale water has higher TDS, metals) or due to human activities, such as fracking or waste disposal activities. A Google Earth view of the Valley Bottom subsystem in the Uncompahgre River and Dry Creek drainages is shown in Figure 29.

Figure 29. Google Earth View of the Conceptual Site Model of the Valley Bottom Shallow Aquifer Subsystem of Uncompahgre River and Dry Creek Valleys Looking South with Groundwater Flow Direction. (Ri = Recharge from irrigation return flow; Dsp = Discharge to springs and seeps).

The second, and perhaps the most major Valley Bottom Subsystem in the UVTD study area is the shallow groundwater in the Gunnison River Valley Subsystem. This Subsystem is dominated by the Quaternary alluvium (Qal), which receives natural recharge by infiltration of precipitation (snow and rain; Rp) and losing streams (Gunnison River) in the upper reaches of the study area (Rs); input from hillside (slope) deposits derived from the terrace gravels (Rsd); input from connected subsystems including Surface Creek surface water and groundwater, Peach Valley and Stirrup Creek surface water and groundwater, Garnet Creek drainage and groundwater, Cummings Gulch surface and groundwater, Bixley Gulch surface and groundwater, and Seep Creek surface and groundwater; additional recharge from leaky irrigation water distribution systems (i.e., Relief Ditch, North Delta Canal, Bonafide Ditch, Heartland Ditch) and associated ditches, and local ditches sourced directly from the Gunnison River (Rd); and return flow from irrigation locally (Ri) (Figures 20, 30, 31 and 32). Water leaking from the unlined ditches and irrigated areas enter into the (connected) gravels underneath and flows downgradient towards the discharge zones (gaining streams reaches, springs and seeps, and wetlands) (Figures 20, 30, 31 and 32).

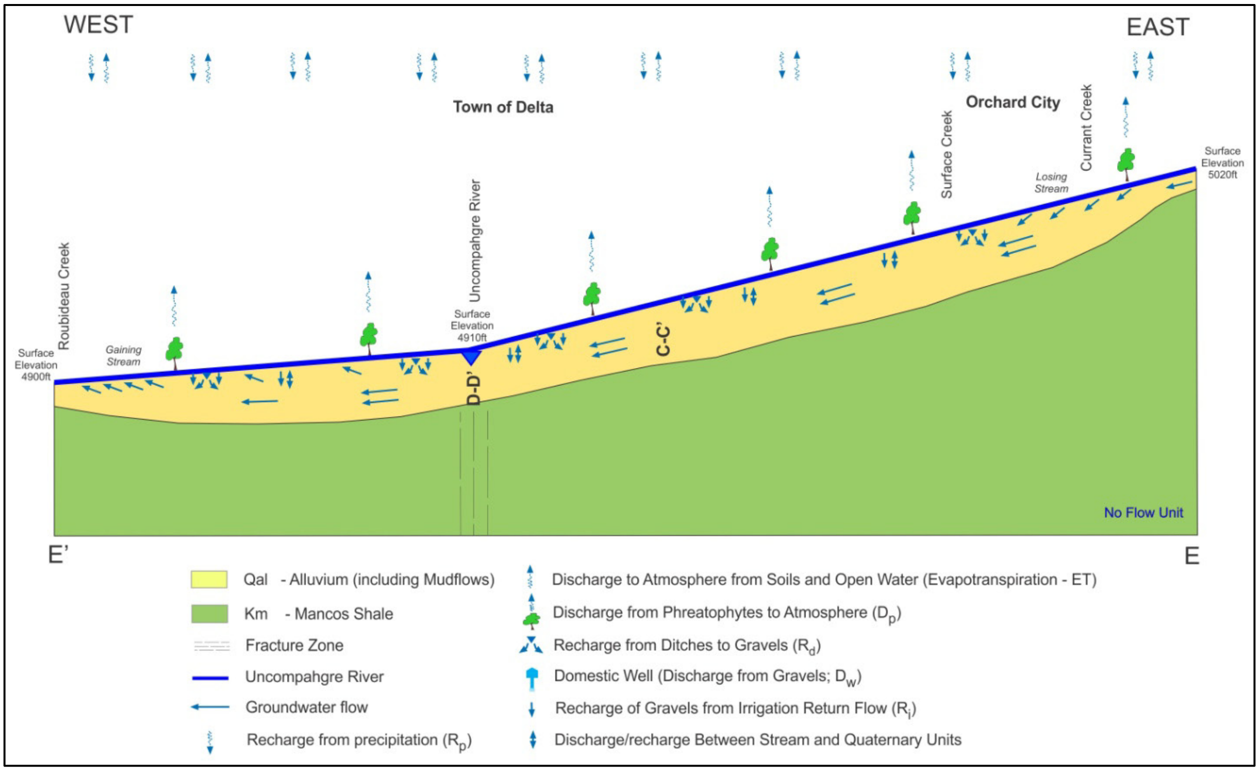

Figure 30.Schematic Cross-sectional View of the Conceptual Site Models of the Valley Bottom Shallow Aquifer Subsystem along the Gunnison River Valley (E-E' in Figure 17).

Groundwater flow in the Gunnison River alluvium moves in the same direction as the Gunnison River Valley with various stream reaches being gaining (Ds) or losing (Rs) depending on subsurface topography, saturated thickness of the alluvium, or the seasonal variations caused by snowpack runoff or storm events. The western reaches of the Gunnison River are basically a gaining stream system as groundwater is upwelling to the River. There is also groundwater discharge from the alluvium locally by groundwater wells (Dw) and by phreatophytes (Dp).

The shallow groundwater in the Gunnison River alluvial subsystems would normally have little connection to the local bedrock or the regional groundwater systems, given the Mancos Shale bedrock. However, underlying the Gunnison River is the east-west trending Gunnison River fracture zone (Figure 16). This hydrostructure may be an open vertical conduit, and the faulted and fractured bedrock may combine with the alluvium (Qal) to form a French Drain affect resulting in increased groundwater flow and storage, and connectivity to deeper hydrologic systems notably the Cretaceous Dakota Sandstone/Burro Canyon Formation hydrogeologic unit. This could result in decreased water quality either naturally (Mancos Shale water has higher TDS, metals) or due to human activities, such as fracking or waste disposal activities. Google Earth views of the Gunnison River Valley Bottom subsystem are shown in Figures 31 and 32.

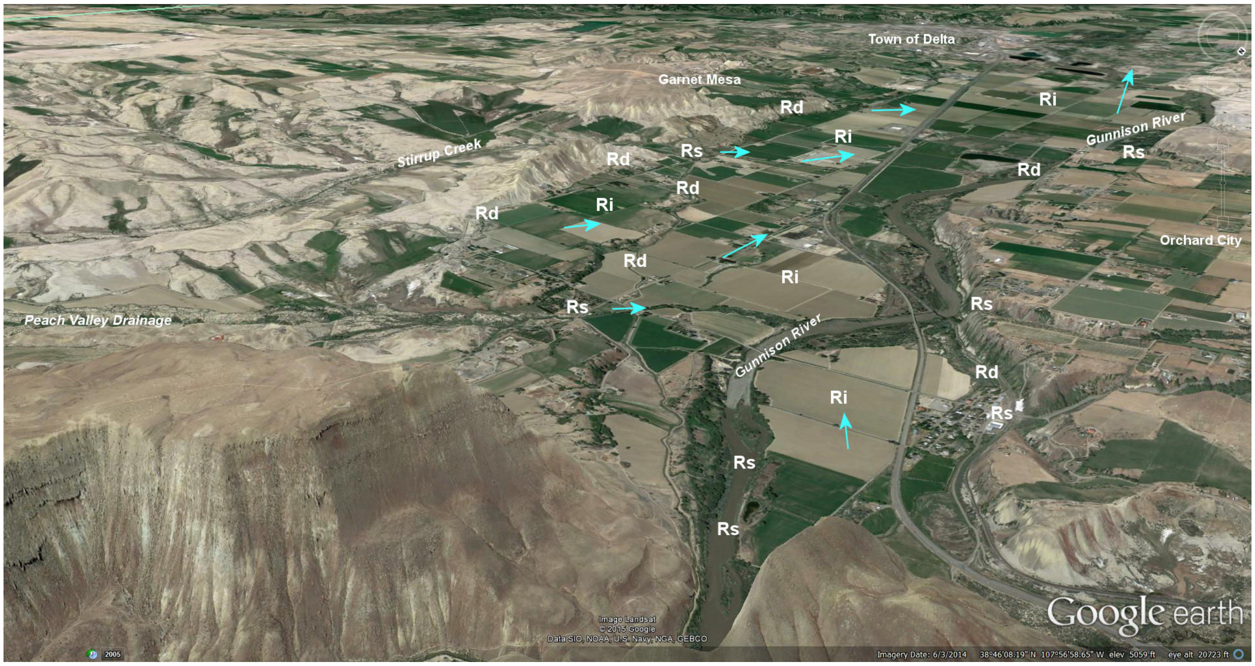

Figure 31. Google Earth View of the Conceptual Site Model of the Valley Bottom Shallow Aquifer Subsystem of the Gunnison River Looking Southwest with Groundwater Flow Direction.

(Ri = Recharge from irrigation return flow; Rs = Discharge from stream; Rd = Recharge from ditch).

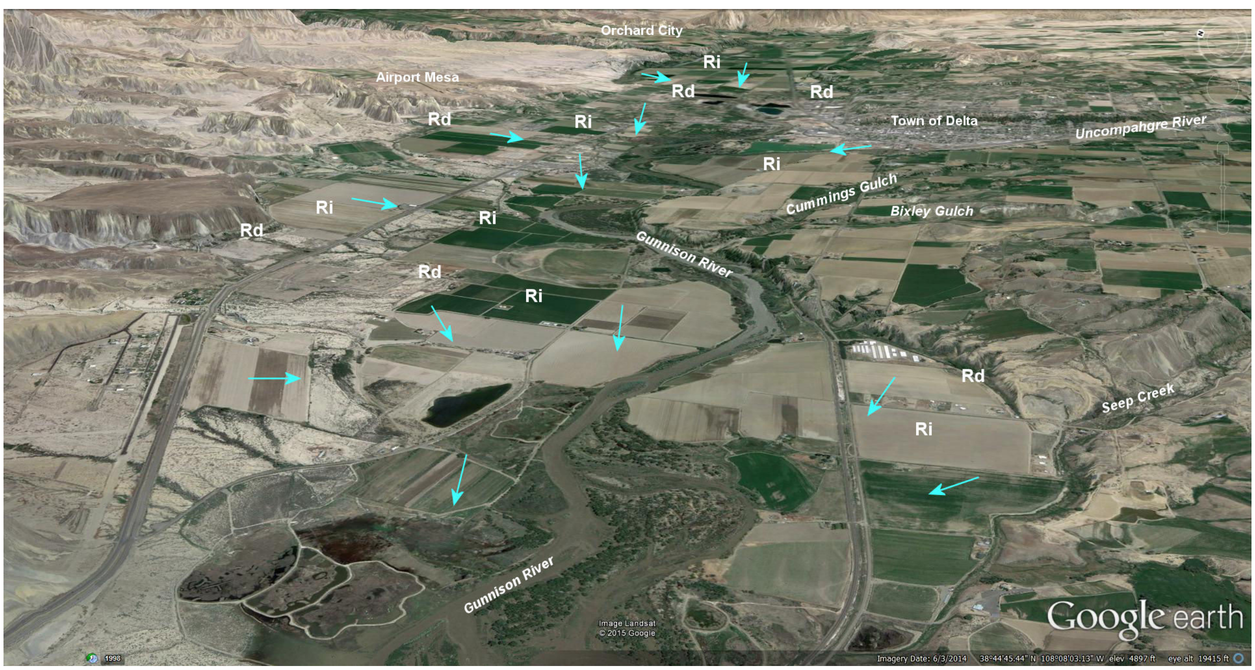

Figure 32. Google Earth View of the Conceptual Site Model of the Valley Bottom Shallow Aquifer Subsystem of the Gunnison River Looking Northeast with Groundwater Flow Direction.

(Ri = Recharge from irrigation return flow; Rs = Discharge from stream; Rd = Recharge from ditch).

2.6.4 Regional Bedrock Aquifer Subsystems

The main regional hydrogeologic units in the UVTD study area, discussed in Section 2.4, are the potentially water-bearing Cretaceous Dakota Sandstone and Burro Canyon Formation (Kdb) and the very low permeable Cretaceous Mancos Shale. The general aspects of the bedrock hydrogeology and hydrostructures are discussed in Section 2.5. The Dakota Sandstone/Burro Canyon bedrock aquifer is variably to fully saturated based on location and proximity to recharge area. In the UVTD study area, groundwater recharge by losing streams is possible only by connection to the Gunnison River and Uncompahgre River fracture zones. The regional groundwater flow direction would be from south to north along the axis of the Uncompahgre Valley syncline, then north beneath the UVTD Study Area and Grand Mesa (Figures 33). This flow direction is away from human activities and Delta County in general.

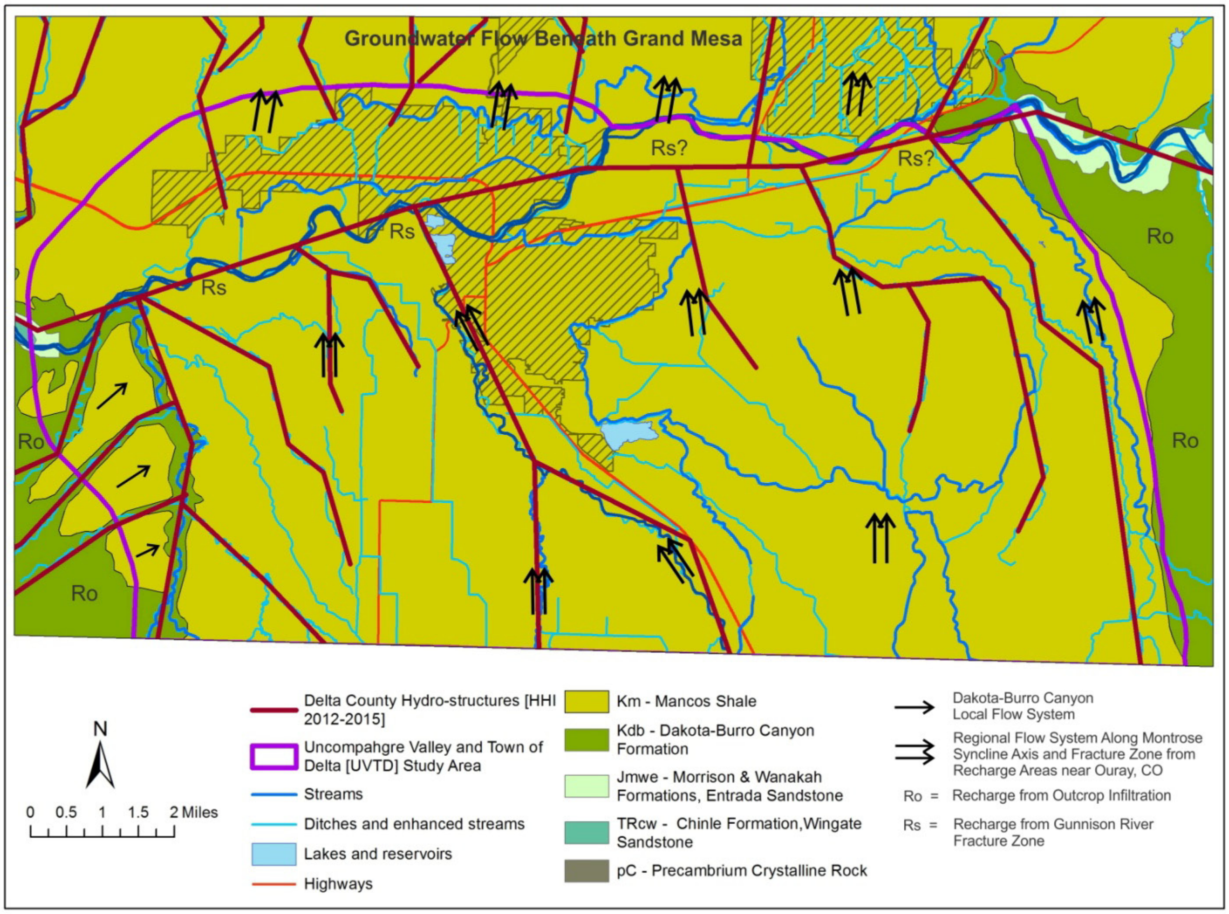

Figure 33. Plan View of the Conceptual Site Model of the Regional Bedrock Subsystems.

2.7 Anthropogenic Influences

Human activity in the UVTD study area has affected both the surface and subsurface parts of the hydrologic systems. Past land use and human activity was mostly associated with agricultural production and reservoir construction and operation, and has resulted in removal of native vegetation, introduction of irrigation and high-ET (evapotranspiration) crops, construction of (often leaking) irrigation ditches, and the drilling of primarily domestic wells. This activity has resulted in long-term increases of water levels in local, shallow aquifers of the Quaternary materials (Qat, Qal, and Qs) both on top of the Mesa Top and Hillslope subsystems, such as the California, Ash, and Garnet Mesas, and the weathered shale, mudflow and earthflow deposits, and alluvium in the Peach Valley/Stirrup Creek and Seep Creek/Cummings Gulch subsystems, and in the alluvium (Qal) of the Gunnison River and the Uncompahgre River (with Dry Creek)

Subsystems. In addition, this activity may result in increased mobility of selenium and various salts in the groundwater and surface water systems, particularly in the Hillslope watershed such as Buttermilk Creek, Wise Creek, Bixley Gulch, Cummings Gulch, Seep Creek, Stirrup Creek, and the Peach Valley drainages, and in the drainages surrounding Airport Mesa (including the golf course).

Current land use and human activity changes are mostly associated with urbanization of natural or agricultural lands, such as the expansion of the Town of Delta and the development of subdivisions in rural areas, recreational uses (such as golf courses), and the potential expansion of the energy industry (such as fracking of shales). 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

Traditionally, agricultural activities take place on the bottomlands (Qal) and terraces (Qat) of the Mesa Top and Valley Bottom Subsystems, while most grazing activities focus in a relative small area on the Hillslope Subsystems. Agricultural production is supported by surface water irrigation, often delivered through an extensive conveyance system. 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 (*i.e.*, Ri: irrigation return flow). At this time, this part of Delta County is experiencing a small shift from agricultural to nonagricultural land use, particularly around the Town of Delta and in parts of the Mesa Top, Hillslope, and Valley Bottom subsystems. This may lead to decreasing return flow from irrigation and subsequent reduced groundwater recharge, and to changes in groundwater quality due to fertilization practices of urban and recreational activities (for example, the golf course on Airport Mesa).

The UVTD study area consists primarily of Mesa Top, Hillslope, and Valley Bottom subsystems, limiting the irrigated areas to the top (Qat: terrace gravels) and lower (Qal: alluvium and (Qs, Km(w); mass wasting material) portions of the subsystems (Figures 34). Here, there are some unlined irrigation ditches and canals that are excavated primarily in unconsolidated Quaternary deposits or in Mancos Shale (Km) (Figures 14 and 34). When carrying water, the ditches may leak into the underlying and surrounding unconsolidated materials, or in weathered shale, as evidenced by the phreatophytes often found alongside. The ditch system in the study area contains three types of ditches: 1) primary ditches, which carry water during most of the growing season; 2) secondary ditches, which carry water only during an actual irrigation cycle; and 3) collection ditches which collect excess irrigation water to be discharged to local drainages. 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 or divide. 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. The leaky ditches and canals may also increase water flow though underlying weather shale of the Mancos Formation resulting in increased mobility and transport of salts and selenium to the surrounding groundwater and surface water systems.

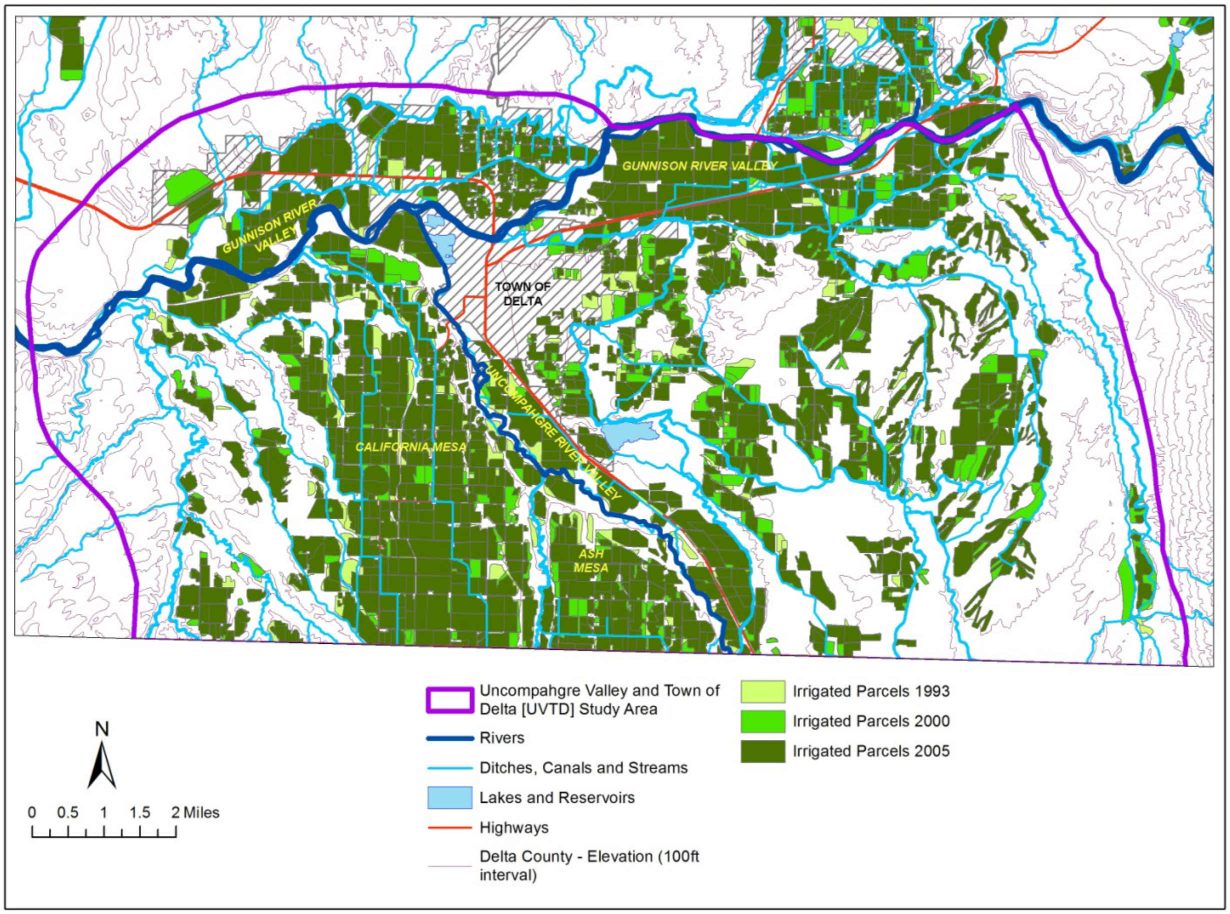

Figure 34. Anthropogenic Influences: Irrigated Areas and Irrigation Ditches in UVTD Area.

As discussed previously, irrigation return flow and leaky irrigation ditches can be a significant recharge element in the local and regional groundwater balance, and in the surface water balance within the watershed. Taking irrigated fields out of production and re-allocating ditch-conveyed water reduces recharge of groundwater resulting in lowered water tables, reduced groundwater discharges to wetlands and streams, and decreased water supplies. Note that the change in irrigation acreage between 1993 and 2005 has been minimal (Figure 34).

Water wells are found throughout the UVTD study area, primarily in the unconsolidated Quaternary deposits at the mesa tops and valley bottoms (Figure 35). 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.

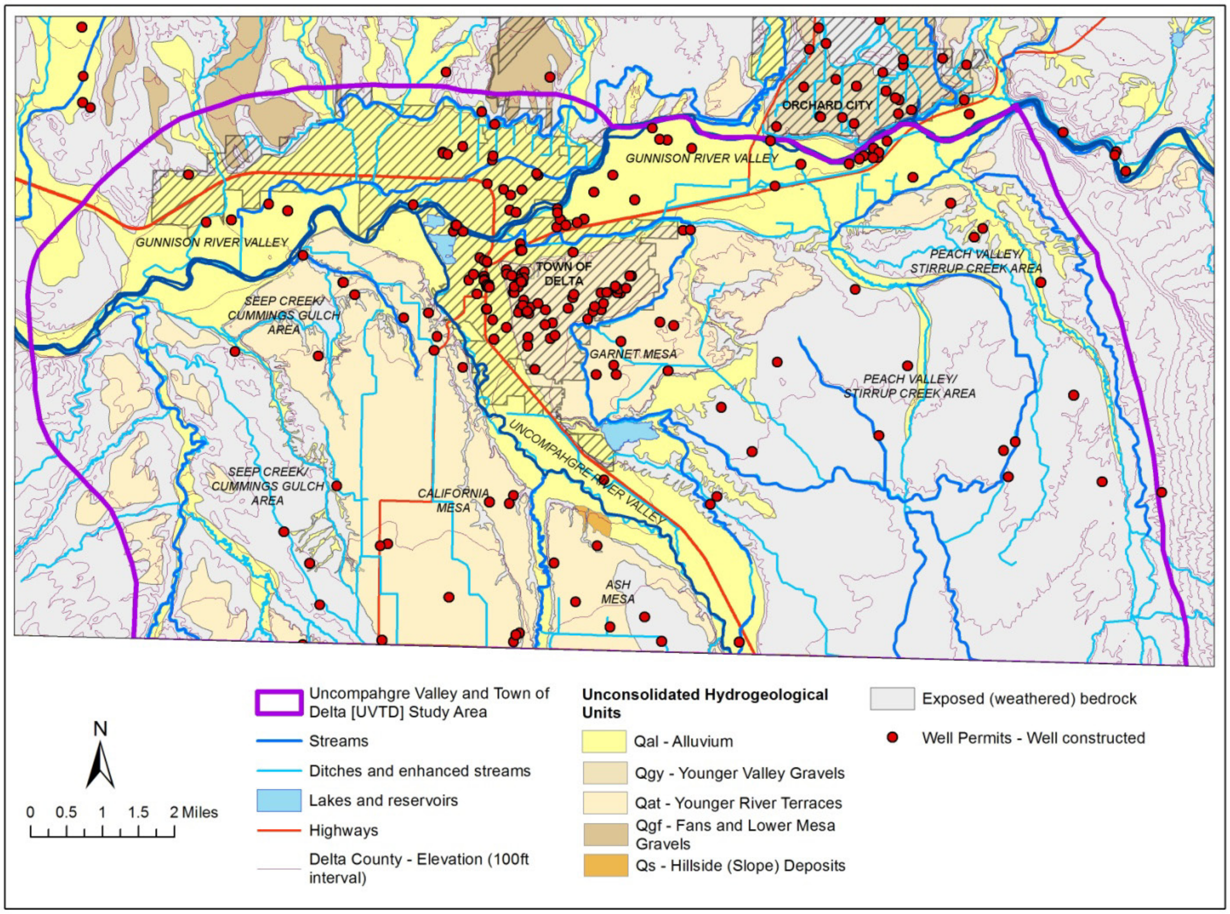

Figure 35. Anthropogenic Influences: Constructed Wells in the UVTD Study Area.

2.7.2 Potential Effects of Oil and Gas on Hydrology

The hydrology of a natural groundwater hydrologic system may be altered by the construction and operation of proposed oil and gas wells. During drilling and fracking, the oil and gas operations may behave like a connection mechanism between the deep and shallow aquifers, mixing water of various chemistries from various bedrock and shallow aquifers. Depending on management strategies for produced water disposal and use, groundwater levels in the shallow unconsolidated systems may be altered with respect to the amount, velocity, storage, and direction of the local groundwater system and related regional groundwater levels and discharges. Changes to the natural groundwater system will likely have ecological, geo-hydrological, and, potentially, legal consequences. The effects of water disposal after fracking and oil and gas well development are not discussed in this report as relevant information on the planned oil and gas development and operations is not available at this time. These management strategies and their effects on the shallow and bedrock aquifer subsystems should be evaluated in more detail. Currently, there are no oil/gas lease parcels present in the UVTD area.

The California Mesa, Ash Mesa, and Garnet Mesa Subsystems are least likely to be affected by oil and gas operations because they are located in the recharge area and have a shallow groundwater flow system above most bedrock dewatering zones and have relatively few hydrostructures that could promote connectivity (Figures 18, 19, 20 and 23). In addition, the potential for groundwater discharge from the deeper bedrock to the shallow aquifers in the

Valley Bottom subsystems, including Uncompahgre River, Dry Creek, and the Gunnison River Subsystems, due to hydrostructures is small, and most of these hydrostructures most likely promote recharge from the surface systems into the deeper aquifer systems if such a connection is verified (Figures 28, 30 and 33).

The regional groundwater subsystem may be affected by the oil and gas operations, but these systems are not currently being explored for water supplies. In addition, the interconnectivity between these deeper systems and the shallow unconsolidated systems is hypothesized to be a downward gradient of flow if at all, but currently undetermined (Figures 13 and 33).

2.7.3 Potential Effects of Groundwater Use on Water Quality

New in the Delta County Phase 4 Groundwater Study is the concept of using the HESA evaluation for assessing the vulnerability of groundwater and surface water to Selenium concentrations that may exceed drinking water and ecosystem standards, whether naturally or human-induced. selenium is very soluble and mobile in oxidizing environments while being stable in reducing environments. The Cretaceous Mancos shale hydrogeologic unit (Km), usually considered a groundwater flow system confining layer, is the main source in Delta County for naturally occurring Selenium in a chemically reduced form. When exposed to oxidized groundwater and/or surface water, Selenium becomes mobile and is transported in the groundwater and/or surface water to exposure sites such as wells, lakes, and surface water bodies like streams where it 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 selenium is being mobilized and transported including: 1) Selenium source location with respect to hydrogeologic framework, specifically the hydrogeology of unweathered and weathered Cretaceous Mancos shale 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 unlined leaky irrigation ditches, irrigation of weathered shale bedrock, and irrigation on geomorphologic deposits on weathered shale bedrock. Historic hydrologic stresses have included the construction and use of non-lined irrigation ditches, and use of irrigation water spread over the land surface with the creation of the “cowboy aquifers”. Current stresses have included newly created recreation sites, such as golf courses, and the industrialization and urbanization of lands previously used for grazing and agriculture (lawn watering and drill pad construction, for example).

2.7.3.1 Mesa Top Subsystems Water Quality

The hydrogeology of the three Mesa Top Subsystems, as previously described in Section 2.6, is Quaternary terrace gravels (Qat) overlying the Cretaceous Mancos Shale (Km). A weathered zone most likely exists as the interface between the two hydrogeologic units (Km(w)). The hydrologic system of the three Mesa Top Subsystems, as previously described in Section 2.6, is recharge dominated by infiltration of irrigation return flow, with some infiltration from ditches (most are piped currently) and from direct precipitation. The groundwater flow system is along the trend of underlying paleo-topography (for example, parallel with the Uncompahgre

River), or direct leakage through the mesa sides and the lower ends of the mesa systems into the Gunnison River. Groundwater discharge, including water quality elements, is into the Hillslope subsystems, Valley Bottom subsystems, or directly into surface water streams where the water quality parameters are measured.

The natural pollutants that are most likely occurring include selenium and sulfur (sulfate), and the most likely source of these pollutants is the weathered zone (Km(w)) at the interface between the two main hydrogeologic units. It is hypothesized that the natural system, pre irrigation, has been flushing selenium and sulfate through this system since the deposition of the glacial gravels as terraces (Qat). The current irrigation systems, involving Project 7 water, use good quality water that may be reactive with the weathered zone. However, given the large water quantities being circulated, and long period of time of flushing, it is unlikely that large amounts of selenium and sulfate are being leached and transported from these subsystems.

The anthropogenic pollutant sources of these subsystems is mostly fertilizers for grass (urban) or crops, industrial pollutants (Town of Delta at lower Garnet Mesa), or rural septic tank waste. Most of these are organics and nutrients, and would need to be monitored accordingly.

2.7.3.2 Hillslope Subsystems Water Quality

The hydrogeology of the two Hillslope Subsystems, as previously described in Section 2.6, is Quaternary alluvium and mudflows (Qal) and Quaternary Hillside (slope) deposits (earth flows and slumps (Qs) overlying the Cretaceous Mancos Shale (Km). A weathered zone exists as the interface between the Quaternary and the Bedrock hydrogeologic units (Km(w)). The hydrologic system of the two Hillslope Subsystems, as previously described in Section 2.6, is similar in that recharge is dominated by infiltration of irrigation return flow, with some infiltration from ditches (some are piped currently) and leaky canals (through weathered shale and Quaternary deposits), and from direct precipitation. The Seep Creek/Cummings Gulch Subsystem is unique in that a large amount of groundwater recharge to the subsystem is from the groundwater discharge leaking from the California Mesa subsystem. The groundwater flow system is along the trend of underlying topography that follows the watershed drainages and drainage divides. Groundwater discharge, including water quality elements, is into the drainage alluvium (Qal) and ultimately to the Valley Bottom subsystems, or directly into surface water streams, such as Buttermilk, Wise, and Seep Creeks; Bixley and Cummings Gulch drainages; and Stirrup Creek and Peach Valley drainages, where the water quality parameters are measured.

The natural pollutants that are most likely occurring include selenium and sulfur (sulfate), and the most likely source of these pollutants is the weathered zone (Km(w)) at the interface between the two main hydrogeologic units. It is hypothesized that the natural system, pre irrigation, has been flushing selenium and sulfate through this system since the erosion of the landscape commences resulting in the deposition of the earth flows, mudflows, and slumps, and the alluvium in the various drainages. The current irrigation systems, involving Project 7 water, use good quality water that may be reactive with the weathered zone. However, given the large water quantities being circulated, and the short period of time of flushing through the weathered shale, it is likely that large amounts of selenium and sulfate are being leached and transported from these subsystems. The observation of large quantities of salt deposition in both areas confirms that leaching of natural pollutants is currently occurring.

The anthropogenic pollutant sources to these subsystems are 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.

2.7.3.3 Valley Bottom Subsystems Water Quality

The hydrogeology of the two Valley Bottom Subsystems, as previously described in Section 2.6, is Quaternary alluvium (Qal) overlying the Cretaceous Mancos Shale (Km). A weathered zone most likely exists as the interface between the two hydrogeologic units (Km(w)). The hydrologic system of the two Valley Bottom Subsystems, as previously described in Section 2.6, is recharge dominated by infiltration of irrigation return flow, with infiltration from ditches (some are piped currently) and canals, and from direct precipitation.

Unique to the Uncompahgre Valley Subsystem is the groundwater inflow from the California Mesa, Ash Mesa, and Garnet Mesa Subsystems. Water quality from these subsystems, particularly from the Town of Delta infiltration and runoff in the Garnet Mesa Subsystem, is passed on directly to the Uncompahgre Valley Subsystem.

Unique to the Gunnison River Subsystem is the groundwater and surface water inflow from the upper Gunnison River passed on through Hotchkiss, CO., the Peach Valley groundwater and surface water systems, the Stirrup Creek groundwater and surface water systems, the Surface Creek basin groundwater and surface water systems, the Uncompahgre River groundwater and surface water systems, the northern tributaries groundwater and surface water systems including the Airport Mesa and Delta Golf Course area, and all of the groundwater and surface water systems connecting with the lower Gunnison Valley below the Town of Delta. Water quality from these subsystems, particularly from the Peach Valley/Stirrup Creek Subsystem, the Seep Creek/Cummings Gulch Subsystem, and the Town of Delta infiltration and runoff in the Garnet Mesa and Uncompahgre River Subsystems, is passed on directly to the Gunnison River Subsystem.

The groundwater flow system is along the trend of underlying paleo-topography parallel to the Uncompahgre and Gunnison Rivers, or influenced by the direct leakage along the Valley Bottom sides and ditches and canals towards the two rivers. Groundwater discharge, including water quality elements, is from the Uncompahgre groundwater system directly into the Gunnison River Subsystem with minor discharge by phreatophytes and wells, and from the Gunnison River groundwater system directly into the Gunnison River in the reaches below the Town of Delta to the Gunnison River gorge below the confluence with Roubideau Creek where the water quality parameters are measured.

The natural pollutants that are most likely occurring include selenium and sulfur (sulfate), and the most likely source of these pollutants is the weathered zone (Km(w)) at the interface between the two main hydrogeologic units. It is hypothesized that the natural system, pre irrigation, has been flushing selenium and sulfate through this system since the deposition of the glacial gravels as terraces (Qat). The current irrigation systems, involving Project 7 water, use good quality water that may be reactive with the weathered zone. However, given the large water quantities being circulated, and long period of time of flushing, it is unlikely that large amounts of selenium and sulfate 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 Gunnison River Subsystem through the Peach Valley groundwater and surface water systems, the Stirrup Creek groundwater and surface water systems, the Cummings and Bixley Gulch groundwater and surface water systems, the Seep Creek and Roubideau Creek groundwater and surface water systems, and the groundwater and surface water associated with the tributaries draining Grand Mesa directly into the Gunnison River subsystem below the Town of Delta, for example the Airport Mesa/Delta Golf Course drainages. These sources collect the pollutants upstream in their associated watersheds and deliver them to the Gunnison River subsystem.

The anthropogenic pollutant sources to these Valley Bottom subsystems are mostly fertilizers for grass (urban or golf courses) or crops, industrial pollutants (Town of Delta at lower Garnet Mesa and the Uncompahgre River Valley; runoff from the Delta County airport), or rural septic tank waste. Most of these are organics and nutrients, and would need to be monitored accordingly.

3 GIS MAPS, LAYERS, DATABASES, AND DATA SOURCES

3.1 GIS and GIS Maps

Geographical information system (GIS)-based maps provide a flexible and efficient way to analyze and display spatial information. The strength of a GIS system is that data from various sources can be collected in local or remotely accessed databases, which can be easily maintained and updated. GIS maps support optimal analysis, specifically in hydrogeologic evaluations at different scales, geographic distribution densities, and different levels of accuracy and information value.

A GIS map consists of a series of layers, each containing a single or multiple topological features. These features can represent a variety of geographic items, such as rivers and lakes, roads, towns and cities, land use, land ownership, wells, etc. Selected features can be further described with associated attribute tables and linked to other types of information by their attribute tables or via their spatial location. At each step of a geographic analysis, individual features can be displayed, analyzed, and combined with other features via layers, and individual features interrogated with respect to their attributes. Switching scales, like enlarging (zooming in to) a particular detail or regionalizing (zooming out) to encompass a larger set of features can be accomplished at any time; the ability to selectively visualize (switch) layers, perform advanced searches, and use select and overlay capabilities, further enhances the utility of a GIS map.

The GIS maps resulting from this study allow for informed planning and management of groundwater resources in the UVTD area. The database formats that have been used in this study include ESRI shape files, database tables, geo-referenced images, Microsoft Excel files, and ESRI GRID files (for the digital elevation model [DEM], among others). The GIS map and database for the UVTD study were prepared using ArcView™version 8.3 and evaluated using Arc-Desktop™ version 10.3 (ESRI®, Redlands, California).

3.2 Use of GIS in the UVTD Area Study

In this study, GIS has been used in support of the HESA described in Chapter 2 and in the preparation of report figures. In addition, the GIS maps and databases will provide a base for further studies of the hydrology and hydrogeology of UVTD area, as well as other parts of Delta County. Two multi-layer GIS maps have been prepared for this study: 1) a map with hydrologic and hydrogeologic features of the UVTD area (Figure 36); and 2) a map with hydrologic and hydrogeologic features of Delta County including the hydrologic and hydrogeologic features of the SCV (Surface Creek Valley) study (*Kolm and van der Heijde 2014*), the NFVT (North Fork Valley and Terraces) study (*Kolm and van der Heijde 2013*), and the Oak Mesa study (*Kolm and van der Heijde 2012*) (Figure 37). The GIS maps consist of a number of layers representing various data types relevant to the assessment of the groundwater resources at user-specified locations. Below is a detailed description of the layers and the related data sources.

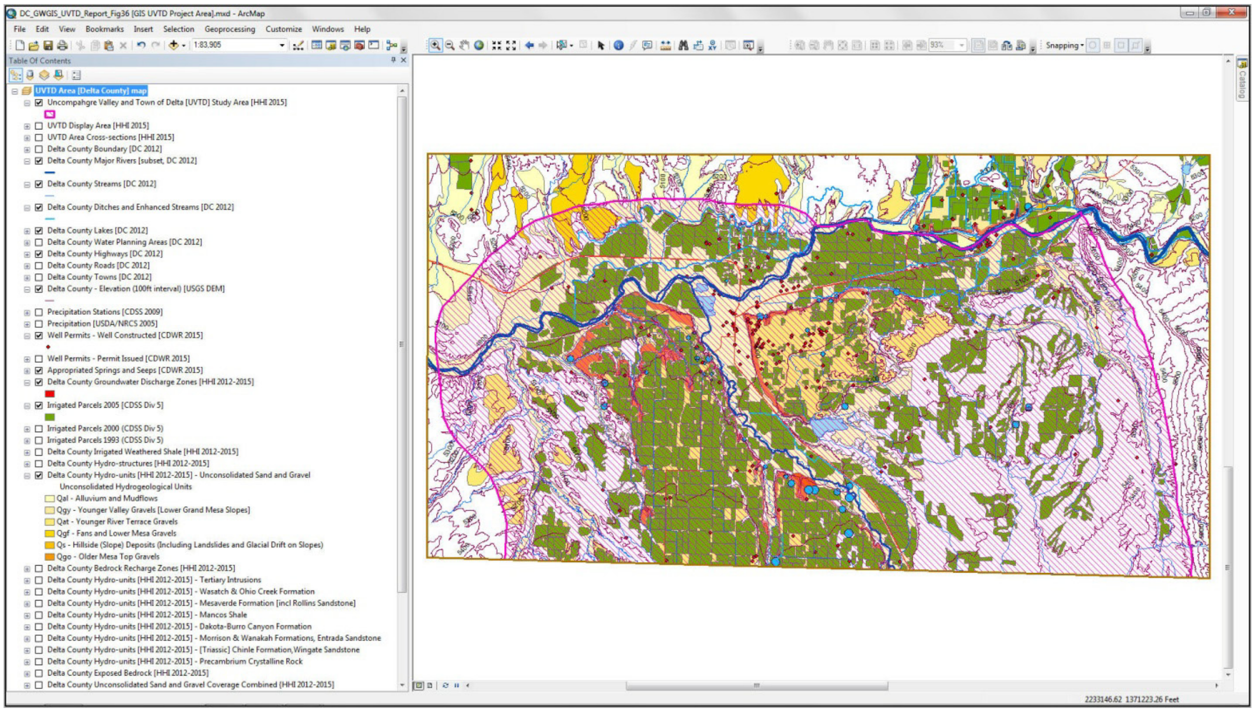

Figure 36. UVTD GIS Map Showing Streams, Ditches and Irrigated Areas on Top of Unconsolidated Hydrogeologic Units and Groundwater Discharge Areas.
(The left display area is the TOC showing all available layers;
the right side of the window is the map display area showing the activated layers.)

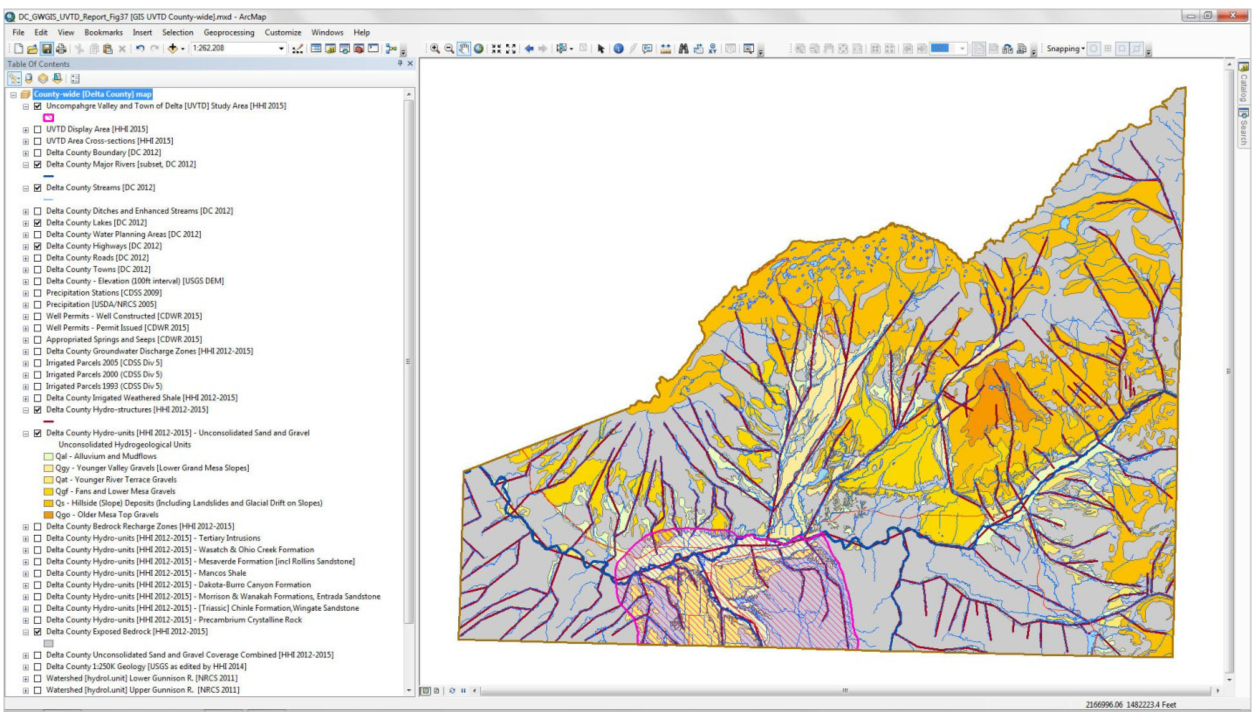

Figure 37. Delta County GIS Map Showing UVTD Study Area, Hydrostructures, Streams, Ditches and Roads on Top of County-wide Shallow Hydrogeologic Units.
(The left display area is the table of contents [TOC] showing all available layers;
the right side of the window is the map display area showing the activated layers.)

Enabling the *Table of Contents* (TOC; the left side of the display in Figures 36 and 37) in ArcGIS provides information on the layers displayed in the *Map Display* area (the right side of the display in Figures 36 and 37). The GIS layers of the three GIS maps contain three types of geographic information: 1) general geographic information (county border, roads, towns, DEM-elevations) used primarily for orientation purposes; 2) hydrologic information (including precipitation, watersheds, streams, lakes/ponds, irrigation ditches, and irrigated areas); and 3) hydrogeologic information (including hydrogeologic units, faults and hydrostructures, springs and wells). Most layers have been geo-referenced with respect to State Plane, Colorado Central Zone, NAD83 (units of measure in feet), except for some public data obtained from state and federal sources.

3.3 GIS Map, Layers, and File Structure

Each line in the TOC is a GIS layer representing a set of features of the same type, such as streams, parcels, wells, etc. By clicking on a check box in the TOC, elements of the activated layer become visible in the map display area. A layer may consist of point values (*e.g.*, wells), line features (*e.g.*, roads, streams, ditches), and area features (*e.g.*, parcels, lakes, hydrogeologic units). Right-clicking on a layer in the TOC and selecting the *open attribute table* option, provides additional information on the layer, such as the names of particular features (Figure 38). This additional information can be used to label the features in the map display area.

The order of the layers in the GIS maps may be changed, affecting which layer(s) are in the foreground in the map and which layers are in the background. When enabled, a layer is shown on top of the layer listed below it in the TOC. When this layer is opaque, the layer beneath it is not visible. Some layers are (partially) transparent, others are opaque, dependent on the type of information they display and the use in the assessment procedure. Layer transparency/opaqueness can be changed by the user using the layer properties option under the display tab. The order of the layers can be changed by the user by dragging a layer to the desired location in the TOC.

The map is designed to show relevant labels (text) for most of the layers based on the contents of one of the fields in the attribute table, such as stream name, well number, etc. When zooming in on a particular area of the map, additional information of a selected layer can be displayed by activating the *Label* feature. This can be done by right-clicking the layer and selecting *Label Feature*. The label feature can be set by right-clicking the layer, selecting *Properties*, clicking the *Label* tab, and selecting the appropriate field of the database table. Database information regarding a particular feature on the map can also be obtained by using the  (*Identify*) option from the *Tools* toolbar, clicking on the feature of interest, and selecting the appropriate layer in the popup *Identify Results* window.

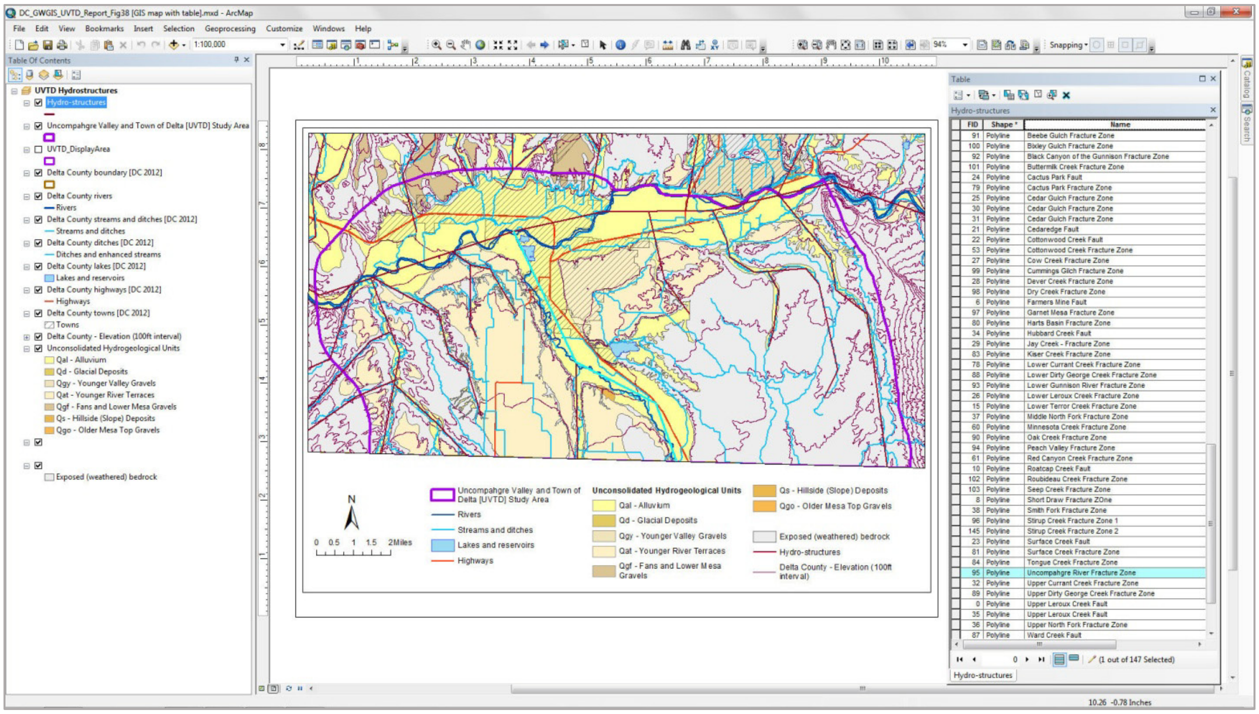

Figure 38. GIS Map Showing the Attribute Table for the Hydrogeologic Structures (Hydrostructures) Layer in the UVTD Area *(right side of figure)*.

3.4 Data Sources and Databases

Delta County and study area GIS maps are produced by retrieving various files included in five relative-path subdirectories: 1) CDWR_CDSS; 2) Delta_County; 3) HHI; 4) NRCS; and 5) USGS_DEM. The directories reflect the various data sources used for the two GIS maps introduced in the previous section. Selection of the relative-path option in the GIS program provides for straightforward portability between computers. Note that layers that refer to a state-wide data set (such as the NRCS precipitation file), or a multi-county data set (such as the CDSS irrigated areas files), have been clipped on the maps to show only the Delta County or UVTD area coverage.

The *CDWR_CDSS* subdirectory contains seven sets of GIS files and databases downloaded from Colorado Division of Water resources (CDWR) water rights and well permits databases and from the Colorado Decision Support System (CDSS), which is managed by the Colorado Water Conservation Board and the Colorado Division of Water Resources (CDWR). These file sets are 1) irrigated areas in CDWR Division 4 on the Western Slope as of 1993 (*Irrigated_Parcels_1993* files); 2) irrigated areas in CDWR Division 4 on the Western Slope as of 2000 (*Irrigated_Parcels_2000* files); 3) irrigated areas in CDWR Division 4 on the Western Slope as of 2005 (*Irrigated_Parcels_2005* files); 4) permitted wells that have been completed (*WellPermits_WellConstructed* files); 5)permitted wells that have not yet been drilled (*WellPermits_PermitIssued* files); 6) appropriated springs and seeps (*dc_Springs* files); and 7) precipitation stations in Colorado (*co_precipstations* files). The well, spring and irrigation data have been downloaded in 2013, 2014 and 2015. The irrigated areas data sets provide a single year snapshot of the irrigated lands and crop types of the western slope of Colorado. In the GIS maps, the 2000 data layer lies on top of the 1993 data layer, and the 2005 data layer lies on top of the 1993 and 2000 data layers, showing the irrigated acreage taken out of production between 1993 and 2000 and between 2000 and 2005. The CDSS files can be downloaded from: *http://water.state.co.us/DataMaps/Pages/default.aspx#onlinedata.*The well records can be accessed at: *http://www.dwr.state.co.us/wellpermitsearch/*, and the springs and seeps records at: *http://cdss.state.co.us/onlineTools/Pages/WaterRights.aspx.* More details about the springs and seeps layer can be found in Appendix 1 of *Kolm and Van der Heijde (2013)*.

The *Delta_County* subdirectory contains selected files received from the Delta County GIS department between 2012 and 2015. Coverages used in this project include county boundary, highways, roads, streams and ditches, lakes, irrigation ditches (and enhanced streams), water planning areas, and towns. The integrated ditch dataset provided by the county in 2014 does not distinguish between primary and secondary ditches. However, a detailed set of descriptive and quantitative information regarding each ditch section was received in 2015 from the County and used as background information for the analyses in this report. It should be noted that the GIS-based aerial photography provided by the county has been used, in conjunction with GIS-based topographic images obtained from the NRCS data portal and Google™ Earth imagery, to remotely assess topography, vegetation and hydrology in preparation of this report.

The *HHI* subdirectory contains the databases produced for this project by Heath Hydrology, Inc. It contains various hydrogeology files, including: *DeltaCounty_Hydrogeol_xxx, DeltaCounty_Hydrostructures,* and *DeltaCounty_Geology*; and files related to the location of current and previous study areas: *SurfaceCreek_StudyArea, NorthForkValley_ StudyArea, OakMesa_StudyArea*, *UVTD_StudyArea,*and *UVTD_DisplayArea).* The *DeltaCounty_ Hydrogeol_xxx* file sets cover the entire county and are produced by adding hydrogeological information to the GIS file sets produced in previous studies *[Kolm and van der Heijde 2012, 2013, and 2014]*. The new GIS data resulted from digitizing and evaluating, among others, the 1:24.000 scale geological map of the Orchard City quad (*Noe and Zawaski 2013*), 1:48,000 scale geologic maps of the Cedaredge and Hotchkiss areas (*Hail, 1972a, 1972b*), and the 1:100,000 scale geologic map of the Paonia and Gunnison area (*Ellis and Others, 1987*), and combining and editing the GIS versions (*Day and Others, 1999*) of the Leadville, Montrose, Grand Junction and Moab 1^o x 2^o quadrangle geologic maps (scale 1:250,000) (*Tweto and Others, 1976; Tweto and Others, 1978; Whitney, 1981; Williams, 1964)*. The county-wide hydrostructures layer is in part based on the 1:100,000 scale geologic map of the Paonia and Gunnison area (*Ellis and Others, 1987*), and enhanced through analysis of geomorphic features, including drainages, by the project team.

There are nine GIS layers and databases for the hydrogeological units in the UVTD area (and county-wide) (*i.e.*, "hydro units" for short) (Figures 14, 15, 36 and 37): 1) a layer showing the Quaternary unconsolidated deposits grouped by their hydrogeological characteristics (*Delta County Hydro-units [HSA/HHI 2012-2015] - Unconsolidated Sand and Gravel*); and 2) eight layers each showing the extent of an individual bedrock hydrogeologic unit (*Delta County Hydro-units [HSA/HHI 2012-2015] - Tertiary Intrusions, Delta County Hydro-units [HSA/HHI 2012-2015] - Wasatch and Ohio Creek Formation, Delta County Hydro-units [HSA/HHI 2012-2015] - Mesaverde Formation [incl. Rollins Sandstone], Delta County Hydro-units [HSA/HHI 2012-2015] - Mancos Shale, Delta County Hydro-units [HSA/HHI 2012-2015] - Dakota-Burro Canyon, Delta County Hydro-units [HSA/HHI 2012-2015] - Morrison & Wanakah Formations, Entrada Sandstone*, *Delta County Hydro-units [HSA/HHI 2012-2015] - [Triassic] Chinle Formation,Wingate Sandstone*, and *Delta County Hydro-units [HSA/HHI 2012-2015] -*

Precambrium Crystalline Rock). When all eight bedrock layers are activated, the GIS map shows top bedrock (see Figure 15).

In addition, the *HHI* subdirectory contains hydrogeological layers showing exposed bedrock (*Delta County Exposed Bedrock [HSA/HHI 2012-2015]*), combined quaternary coverage (*Delta County Unconsolidated Sand and Gravel Coverage Combined [HSA/HHI 2012-2015])*, bedrock recharge zones (*Delta County Bedrock Recharge Zones [HSA/HHI 2012-2015]*), and zones with groundwater discharge from quaternary sand and gravels (*Delta County Groundwater Discharge Zones [HSA/HHI 2012-2015]*).

The *NRCS* subdirectory contains state-wide averaged annual precipitation data for the period 1961–1990 obtained from the NRCS (*precip_a_co* files). These data have been developed from the NWS precipitation data using PRISM (Parameter elevation Regression on Independent Slopes Model), which utilizes a rule-based combination of point measurements and a DEM and includes consideration of topographic facets *(Daly and Johnson, 1999)*. The *NRCS* subdirectory also includes files for the watersheds in the county (*wbdhu12_a_14020002 - 06*). The NRCS data can be downloaded from: *http://datagateway.nrcs.usda.gov/GatewayHome.html*.

The *USGS_DEM* subdirectory contains the raster-based DEM and the 100ft elevation contours for Delta County. In the database, surface elevations are stored in meters; however, in the TOC of the GIS maps, the elevations are given in feet for display purposes. The USGS DEM was downloaded from the NRCS Data Gateway portal in May 2012 and is based on the USGS version published in April 2012.

3.5 County-wide Hydrogeological GIS Maps and Databases

As stated in chapter 1, this project extends the GIS databases and maps of hydrogeologic and hydrologic characteristics of the groundwater systems developed in earlier studies by Kolm and van der Heijde (*2012, 2013, and 2014*) to the entire county. Using the county-wide nomenclature of hydrogeological units described in Tables 2a and 2b, this study integrated the various hydrogeological databases developed in this and the earlier groundwater studies (*Kolm and van der Heijde 2012, 2013, and 2014*) into a single set of hydrogeological databases covering the entire county. This study also included the preparation of county-wide hydrological databases on springs and seeps, digitized in this and the previous studies; permitted and drilled water wells; long term average precipitation distribution, and irrigated acreage for 1993, 2000 and 2005. Each of these hydrological and hydrogeological databases is represented in the county-wide GIS map by a separate layer (Figure 39). It should be noted that the bedrock hydrogeological layers each have their own database as shallower bedrock units may overlap deeper units; the unconsolidated hydrogeological units are represented by a single database as these units are not overlapping. The resulting maps are shown in Figures 40-48.

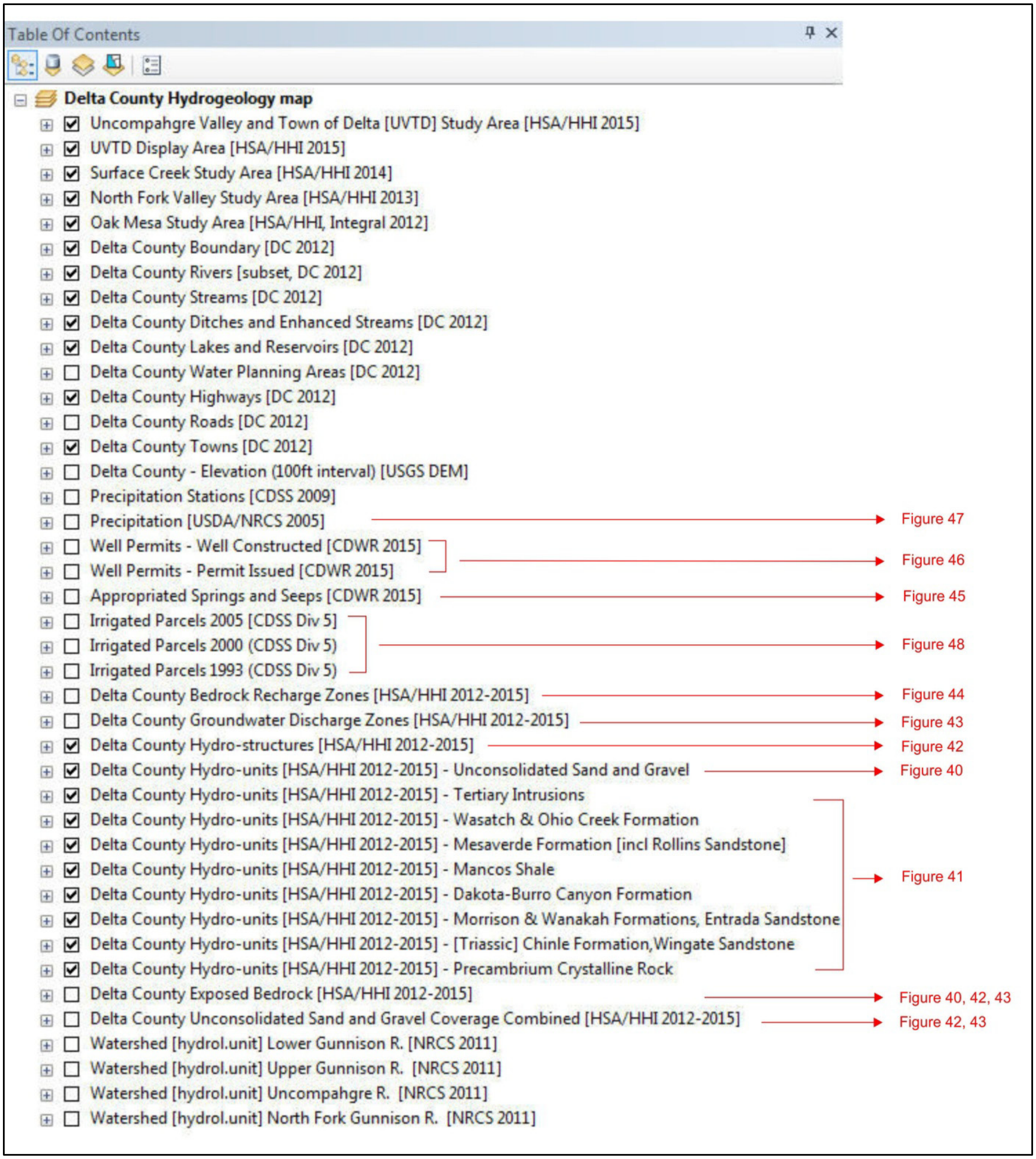

Figure 39. Annotated Table of Contents for County-wide Hydrology and Hydrogeology Maps.

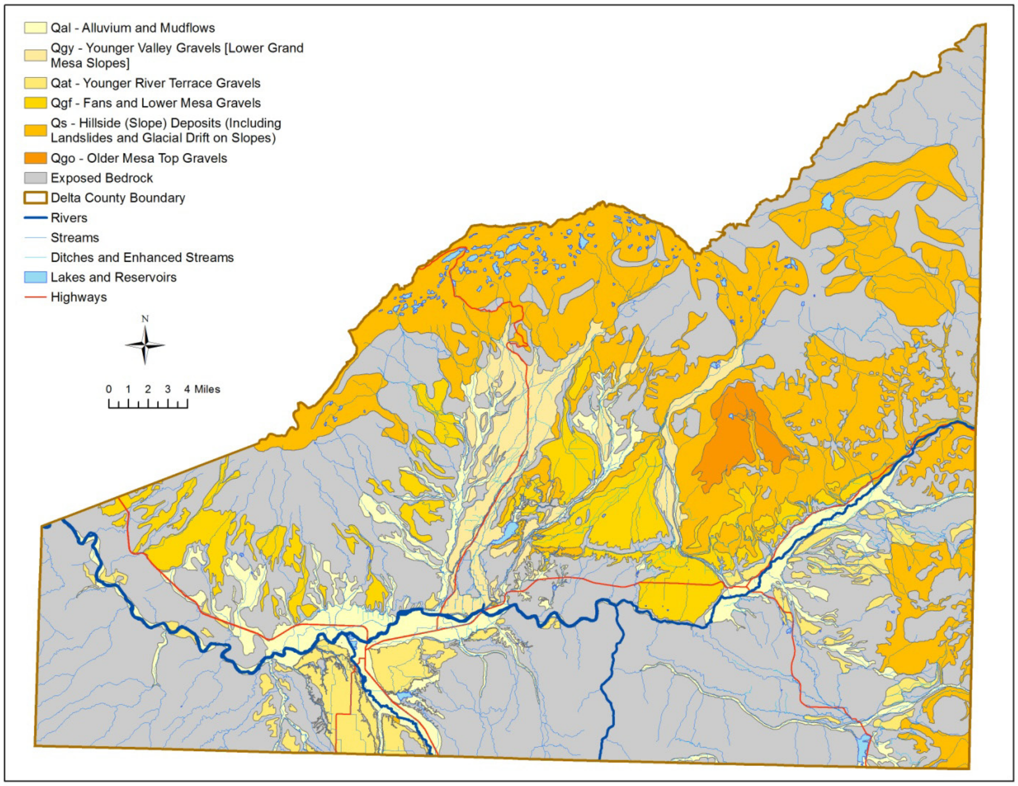

Figure 40. County-wide Map of Unconsolidated Shallow Hydro-units. See Figure 39 for Specific Layer.

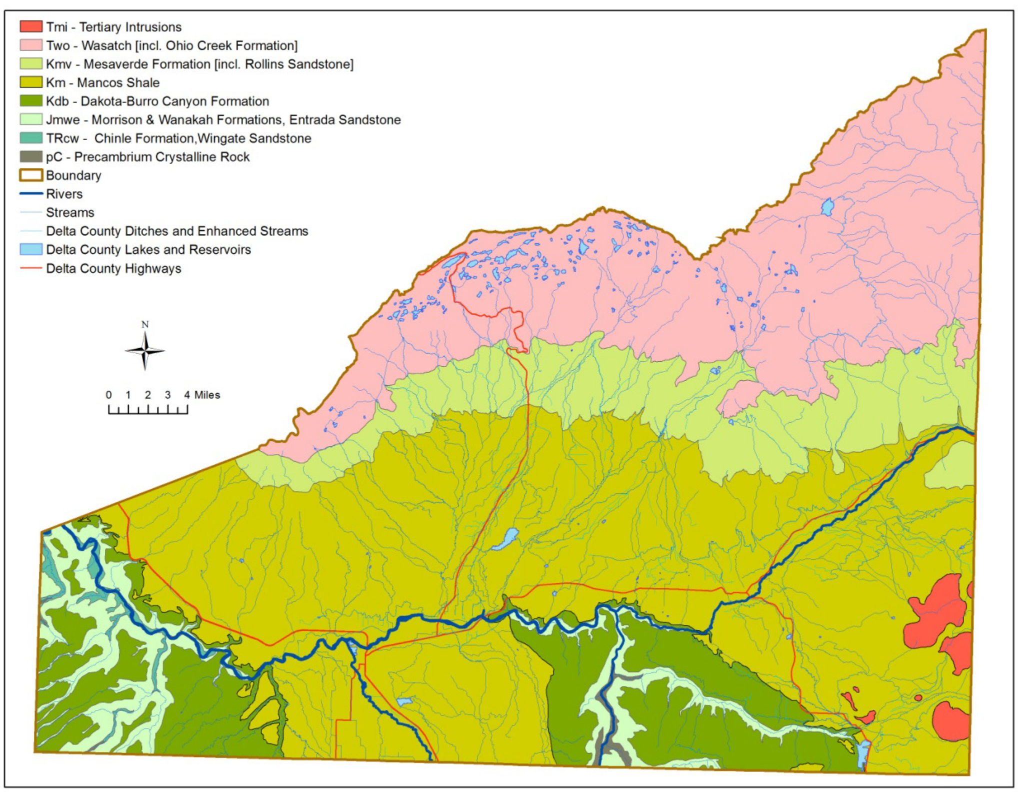

Figure 41. County-wide Map of Bedrock Hydro-units. See Figure 39 for Specific Layer.

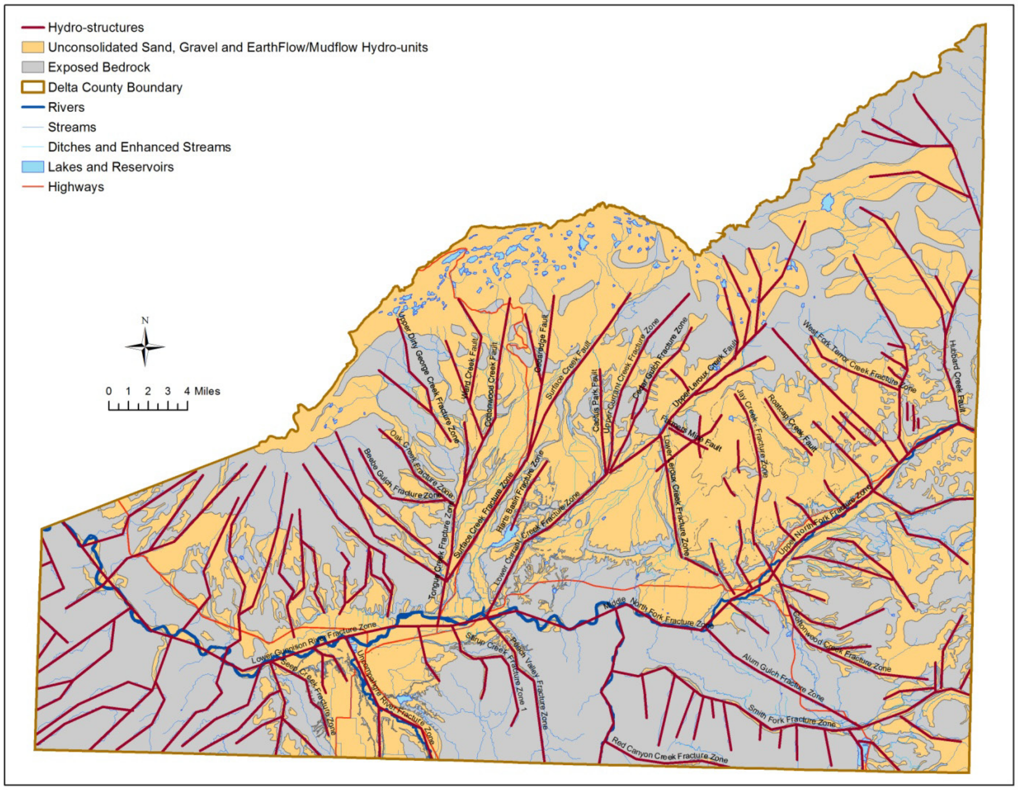

Figure 42. County-wide Map of Hydrostructures.
See Figure 39 for Specific Layer.

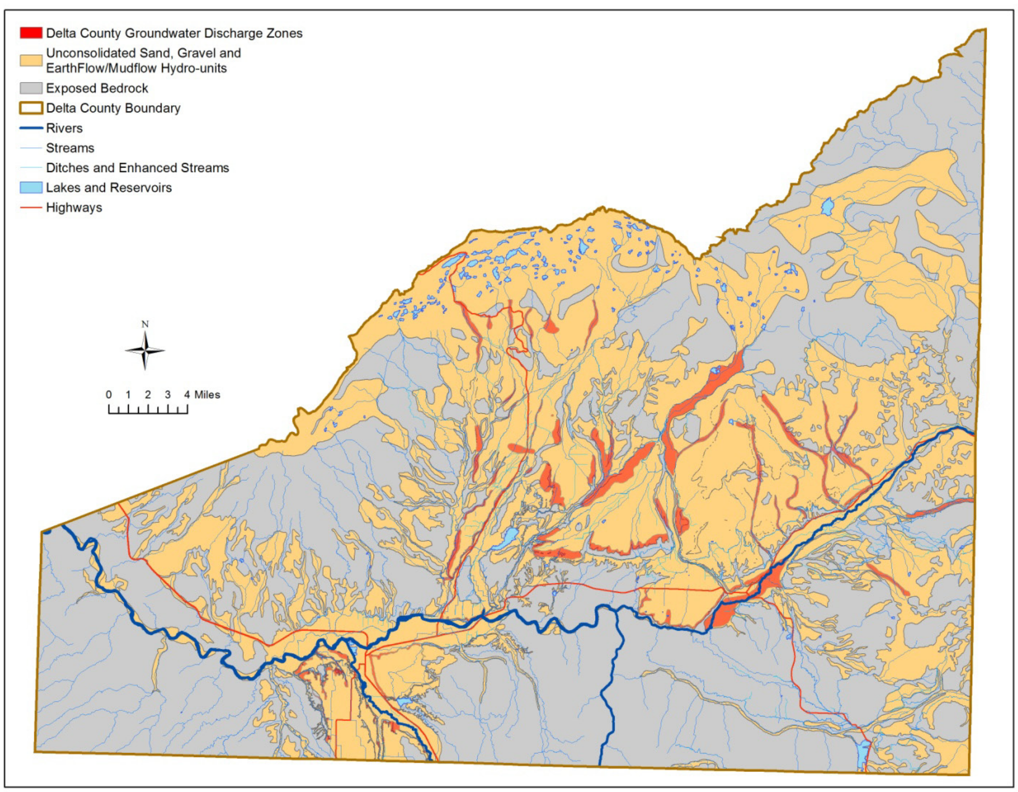

Figure 43. County-wide Map of Local Groundwater Discharge Zones.
See Figure 39 for Specific Layer.

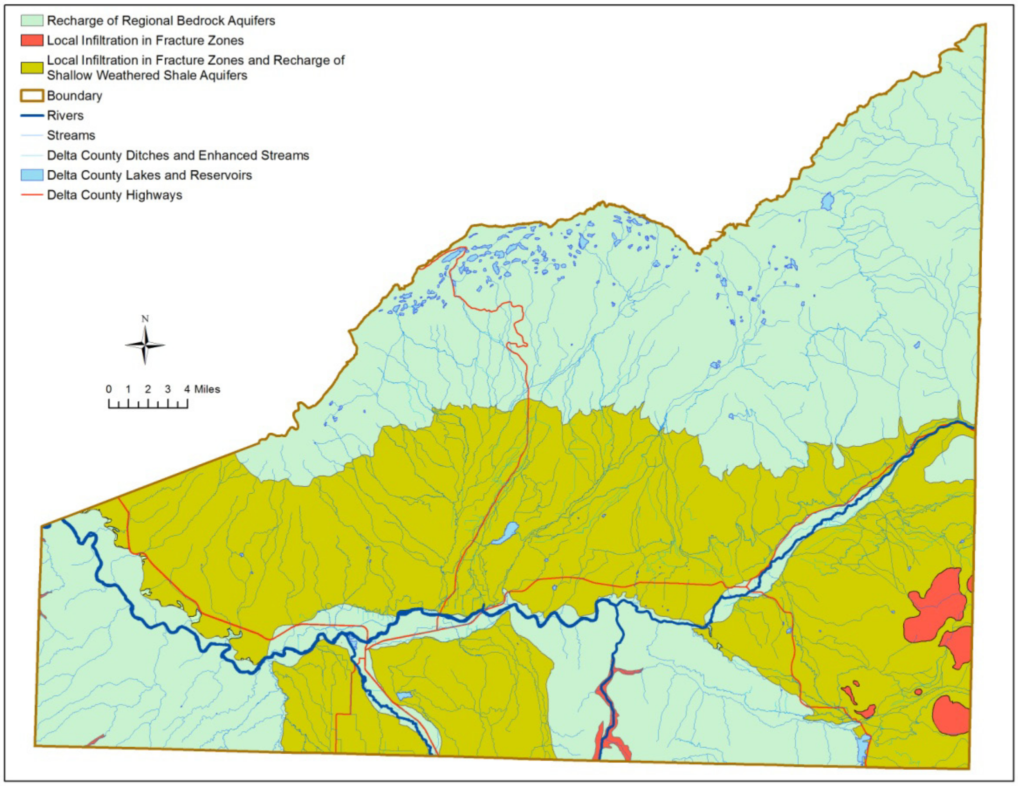

Figure 44. County-wide Map of Bedrock Recharge Zones (Recharge of Regional System). See Figure 39 for Specific Layer.

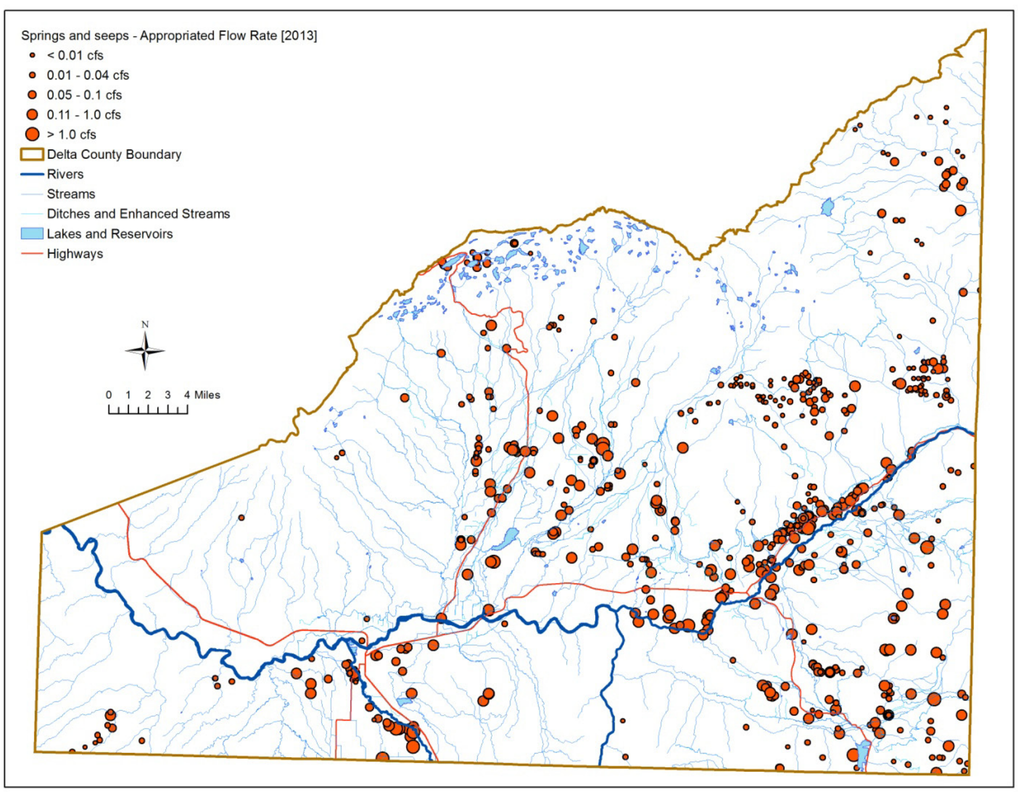

Figure 45. County-wide Map of Springs and Seeps. See Figure 39 for Specific Layer.

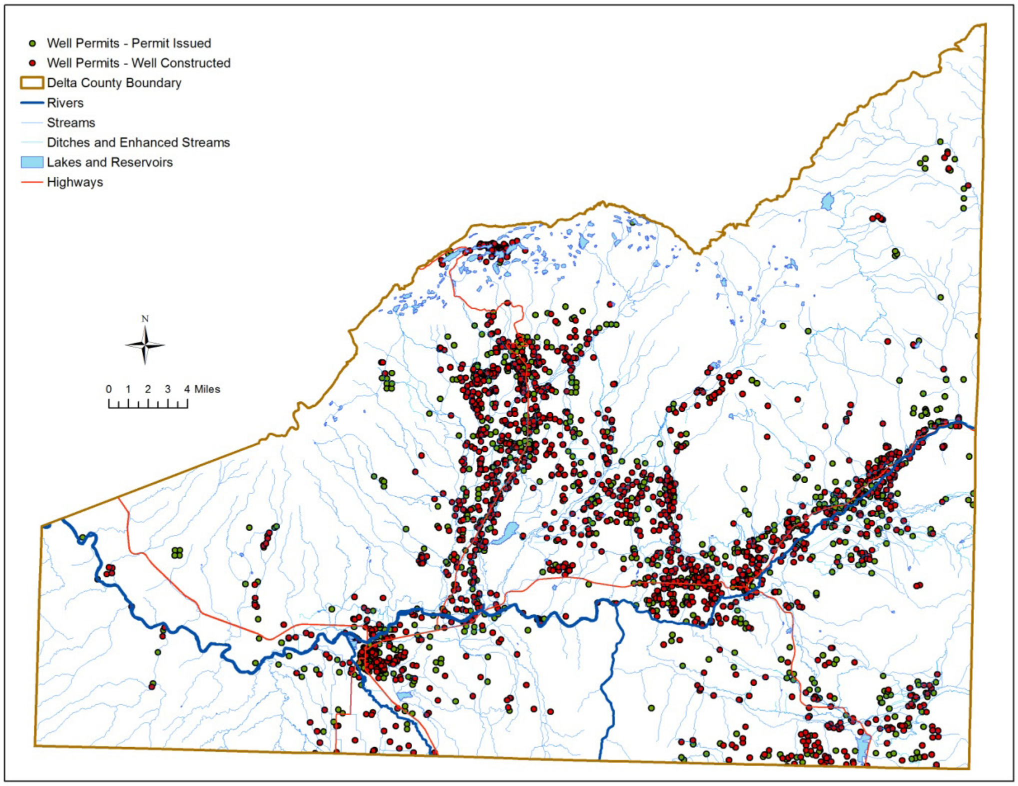

Figure 46. County-wide Map of Permitted and Drilled Wells (as of 2014).
See Figure 39 for Specific Layer.

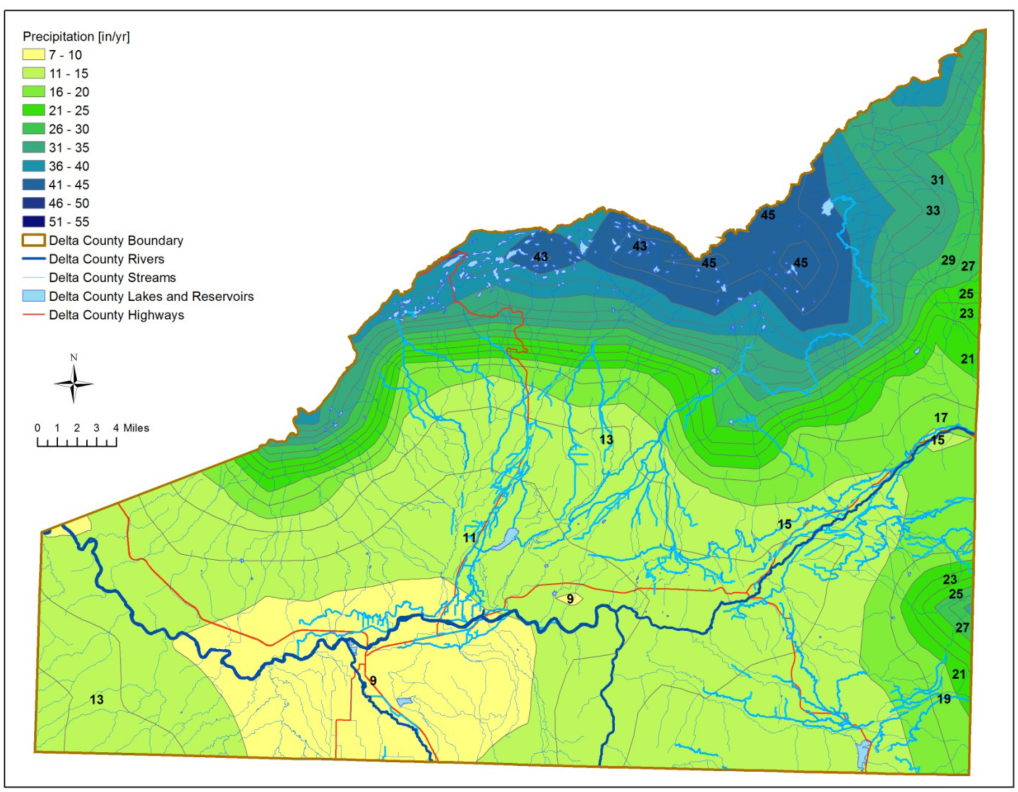

Figure 47. County-wide Map of Precipitation Distribution.
See Figure 39 for Specific Layer.

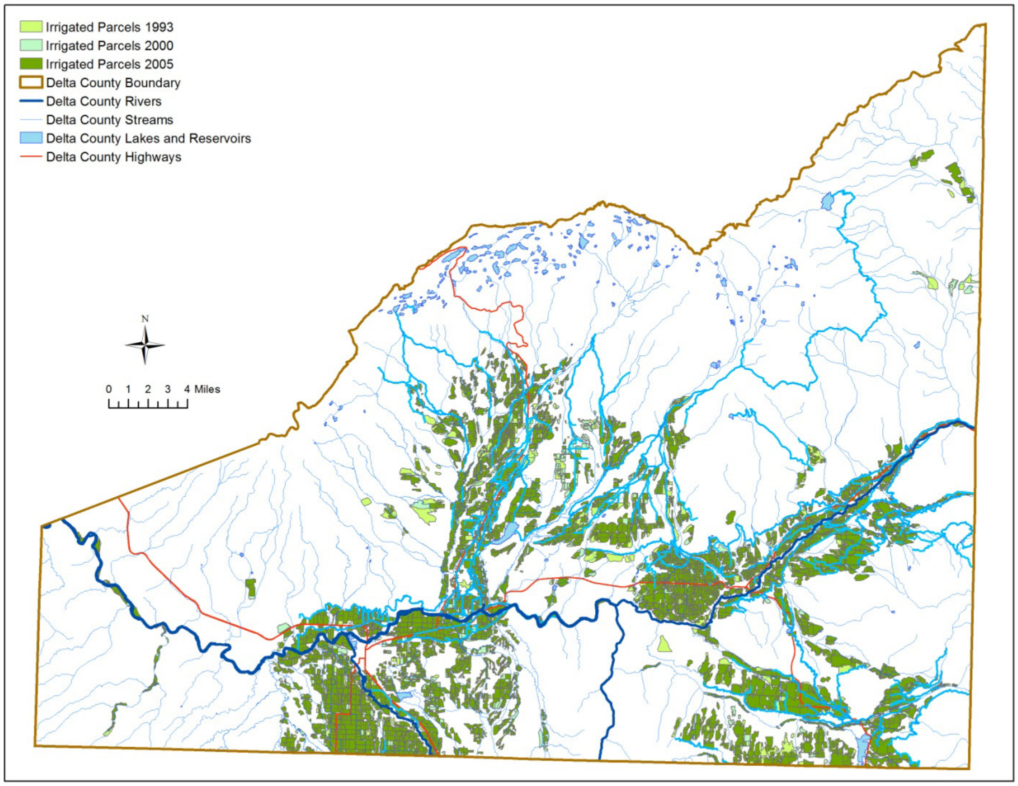

Figure 48. County-wide Map of Irrigated Acreage in 1993, 2000, and 2005.
See Figure 39 for Specific Layer.

4 SUMMARY AND CONCLUSIONS

This is the fourth in a series of studies of the groundwater systems in Delta County, Colorado performed by Hydrologic Systems Analysis, LLC of Golden, Colorado, Heath Hydrology, Inc. of Boulder Colorado, and Integral Consulting of Louisville, Colorado. The focus of this study is the irrigated and developed areas in the Uncompahgre and Gunnison valleys in the vicinity of the Town of Delta (*i.e.*, the UVTD study area). These hydrogeological studies consisted of conducting a Hydrologic and Environmental Systems Analysis (HESA) of the relevant groundwater systems in conjunction with the development of supporting GIS databases and maps of hydrogeologic and hydrologic characteristics. These studies aimed to provide insights in the groundwater systems present, their recharge, discharge and flow characteristics, and to evaluate the availability, sustainability and quality of groundwater present as a water resource. The UVTD study reported here consisted of two major elements: 1) Conducting a comprehensive HESA and developing supportive GIS maps and databases for the UVTD study area; and 2) Preparing a set of consistent and continuous county-wide GIS maps and databases of various hydrologic and hydrogeologic characteristics.

The HESA analysis showed that there are two significant groups of hydrogeologic units in the UVTD study area: 1) Quaternary unconsolidated clastic materials, which are predominantly glacial-fluvial terrace gravels, hillside (slope) deposits including earthflows and mudflows, younger valley gravels and river terraces, and alluvial valley bottom deposits; overlying 2) Cretaceous bedrock units, including the very low permeable Mancos Shale and the potentially water-bearing Cretaceous Dakota Sandstone and Burro Canyon Formation.

The Quaternary unconsolidated clastic units are locally heterogeneous, with predominantly a mix of coarser and finer materials in the older alluvial deposits, 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, and by the incidental leaky irrigation ditch and irrigation return flow. The unconsolidated units are variably to fully saturated based on spatial location and seasonal precipitation events. There may be lateral and vertical groundwater flow connection between the unconsolidated materials and the underlying bedrock formations, especially in fracture zones and in areas where the unconsolidated units are in direct contact with the Dakota Sandstone and Burro Canyon Formation.

Of special hydrological interest is the possible occurrence of a weathered zone and mass wasting (earthflows, mudflows, slumped areas) on the surface of the Mancos Shale. This occurs in the Peach Valley and drainages in the southeastern and eastern areas of the study area, near the topographic surface of exposed or shallow Mancos Shale bedrock on the top of and along the hills and escarpments on California and Ash Mesa, and in the exposed hills west of California Mesa by Seep Creek, Bixley Gulch, Buttermilk Creek, Wise Creek, and. Cummings Gulch. These weathered shale and mass-wasting areas may transmit water of variable water quality along the topographic gradient of occurrence, and as a result, Mesa Top gravels and soils can be connected to the Hillslope deposits and/or Valley Bottom deposits as they provide a subsurface pathway for groundwater.

Geological structures of hydrological importance such as folds, faults and fracture zones, are called *hydrostructures*. Hydrostructures control the location of the major valleys (Uncompahgre and Gunnison River Valleys) and of most of the main drainages, and exist sub-regionally and regionally. The main regional fold structure, the Uncompahgre Valley or Montrose Syncline, is hydrologically important in that the entire valley is underlain by flat lying Mancos Shale dipping gently to the north. The Uncompahgre Valley Syncline controls the bedrock regional groundwater systems, like the Cretaceous Dakota Sandstone/Burro Canyon Formation, and promotes bedrock groundwater flow from south to north parallel to the Uncompahgre river Valley with the regional dip of the bedrock.

Three broad hydrostructure sets occur in the UVTD area: 1) the northeast-southwest trending faults and fractures that parallel the Uncompahgre River fracture zone and are parallel to the bounding faults of the Uncompahgre Plateau uplift and the Black Canyon of the Gunnison River uplift structures; 2) the north-south-trending Dry Creek and Roubideau Creek fracture zones; and 3) the east-west trending Gunnison River fracture zone. The northeast-trending, north-south trending, and east-trending faults and fractures are relatively young, as the geomorphic systems of the Gunnison and Uncompahgre Rivers; Roubideau, Seeps, and Dry Creeks; and Cummings, Bixley, Peach Valley, and Stirrup drainages are responding with considerable downcutting, allowing for partial to full penetration of the unconsolidated hydrogeologic unit aquifers. It is hypothesized that the northeast, north-south, and east fracture zones are “open” and function like French drains. Groundwater moves laterally down valley and vertically downward along the northeast, north-south, and east-trending fault and fracture zone planes, and may move vertically up along the fault and fractures plane near the lower reaches of the various drainages (this would be evidenced by gaining reaches in streams or increased groundwater head with depth in local wells).

Based on the presence and orientation of various hydrogeologic and hydrostructural units, hydrography and topography, four categories of Conceptual Site Models (CSMs) are discussed in the UVTD study area: 1) Mesa Top Shallow Aquifer Subsystems, which include the California Mesa, Ash Mesa, and Garnet Mesa Subsystems; 2) Hillslope Shallow Aquifer Subsystems, which include the Peach Valley/Stirrup Creek and Seep Creek/Cummings Gulch group; 3) Valley Bottom Shallow Aquifer Subsystems, which include the Uncompahgre River (including Dry Creek) and Gunnison River Valley Subsystems; and 4) Regional Bedrock Aquifer Subsystems. The shallow aquifers in the UVTD area receive up to an inch annually of natural recharge by infiltration of precipitation (snow and rain), which in large portions of the study area is enhanced or even dominated by recharge from irrigation practices, including recharge from leaky irrigation ditches and return flow from sprinkler and flood irrigation. Water leaking from the unlined ditches and irrigated areas enter into the gravels underneath and flows downgradient towards the discharge zones (streams and adjacent wetlands, springs and seeps at exposed contacts with underlying shale, and connecting hillside (slope) deposits, earthflows and mudflows).

The Mesa Top Shallow Aquifer Subsystems are characterized by the presence of Quaternary unconsolidated clastic units, predominantly terrace gravels and some slope deposits, on top of Cretaceous Mancos Shale. The highly-permeable Quaternary deposits are locally heterogeneous, with a mix of coarser, gravelly, and finer, sandy and silty, materials in all of the deposits. They are underlain by a paleo-topographic surface carved out by paleo-fluvial systems in the Mancos Shale bedrock. On California and Ash Mesas, groundwater flows in a northerly direction through the terrace gravels towards the various discharge zones. The Mesa Top Shallow Aquifer Subsystem on Garnet Mesa, which extends from Sweitzer Lake on the south to the Gunnison Valley to the north, and encompasses most of the eastern part of the Town of Delta, is dominated by the Quaternary terrace gravels derived from the paleo Gunnison River.

Unlike California and Ash Mesas, Garnet Mesa is well dissected by drainages that fully penetrate the bottom of the gravels into the Mancos shale. In addition, the northwestern part of Mesa has been urbanized, which significantly alters the amount of water and flow characteristics of that part of the groundwater system. Groundwater flow on top of the gravel-capped Garnet Mesa moves with topography or subsurface paleo-topography to discharge into springs at the gravel/Mancos Shale interface along the incised drainages and to discharge directly out the north or west side of the mesa as seeps or springs at the gravel/Mancos Shale interface. The shallow mesa top groundwater systems have little connection to the local bedrock or the regional groundwater systems, but they have connection to nearby hillslope and alluvial systems near the discharge zones, and may directly connect locally to the lower Gunnison River alluvium and/or the lower Uncompahgre River alluvium.

Two sections of the UVTD study area contain Hillslope Shallow Aquifer Subsystems: the Peach Valley/Stirrup Drainages groundwater system, and the Seeps Creek/Cummings Gulch/Bixley Gulch groundwater system. These groundwater systems are characterized by Quaternary hillside (slope) deposits and modern day alluvium on top of Cretaceous Mancos Shale. The shallow Quaternary unconsolidated materials in these two subsystems are ubiquitous, but not necessarily continuous, and consist of modern day weathering (weathered shale), mass wasting (slumps, earthflows, mudflows), and alluvial deposits. These fine-grained, moderately-permeable deposits are locally heterogeneous. These groundwater systems are underlain by a modern topographic surface carved out by modern weathering, mass wasting and fluvial systems that deposited these unconsolidated materials.

Groundwater flow in the Peach Valley/Stirrup Creek watershed is extremely localized, in part because of the sparseness and wide-spaced distribution of irrigated fields, and occurs primarily within the fine-grained weathering, mass wasting and fluvial deposits on top of the Mancos Shale. This groundwater moves with topography or subsurface paleo-topography to discharge into springs, gullies, or drainages at the alluvium/Mancos Shale interface along the incised drainages that dissect the Peach Valley/Stirrup Creek watershed. The shallow groundwater subsystems in this hillslope area have little connection to the local bedrock or the regional groundwater systems, or to nearby alluvial systems until the very end of the surface water system where Peach Valley drainage and Stirrup Creek discharge into the alluvium of the Gunnison River. This is a critical juncture as any selenium derived in these upper basins due to irrigation or flooding would be delivered to the Gunnison river system at these locations.

The Seeps Creek/Cummings Gulch hillslope groundwater system, located to the west and northwest of California Mesa, is very different from the shallow groundwater system in the Peach Valley/Stirrup Creek watersheds. Although both groundwater systems are dominated by weathered Mancos Shale, hillslope deposits, and alluvium and receive less than an inch annually of natural recharge by infiltration of precipitation, the Seeps Creek/Cummings Gulch groundwater system receives significant additional recharge from the extensive irrigation on California Mesa as this latter groundwater system is upgradient from the Seeps Creek/Cummings Gulch groundwater system. Essentially the groundwater discharge from the California Mesa groundwater system becomes the recharge for much of the Seeps Creek/Cummings Gulch groundwater system.

Groundwater flow in the Seeps Creek/Cummings Gulch groundwater system is highly localized and within the fine-grained weathering, mass wasting and fluvial deposits on top of the Mancos Shale. Groundwater moves with topography to discharge into springs, gullies, or drainages at the alluvium/Mancos Shale interface along the incised drainages that dissect the landscape: Buttermilk, Seeps, and Wise Creeks, and Bixley and Cummings Gulches. The shallow groundwater subsystems in this hillslope area have little connection to the local bedrock or the regional groundwater systems, or to nearby alluvial systems until the termination of the surface water system where Seeps Creek, Bixley and Cummings Gulches discharge into the alluvium of the Gunnison River. As is the case in the Peach Valley/Stirrup Creek groundwater system, this is also a critical juncture as any selenium derived in these lower Mancos Shale basins due to irrigation or flooding would be delivered to the lower Gunnison river system at these locations.

The third group of groundwater systems in the UVTD area is formed by the two Valley Bottom Shallow Aquifer Subsystems: the Gunnison River Alluvial Subsystem and the Uncompahgre River Alluvial Subsystem. They are characterized by unconsolidated alluvial valley bottom and terrace deposits on top of the Mancos Shale and Dakota Sandstone/Burro Canyon bedrock units, and by major hydrostructures (*e.g.*, the east-west trending fracture zone in the Gunnison River valley, and the gently dipping, northerly trending Uncompahgre Valley Syncline with associated fracture zones trending north-south and northwest-southeast).

The shallow groundwater system in the Uncompahgre River and Dry Creek Valleys is dominated by the Quaternary alluvium, which receives natural recharge from precipitation and losing streams. This system also receives input from adjacent groundwater systems through surrounding hillslope deposits and from irrigated acreage at the valley bottom. Groundwater flows parallel to the valley axis through the (connected) gravels towards the discharge zones (gaining stream reaches, springs and seeps, and wetlands) downgradient.

The second Valley Bottom Subsystem in the UVTD study area is the shallow groundwater system in the Gunnison River Valley. This system receives natural recharge from precipitation and losing stream sections (Gunnison River) in the upper reaches of the study area and recharge from irrigation of valley bottom fields and irrigation conveyances. In addition, this Valley Bottom Subsystem receives input from adjacent groundwater systems through surrounding hillslope deposits and input from connected subsystems including the Uncompahgre Valley, Surface Creek, Peach Valley/Stirrup Creek, Garnet Creek, Cummings and Bixley Gulches and Seep Creek subsystems. Water entering into the (connected) gravels underneath the Valley flows downgradient towards the discharge zones, including sections of the Gunnison River in the central and western portions of the Valley, and downgradient wetlands.

Shallow groundwater in the Gunnison River, Uncompahgre River and Dry Creek valleys would normally have little connection to the local bedrock or the regional groundwater systems, given the Mancos Shale bedrock. However, the fracture zones underlying these valleys may be open vertical conduits, where the faulted and fractured bedrock connect with the alluvium to form a French Drain affect resulting in increased groundwater flow and storage, and connectivity to deeper hydrologic systems notably the Cretaceous Dakota Sandstone/Burro Canyon Formation hydrogeologic unit.

The main regional hydrogeologic bedrock unit is the potentially water-bearing Cretaceous Dakota Sandstone and Burro Canyon Formation. This bedrock aquifer is variably to fully saturated based on location and proximity to recharge areas. Groundwater recharge by losing streams is possible only by connection to the Gunnison River and Uncompahgre River fracture zones. The regional groundwater flow direction in this unit would be from south to north along the axis of the Uncompahgre Valley syncline, then north beneath the UVTD Study Area and Grand Mesa. This flow direction is away from human activities and Delta County in general.

Human activity in the UVTD study area has affected both the surface and subsurface parts of the hydrologic systems. Past land use and human activity was mostly associated with agricultural production and reservoir construction and operation, and has resulted in removal of native vegetation, introduction of irrigation and high-ET (evapotranspiration) crops, construction of (often leaking) irrigation ditches, and the drilling of primarily domestic wells. This activity has resulted in long-term increase of water levels in the shallow gravel aquifers on California and Ash Mesas; the weathered shale, mudflow and earthflow deposits, and alluvium in the Peach Valley/Stirrup Creek and Seep Creek/Cummings Gulch subsystems; and in the alluvium of the Gunnison River and the Uncompahgre River Valley Bottom Subsystems. Therefore, irrigation return flow and leaky irrigation ditches can be the significant recharge element in the local and regional groundwater balance. Taking irrigated fields out of production and re-allocating ditch-conveyed water reduces recharge of groundwater resulting in lowered water tables, reduced groundwater discharges to wetlands and streams, and decreased water supplies. The same effect occurs when leaky ditches are lined or replaced by piping.

New in the Delta County Phase 4 Groundwater Study is the concept of using the HESA evaluation for assessing the vulnerability of groundwater and surface water to selenium concentrations that may exceed drinking water and ecosystem standards, whether naturally or human-induced. Selenium is very soluble and mobile in oxidizing environments while being stable in reducing environments. The Cretaceous Mancos shale hydrogeologic unit, usually considered a groundwater flow system confining layer, is the main source in Delta County for naturally occurring selenium in a chemically reduced form, as well as sulfur (sulfate). When exposed to oxidizing groundwater and/or surface water, selenium becomes mobile and is transported in the groundwater and/or surface water to exposure sites such as wells, and surface water bodies like streams and lakes where it 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 selenium is being mobilized and transported. One such factor is selenium source location with respect to hydrogeologic framework, specifically the hydrogeology of unweathered and weathered Cretaceous Mancos shale bedrock and the hydro-geomorphology of overlying unconsolidated Quaternary deposits, such as landslides, glacial and alluvial gravels, soils and weathering profiles. Another important factor is the presence of groundwater flow pathways towards potential exposure sites such as groundwater discharge zones to the surface water systems. A third factor is formed by past, present, and future hydrologic “stresses” to the system, such as the presence of leaky ditches and lining or piping of unlined ditches, and changes in irrigation practices of weathered shale bedrock from flood irrigation to drip irrigation.

The Quaternary terrace gravels of the mesa top groundwater systems are located on top of the Cretaceous Mancos Shale and a weathered zone most likely exists as the interface between the two hydrogeologic units. Groundwater flows along the trend of underlying paleo-topography, or as direct leakage through the mesa sides and the lower ends of the mesa systems into the Gunnison River. The sources of selenium and sulfur in these mesa top systems most likely are found in this weathered zone. It is hypothesized that the natural system, pre-irrigation, has been flushing selenium and sulfate through this system since the deposition of the glacial gravels as terraces. The current irrigation systems use good quality water that may be reactive with the weathered zone. However, given the large water quantities being circulated, and long period of time of flushing, it is unlikely that large amounts of selenium and sulfate are being leached and transported from these subsystems. The anthropogenic pollutant sources to these subsystems is mostly fertilizers for grass (urban) or crops, industrial pollutants (Town of Delta at lower Garnet Mesa), or rural septic tank waste.

In the two Hillslope Subsystems, Quaternary alluvium, mudflows, earthflows, and slumps cover the Cretaceous Mancos Shale. Here, a weathered shale zone exists as the interface between the Quaternary and the bedrock hydrogeologic units. The recharge in these groundwater systems is dominated by irrigation return flow, with some infiltration from ditches and canals through weathered shale and Quaternary deposits, and from direct precipitation. The Seeps Creek/ Cummings Gulch Subsystem is unique in that a large amount of groundwater recharge to the subsystem is from additional discharge from California and Ash Mesas. The groundwater flow system is along the trend of underlying topography that follows the watershed drainages and drainage divides. Groundwater discharge, including water quality elements, is into the drainage alluvium and ultimately to the Valley Bottom Subsystems, or directly into surface water streams, such as Buttermilk, Wise, and Seeps Creeks; Bixley and Cummings Gulch drainages; and Stirrup and Peach Valley drainages. The source of selenium and sulfur is the weathered shale zone at the top of the Mancos Shale and the earthflow and mudflow deposits. It is hypothesized that the natural system, pre-irrigation, has been flushing selenium and sulfate through this system since the erosion of the landscape commenced, resulting in the deposition of the earthflows, mudflows, and slumps, and the alluvium in the various drainages. The current irrigation systems involve good quality water that may be reactive with the weathered zone. Given the large water quantities being circulated, and the short period of time of flushing through the weathered shale, it is likely that large amounts of selenium and sulfate are being leached and transported from these subsystems. The observation of large quantities of salt deposition at the soil surface in both areas confirms that leaching of natural pollutants is currently occurring. Additionally, fertilizers for grass (urban) and crops, as well as rural septic tank waste represent anthropogenic pollutant sources to these subsystems.

In the two Valley Bottom groundwater systems the Cretaceous Mancos Shale is overlain by Quaternary alluvium. A weathered shale zone most likely exists as the interface between the two hydrogeologic units, at least at the alluvial terraces away from the main river stems. The hydrologic system of the two Valley Bottom Subsystems is recharge dominated by infiltration of irrigation return flow, with some infiltration from leaky ditches, and from direct precipitation. Unique to the Uncompahgre Valley Bottom Subsystem is the groundwater inflow from the California, Ash, and Garnet Mesas groundwater systems. Water quality from these systems, particularly from the Town of Delta infiltration and runoff in the Garnet Mesa Subsystem, is passed on directly to the Uncompahgre Valley Bottom Subsystem. Unique to the Gunnison River Valley Bottom Subsystem is the groundwater and surface water inflow from the upper Gunnison River passed on through the gap west of Hotchkiss, CO., and from the various drainages and groundwater systems to the north and south of the Gunnison River Valley. Water quality from these drainages and groundwater systems, particularly from the Peach Creek/Stirrup Creek subsystem, the Seeps Creek/Cummings Gulch subsystem, and the Town of Delta infiltration and runoff in the Garnet Mesa and Uncompahgre River subsystems, is passed on directly to the Gunnison River groundwater system.

The groundwater flow system in the Valley Bottom Subsystems is along the trend of underlying paleo-topography parallel to the Uncompahgre and Gunnison Rivers, or influenced by the direct leakage along the Valley Bottom sides and ditches and canals towards the two rivers. Groundwater discharge, including water quality elements, is from the Uncompahgre groundwater system directly into the Gunnison River Valley Bottom Subsystem with minor discharge by phreatophytes and wells, and from the Gunnison River groundwater system directly into the Gunnison River in the reaches below the Town of Delta to the Gunnison River gorge below the confluence with Roubideau Creek. The most likely source of selenium and sulfur (sulfate) in this subsystem is the weathered zone at the interface between the alluvium and the Mancos Shale. It is hypothesized that the natural system, pre-irrigation, has been flushing selenium and sulfate through this system since the deposition of the glacial gravels as terraces. The current irrigation systems use good quality water that may be reactive with the weathered zone. However, given the large water quantities being circulated, and long period of time of flushing, it is unlikely that large amounts of selenium and sulfate 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 Gunnison River Valley Bottom Subsystem through the Peach Creek, Stirrup Creek, Cummings and Bixley Gulches. Seep Creek and Roubideau Creek groundwater and surface water systems, and the groundwater and surface water associated with the tributaries draining Grand Mesa directly into the Gunnison River Valley Bottom Subsystem below the Town of Delta. These sources collect the pollutants upstream in their associated watersheds and deliver them to the Gunnison River Valley Bottom Subsystem. The anthropogenic pollutant sources to these Valley Bottom Subsystems are mostly fertilizers for grass (urban or golf courses) or crops, industrial pollutants (Town of Delta at lower Garnet Mesa and the Uncompahgre River Valley; runoff from the Delta County airport), or rural septic tank waste.

The GIS maps resulting from this study provide for use in planning and management of groundwater resources in UVTD study area as well as the entire county. The database formats that have been used in this study include shape files, database tables, geo-referenced images, and grid files (for the DEM, among others). The GIS map and database for this study were prepared using Arc-Desktop™ (ESRI®, Redlands, California).

Two multi-layer GIS maps have been prepared for this study: 1) a map with hydrologic and hydrogeologic features of Delta County in its entirety; and 2) a map with hydrologic and hydrogeologic features of the UVTD area. The GIS maps consist of a number of layers representing various data types relevant to the assessment of groundwater resources at user-specified locations. The GIS layers of the Delta County and UVTD maps contain three types of geographic information: 1) general geographic information (county border, roads, towns, imagery) used primarily for orientation purposes; 2) hydrologic information (including precipitation, watersheds, streams, lakes/ponds, irrigation ditches, and irrigated areas); and 3) hydrogeologic information (including hydrogeologic units, faults and hydrostructures, recharge and discharge areas, springs/seeps, and wells.

This project extends the GIS databases and maps of hydrogeologic and hydrologic characteristics of the groundwater systems developed in earlier studies by Kolm and van der Heijde (Oak Mesa, 2012; North Fork Valley and Terraces, 2013; and Surface Creek Valley, 2014) to the entire county. Using a county-wide nomenclature of hydrogeological units, this study integrated the various hydrogeological databases developed in this and the earlier groundwater studies into a single set of hydrogeological databases covering the entire county. This study also included the preparation of county-wide hydrological databases on springs and seeps, digitized in this and the previous studies; permitted and drilled water wells; long term average precipitation distribution, and irrigated acreage for 1993, 2000 and 2005.

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