GIS-BASED GROUND WATER RESOURCES EVALUATION OF THE CAPITOL AND SNOWMASS CREEK (CSC) STUDY AREAS, PITKIN COUNTY, COLORADO

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Executive Summary

Under an agreement with Pitkin County, Hydrologic Systems Analysis, LLC (HSA) of Golden, Colorado, in cooperation with Heath Hydrology, Inc. (HHI) of Boulder, Colorado, created a GIS-based, step-wise, ground water resources evaluation procedure for use as decision/land use management tools by Pitkin County. The procedure, supported by a GIS map and supporting databases, guides the site-specific analysis with respect to: 1) ground water resources availability in terms of sufficient quantities for the purpose of its usage, and economical exploitability; 2) long-term sustainability of the utilization of the resources for water supply; and 3) the vulnerability of the resources to contamination. In addition, the GIS map provides information with respect to wells for which augmentation is required, and shows well applications approved or denied, and wells actually drilled.

Key elements in this project are the adaptation of the step-wise ground water resources evaluation procedure developed in a previous HSA/HHI study for Pitkin County, as well as the hydrologic systems analysis and the formulation of conceptual models for the study area. The incorporated databases include delineated hydrogeological units created by HSA/HHI by combining published hydrogeologic information with the results of the hydrologic systems analysis, as well as databases from Pitkin County, the Colorado Division of Water Resources/Colorado Water Conservation Board, and the Natural Resources Conservation Survey (USDA).

Based on field work and hydrologic systems analysis, five general conceptual models are identified within the regional scale context of the CSC area: 1) Upper Snowmass Creek (USC) Subsystem; 2) Lower Snowmass Creek (LSC) Subsystem; 3) Upper Capitol Creek (UCC) Subsystem; 4) Lower Capitol Creek (LCC) Subsystem; and 5) Ft. Hays/Dakota-Burro Canyon Bedrock (FDB) Subsystem. Each of the five subsystems has a unique set of natural system parameters defining recharge and discharge, ground water levels and fluctuations, ground water flow velocities and direction, and ground water storage. In addition, each of these subsystems have important anthropogenic hydrologic system parameters, including ground water recharge from irrigation and irrigation ditches, and ground water discharge from wells.

Three case history examples are presented to illustrate the analysis procedure, using the GIS map and databases provided with this report. Site 1 is located in the lower Capitol Creek valley; site 2 is located in the Lime Creek area, and site 3 is located on the ridge between Upper Snowmass Creek and Upper Capitol Creek near Hunter Creek. The examples show the existing uncertainties in evaluating local ground water resources due to data limitations, and illustrate the variability of drinking water supplies, both in availability and sustainability, dependent on the local hydrogeology and hydrological system. All three sites are vulnerable to ground water pollution.

1.0 Introduction

Under an agreement with Pitkin County, Hydrologic Systems Analysis, LLC (HSA) of Golden, Colorado, in cooperation with Heath Hydrology, Inc. (HHI) of Boulder, Colorado, was tasked to create a series of GIS (Geographic Information System) maps and a ground water resources evaluation procedure for use as decision/land use management tools by Pitkin County. The GIS maps and ground water resources evaluation methodology covers the non-Federal lands in the Snowmass and Capitol Creek watersheds, as well as the non-Federal lands in the upper reach of the East Sopris Creek watershed (Figure 1). The maps identify locations in designated areas of Pitkin County:

A. Where ground water resources are: (i) available in reasonable, sustainable quantities, at reasonable depths, (ii) available in reasonable quantities, at reasonable depths, but vulnerable/not sustainable (e.g., because of artificial recharge, such as leaking ditches or irrigation), and (iii) not available in reasonable quantities, at reasonable depths.

B. Where ground water resources are vulnerable (using a rating of High-Medium-Low) to contamination (e.g., because of the absence of a confining layer, shallow water table and a substrate consisting of unconsolidated gravels, alluvium, etc.).

C. Where the ground water table is likely to fluctuate significantly (e.g., due to spring runoff or upland flood irrigation), resulting in a high water table at different times of the year.

D. Where, if feasible, (1) augmentation plans have been required , due to a well's impact on surface water resources, and (2) instances where well permits have been denied, due to potential deleterious impact on surface water resources.

The study relies on the use of existing data and does not include additional collection of field data. The maps and methodology are produced following the procedure developed in a previous HSA/HHI study for the Upper and Middle Roaring Fork areas (Kolm and van der Heijde, 2006).

Objective A has two elements: 1) determining *availability* of a ground water supply, and 2) assessing *sustainability* of an available ground water supply. Objective B focuses on the *vulnerability* of a ground water resource to contamination from the surface. Objective C relates to the both the *availability* of a ground water supply (is it always present in case of seasonal fluctuations and is it economical to use?) and its *sustainability* (in case of multi-year fluctuations). Objective D is a water rights issue and relates to administrative considerations. A more detailed discussion of availability, sustainability, vulnerability and augmentation follows later in this chapter.

Computer-based GIS maps provide a flexible and efficient way to display and analyze geographic information. Data from various sources can be collected in local or remotely accessible databases, which can be easily maintained and updated, independently of the display and analysis procedures. Computer-based GIS maps support optimal usage of data obtained from different sources containing features of significant importance 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, landuse, land ownership, wells, etc. Selected features can be further described with associated attribute tables. All data are collected in sets of layer-related files. At each step of a geographic analysis, individual layers can be analyzed, combined, or/and stored (turned on and off) and individual features interrogated with respect to their attributes. 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 randomly visualize (switch) between layers; and the availability of advanced search, selection and overlay capabilities further enhances the utility of a GIS map. The GIS-based evaluation of ground water resources in the CSC study areas makes extensive use of the fore mentioned GIS capabilities.

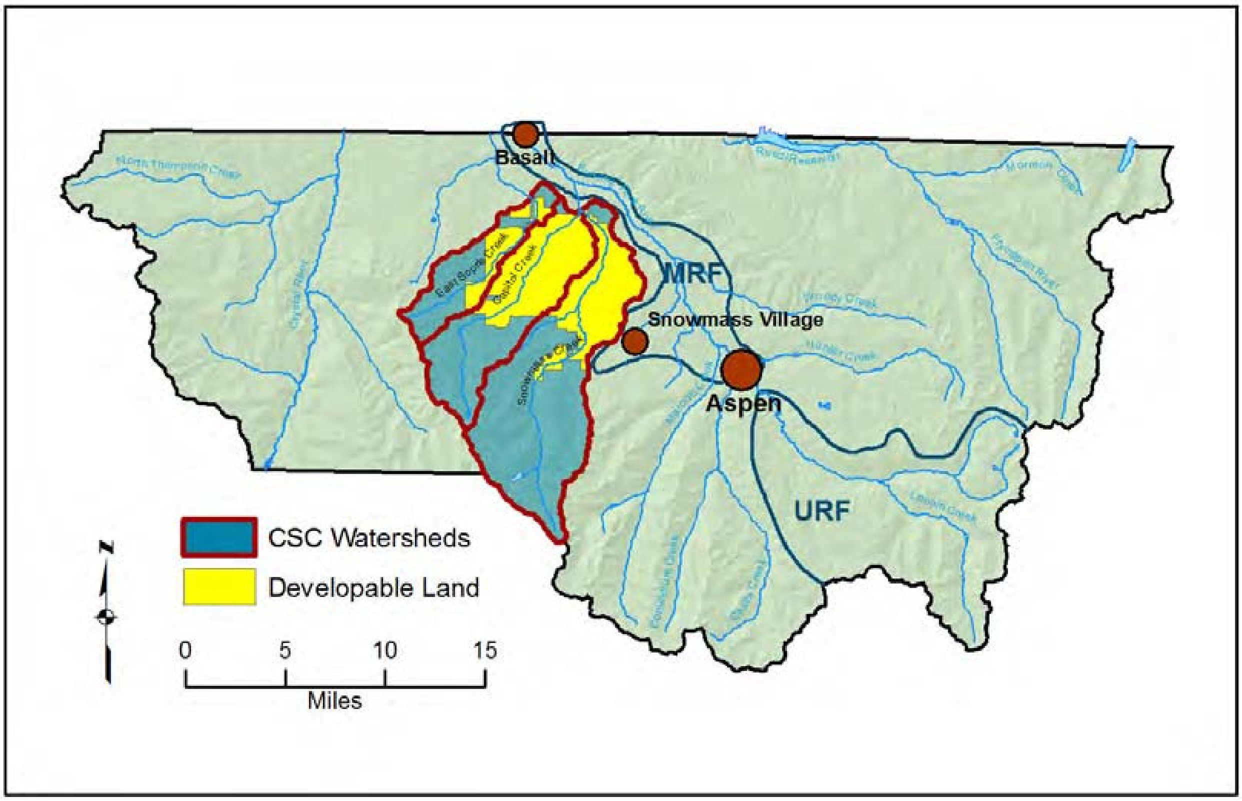

Figure 1. Roaring Fork Watershed and Capitol and Snowmass Creek (CSC) Study Areas, Pitkin County, Colorado, including the Upper Reach of the East Sopris Creek.

<u>1.1 Availability, Sustainability, Vulnerability, and Augmentation</u>

Availability of a ground water supply, as described under study objective A, is a function of demand (amount of water needed; peak demand versus average demand), local hydrogeology and hydrology (type and thickness of permeable soil and rock formations, presence of fracture zones, depth to water table, seasonal and multi-year water table fluctuations), and environmental and water rights restrictions (stream flow requirements, wetlands, ecosystems). In the context of this study, availability pertains both to the study area in general (where are the aquifers?) and to site-specific conditions (i.e., at a specific development, parcel, ranch, or structure). Thus, ground water resources availability is evaluated in terms of sufficient quantities for the purpose of usage; absence of excessive drawdowns during pumping and periodic water table fluctuations due to spring runoff or upland flood irrigation, and economical exploitability (e.g., at reasonable depth and with sufficient permeability).

Sustainability in the development of water resources is obtained when the present-time needs are met without compromising the ability of future generations to meet their own needs. The objective of sustainable water use is to maintain the water supply for a prolonged period of time without injuring vested interests (e.g., water rights) or ecological and other values. In nature, increased ground water pumping will be balanced by a change in one or more water balance components: 1) reducing ground water storage, resulting in lowering the water table; 2) reducing evapotranspiration, resulting, among others, in diminishing the water supply for phreatophytes and wetlands; 3) increasing stream bank infiltration, that is, increasing recharge from streams and, thus, reducing in-stream flow; and 4) reducing discharge to streams, resulting in lower flow rates downstream (Sophocleous, 1998; Devlin and Sophocleous, 2005; Bredehoeft, 2006). In small, local aquifers and in permeable fracture zones, storage capacity is rather small and changes in other water balance components will dominate. Devlin and Sophocleous (2005) note that *sustainability* and *sustainable pumping* are two different concepts, the latter referring to a pumping rate that can be maintained indefinitely without dewatering or mining an aquifer. A particular rate of pumping will result in a new steady state condition over the long term with particular implications for sustainability.

In the approach to sustainability presented in this study, only maintaining a supply for a prolonged time period is considered, not the broader consequences on streams, vegetation, and neighboring wells. A prolonged time period is defined as a period of time in which no major natural or man-made changes in the hydrologic system occur that cause a noticeable change in the water balance components. Thus, to determine sustainability, the question to be answered is: Are there significant, reliable, long-term, recharge mechanisms present? To answer that question, the following is evaluated: 1) source(s) of replenishment/recharge; 2) relevant man-made conditions; and 3) dynamic character of demand. In the study area, replenishment may come from 1) precipitation (rain/snow; seasonal, multi-year effects); 2) stream infiltration (seasonal, multi-year effects); and 3) interflow (displaced recharge). Human-made conditions of importance in the study area may include: 1) recharge from ponds, reservoirs, golf courses, irrigated acreage, etc.; and 2) recharge from leaking irrigation ditches.

Vulnerability of ground water resources can be defined as the tendency or likelihood for contaminants to reach a specific position in the saturated zone of the subsurface after their introduction at some location at or near the surface (NRC, 1993; modified). Vulnerability is not an absolute property, but a relative indication of where contamination is likely to occur. The concept of vulnerability has received broad attention in relation to ground water protection, both from the research community and from the public policy and enforcement sectors (NRC, 1993; van der Heijde et al., 1997).

The potential of contaminants to leach into a ground water resource and reach water supply wells depends on many factors, including the composition, structure, texture and permeability of soils and rock, depth to ground water (to allow for natural attenuation and remediation in soils), the topography of the local terrain (specifically slope), the amount of precipitation available for infiltration in the subsurface and subsequent percolation through the unsaturated zone, and type and control of land use. The vulnerability of a site to ground water contamination is determined as follows: 1) identify and characterize potential contaminant sources; 2) determine the presence and nature of contaminant pathways from these potential contaminant sources at or near the land surface to the ground water resource; (3) determine potential impacts from these anthropogenic sources on the ground water flow system and the ground water quality; and 4) evaluate the likelihood of future contamination of the ground water resource (van der Heijde et al 1997). Determining that ground water at some sites have a high vulnerability with respect to contamination from sources at the land surface may be straightforward, e.g., in the presence of mature karst or alluvial sand and gravel deposits and absence of protecting low-permeable formations. However, it is typically more difficult to determine that an area has a low ground water vulnerability. The integrity of low permeable rock may be compromised by the existence of preferential pathways from faulting and fracturing, or because of the differential rock properties within the formations at a scale not detected by field exploration.

The determination of the vulnerability of the ground water resources in the study area has been limited to a qualitative assessment based on systematic characterization and conceptualization of the local hydrologic system. The assessment of risk posed by the potential sources, a more quantitative procedure by nature, has not been performed due to the complexity of the hydrogeologic system, the lack of ground water level data, the sparseness of hydrogeologic parameter information, and the limited time and funding available for this project. Therefore, the selected study approach was based on extensive and detailed mapping of relevant physical entities, analyzing their impact through GIS-based overlay techniques, and using qualitative classification terminology (*high, medium, low*).

Augmentation —New wells drilled in Colorado require a permit from the Department of Natural Resources (i.e., the State Engineer Office or SEO). The SEO will issue the permit if the well will not injure vested water rights of others. Colorado law distinguishes between two classes of wells: 1) those that are exempt from water administration and are not administered under the priority system, and 2) those that are non-exempt and are governed by the priority system (CDNR, 2006). There are several types of exempt well permits. Each well permit contains a specific set of conditions when issued. Exempt wells include: 1) Household Use Only wells (HUO), 2) Domestic and Livestock wells, 3) Commercial Exempt wells, and 4) Unregistered Existing wells. Exempt wells are limited to 15 gallons per minute, and other restrictions may apply, such as the use of non-evaporative wastewater disposal systems (e.g., septic tanks). All other well types are non-exempt, including high flow irrigation wells, high-capacity drinking water supply wells, such as used for subdivisions and municipalities, and any non-exempt water supply well for commercial use in businesses (see CDNR, 2006 for details).

A non-exempt well permit is not available in over-appropriated areas without augmentation. These type of wells are required to replace any out-of-priority stream depletion by having augmentation water available when a *river call* is made. Such augmentation arrangements are described in an augmentation plan that requires approval by the water court before a well permit is issued. Augmentation typically takes the form of providing replacement water. Sources of such replacement water include: surface water ditches, reservoirs or ponds, augmentation wells and (artificial) recharge projects, and leased municipal effluent. (Stenzel, 2006). For non-exempt wells in the Roaring Fork watershed, an augmentation plan needs to be submitted to the Water Court or Water Division 5 office in Glenwood Springs. Information regarding approved or pending augmentation plans are also available from that office. For more information visit the Monthly Water Resumes for Colorado Judicial Branch, Water Courts, Division 5 web site: www.courts.state.co.us/supct/watercourts/wat-div5/water5index.htm (starting December 1998).

Three separate well layers are included in the ground water GIS to display information on permit status and augmentation: 1) wells with augmentation plans; 2) wells with approved permits (drilled or not); and 3) wells with given depth, i.e., these wells have actually been drilled. Note, that the *receipt* field in the state well database contains the only unique identifier. These layers are linked to the state well database file. The well permitting procedure is illustrated in Figure 2.

1.2 Project Approach

In an earlier study regarding availability, sustainability, and vulnerability of ground water resources in Pitkin County (Kolm and van der Heijde, 2006), it was concluded that not enough data were available to take a quantitative approach and prepare specific maps identifying the area of resource availability and sustainability, and that vulnerability could only be assessed using a few categories (*high, medium, low*). Issues included the presence of few deep wells; the clustering of shallow wells in the lower parts of the valleys, the absence of ground water level information (except for the static water level at the time of the drilling of a well); and the absence of a three-dimensional geologic model (only maps of the top of the geologic stack and a generalized stratigraphic sequence were available). Therefore, a step-wise evaluation procedure was developed to use the available data, collected and organized in a GIS, to address the study objectives on a site-specific scale.

In developing the proposal for the CSC study area, it was recognized that the absence of an understanding of the hydrologic system (in terms of hydrogeologic framework, type and scale of hydrologic processes, process parameters, and water budgets) would prevent the use of the previously developed assessment procedure. A hydrologic system analysis, at least in qualitative terms, was required before proceeding to the preparation of the GIS data files and map, and selecting illustrative examples.

In translating objectives into a project approach, recognizing the limited availability of data, this study is divided in five sections: 1) hydrologic system analysis and conceptual hydrologic model formulation to formulate the physical framework for the availability, sustainability and vulnerability assessments (chapter 2); 2) digitizing existing geologic maps and converting them to hydrogeologic system layers in the GIS (chapter 2 and 3); 3) development of

GIS maps and databases from existing data from various sources (chapter 3); 4) adaptation of the previously developed ground water resources evaluation procedure to address the current study objectives (chapter 4); and 5) application of the procedure using examples in characteristic settings (chapter 5). Deliverables include a report of the hydrologic system analysis (HSA), a report of the complete study including the HSA, a GIS map and supporting data files, and presentations for the Board of Pitkin County Commissioners and county staff. In addition to the Capitol and Snowmass Creek watersheds, this study includes the upper reach of the East Sopris Creek (the stretch upstream from the turn along East Sopris Creek Road into the NW-SE trending canyon) because of the hydrologic complexity at the divide between the East Sopris Creek and Capitol Creek watersheds.

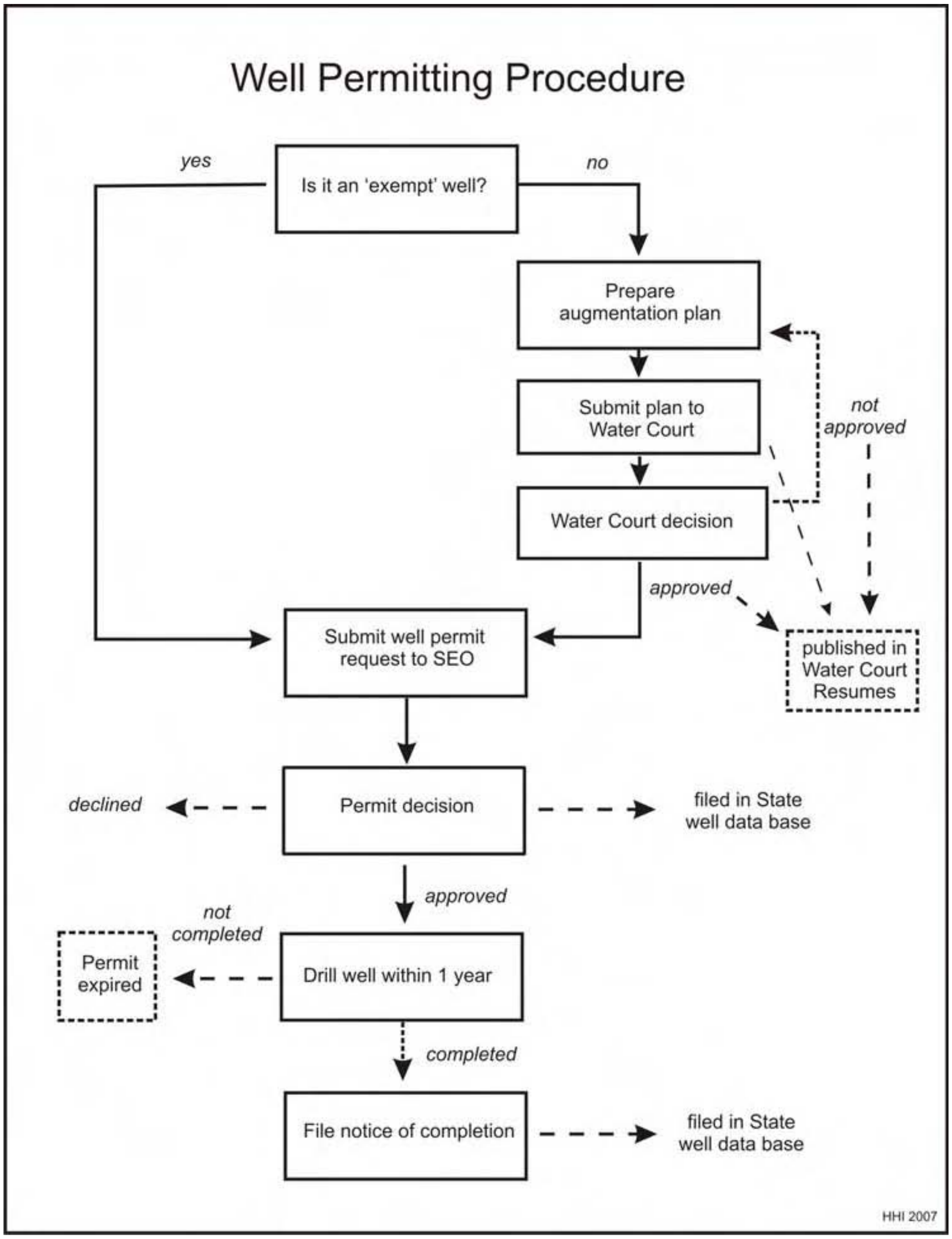

Figure 2. Flow Chart of Well Permitting Procedure.

2.0 Hydrologic Systems Analysis and Formulation of Conceptual Models for Hydrologic Subsystems in the Capitol and Snowmass Creek Study Area

The development of the conceptual model of the hydrogeology followed the watershed-based, hierarchical analysis described by Kolm and Langer (2001) and codified in ASTM D5979 Standard guide for Conceptualization and Characterization of Ground Water Systems. The conceptual model covers, in a qualitative manner, elements of climate, topography, soils and geomorphology, vegetation distribution, surface water characteristics, hydrogeologic framework, hydrology, and anthropogenic activity as related to the ground water system in the study area.

2.1 Hydrologic System Analysis for CSC Study Area

2.1.1 Climate

Tables 1 and 2 summarize average monthly and annual temperatures and precipitation during 2 multi-year observation periods for Basalt, Colorado. Table 1 also presents average monthly and annual snow fall and snow depth. These numbers provide estimates for the actual precipitation and snow fall in the study area as elevation and slope aspect may have a significant influence on local microclimates.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Average Max. Temperature (F)	37.7	42.6	50.5	59.2	69.9	78.5	86.6	83.8	75.1	63.0	49.4	36.9	61.1
Average Min. Temperature (F)	7.4	12.2	19.7	25.6	34.4	40.0	46.9	45.4	36.4	25.8	18.7	10.0	26.9
Average Total Precipitation (in.)	0.84	0.79	0.58	1.35	1.02	1.73	1.14	1.99	1.96	1.57	0.80	1.32	15.10
Average Total Snow Fall (in.)	15.2	12.0	6.3	3.4	0.0	0.0	0.0	0.0	0.6	5.2	5.7	17.9	66.3
Average Snow Depth (in.)	7	3	1	0	0	0	0	0	0	0	0	4	1

Table 1. Monthly Climate Summary for Basalt, Colorado [station 050514] for period 7/1/1965 to 5/31/1972 (source: Western Regional Climate Center, Desert Research Institute, Reno, Nevada).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Average Max. Temperature (F)	38.0	43.8	53.4	61.2	68.8	81.2	86.7	85.0	75.2	66.3	45.0	32.9	61.6
Average Min. Temperature (F)	11.8	16.0	23.4	30.7	35.5	43.9	48.9	46.4	36.3	30.3	17.7	8.7	29.2
Average Total Precipitation (in.)	0.88	0.94	0.77	1.15	0.96	0.59	0.46	1.64	1.80	1.04	1.32	2.00	13.54

Table 2. Monthly Climate Summary for Basalt, Colorado [station 050514] for period 1/1/1971 to 12/31/2000 (source: Western Regional Climate Center, Desert Research Institute, Reno, Nevada).

2.1.2 Topography, Geomorphology, and Soils

The topography of the CSC area has three distinct terrains (Figures3 and 4): 1) well-dissected uplands and hill-slope terrains; 2) connected and disconnected, continuous and discontinuous terraces and landslides; and 3) well-dissected valley bottoms. The well-dissected uplands indicate that surface water and shallow ground water systems will be localized by topography (subregional system). The terraces are often topographically isolated representing discrete, localized ground water systems. The topographic gradients in the CSC study area can be divided into two types (Kolm and Gillson, 2004): steep gradient hill slopes (greater than 2% slope); and 2) low gradient valley bottoms and terrace levels. The topographic gradient is useful in estimating water table surfaces, and estimating the amounts of infiltration versus overland flow and interflow.

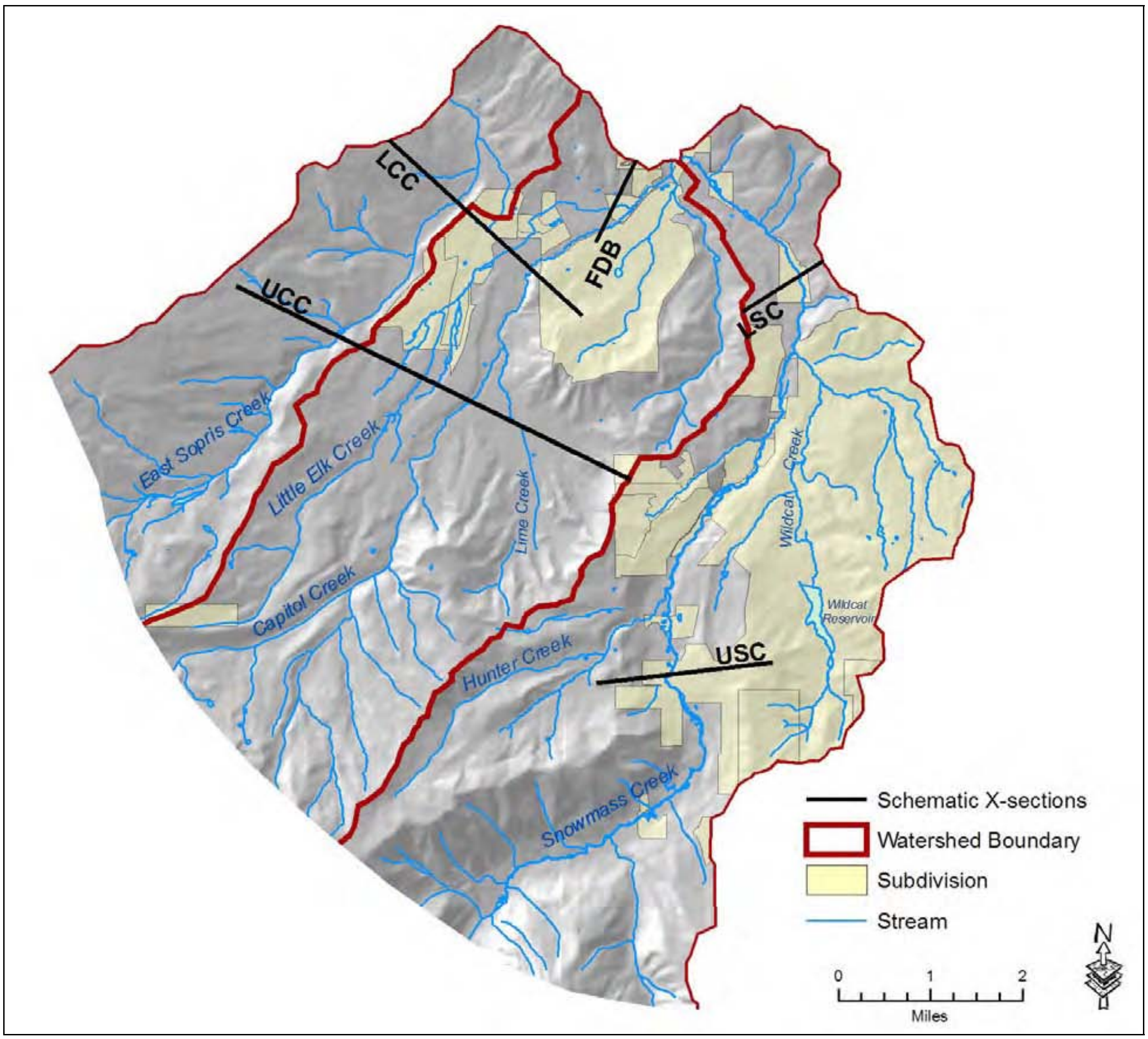

Figure 3. Topography and Surface Water.

Slope aspect of steeper hill sides controls local microclimate and, therefore, the distribution of precipitation, snowmelt, and evapotranspiration. This, in turn, influences the redistribution of available water in time and space between overland flow/interflow and ground water recharge (Kolm and Gillson, 2004). Typically, the south and west facing steep hill slopes are hotter and drier than the north and east facing slopes. These south and west facing slopes will have less winter moisture and snow pack available for the hydrologic system during the spring melt and will have higher evapotranspiration during the growing season. In addition, winter winds are typically westerly, redistributing snow pack to the east facing slopes.

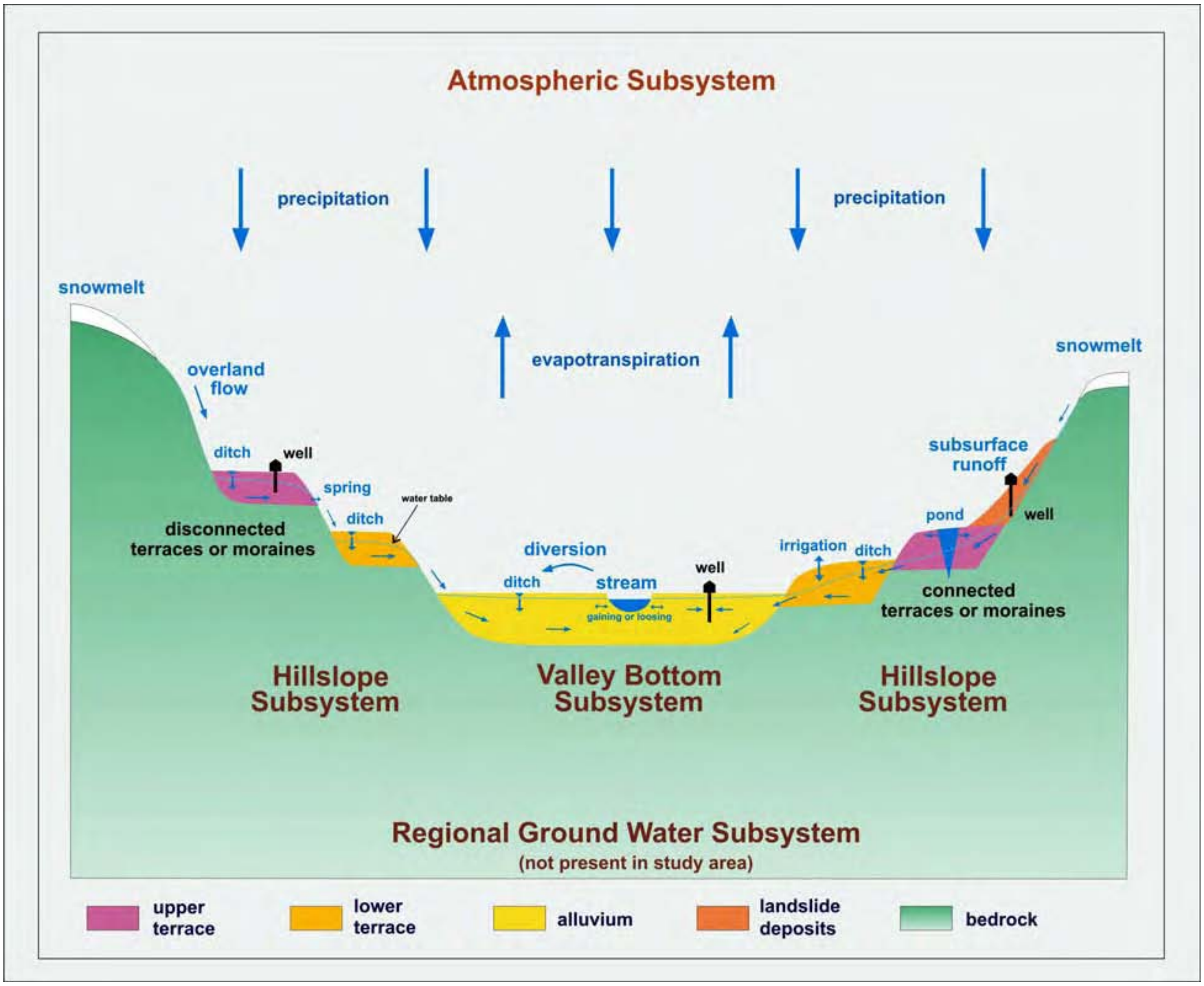

Figure 4. General Conceptual Model of Capitol and Snowmass Creek Ground Water Flow System.

2.1.3 Surface Water Characteristics

The study area contains three watersheds (Figure 3): 1) Snowmass Creek watershed, including Hunter Creek and Wildcat Creek; 2) Capitol Creek watershed, including (Little) Elk Creek and Lime Creek; and 3) East Sopris watershed. Streams can be gaining (from ground water) or loosing (to ground water), dependent on local hydrology and time of year. The study area also contains a reservoir (Wildcat Reservoir), various ponds, and an extensive network of ditches. Many ditches carry water, at least during part of the year. Springs, seeps, and most wetlands are indicators of ground water discharge to the land surface. Many of the irrigation ditches located on the terraces have phreatophytes and seeps, indicative of leaky, unlined ditch perimeters. Non-bottomland ditches can transport water over long distances from the diversion points. Some ditches provide trans-boundary transport of water.

2.1.4 Hydrogeologic Framework

The hydrogeologic framework of the Capitol and Snowmass Creek study area hydrological system has multiple distinct hydrogeologic units, including 6 bedrock units, and 4 unconsolidated units consisting of various Quaternary deposits (Figure 5; Appendix 1) (Bryant 1972; Bryant and Martin 1988; Freeman 1972; Streufert et al 1998; Tweto et al 1978). The Dakota/Burro Canyon, Ft. Hays, and Mancos Sandstone aquifers are unconfined systems near their recharge areas, and confined systems at depth. The various shale layers of Mancos Shale and the Lower Bedrock units, consisting of Morrison and older rocks, are confining layers throughout most of the system. The unconsolidated hydrogeologic units are unconfined aquifers at the subregional scale, and can consist of a variety of aquifers and confining units at the local scale depending on composition (amount of clay, for example). In this study, hydrogeologic units that are considered significant include the saturated, medium- to high- permeability, unconsolidated sediments, and the water-bearing bedrock units with well-connected fracture zones, as well as the low-permeability, confining bedrock units.

Hydro-structures may exist subregionally and locally. Hydro-structures are fault and fracture zones that are observed or hypothesized to transmit ground water either vertically or laterally along the fault or fracture plane or zone. These structures may serve as aquifers, or may connect multiple aquifers together. An example of a major hydrostructure is the Snowmass Creek fault zone, discussed in a forthcoming section of the report.

The major saturated hydrogeologic units consist of: 1) Quaternary landslide, hillslope and sheet wash deposits, and colluvium; 2) glacial gravel deposits, terraces and fans; 3) glacial moraines; and 4) alluvial deposits (Figures 4 and 5). In some specific areas, the Upper and Lower Mancos sandstone, Ft. Hays Limestone, and the Dakota/Burro Canyon bedrock units are aquifers. However, these bedrock units are generally not high-volume, saturated hydrogeologic units of importance in most of the CSC area. Hence, despite their regional presence as geologic units, these units do not represent a regional ground water subsystem (Figures 4 and 5). Deeper bedrock hydrogeologic units, such as the Leadville Fm., are not considered viable as water sources in this area due to costs of acquisition, and due to such issues as drilling depths to water and low well yields.

2.1.5 Ground Water Flow System

The general conceptual model of the ground water flow system consists of inputs and outputs based on climate (infiltration of precipitation and snowmelt), stream functions (gaining or losing), vegetation (evapotranspiration), topography (steepness, aspect, degree of landscape

GIS Layer	Geol Unit Symbol	Geological Unit	Unconsolidated Hydrogeological Unit	Bedrock Hydrogeological Unit	Hydrogeol. Unit Symbol	Hydrostructural Unit	Approx. Thickness
1	Qal	Quarternary Alluvium	Quarternary Alluvium		Qal		varying
2	Qg, Qf, $Qt_{1,2,3}$ & Ts	Quarternary Gravels, Fans & Terraces, & Tertiary Sediments	Quarternary/Tertiary Gravels, Fans & Terraces		Qgf		varying
3	Qm	Quarternary Moraine Deposits	Quarternary Moraine Deposits		Qm		varying
4	Qls, Qc, Qh, Qdfy, Qt & Qcs	Quarternary Landslide Deposits, Colluvium, Hillslope Deposits, Younger Debris Flow Deposits, Talus, & Colluvium & Sheet wash Deposits	Quarternary Landslide, Hillslope and Debris Flow Deposits, & Colluvium		Qlsc		varying
5	Km	Mancos Shale		Mancos Shale - Main Body	Km	Snowmass Creek Fault Zone	main body > 4500ft
6				Upper Sandstone Member [present in eastern part of study area]	Kms		40ft
7				Mancos Shale - Main Body	Km		see above
8				Lower Sandstone Member [present in eastern part of study area]	Kmsl		80ft
9				Mancos Shale - Main Body	Km		see above
10				Fort Hays Limestone member [present across study area]	Kmf		40ft
11				Mancos Shale - Lower Shale Member	Kml		400ft
12	Kd	Dakota Sandstone		Dakota & Burro Canyon Sandstone	Kdb		up to 400ft
	Kb	Burro Canyon Formation					
13	Jmc	Morrison and Curtis Formation		Lower Bedrock [impermeable basis]	LB		

Figure 5. Correlation of Geological, Hydrogeological and Hydrostructural Units in the Capitol and Snowmass Creek Study Area.

dissection), geomorphology and soils, and human activity (irrigation ditches and irrigation, urbanization, ISDS, wells), and geology (Figure 4). Based on the hierarchical approach of Kolm and Langer (2001), no regional system has been identified as being important, and subregional and local scale ground water flow systems dominate in the Capitol and Snowmass Creek study area (Figure 4).

The regional hydrologic inputs include infiltration of precipitation as rain and snowmelt, areas of losing streams and water bodies (reservoirs, ponds), and upland irrigation areas (irrigation return flow). The hillslope subsystem consists of the hydrologic processes of surface runoff (overland flow) and rapid near surface runoff (interflow or shallow through flow) as illustrated with arrows on left slope in Figure 4, saturated ground water flow in parts of the terraces, moraines, and valley bottoms (see water table and corresponding arrows in Figure 4), and discharge to springs and seeps and by plants as evapotranspiration. In general, flow in these systems is towards the valley bottom, perpendicular to the major streams. Where bedrock aquifers intersect hill slopes, local recharge may force the ground water into a more regional pattern determined by geostructure and independent from local topography and hydrography.

The Terrace subsystems have a unique, sometimes complex ground water story, often resulting from human interference as described in subsequent paragraphs and figures of local conceptual models. The Valley Bottom subsystems, where stream-aquifer-wetland interactions occur, are areas of both ground water recharge and discharge (Figure 4). Here, ground water flow can have a rather diffuse character and often aligns more or less with the streams. These subsystems depend primarily on interactions with the Snowmass and Capitol Creeks and subsidiary streams, and the associated wetlands are usually considered riverine given the lack of a supporting regional or subregional ground water system (Figure 4).

2.2 Conceptual Ground Water System Models

There are five general conceptual models within the regional scale context of the CSC area: 1) Upper Snowmass Creek (USC) Subsystem near the White River National Forest boundary; 2) Lower Snowmass Creek (Watson Divide area) (LSC) Subsystem; 3) Upper Capitol Creek (UCC) Subsystem; 4) Lower Capitol Creek (LCC) Subsystem; and 5) Ft. Hays/Dakota-Burro Canyon Bedrock (FDB) Subsystem. The location of representative, generalized cross-sections for these conceptual models are shown in Figure 6. The conceptual models are discussed in forthcoming sections.

2.2.1 Upper Snowmass Creek (USC) Area

There are two significant hydrogeologic units in the USC area: (1) Quaternary unconsolidated materials, which are predominantly glacial, colluvial, and alluvial deposits, overlying (2) Mancos Shale (bedrock confining layer) (Figures 7 and 8). The Quaternary unconsolidated materials are locally heterogeneous, with predominantly coarser materials in the glacial moraine and landslide deposits, and finer materials in the alluvial deposits. The thickness of the sediments ranges from less than 1 ft. to greater than 100 ft. Estimates of hydraulic conductivity (K) ranges from 10 to 100 ft per day (Harlan and others, 1989). The Mancos shale bedrock is the dominant underlying confining layer with small hydraulic conductivity values less than .01 ft per day.

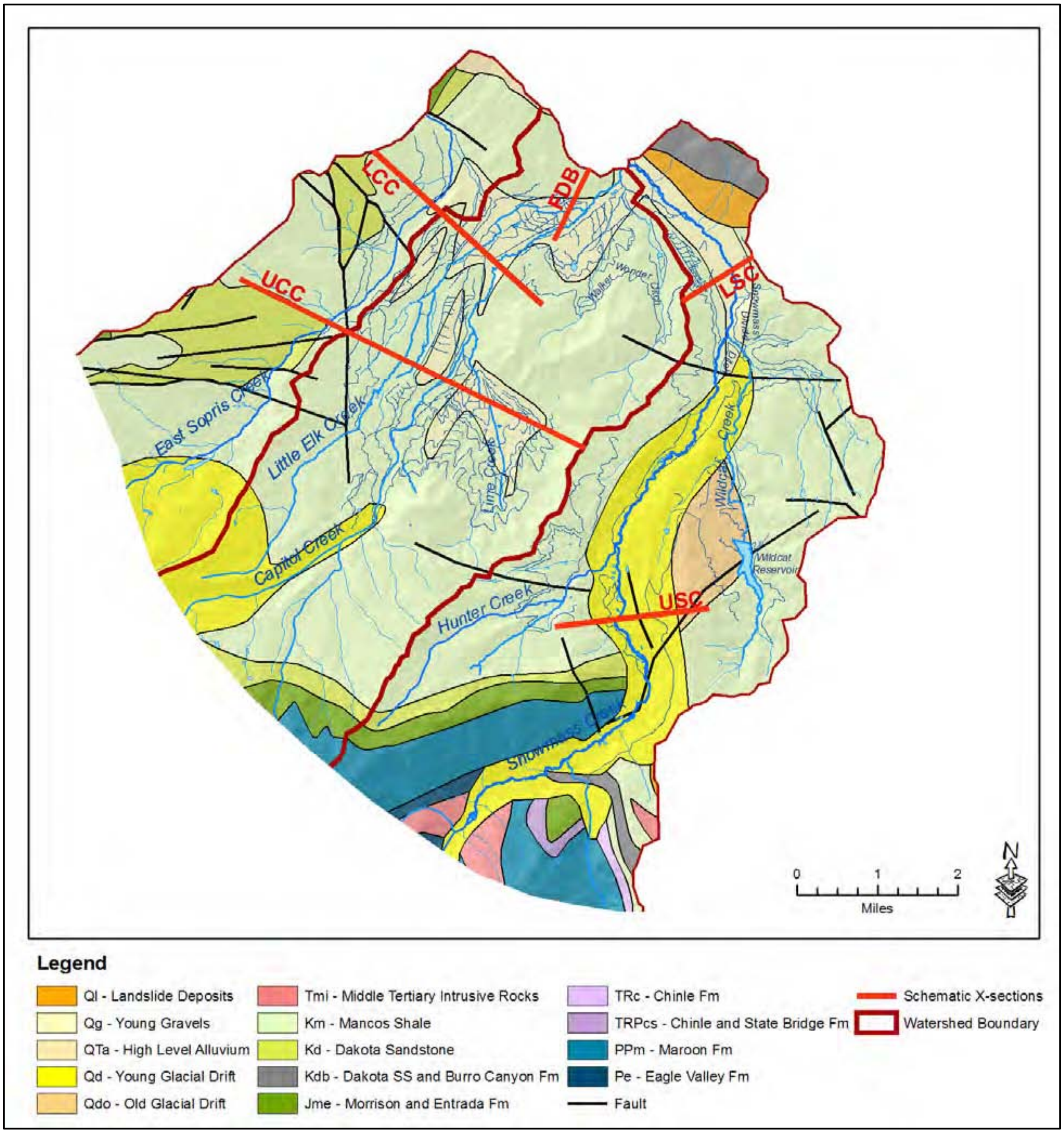

Figure 6. Location CSC Conceptual Models Cross Sections (Geology based on Tweto et al. 1972).

Locally, the thinly bedded Mancos sandstone units may serve as minor aquifers in areas where glacial gravels are not adequate for water supply (Kms in Figure 7). These thinly bedded sandstone units occur mainly on the shale hilltops between Snowmass and Capitol Creeks and have an average thickness of 40ft. Several wells have been drilled or were deepened to reach these units when surficial materials failed to yield sustainable water supplies for various households. In addition, the Ft. Hays Limestone and the Dakota/Burro Canyon units may be sources of water supplies underneath the surface layers of Mancos Shale. Most wells have not tapped these potential aquifers in this area. It is possible that these underlying aquifers may be hydraulically connected to the unconsolidated materials in areas around the Snowmass Creek Fault Zone (Figure 7). Note that the Hunter Creek drainage consists primarily of fan and landslide materials on Mancos Shale.

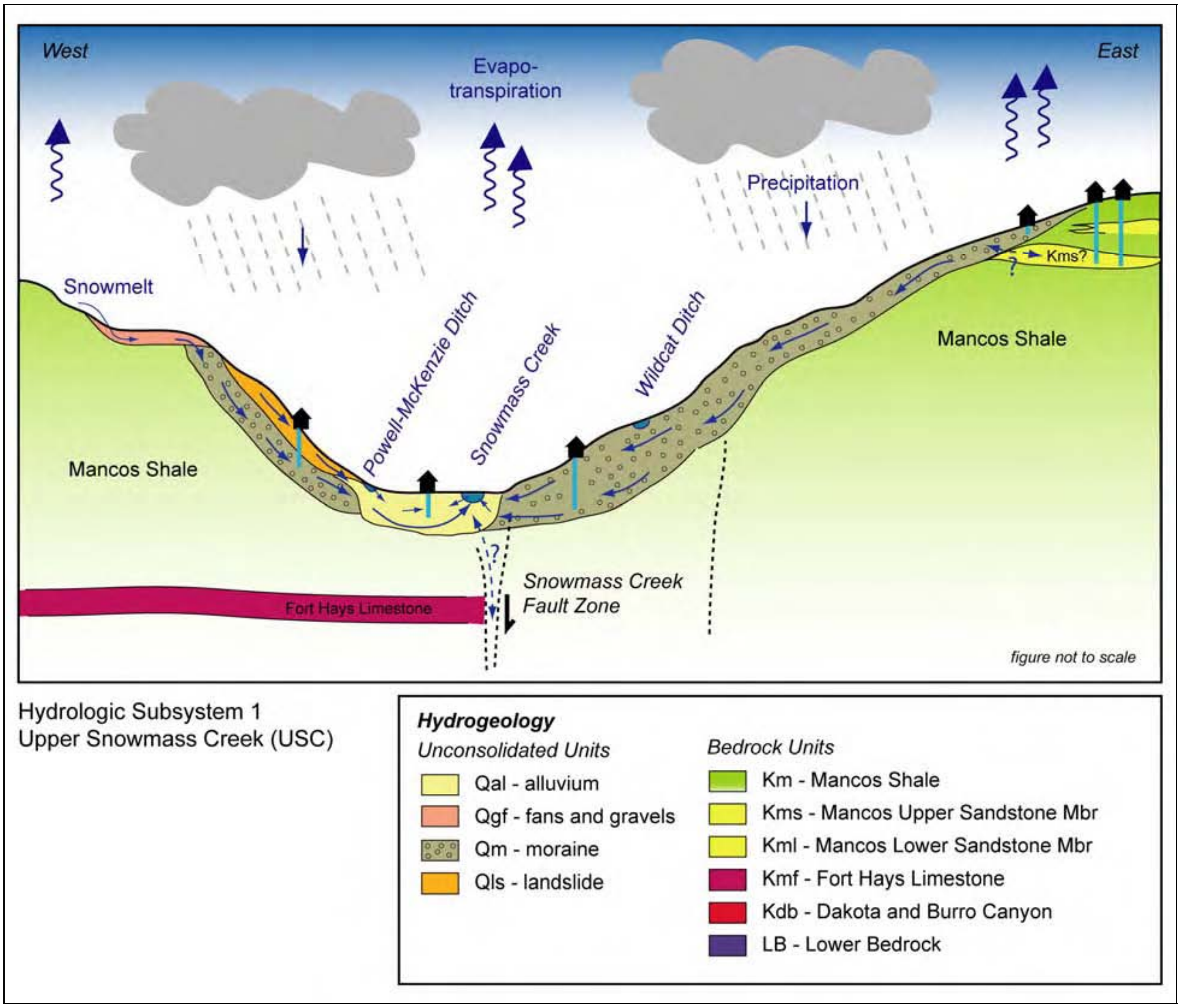

Figure 7. Conceptual Model of the Upper Snowmass Creek (USC) Subsystem.

The Quaternary unconsolidated materials 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 leaky irrigation ditches (Figure 7). The unconsolidated units are variably to fully saturated based on spatial location and seasonal precipitation events. There may be lateral and vertical connection between the Mancos sandstones and the unconsolidated materials in some locations (Figure 7). Otherwise, the Mancos Shale does not allow significant lateral or upward/downward movement of ground water from the Ft. Hays or Dakota/Burro Canyon aquifers into the unconsolidated materials. The unconsolidated units discharge locally into Snowmass Creek (Figure 7). Therefore, the local flow is from the unconsolidated glacial and colluvial materials into unconsolidated alluvium and, finally, to springs, seeps, or Snowmass Creek. Some of the ground water entering the alluvium may run parallel to the stream for some distance before discharging to the stream. Additional discharges from the unconsolidated units occur as evapotranspiration and well withdrawal (Figure 7).

Figure 8. Photograph of Upper Snowmass Creek (USC) Subsystem (looking southeast).

In summary, ground water in the USC may be locally available in the Quaternary unconsolidated materials unit, and to a lesser extend, in the Ft. Hayes and Dakota/Burro Canyon bedrock units. The ground water in the Quaternary unconsolidated materials unit is locally and variably sustainable depending on the climate processes, slope steepness and aspect, and anthropogenic land use. However, this shallow unit is vulnerable as there is no natural protective cover to prevent contaminants from infiltrating into the water supply. The Ft. Hayes and Dakota/Burro Canyon bedrock units may be sustainable for smaller quantities of ground water based on well location and position in the context of a more subregional system. Given the Mancos Shale natural protective cover, these units are vulnerable mostly at the outcrop where recharge processes are occurring.

2.2.2 Lower Snowmass Creek (LSC) Area

There are two significant hydrogeologic units at the LSC site: Quaternary and recent unconsolidated materials (predominantly glacial terrace gravels and modern alluvium) overlying the bedrock unit of the Mancos Shale (Figures 9 and 10). The Quaternary unconsolidated materials are locally heterogeneous, and consist of clay, silt, sand, gravel, cobbles, and boulders. The average thickness is variable, ranging from less than 1 ft to over 100 ft. The estimates of hydraulic conductivity range generally between 1 to 100 ft per day (Harlan and others, 1989). The Mancos Shale underlies most of the unconsolidated units at the LSC site (Figure 9). This bedrock unit has minimal transmissivity and storage, and is considered a confining unit in the LSC hydrologic system. Note that the subsidiary drainages east of Snowmass Creek consist of shallow modern alluvium on Mancos Shale.

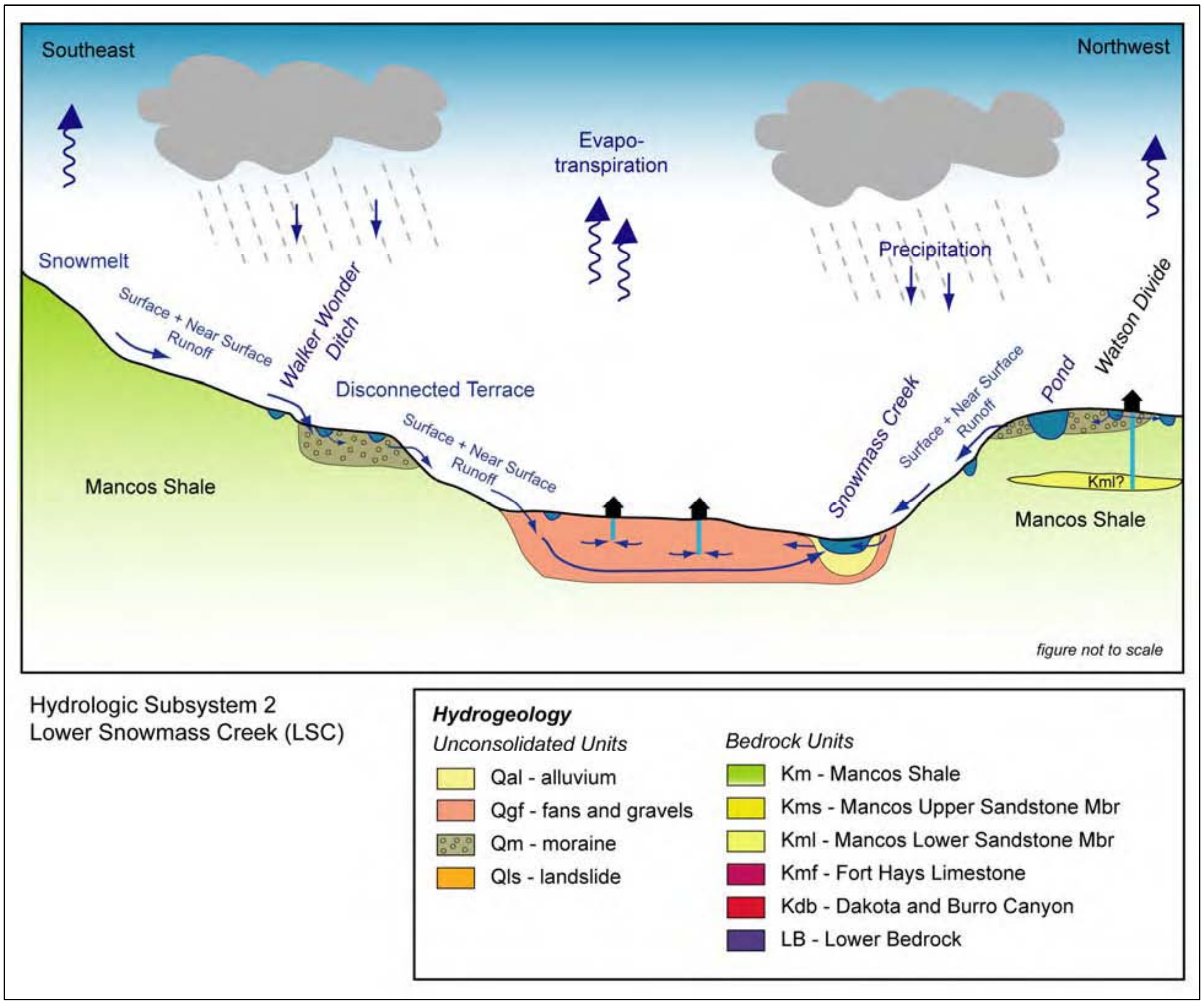

Figure 9. Conceptual Model of the Lower Snowmass Creek (LSC) Subsystem.

The Quaternary unconsolidated materials are recharged by infiltration from precipitation that is non-uniformly distributed due to the location of open areas and position in the landscape. The unconsolidated units are variably to fully saturated based on spatial location and seasonal precipitation events. There is negligible lateral and upward recharge from the underlying bedrock units into the unconsolidated materials in most locations (Figure 9). Ground water in the unconsolidated units laterally recharges the unconsolidated units located topographically below by the interflow and overland flow processes, and the lowest terraces recharge the modern alluvium by interflow (Figure 9). In addition, irrigation ditches located on each terrace are influent (losing) and locally recharges the unconsolidated units as does irrigation return flow (Figure 9).

Ground water in the unconsolidated units discharges locally into streams that cut through the terraces, and from the alluvium into Snowmass Creek. Other sources of discharge from the unconsolidated units include phreatophytes and well withdrawals (Figure 9). It should be noted that surface water sometimes leaves the Snowmass Creek basin due to irrigation ditch diversion, as observed at the Watson Divide.

Figure 10. Photograph of Lower Snowmass Creek (LSC) Subsystem (looking south).

In summary, ground water in the LSC may be locally available in the Quaternary and Recent unconsolidated materials units. The ground water in these unconsolidated materials units is locally and variably sustainable depending on the climate processes, slope steepness and aspect, connection to Snowmass Creek, and anthropogenic land use (notably irrigations ditches). However, these shallow units are vulnerable as there is no natural protective cover to prevent contaminants from infiltrating into the water supply, or from leaking into the aquifers from irrigation ditches or Snowmass Creek.

2.2.3 Upper Capitol Creek (UCC) Area

There are two significant hydrogeologic units at the UCC site: Quaternary and recent unconsolidated materials (predominantly glacial terrace gravels, glacial moraines, and modern alluvium) overlying the bedrock unit of the Mancos Shale (Figures 11 and 12). The Quaternary unconsolidated materials are locally heterogeneous, and consist of clay, silt, sand, gravel, cobbles, and boulders. The average thickness is variable, ranging from less than 1 ft to over 100 ft. The estimates of hydraulic conductivity range generally between 1 to 100 ft per day (Harlan and others, 1989). The Mancos Shale underlies most of the unconsolidated units at the UCC site (Figure 11). This bedrock unit has minimal transmissivity and storage, and is considered a confining unit in the UCC hydrologic system.

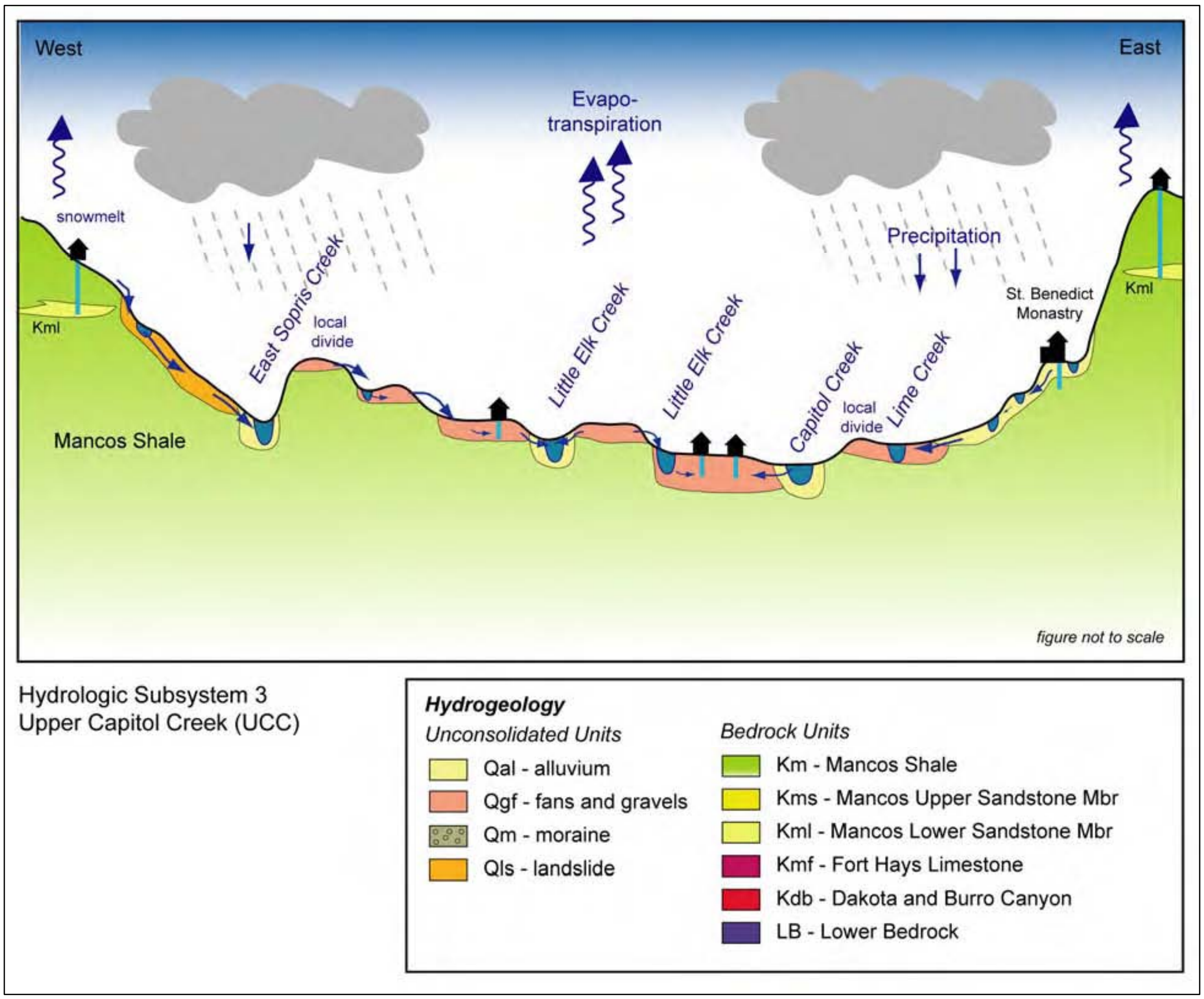

Figure 11. Conceptual Model of the Upper Capitol Creek (UCC) Subsystem.


Figure 12. Photograph of Upper Capitol Creek (UCC) Subsystem (looking east to Lime Creek valley).

Quaternary unconsolidated materials are recharged by infiltration from precipitation that is non-uniformly distributed due to the location of open areas and position in the landscape. Locally, ground water may be recharged by leaking irrigation ditches and irrigation return flow. The unconsolidated units are variably to fully saturated based on spatial location and seasonal precipitation events. There is negligible lateral and upward recharge from the underlying bedrock units into the unconsolidated materials in most locations. Ground water in the unconsolidated units laterally recharges the unconsolidated units located topographically below by the interflow and overland flow processes. Likewise, the lowest terraces recharge the modern alluvium by interflow and overland flow (Figure 11). In addition, ditches located on each terrace are influent (losing) and, together with irrigation return flow, locally recharges the unconsolidated units (Figure 11). Note that the subsidiary Lime Creek watershed consists primarily of alluvium on Mancos shale with landslide and fan deposits at the lower surrounding slopes (Figure 11 and 12).

Ground water in the unconsolidated units discharges locally into streams that cut through the terraces, and from the alluvium into both East Sopris Creek and Capitol Creek. Other sources of discharge from the unconsolidated units include phreatophytes (evapotranspiration) and well withdrawals. It should be noted that ground water does not flow from East Sopris Creek into the Capitol Creek basin due to the presence of the Mancos Shale ridge between the two watersheds (Figure 11). However, ground water may flow between ephemeral Little Elk Creek and perennial Capitol Creek (both as surface water and as ground water), and between ephemeral Lime Creek and perennial Capitol Creek depending on location and season.

In summary, ground water in the UCC may be locally available in the Quaternary and recent unconsolidated materials units. The ground water in these unconsolidated materials units is locally and variably sustainable depending on the climate processes, slope steepness and aspect, and anthropogenic land use (notably irrigations ditches). However, these shallow units are vulnerable as there is no natural protective cover to prevent contaminants from infiltrating into the water supply, or from leaking into the aquifers from irrigation ditches.

2.2.4 Lower Capitol Creek (LCC) Area

There are two significant hydrogeologic units at the LCC site: Quaternary and recent unconsolidated materials (predominantly glacial terrace gravels, mass wasting deposits, and modern alluvium) overlying the bedrock unit of the Mancos Shale (Figures 13, 14 and 15).

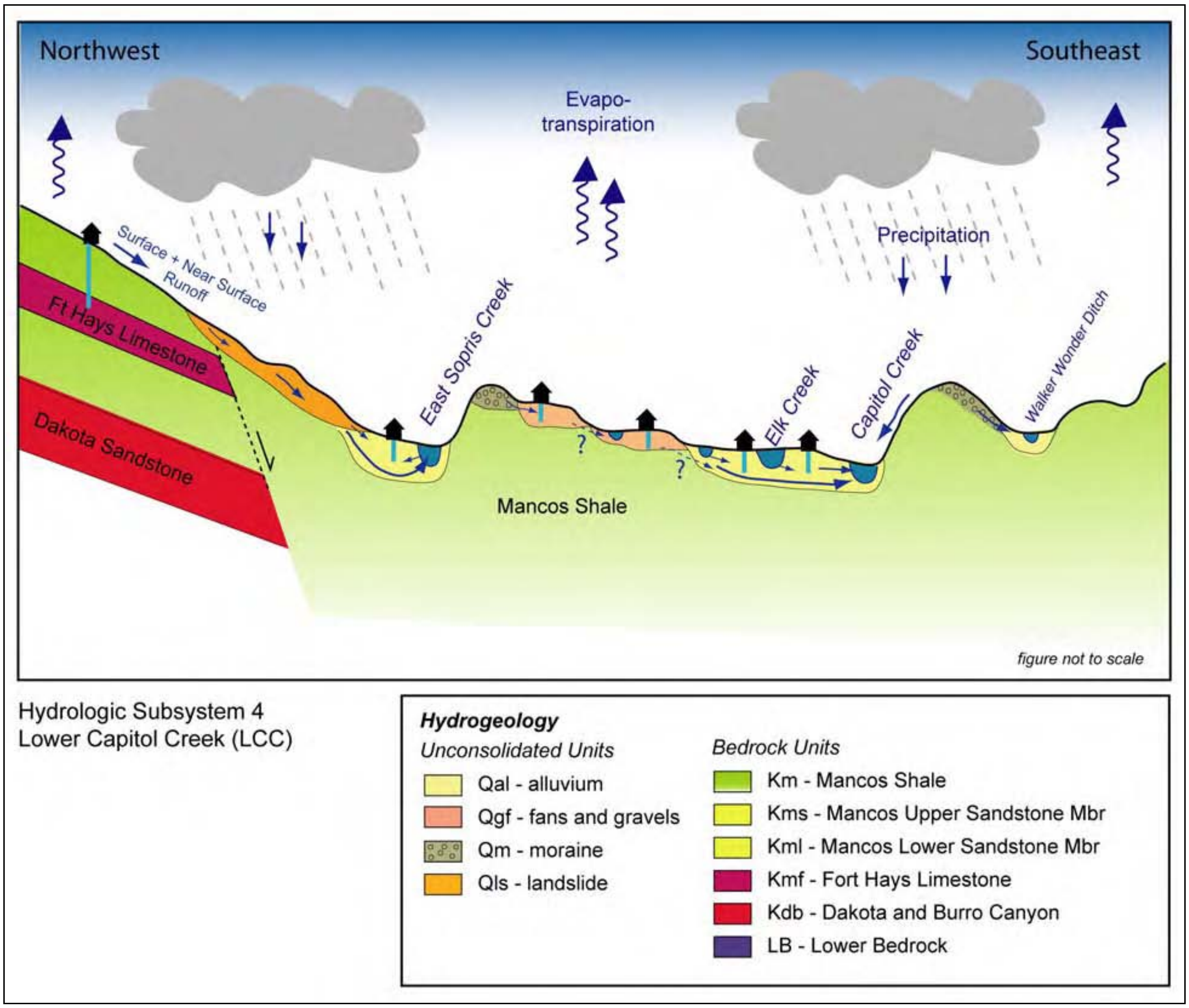

Figure 13. Conceptual Model of the Lower Capitol Creek (LCC) Subsystem.

The Quaternary unconsolidated materials are locally heterogeneous, and consist of clay, silt, sand, gravel, cobbles, and boulders. The average thickness is variable, ranging from less than 1 ft. to greater than 100 ft. The estimates of hydraulic conductivity range generally between 1 to 100 ft per day (Harlan, and others, 1989). The Mancos Shale underlies most of the unconsolidated units at the LCC site (Figure 13). This bedrock unit has minimal transmissivity and storage, and is considered a confining unit in the LCC hydrologic system. Note that the terraces identified on the geologic map of the Basalt quadrangle (Streufert et al., 1998) as Qt1, Qt2, and Qt3 are classified as hydrogeologic unit Qgf.

Figure 14. Photograph of Lower Capitol Creek (LCC) Subsystem (looking southwest).

The Quaternary unconsolidated materials are recharged by infiltration from precipitation that is non-uniformly distributed due to the location of open areas, irrigation ditch location, and position in the landscape. The unconsolidated units are variably saturated based on spatial location and seasonal precipitation events. There is negligible lateral and upward recharge from the underlying bedrock units into the unconsolidated materials in most locations (Figure 13). Ground water in the unconsolidated terrace units laterally recharges the unconsolidated terrace units located topographically below by ground water flow through mass wasting units, and the lowest terraces and mass wasting units recharge the modern alluvium by ground water flow (Figure 13). In addition, ditches located on each terrace or mass wasting unit are influent (losing) and locally recharges the unconsolidated units (Figure 13).

Ground water in the unconsolidated units discharges locally into streams that cut through the terraces, and from the alluvium into East Sopris and Capitol Creeks. Other sources of discharge from the unconsolidated units include phreatophytes and well withdrawals (Figure 13). It should be noted that ground water does not flow from East Sopris Creek directly into the Capitol Creek basin (Figure 13). However, ground water may flow between the Little Elk Creek and Capitol Creek, depending on location. In addition, surface water may leave the East Sopris Creek basin into the Capitol Creek basin due to irrigation ditch diversion, as observed at the East Sopris Creek Divide (Figures 14 and 15). Additionally, water may enter the Capitol Creek basin from the Snowmass Creek basin due to irrigation ditch diversion, as observed at the Walker Wonder Ditch (Figure 13).

Figure 15. Photograph of the East Sopris-Capitol Creek Divide (looking southwest).

In summary, ground water in the LCC may be locally available in the Quaternary unconsolidated materials units. The ground water in these unconsolidated materials units is locally and variably sustainable depending on the climate processes, slope steepness and aspect, and anthropogenic land use (notably irrigations ditches). However, these shallow units are vulnerable as there is no natural protective cover to prevent contaminants from infiltrating into the water supply, or from leaking into the aquifers from irrigation ditches.

2.2.5 Ft. Hays/Dakota-Burro Canyon Bedrock (FDB) Area

There are two significant hydrogeologic units at the FDB site: The Ft. Hays limestone, and the Dakota/Burro Canyon sandstone bedrock units (Figures 16 and 17; note that the Capitol Creek/Little Elk Creek system depictured in Figure 16 is described in section 2.6.4). The Ft. Hays limestone has an average thickness of about 40ft. The Dakota/Burro Canyon Sandstone has an average thickness of about 425ft. Mancos Shale underlies and overlies these bedrock units at the FHB site (Figure 16). The Mancos Shale bedrock unit has minimal transmissivity and storage, and is considered a confining unit in the FDB hydrologic system.

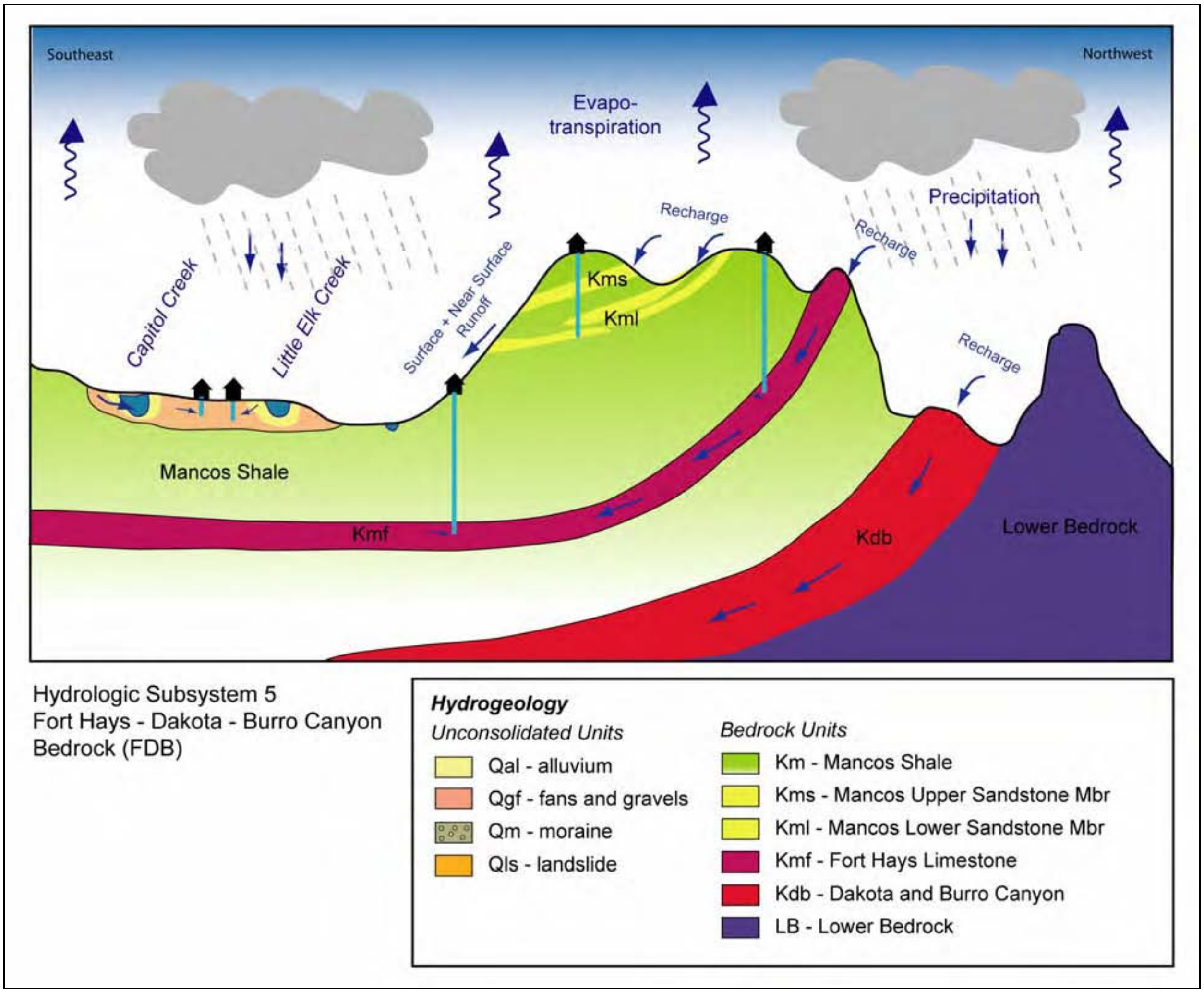

Figure 16. Conceptual Model of the Ft. Hays/Dakota-Burro Canyon Bedrock (FDB) Subsystem.

The Ft. Hays and Dakota/Burro Canyon aquifers are recharged by infiltration from precipitation, predominantly at the outcrop areas (Figure 16), that is non-uniformly distributed due to the location of open areas and position in the landscape. These bedrock units are unconfined at the outcrop areas, and become confined as the aquifers dip into the subsurface (Figure 16). There is negligible lateral and upward recharge from the underlying bedrock units into these bedrock units in most locations.

Ground water flow in the Ft. Hays and Dakota/Burro Canyon aquifers naturally follows the downward slope of the aquifer and discharges outside of the CSC area. Other points of discharge from the bedrock units are well withdrawals (Figure 16). It should be noted that this ground water is primarily used in an older subdivision located topographically high above the confluence of Snowmass and Capitol Creeks (Figure 17).

Figure 17. Photograph of Subdivision on FDB Subsystem (looking northwest).

In summary, ground water in the FDB may be locally available in the Ft. Hayes and Dakota/Burro Canyon bedrock units. The Ft. Hayes and Dakota/Burro Canyon bedrock units may be sustainable for smaller quantities of ground water based on well location and position in the context of a more subregional system. Given the Mancos Shale natural protective cover, these units are vulnerable mostly at the outcrop where recharge processes are occurring.

2.3 Anthropogenic Influences

Human activity in hill slope and valley bottom subsystems in the 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 has resulted in removal of native vegetation, introduction of irrigation, construction of (often leaking) irrigation ditches, and drilling of primarily domestic wells. More recent human activity included the development of residential subdivisions, resulting in changes in ditch water allocation patterns, increased well pumping and ISDS density, reduced pasture and crop irrigation, increased garden watering, and modification of vegetative cover and related evapotranspiration.

There are numerous ditches in the study area (Figure 18). These are mostly unlined. They may have been excavated in unconsolidated Quaternary deposits, weathered shale, or more solid shale. When carrying water, the ditches may leak, as evidenced by the phreatophytes often found lining the ditch trajectories. The ditch system in the study area contain two types of ditches: 1) primary ditches, carrying water during most of the growing season; and 2) secondary ditches, carrying water only during an actual irrigation cycle. The water leaking from the ditches may be used by vegetation discharging as evapotranspiration, or it may recharge the ground water forming a local ground water mound. As most of the ground water systems in the study area are rather local in nature, ditch leakage may contribute significantly to the local water balance, increase the water table elevation, and alter ground water flow directions.

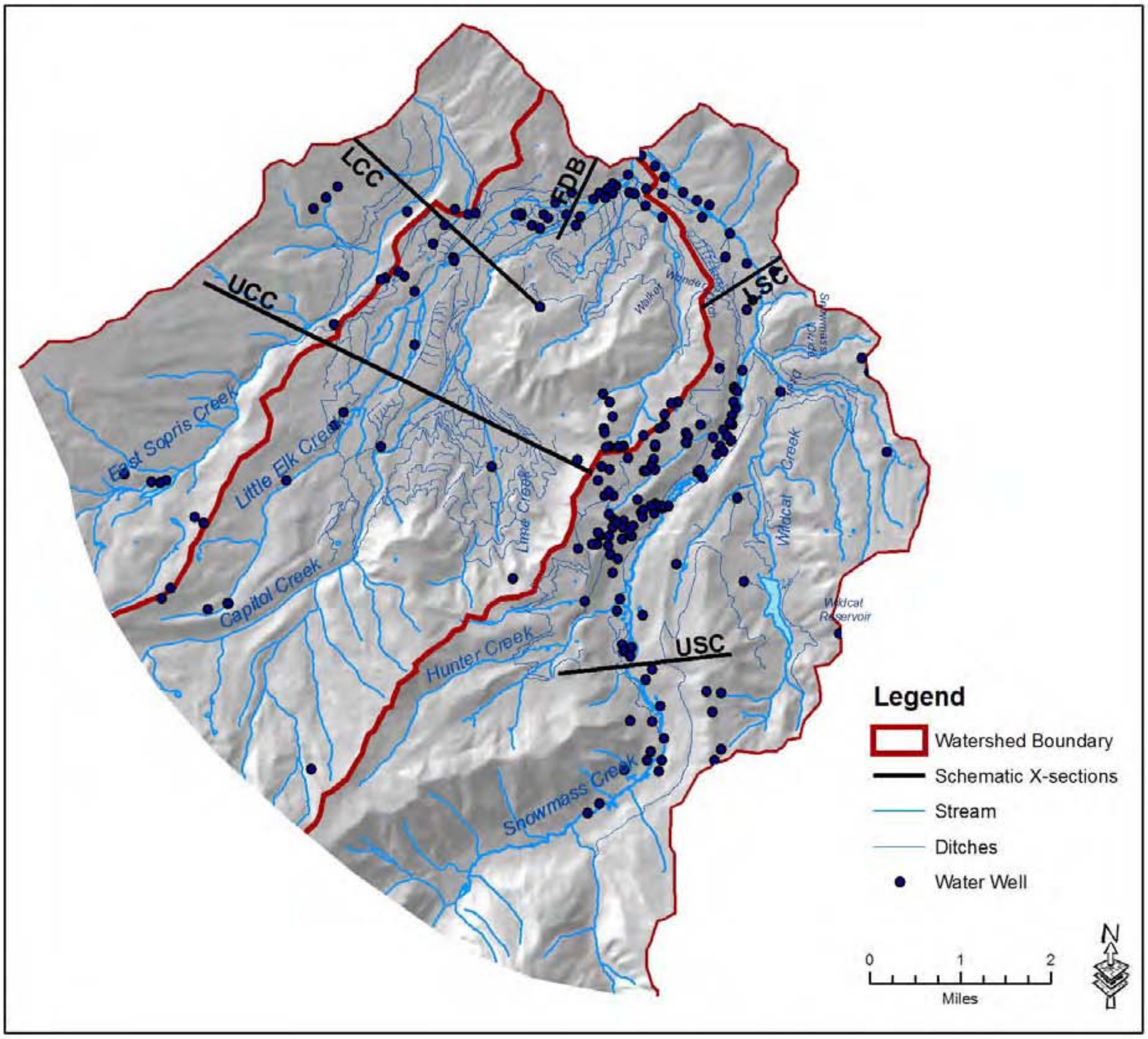

Figure 18. Streams, Ditches, and Wells in the CSC Study Area.

The wells in the study area are clustered along Snowmass Creek, the lower reach of Capitol Creek, the subdivision above the Capitol-Snowmass Creek confluence, and on the ridge between the upper Capitol and Snowmass Creek watersheds (Figure 18). As most of these wells serve domestic water supply needs, their individual influence on the ground water system is limited. However, when they are clustered, as identified above, their accumulated effect on the ground water system may be significant, resulting in a possible lowering of the water table, changes in flow direction, decreasing discharge to streams or increasing stream loss to ground water, draining of wetlands, or even depletion of local aquifers. Well records filed with the State Engineer Office indicate local depletion requiring significant deepening of well bores.


Figure 19. Photograph of Irrigation on Valley Bottoms and Terraces in the Lower CSC area (looking south).


Figure 20. Photograph of a Pond near the Watson Divide (looking southwest).

Other human interaction with the ground water flow system include recharge from ISDS, recharge from irrigation return flow (Figure 19), and recharge from (leaking) ponds (Figure 20). Irrigation return flow can be a significant recharge element in the local ground water balance. Taking irrigated fields out of production may cause a lowering of the water table and reduction in ground water flow velocities. Leaking ponds act like leaking ditches, causing mounding of the water table, increased recharge of ground water system, and changes in flow direction.

2.4 Summary

The hydrogeologic framework of the Capitol and Snowmass Creek (CSC) study area hydrological system has multiple distinct hydrogeologic units, including 6 bedrock units, and multiple unconsolidated units consisting of various Quaternary and Tertiary deposits. The Quaternary glacial moraines, terrace gravels, and modern alluvium comprise the major source aquifers of interest, and the Dakota/Burro Canyon, Ft. Hays, and Mancos Sandstone aquifers are the bedrock units that serve as minor aquifers.

The general conceptual model of the ground water flow system consists of inputs and outputs based on climate (infiltration of precipitation and snowmelt); stream functions (gaining or losing), springs and seeps; vegetation and wetlands (evapotranspiration); topography (steepness, aspect, degree of landscape dissection), geomorphology and soils; human activity (irrigation ditches and irrigation, ponds and reservoirs, urbanization, ISDS); and geology. Based on the hierarchical approach of Kolm and Langer (2001), no regional system has been identified as being important, whereas subregional and local scale ground water flow systems are important in the Capitol and Snowmass Creek study area.

Based on field work and HSA, five general conceptual models are identified within the regional scale context of the CSC area: 1) Upper Snowmass Creek (USC) Subsystem near the White River National Forest boundary; 2) Lower Snowmass Creek (Watson Divide area) (LSC) Subsystem; 3) Upper Capitol Creek (UCC) Subsystem; 4) Lower Capitol Creek (LCC) Subsystem; and 5) Ft. Hays/Dakota-Burro Canyon Bedrock (FDB) Subsystem. Each of the five subsystems has a unique set of system parameters. In general, the most important anthropogenic hydrologic system parameters are ground water recharge from irrigation return flow and irrigation ditches and ground water discharge from wells. If water rights and allocations should change for these ditches, the hydrodynamics of the Quaternary glacial and alluvial aquifers would change, and water supplies from ground water may decline or vanish. These considerations will be discussed in the forthcoming report sections integrating the GIS-based analysis and maps with the Hydrologic System Conceptual Model.

3.0 GIS Map, Layers, 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, landuse, 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 randomly visualize (switch) between layers; and the availability of advanced search, selection and overlay capabilities further enhances the utility of a GIS map.

The GIS-based evaluation of ground water resources in the CSC study areas makes extensive use of the aforementioned GIS capabilities. The database formats we have used in this study include: ESRI shape files, database tables (e.g., the well database), georeferenced images (e.g., aerial photographs and topographic maps) and ESRI GRID file (for the digital elevation model (DEM)). Hyperlinks have been included from the map to scanned images of a selected set of well descriptions.

The GIS map and database for the CSC study were prepared using ArcGIS™ (ESRI®, Redlands, California), and requires ArcGIS™ version 8.3 or higher to utilize. The ArcGIS system contains three components: ArcMap, ArcCatalog and ArcToolbox. ArcCatalog is specifically used as a GIS data browser and data management tool. ArcMap is used to view and analyze GIS data and compile maps serving a particular application. ArcToolbox is the component of ArcGIS which is primarily used for data conversion operations. For applying the ground water resources evaluation procedure in the CSC study area, the use of ArcMap is sufficient. A good reference on and introduction to the ESRI ArcGIS system is the book "Getting Started with ArcGIS™" (ESRI, 2002).

3.2 Use of GIS in CSC Study

In this report, the ground water resources evaluation procedure developed by HSA/HHI for Pitkin County *(HSA/HHI 2006)* has been applied to the CSC study area using a multi-layer GIS map [file: PitkinCounty_GWGIS_CSC.mxd] (Figure 21). The GIS map consists of a number of layers representing various data types relevant to the assessment of the ground water resources at user-specified locations. Below is a detailed description of the layers and the related data sources.

The GIS layers of the CSC map contain four types of geographic information: 1) general geographic information (county border, roads, parks, parcels, structures, etc.); 2) hydrologic information (precipitation, streams, lakes/ponds, ditches, irrigated areas); 3) hydrogeologic information (alluvial aquifer, hydrogeologic units, wells); and 4) topographic information (topo maps, DEM, 10ft elevation contours). Type 1 information is used to locate the site of interest and obtain some general geographic data. Type 2 and Type 3 information is integral to the evaluation of ground water resources. Type 4 information provides elevation and background data as needed. All layers have been georeferenced with respect to Pitkin County's projection and datum: State Plane, Colorado Central Zone, NAD83 (units of measure in feet).

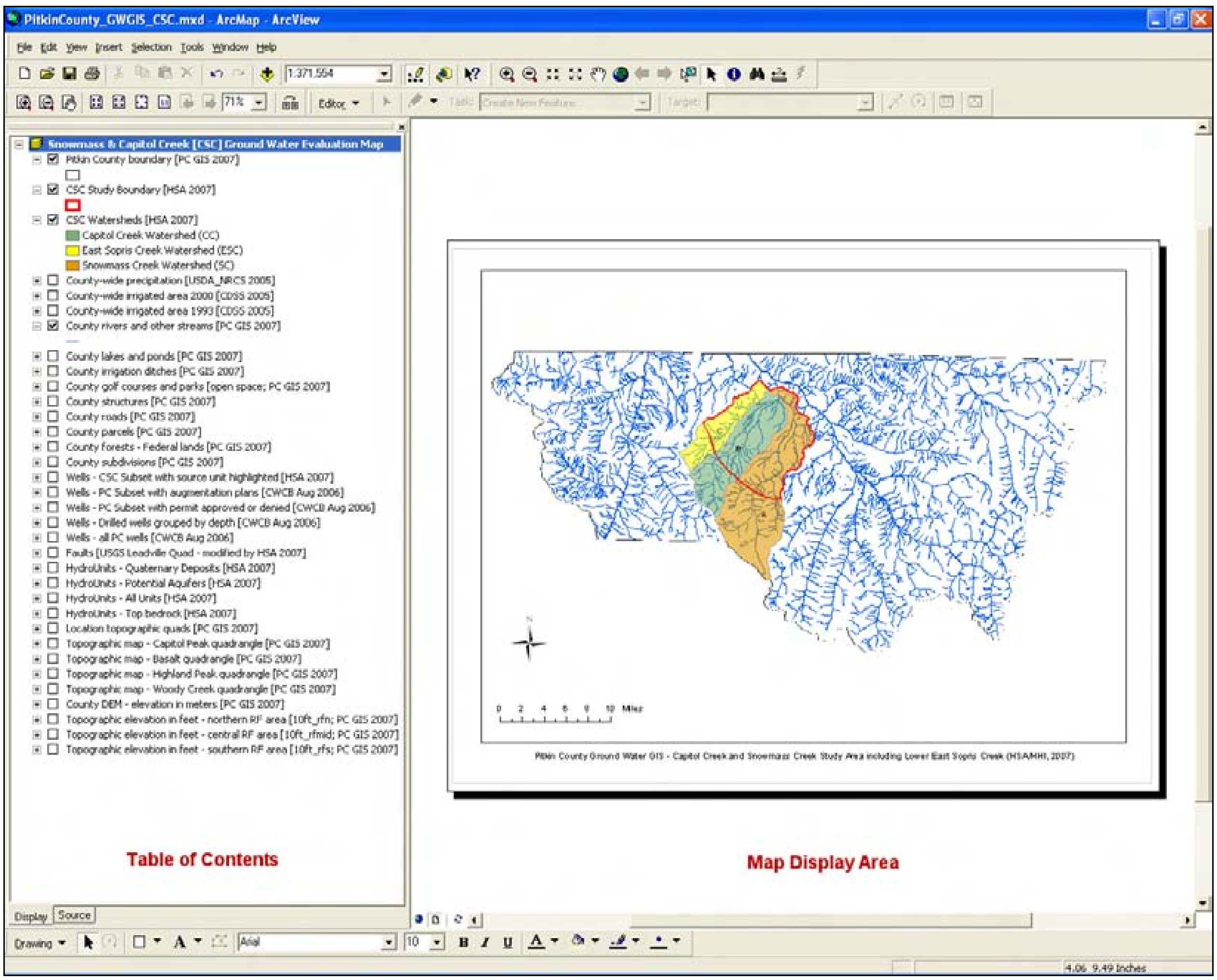

Figure 21. Pitkin County GIS Map with CSC Study Area, CSC Watersheds and County-wide Stream Layer.
(ESC - East Sopris Creek Watershed; CC - Capitol Creek Watershed; SC - Snowmass Creek Watershed)

3.3 GIS Map, Layers, and File Structure

The CSC GIS map consists of a *Table of Contents* (the left display area of Figure 21) and a *Map Display* area (the right display area of Figure 21). Each line in the table of contents 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, details of the layer's features become visible in the map display area (e.g., Figure 22). A layer may consist of point values (e.g., wells), line features (e.g., roads, streams, ditches), and area features (e.g., watersheds, areas of equal precipitation, areas with a particular hydrogeologic unit). Right-clicking on the layer and selecting the *open attribute table* option, provides additional information on the layer (Figure 22).

The layers in the CSC GIS map are purposely listed in the order as shown in Figure 21 to enable the use of the GIS based ground water resources assessment procedure described in Chapter 4 of this report. When enabled, a layer is shown on top of the layer listed below it in the table of contents. 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. The order of the layers can be changed by the user by dragging a layer to the desired location in the table of contents.

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.

3.4 Data Sources

The CSC ground water GIS map calls up various files included in five relative-path subdirectories: 1) NRCS_Data_Gateway; 2) Colorado_DSS; 3) Pitkin_County_GIS; 4) HSA_PCGIS; and 5) Wells_DWRSC_Pitkin. The directories reflect the various data sources used for the map. Selection of the relative-path option of ArcMAP provides for straightforward portability between computers. Note, that files that represent state-wide or multi-county data have been clipped to show only the Pitkin County area coverage (e.g., Colorado DSS and NRCS files).

The *NRCS_Data_Gateway* subdirectory contains county-wide annual precipitation data from the Natural Resources Conservation Service of the USDA (*precip_a_co* files). These data have been developed using PRISM (Parameter elevation Regression on Independent Slopes Model) which utilizes a rule-based combination of point measurements and a digital elevation model (DEM). A description of PRISM can be found in the *PRISGUID.PDF* file in the metadata subdirectory *(Daly and Johnson, 1999)*. The NRCS data source can be found at:

http://datagateway.nrcs.usda.gov/GatewayHome.html. Layers based on these data are referenced in the GIS map as *USDA_NRCS 2005* (Figure 22).

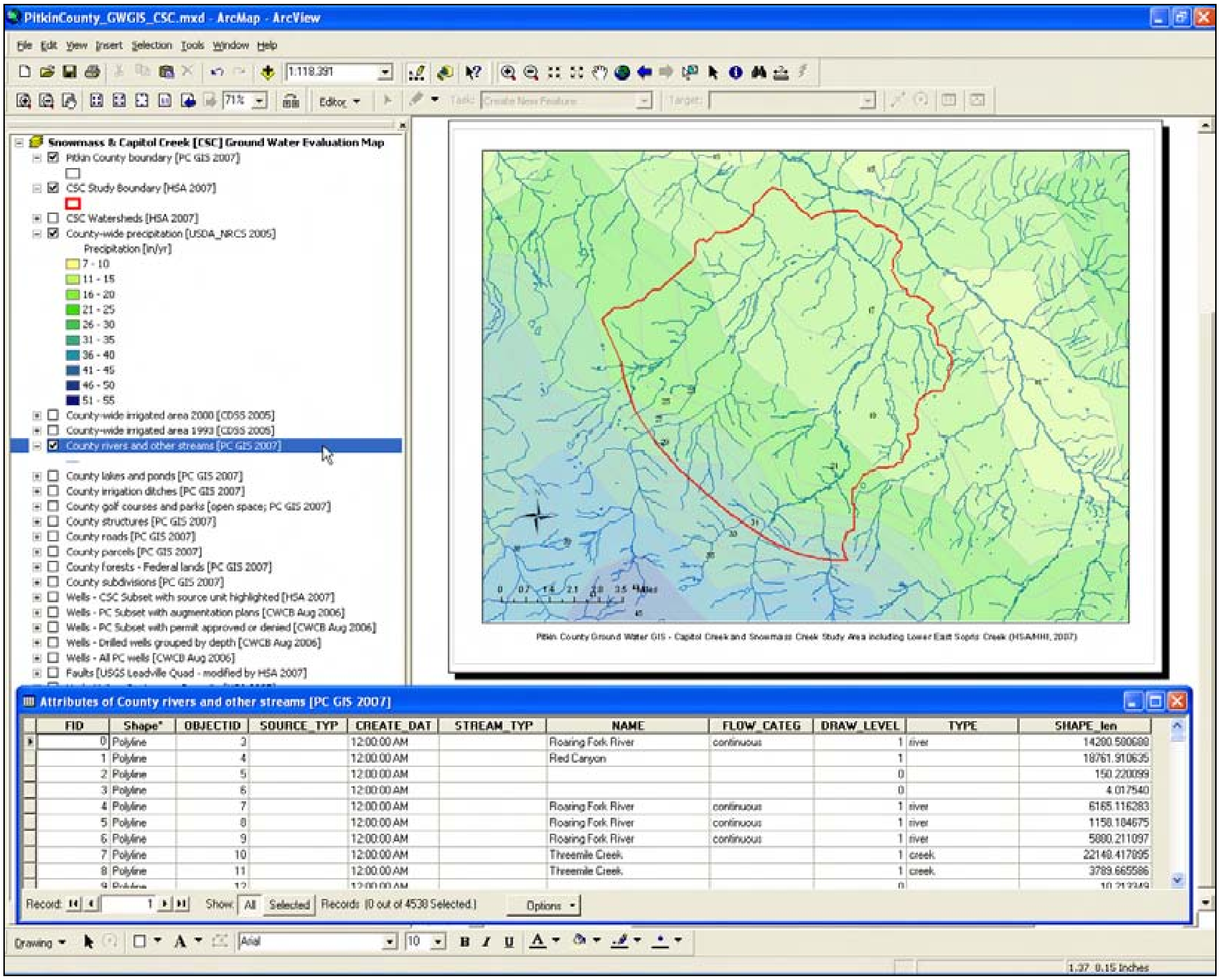

Figure 22. Pitkin County GIS Map with CSC Study Area and County-wide Precipitation and Attribute Table for Streams Layer.

The *Colorado_DSS* subdirectory contains 2 sets of GIS files downloaded from the Colorado Decision Support System (CDSS), which is under development by the Colorado Water Conservation Board and the Colorado Division of Water Resources (http://165.127.23.116/website/cdss/). These file sets are: 1) irrigated areas on the Western Slope as of 1993 (*WS_Irrig_93* files); and 2) irrigated areas on the Western Slope as of 2000 (*WS_Irrig_2000* files). Layers based on these data are referenced as *CDSS 2005*. Initially, a third layer from the CDSS was considered, showing the state-wide presence of an alluvial aquifer. The information incorporated in this CDSS layer is based on *Topper et al. (2003)* and resulted from the digitizing and analyzing of existing 1 by 2 degree (1:250,000 scale) geologic quadrangle maps for Colorado to map alluvial deposits excluding aeolian, glacial drift, and landslide deposits. However, the scale of this state-wide map is not sufficient to assist in the evaluation of ground water resources in the CSC area. Therefore, this layer is not included in the CSC GIS map.

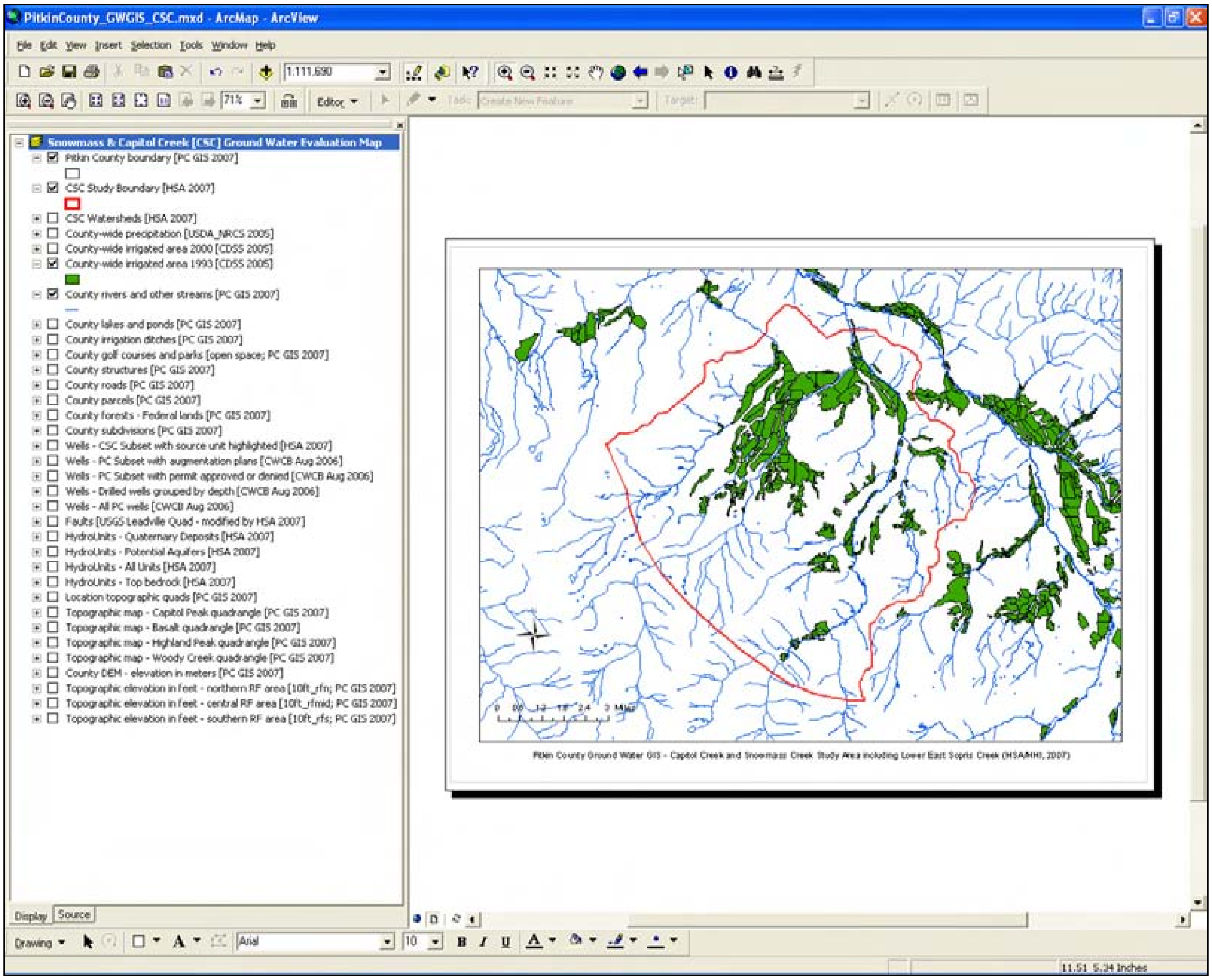

Figure 23. Pitkin County GIS Map with CSC Study Area and the CDSS 1993 Irrigation Layer.

The irrigated areas layers are based on compilations of the irrigated lands data from the 4 Western Slope Divisions of the Colorado Division of Water Resources. These data sets provide a single year snapshot of the irrigated lands and crop types of the western slope of Colorado (Figures 23 and 24). In Figure 24, the 2000 data layer lies on top of the 1993 data layer, showing the irrigated acreage taken out between 1993 and 2000 in pink. According to the 2005 Annual Report of the CDSS, a new compilation of the irrigated land data is planned, covering the 2006 irrigation season.

The *Pitkin County GIS* subdirectory contains the shape, DEM and DRG files from the Pitkin County GIS as well as the relevant meta files as received in February 2007. Coverages include county border and area, roads, streams, lakes and ponds (waters layer), (irrigation) ditches, parcels, subdivisions, structures, forest and open space coverage, 10ft elevation contours for selected areas, topographic maps, and the county-wide digital elevation model (DEM). Examples of layers based on these data are presented in Figures 25, 26, and 27. Note that the ditch layer includes active and non-active ditches, and primary, secondary and tertiary ditches, but the distinction between active and inactive ditches as well as size of the ditches cannot be determined within this GIS layer. Additional field verification is needed to assess the hydrologic importance of individual ditches. Pitkin County's GIS data were made available to HSA by the County as part of the project agreement. Layers based on these data are referenced as *PC_GIS 2007*.

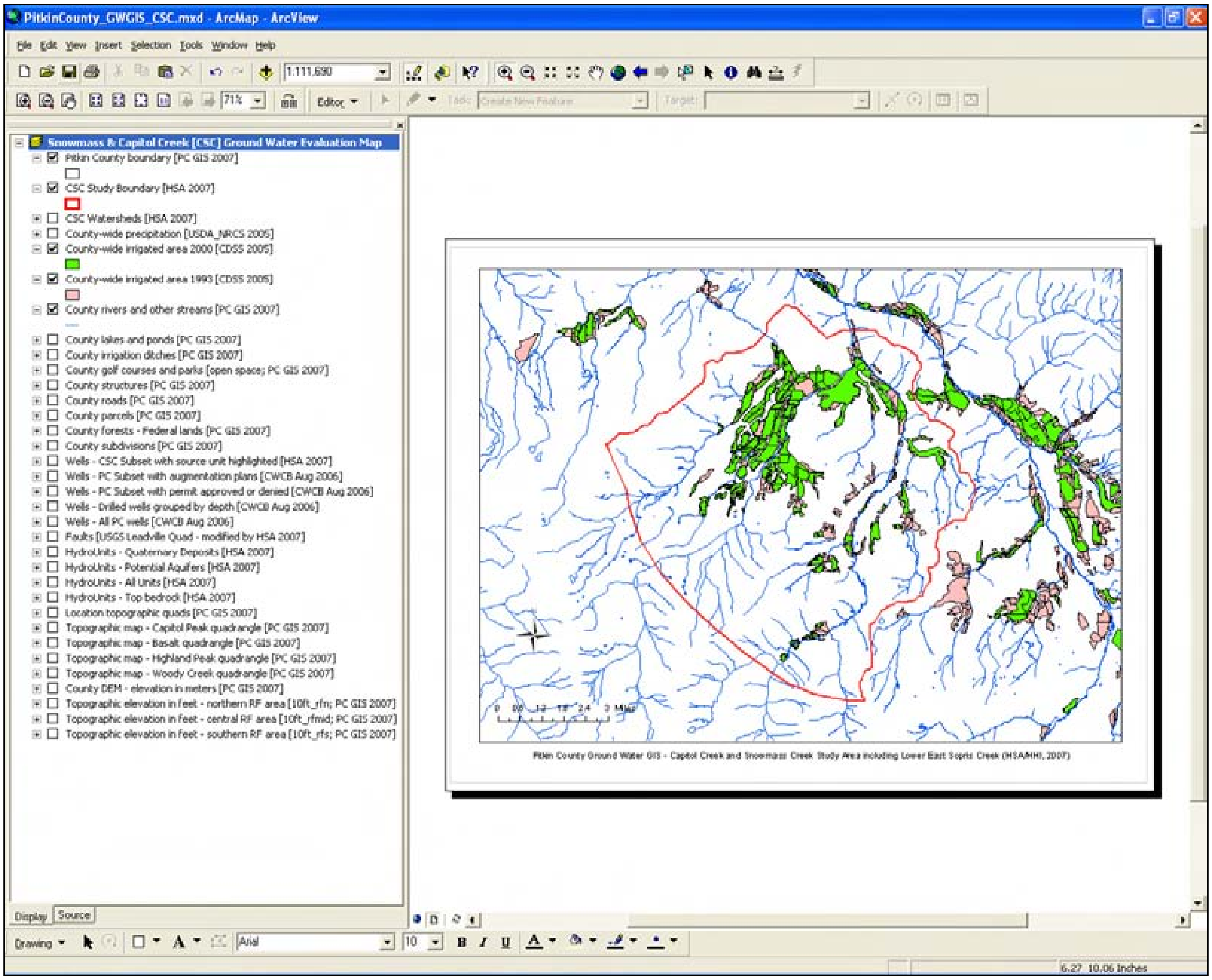

Figure 24. Pitkin County GIS Map with CSC Study Area and the CDSS 2000 Irrigation Layer (Green) Overlaying the 1993 Irrigation Layer (Pink).

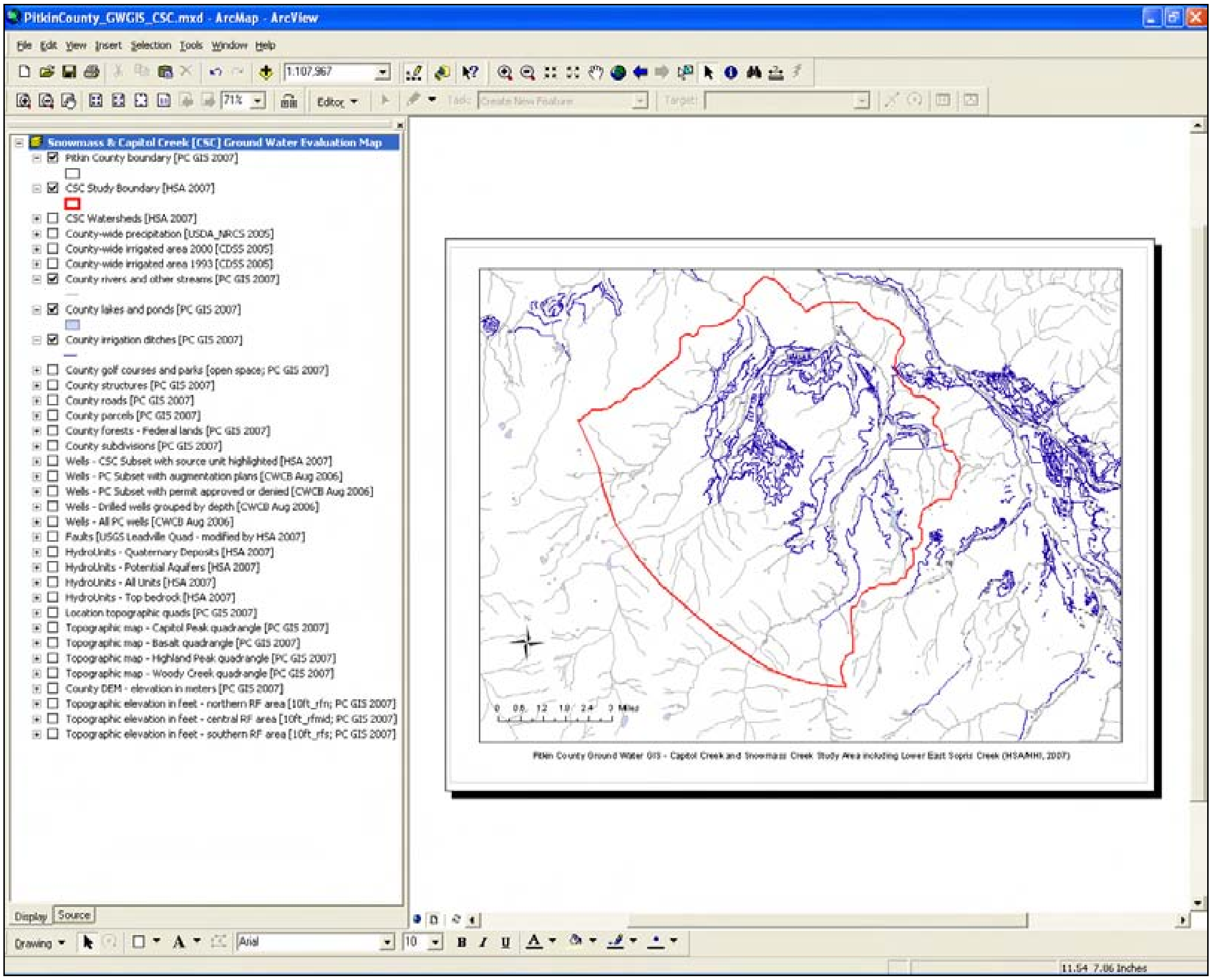

Figure 25. Pitkin County GIS Map with CSC Study Area and Irrigation Ditches.

The *HSA_PCGIS* subdirectory contains the HSA/HHI-produced files for the watershed boundaries (*CSC Watersheds* files) and the CSC study area outline (*CSC_Studyboundary* files) (Figure 21). The study area comprises the non-public lands in the three-watershed area (Figure 26). The watershed boundaries were derived by a watershed analysis performed on the DEM provided by Pitkin County. The *HSA_PCGIS* subdirectory also contains various HSA/HHI-produced hydrogeology layers (*CSC_HydroUnits_Aquifers*, *CSC_HydroUnits_All*, *CSC_HydroUnits_Bedrock* and *Faults_LeadvilleModified* files), and the *Wells_WithAdditionalGeoInfo.dbf* file, containing a subset of the State well database with additional hydrogeologic information collected from well logs filed with the Colorado State Engineer Office. The hydrogeology layers resulted from digitizing and evaluating the 1:24,000 scale geologic quadrangle maps Basalt (*Streufert et al., 1998*), Highland Peak (*Bryant, 1972*), and Woody Creek (*Freeman, 1972*), and the Leadville 1^o x 2^o Quadrangle Geologic Map (scale 1:250,000) (*Tweto, et al., 1978*) for the Capitol Peak quadrangle.

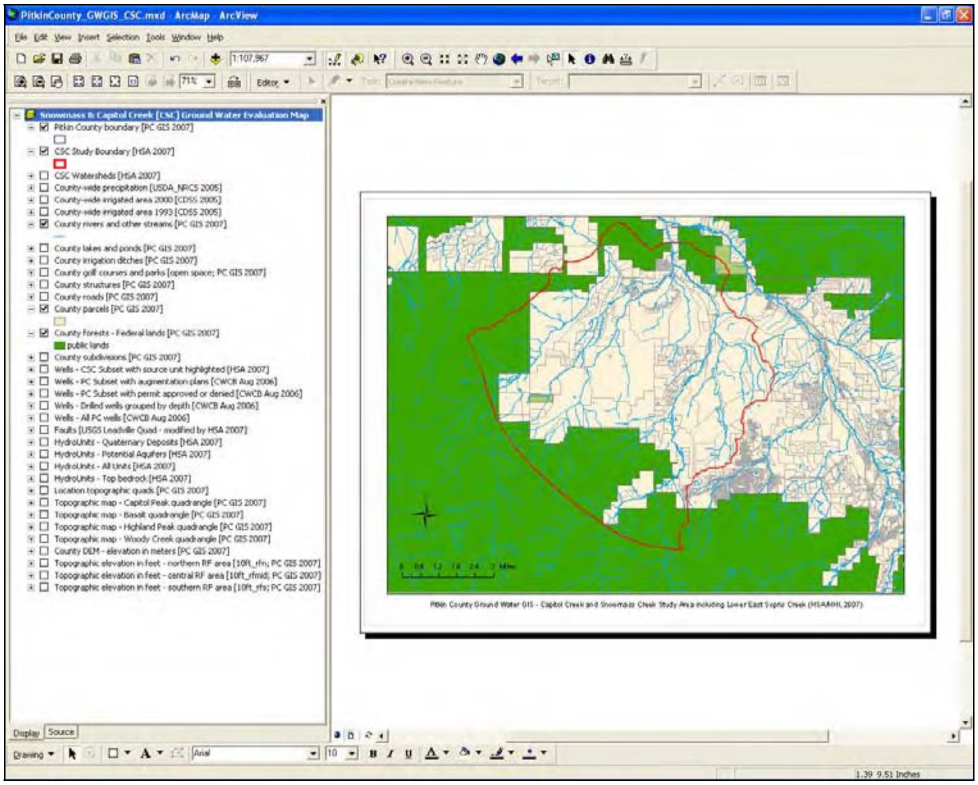

Figure 26. Pitkin County GIS Map with CSC Study Area and County Parcels and Non-developable Federal Lands Area.

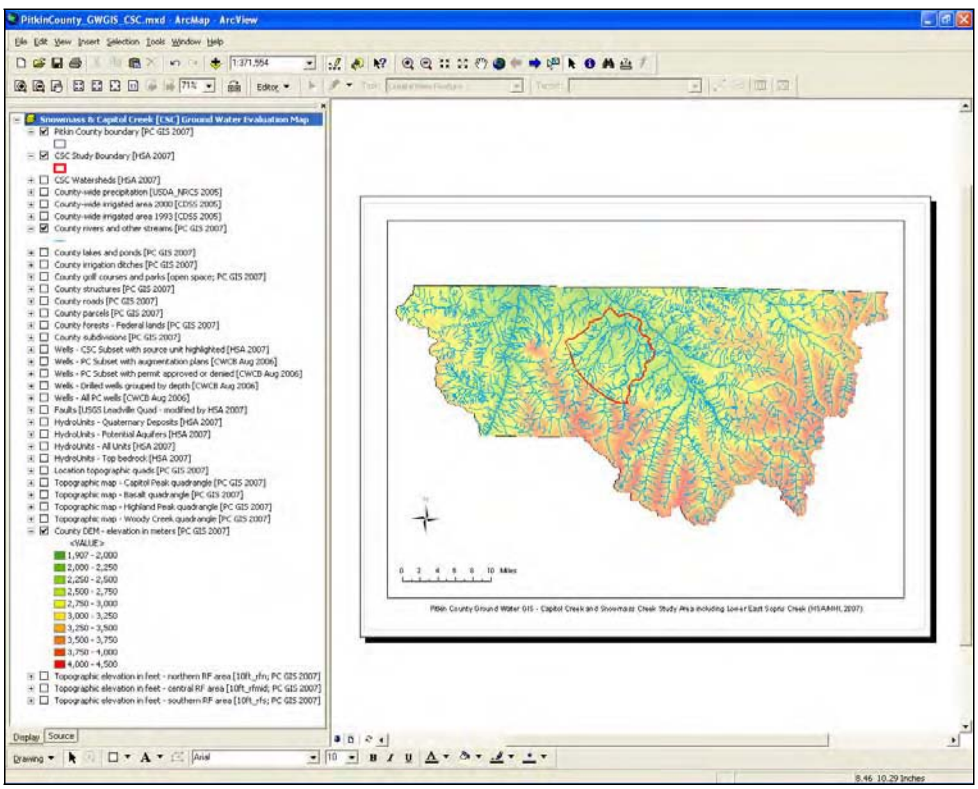

Figure 27. Pitkin County GIS Map with CSC Study Area and Digital Elevation Model (DEM) Layer.

There are 4 hydrogeologic system layers and 1 hydro-structure layer on the GIS map (i.e., "hydro units" for short): 1) *Quarternary Deposits* layer (Figure 28); 2) *Potential Aquifer* layer (Figure 29); 3) *All Units* layer (the top unit present at a location is shown; includes both the high and low permeable units) (Figure 30); 4) *Top Bedrock* layer (Figure 31); and 5) *Faults* layer (Figure 32). Figure 33 shows the *Wells - CSC Subset with Source Unit Highlighted* layer based on the HSA/HHI edited well database. These layers connect to the files described above. All HSA/HHI produced layers are referenced as *HSA/HHI 2007*. Note that the geologic maps used for the digitizing are on different scales, the digitized maps show different levels of resolution with respect to the (hydro)geology. The Capitol Peak quad has been digitized using the Leadville 1:250,000 geologic map, while the rest of the area has been digitized using 1:24,000 geologic maps. The faults map has been prepared by combining the Leadville faults layer with digitized details of hydrogeologic importance from the other geologic maps.

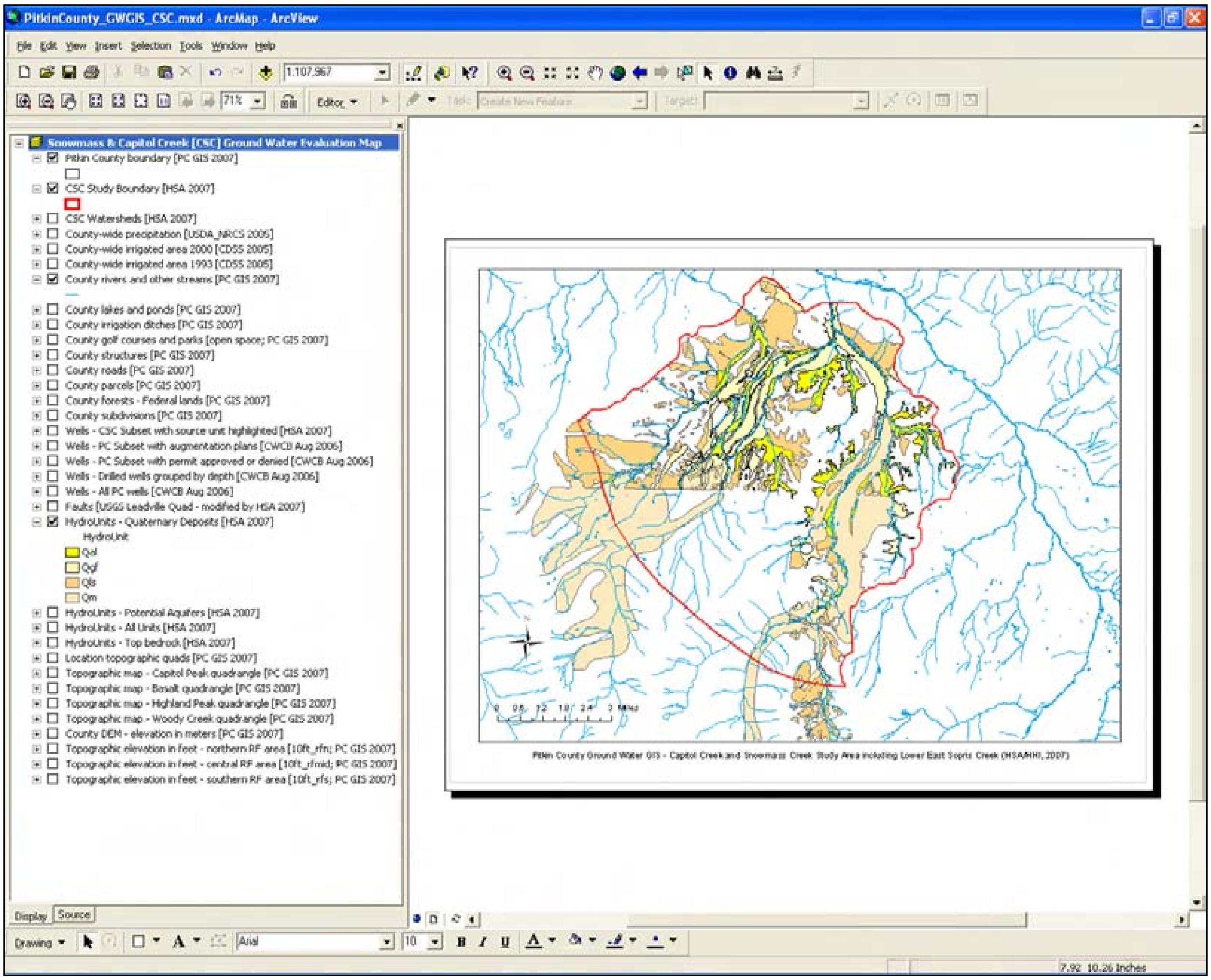

Figure 28. Pitkin County GIS Map with CSC Study Area and the HydroUnits-Quarternary Deposits Layer.

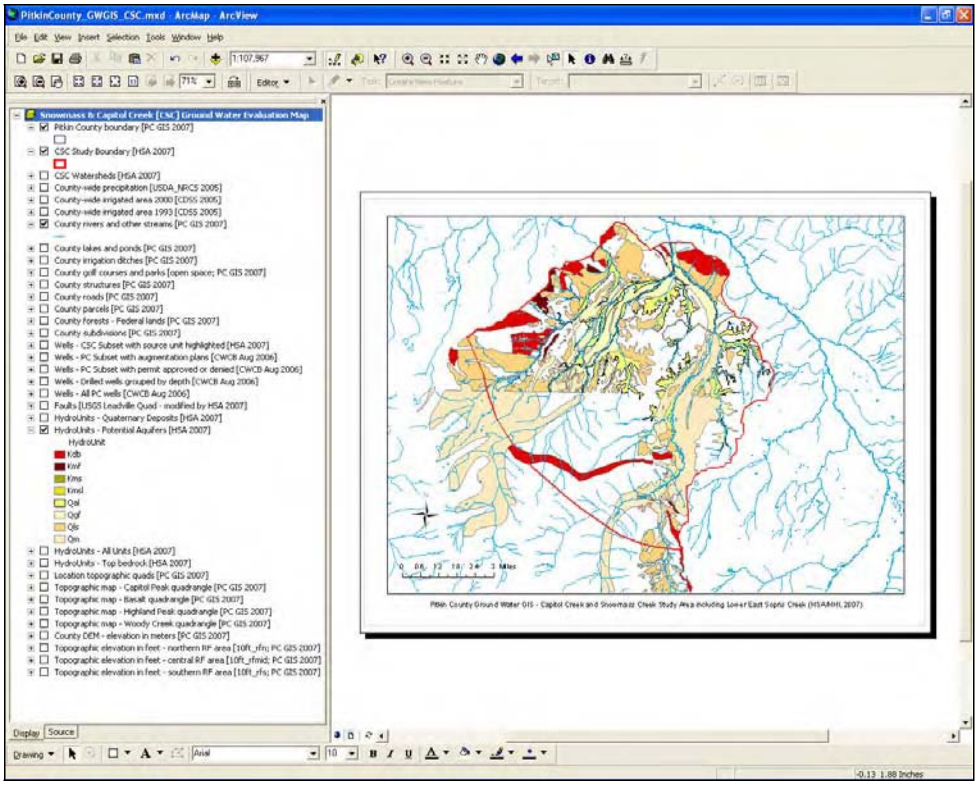

Figure 29. Pitkin County GIS Map with CSC Study Area and the HydroUnits-Potential Aquifer Layer.

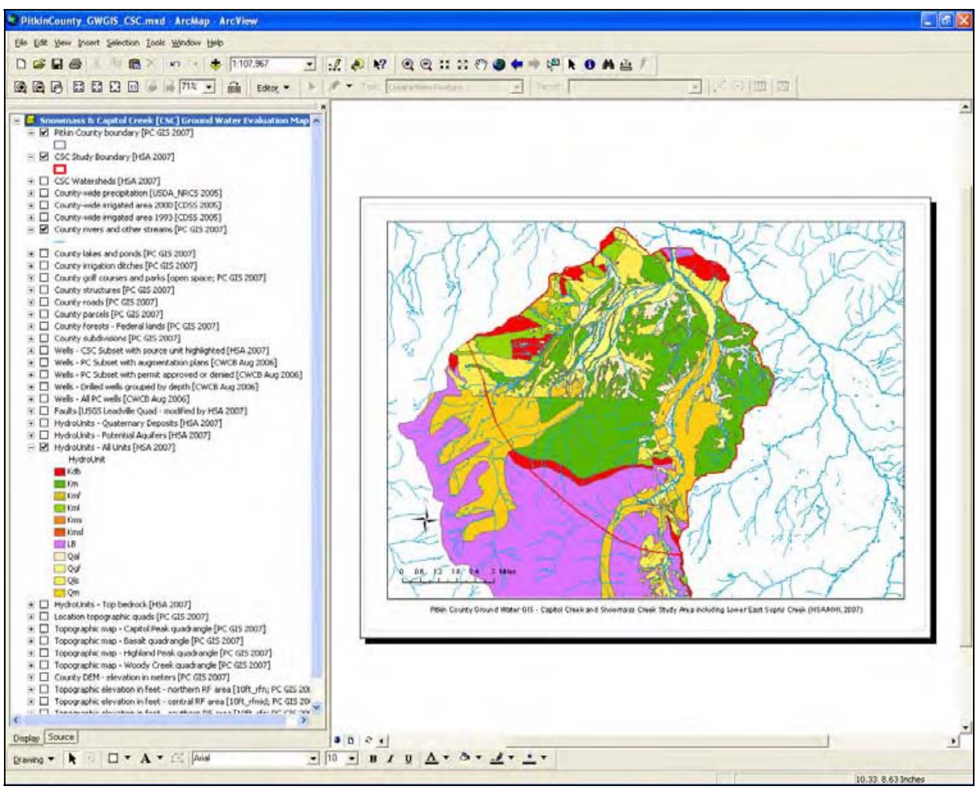

Figure 30. Pitkin County GIS Map with CSC Study Area and the HydroUnits-All Units Layer.

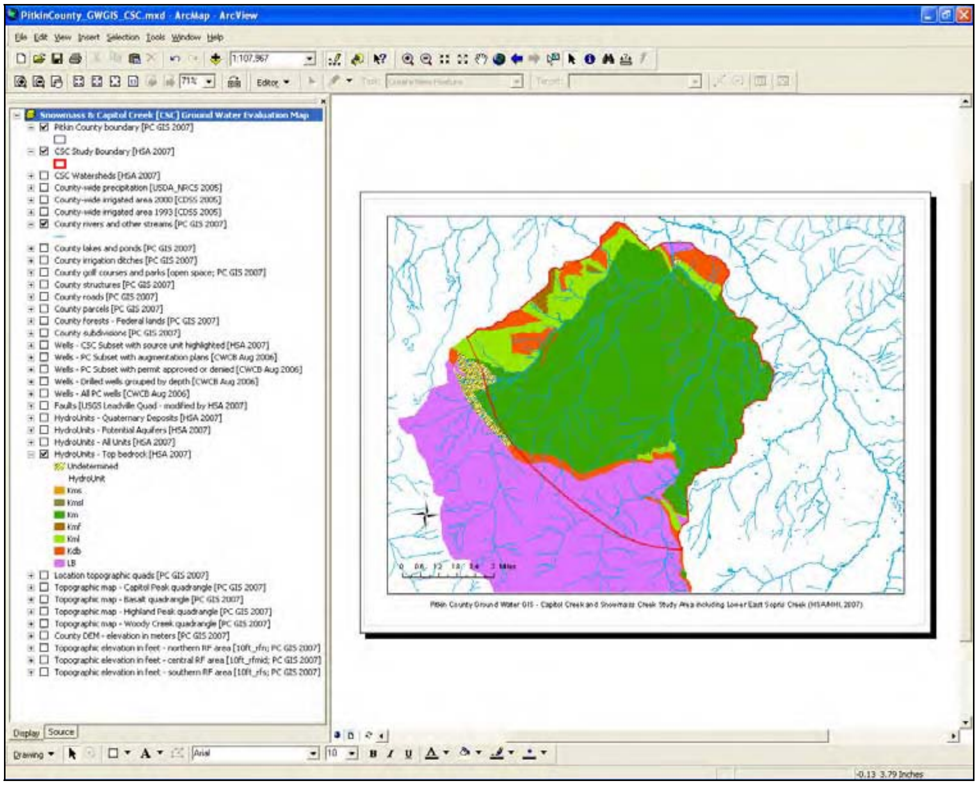

Figure 31. Pitkin County GIS Map with CSC Study Area and the HydroUnits-Top Bedrock Layer.

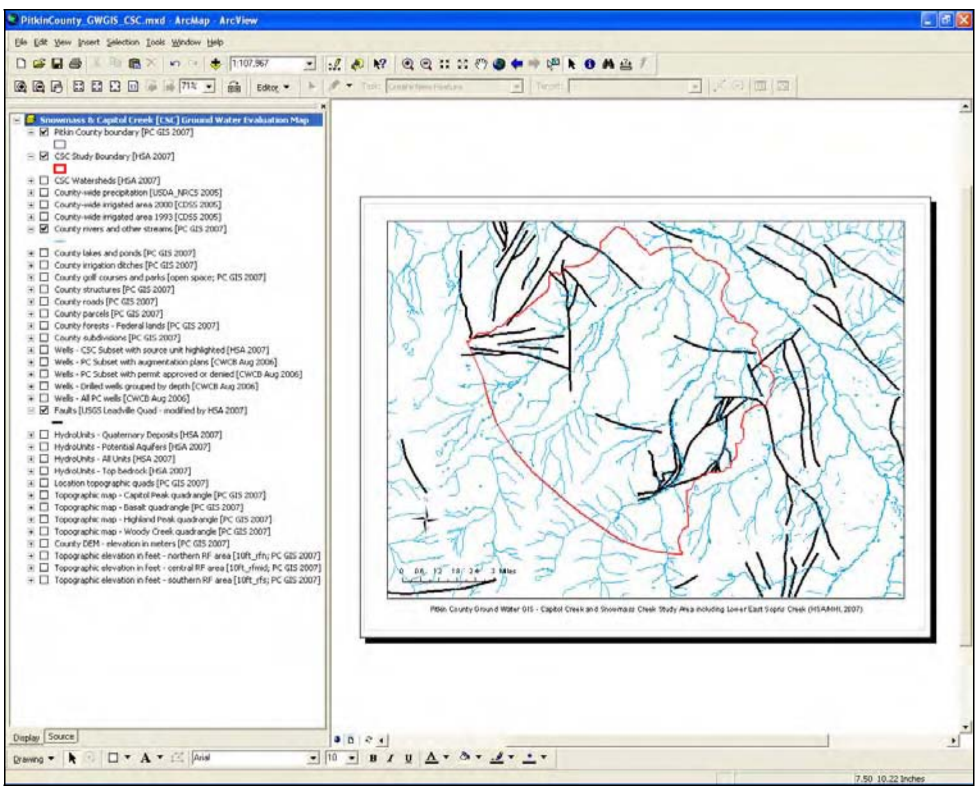

Figure 32. Pitkin County GIS Map with CSC Study Area and the Faults Layer.

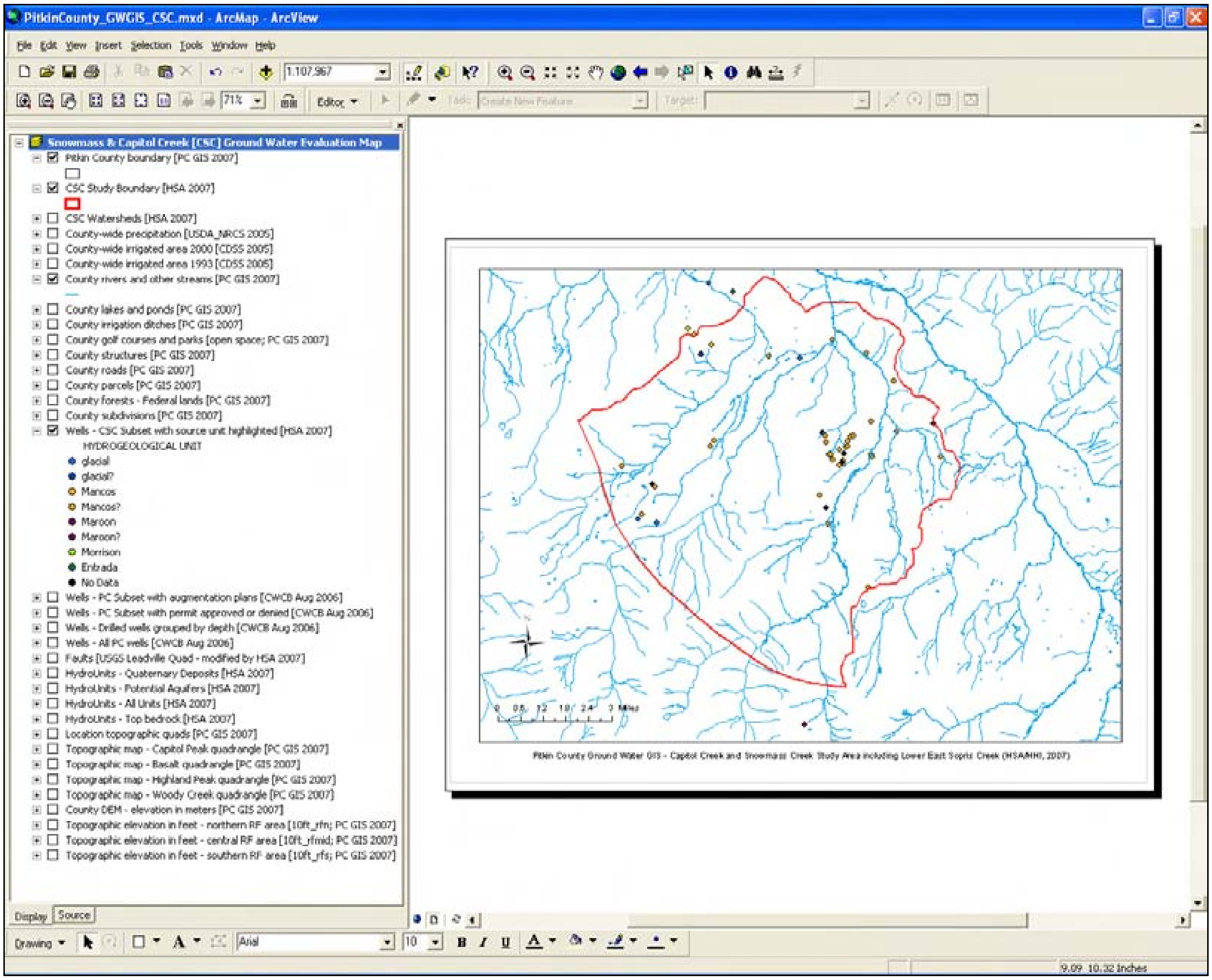

Figure 33. Pitkin County GIS Map with CSC Study Area and the Wells - CSC Subset with Source Unit Highlighted Layer.

The *Wells_DWRSC_Pitkin* subdirectory contains a subset of the August 2006 version of the state-wide well database, maintained by the State of Colorado Division of Water Resources (http://www.water.state.co.us/pubs/welldata.asp). The database subset is restricted to Pitkin County (county code 49) and includes both well permits (drilled or not) and drilled wells. The well coordinates are transformed 'on the fly' from UTM Zone 13N, NAD 1983 to CSP/NAD83 when the *wells.dbf* file is accessed by ArcMap. The attribute table [right-click on layer in contents column and select *Open Attribute Table*) includes fields for completion date, total well depth and depth to water (water table), as well as fields containing information regarding required augmentation plans and permit status. The subdirectory also contains the file *WELLVIEW_CODES.pdf* with explanations of the fields in the wells attribute table (Appendix 2). Layers based on these data are referenced as *CWCB_Aug2006*. As part of this project, the state database has been used to prepare separate layers to identify approved permits, required augmentation, well completion, and well depths (Figures 34, 35, and 36). Figure 37 shows an overlay of all drilled wells on top of the permitted and permit-pending wells. This figure has been prepared by adding an extra layer *Wells - PC Subset with given depth* identical to the layer

"Wells - Drilled wells grouped by depth" but with the depth categories replaced by a single symbol. Note that these well layers are different symbolizations (classifications) of the same data source-file.

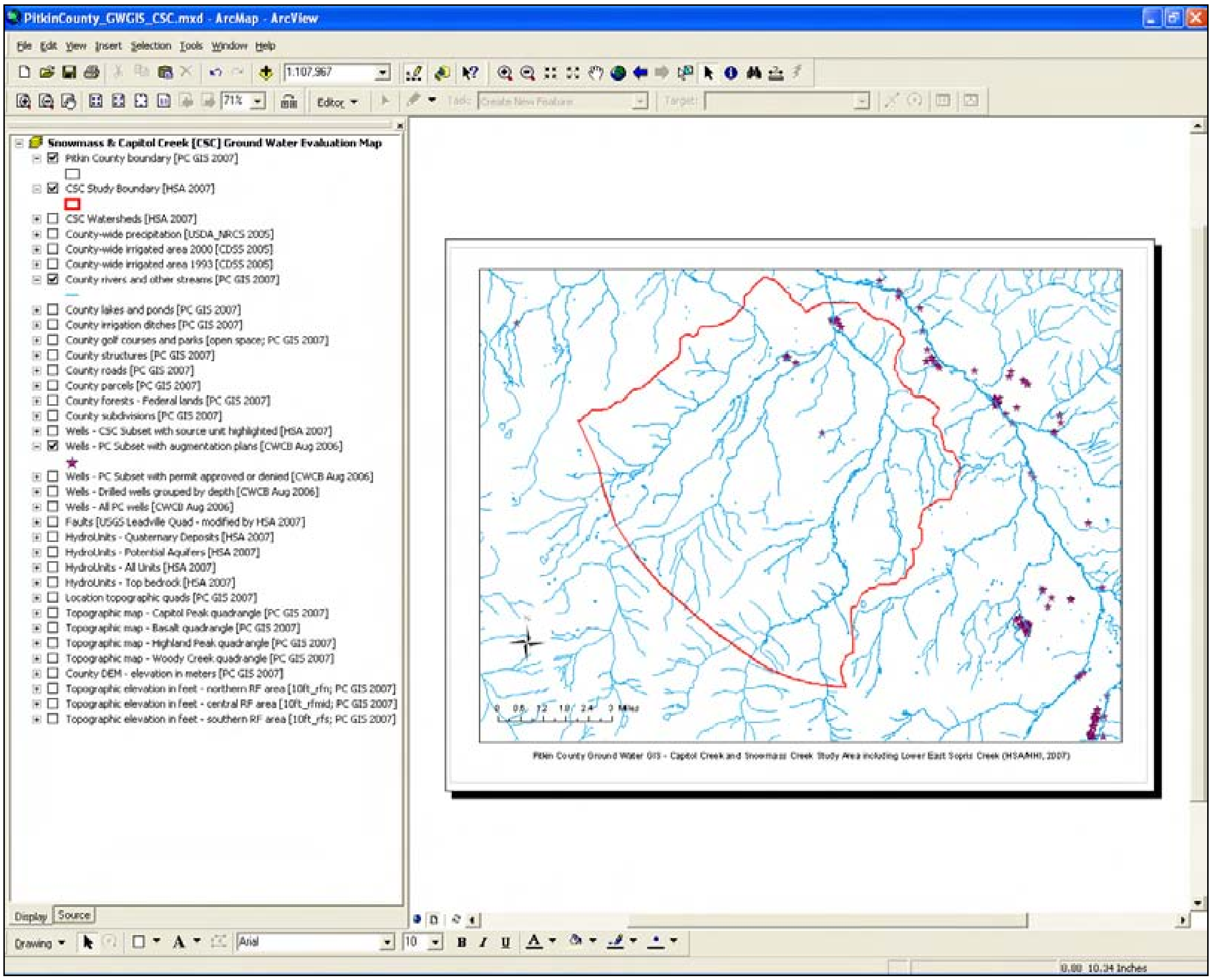

Figure 34. Pitkin County GIS Map with CSC Study Area and the Wells - Subset with Augmentation Plans Layer.

The files in the *Colorado DSS*, *Pitkin County GIS*, *NRCS Data Gateway* and *Wells_DWRCS_Pitkin* directories may require regular updating from the data source/owner/custodian. Specifically, the well database maintained by the State of Colorado is updated on a quarterly basis. Appendix 3 describes the procedure for updating the GIS files for these well data.

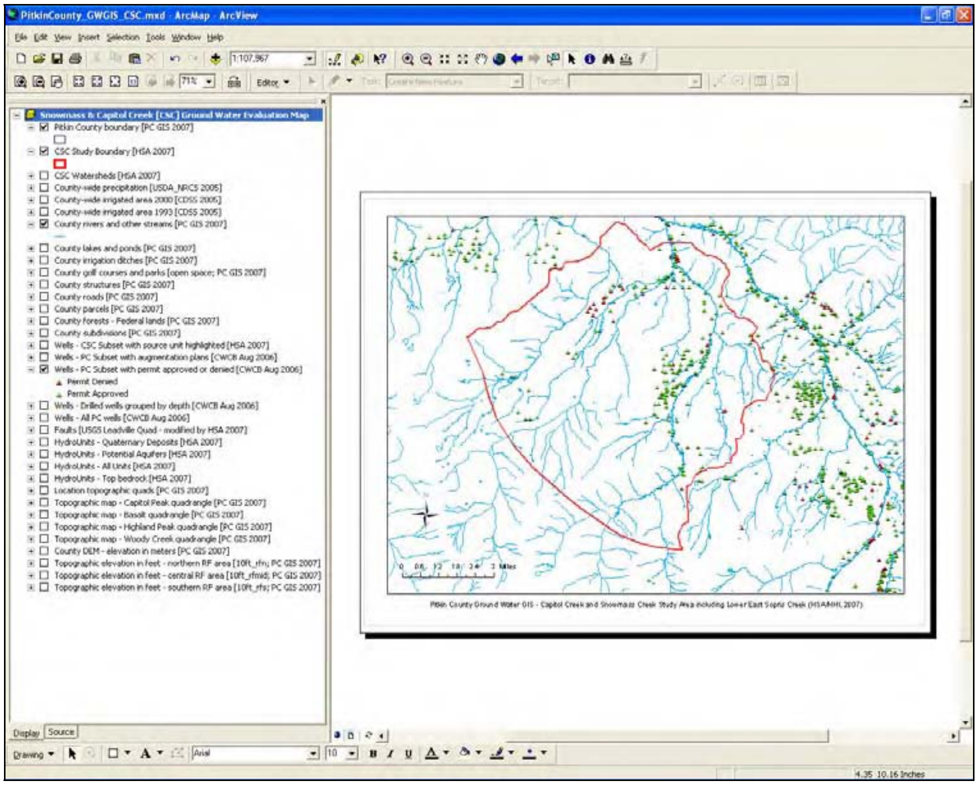

Figure 35. Pitkin County GIS Map with CSC Study Area and the Wells - Subset with Permit Approved or Denied Layer.

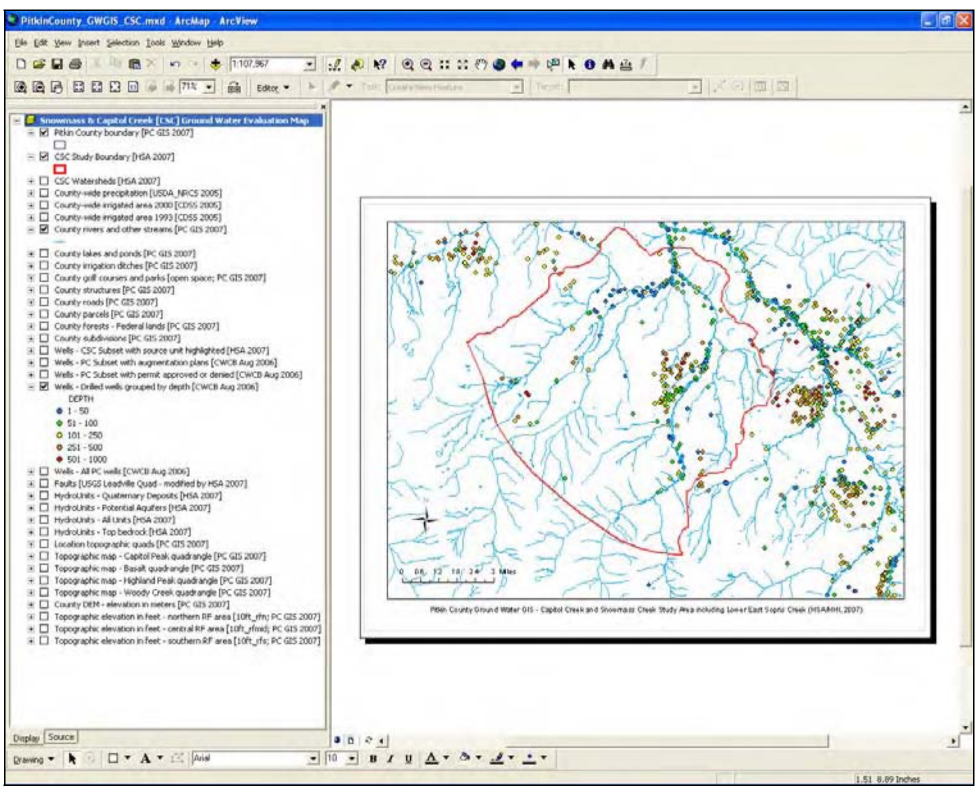

Figure 36. Pitkin County GIS Map with CSC Study Area and the Wells - All Drilled Wells Grouped by Depth Layer.

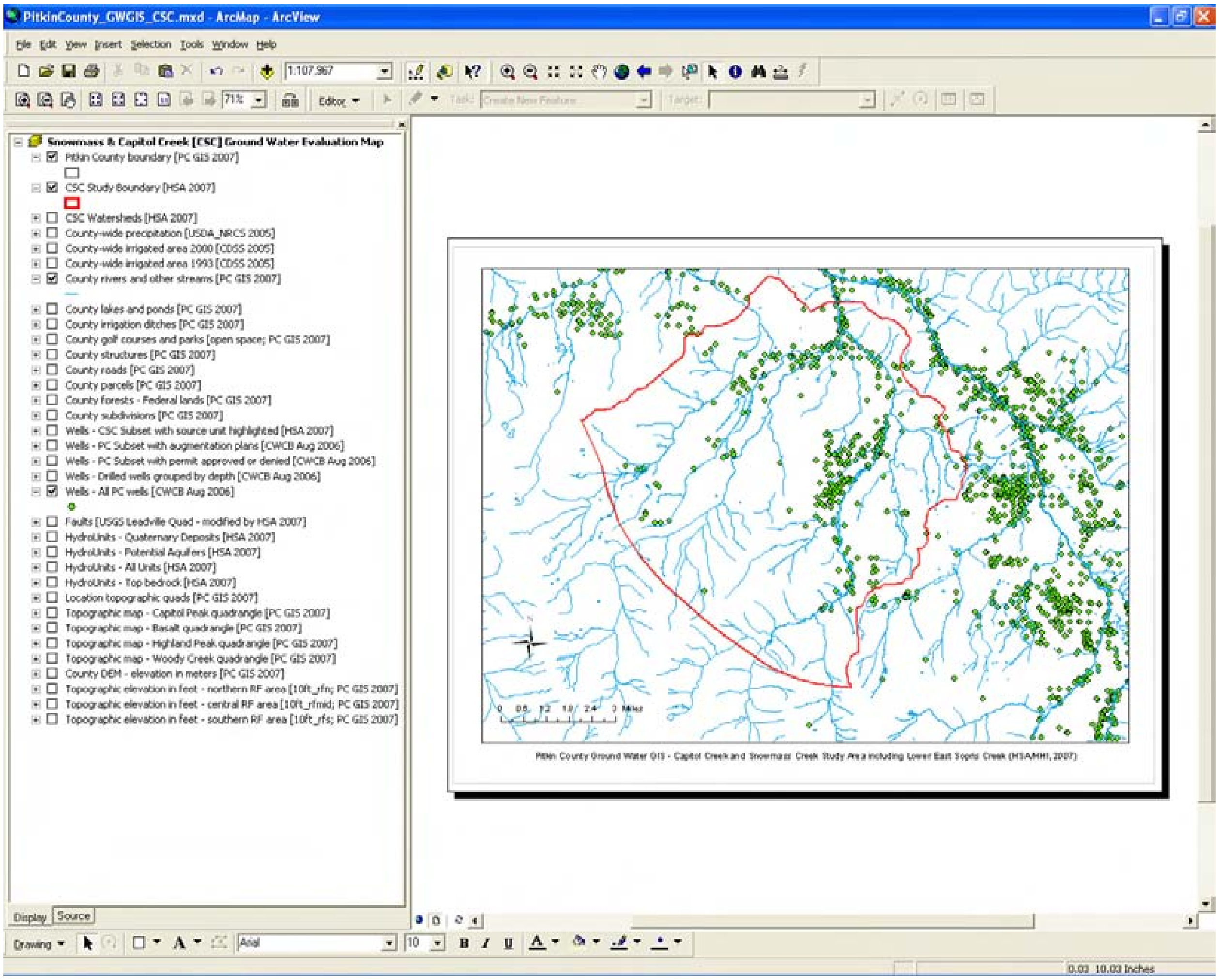

Figure 37. Pitkin County GIS Map with CSC Study Area and the Wells - All Permitted and Permit-Pending Wells Layer Overlain by the Drilled Wells Layer.

4.0 Ground Water Resources Evaluation Procedure

The complexity of the hydrogeology in CSC study area and the disparity in type, distribution and accuracy of available data do not support the preparation of a single-layer, multi-feature map addressing the area's ground water availability, sustainability of its utilization, and its vulnerability with respect to contamination from the surface. Specifically, the absence of detailed and up-to-date information on water table elevations and fluctuations, aquifer permeability distributions, and water budgets limits the quantitative analysis of ground water resources availability and sustainability. To achieve the project's objectives, an intuitive and flexible analysis procedure has been developed that optimally utilizes existing geo-information and the capabilities of a GIS. This stepwise procedure facilitates the evaluation of ground water availability, sustainability, and vulnerability on a site-specific base. A summary of this procedure is included in Appendix 4.

At each step of the assessment procedure, notes refer to individual layers in the CSC GIS map. For ease of reference in this chapter, each layer in the GIS map has been numbered as shown in Figure 38. To view a referenced layer in ArcMap, place a check mark in the layer's checkbox in the Table of Contents; these check marks should be removed when moving to the next step in the procedure.

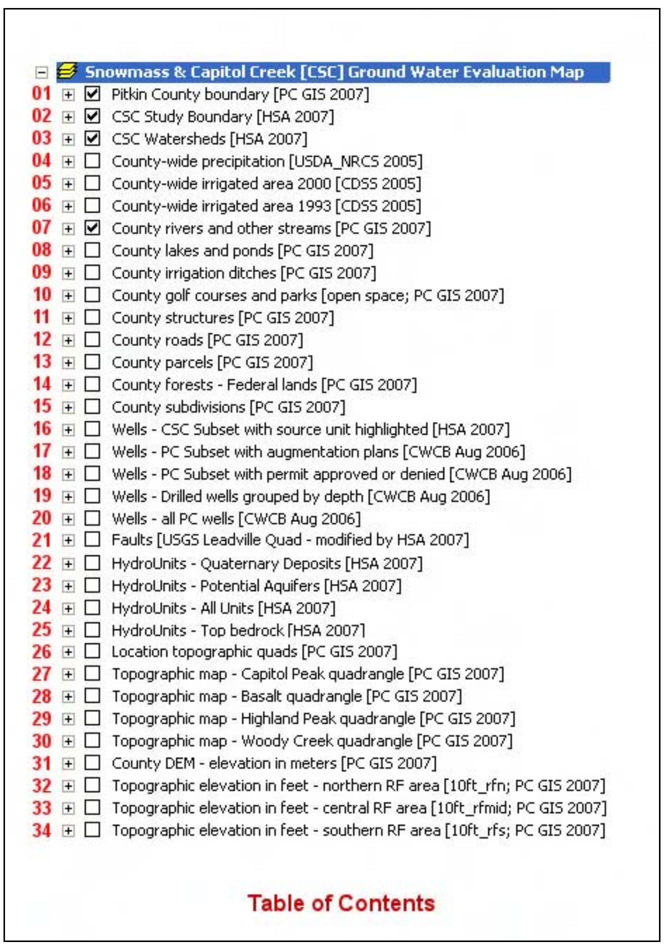

Figure 38. Annotated Table of Contents for CSC GIS Map.

It is assumed that the starting point of the assessment procedure is a permit application for development of one or more parcels in the CSC study area. Note, that the stepwise procedure may also be used for other planning applications. Upon receipt of a permit application, the first step is to determine the precise location or platting of the selected site, and to use this location in conjunction with the hydrology and hydrogeology GIS layers to determine the presence of ground water (Objective 1a). The succeeding tasks include determining the level of ground water availability (Objective 1b), sustainability as a resource at the site (Objective 2), and vulnerability to contamination and subsequent loss of supply (Objective 3). The GIS map includes layers showing wells with augmentation requirements, approved wells (drilled or not), drilled wells, and denied permit (Objective 4). It should be noted that due to limitations in data availability and quality, this analysis is primarily qualitative in nature. It does not replace due diligence by the permit applicant.

4.1. Potential Availability of Ground Water for Water Supply

This section provides a description of how objective 1a is achieved: determining the potential availability of ground water for water supply by identifying the areas covered by hydrogeologic formations that may be an aquifer (either unconsolidated surficial materials or bedrock). Excluded will be areas that consist mainly of shale or lower bedrock. The aquifer may be in surficial material or bedrock formations.

4.1.1. Potential Unconfined Surficial Aquifer Material in the Study Area

The following surficial materials may be aquifers in the study area:

Modern Alluvium (Qal). This material is primarily located in the valleys along the modern streams, i.e., lower Capitol Creek, lower Snowmass Creek and East Sopris Creek. These materials usually are natural aquifers that are in direct contact with and are sustained by the nearby surface water bodies. They are subject to seasonal fluctuations and changes in surface water body use (withdrawal for irrigation, for example). They may be recharged from seepage from higher terraces or leaking ditches, and/or from irrigation return flow. *(GIS layer 23 in Figure 38).*

Terrace Gravels and Fans (Qgf). This material is primarily located above the modern stream levels on the hillslopes. These materials usually are dry, but can be aquifers created and sustained by anthropogenic activity, such as irrigation ditches or irrigation return flow. (*GIS layer 23 in Figure 38).*

Moraines (Qm). This material is primarily located at mountain canyon mouths, such as the Snowmass and Capitol Creek canyons. The moraines of the CSC area are dry near the surface, but frequently contain natural ground water at depth, depending on connection to subsurface bedrock units, anthropogenic activities that promote recharge, or climate/precipitation input at higher elevations. *(GIS layer 23 in Figure 38).*

Landslides (Qls). This material is primarily located along the hillslopes surrounding lower Snowmass Creek and lower Capitol Creek, and along East Sopris Creek. These materials are primarily dry, but in areas of irrigation ditches and other anthropogenic activity, may become aquifers. *(GIS layer 23 in Figure 38).*

These surficial materials, when saturated, will be primarily unconfined or water table systems. Therefore, the water table will fluctuate naturally with climate input (seasonal rainfall and snowmelt). In addition, these aquifers will be vulnerable to contamination from land surface activity, such as irrigation, industrial, or urban uses.

4.1.2 Potential Unconfined And Confined Bedrock Aquifer Material

The following bedrock materials may be aquifers in the study area *(GIS layer 23 in Figure 38)*:

Upper Mancos Sandstone Member (Kms). This unit is primarily a rather thin sandstone that may have either matrix or fracture permeability. Given the age of the unit, fracture permeability is likely to be most significant for water supply. However, due to its limited thickness, this unit is not expected to have available large quantities of water. This unit is covered by the Mancos Shale except for outcrops and subcrops and is present in the eastern part of the CSC study area.

Lower Mancos Sandstone Member (Kmsl). This unit is primarily a rather thin sandstone that may have either matrix or fracture permeability, comparable to the Kms unit. Given the age of the unit, fracture permeability is likely to be most significant for water supply. However, due to its limited thickness, this unit is not expected to have available large quantities of water. This unit is covered by the Mancos Shale except for outcrops and subcrops and is present in the eastern part of the CSC study area.

Fort Hays Limestone Member (Kmf). This unit is primarily a limestone of significant thickness that may have fracture permeability and/or bedding plane permeability. This unit may provide a local water resource. This unit is covered by the Mancos Shale except for outcrops and subcrops and is present in the eastern part of the CSC study area.

Dakota-Burro Canyon Sandstone (Kdb; unconfined or confined). This unit is primarily a sandstone that may have either matrix or fracture permeability. Given the age of the unit, fracture permeability is likely to be most significant for water supply. This unit is covered by the Mancos Shale except for outcrops and subcrops in the northwestern and northern sections of the study area, and a relatively small outcrop band on the south side of the study area.

Recharge of the bedrock units take place at outcrops and subcrops or where streams and associated fracture zones cross the units. These units are primarily confined, except where they are near the land surface or outcrops. The Snowmass Creek fault and fracture zone may have significant hydrogeologic effects, the nature of which can not be established with current information.

4.1.3 Is the Potential Alluvial/Colluvial Aquifer Connected/Not Connected with a Bedrock Aquifer?

If it has been determined that the site is located in an area with a potential alluvial/colluvial aquifer (Section 4.1.1), the presence of a direct connection with an underlying bedrock aquifer needs to be established. This connection may indicate a more regional availability of ground water than would be the case if only an alluvial/colluvial aquifer is present. This alluvial/colluvial–bedrock aquifer connectivity can be evaluated by locating the permit site with respect to the layers discussed in sections 4.1.1 and 4.1.2. Sites where unconsolidated materials overlie impermeable shale (Km) or lower bedrock unit (LB) are areas where connectivity is not likely. Areas where landslide and alluvial material overlie the Dakota-Burro Canyon Sandstone, the Upper or Lower Mancos Sandstone Member or the Fort Hays Limestone have direct bedrock connectivity. In these connected areas, ground water may flow either upward from bedrock to unconsolidated deposits (i.e., bedrock recharges unconsolidated deposits), or downward from unconsolidated deposits to bedrock (i.e., unconsolidated deposits recharges bedrock).

4..1.4 Is Alluvial/Colluvial Material Saturated or Unsaturated?

The final questions in determining the availability of ground water as water supply relate to the actual presence of ground water in the potential aquifer units, the saturated thickness, and the potential yield (Objective 1b). In order to answer these questions, information from nearby wells is evaluated. Only wells located in the same hydrogeologic unit are of interest. GIS layers 16-20 show the locations of the wells recorded in the state well database. The attribute table for these layers contain information with respect to depth to water table at time of drilling, screen placement, depth to well bottom, saturated thickness (if bottom of aquifer has been reached), and well yields, among others. In some cases, ground elevation is included; if not, it can be obtained from the DEM layer *(GIS layer 31 in Figure 38)*, the 10ft elevation contours layers *(GIS layers 32-34 in Figure 38)*, or the topographic map layers *(GIS layers 27-30 in Figure 38)*. Note, that in absence of sufficient well data, analysis of topography, vegetation, and nearby stream elevations may provide some information on water table elevation.

4.2 Potential Sustainability of a Water Supply from Ground Water

This section describes the approach to accomplish objective 2: potential sustainability of a water supply from ground water. This is done through the performance of a 3-step qualitative analysis of the aquifer recharge mechanisms and dynamics. A major consideration in this phase of the analysis procedure is the distinction that exists between aquifers subject primarily to natural recharge (precipitation and influent streams) and aquifers dependent on anthropogenic recharge (leakage from irrigation ditches and irrigation return flow). At this time, data are lacking for a quantitative approach with respect to water budget terms and their fluctuations in time.

4.2.1 Is There Direct Infiltration of Precipitation into the Alluvial/Colluvial Aquifer or the Bedrock Aquifer, and How Much?

Every part of the surficial aquifers in the study area has the potential for ground water recharge, and downward gradients potentially exist for all aquifers. Actual recharge is dependent on local slope steepness, slope aspect, soils and geomorphic deposits, bedrock, vegetation type and distribution, human activity, and other factors. Generally, recharge potential is about 10 percent of precipitation in the 10-15 inch per year range, and recharge percentage increases with increasing precipitation above 15 inches per year. To determine the recharge potential from precipitation in the vicinity of the site, a precipitation layer is included in the GIS map *(layer 4 in Figure 38)*. This layer contains an estimated annual precipitation distribution for the county based on point measurements and various characteristics derived from a Digital Elevation Model (DEM) for the area. Note, that low-lying areas (valley bottoms) receive significantly less precipitation than higher elevations.

4.2.2 Is the Alluvial/Colluvial Aquifer Connected/Not Connected with a Perennial Stream?

In order to determine if the aquifer of interest is recharged by an influent stream, the presence of a direct hydraulic connection between the aquifer and the stream needs to be established, the stream must be perennial (or at least flowing for most of the year), and the water table near the stream should be below stream level. GIS layer 7 is Pitkin County's waterline layer, containing, among others, a field indicating intermittent stream flow (ephemeral stream) or continuous stream flow (perennial stream). By comparing hydrogeologic unit information from layer 23 with the streams layer 7, the existence of a hydraulic connection can be assessed. There is no hydraulic connection between a stream and the aquifer, if no streams intersect or border the hydrogeologic unit of interest in the vicinity of the permit site. Sites that are close to a stream may experience seasonal water fluctuations in the water table in sync with those of the stream. Sites located near perennial streams will tend to be sustainable for longer time periods. Finally, determining if the aquifer's water table is below stream level, involves comparing water table information from wells in the vicinity of the stream (from the wells layer) with stream elevation data (for example, from the topographic map layers). Note, that the existence of a stream/aquifer connection in developing a ground water supply in the area may have implications regarding water rights issues.

4.2.3 Is the Saturated Alluvial/Colluvial Aquifer Connected with an Irrigation Ditch or Subject to Return Flow of Irrigation Water?

This step determines if recharge occurs as a result of irrigation practices. There are two potential recharge mechanisms related to such practices: infiltration of non-consumed irrigation water (return flow) and leakage from unlined irrigation ditches. Sites located near irrigated acreages and active (i.e., regularly water-carrying) upgradient irrigation ditches are mostly sustained by irrigation activity, and changes in irrigation practices, water rights and long-term land use may greatly affect the sustainability of a ground water supply. In addition, wells in such locations may see fluctuations in water levels based on irrigation schedules.

In order to establish if the saturated portion of the potential aquifer of interest is connected with an irrigation ditch, hydrogeologic unit information from GIS layer 23 is compared with the county's ditches layer (GIS layer 9 in Figure 38). There is no recharge if no active ditches intersect or border the hydrogeologic unit of interest in the vicinity of the permit site. The absence in the county's ditch-attribute table of information regarding major versus minor ditches, mostly continuous versus intermittent water carrying, in-use versus out-of-use, precludes the quantification of this step in the analysis.

The potential effect of the return flow of irrigated acreage on recharge can be evaluated by plotting the permit site on the 2000 or 1993 irrigated acreage layer (GIS layers 5 and 6, respectively). There is no recharge if irrigation is not or no longer present at or near the permit site. Note the decrease in irrigated acreage between 1993 and 2000.

4.3 Vulnerability of Ground Water Supplies to Contamination from the Surface

This section describes the approach to accomplish objective 3: determining the vulnerability of a ground water supply to contamination from the surface. Virtually all of the hydrogeologic units in the study area lack the presence of a confining layer (shale, clay, peat), protecting the aquifer from contamination originating at the land surface or near surface (for example, ISDSs, agricultural chemicals). Therefore, the ranking (high versus low) of the vulnerability of these aquifers is high, except for the areas where Dakota-Burro Canyon Sandstone, Upper and Lower Mancos Sandstone Members, and Ft Hays Limestone is overlain by Mancos Shale.

All potential aquifers shown in layer 23 (Figure 38) are vulnerable; natural protection is only available in the green-colored areas shown in layer 24 (Mancos Shale) for bedrock aquifers underneath the Mancos Shale.

In order to further evaluate aquifer vulnerability, the potential for occurrence of contamination needs to be determined. The location, characteristics and likelihood of potential contamination sources need to be identified. For example, some sites may be vulnerable to contamination from one or more ISDSs nearby, a rather likely and continuing point source. Others may be vulnerable to contamination from agricultural land use, a seasonal, distributed source. To determine ground water vulnerability, separate potential source layers need to be constructed, for example, showing location and density of ISDSs, gas stations, urban runoff, and agricultural land use. However, such an analysis goes beyond the scope of this project.

5.0 Case History Examples

In this section, three examples are presented illustrating the step-wise approach developed for determining if ground water can provide the water supply for a given site (Figure 39). Site 1 is located in the lower Capitol Creek valley; site 2 is located in the Lime Creek area, and site 3 is located on the ridge between Upper Snowmass Creek and Upper Capitol Creek. The examples illustrate the variability of drinking water supplies, both in availability and sustainability, dependent on the local hydrogeology and hydrological system. All three sites are vulnerable to ground water pollution. Note, that the map display is in 'Data View' mode (Click View →Data View on the menu bar of the ArcMap window). The GIS layer numbers in the following discussions refer to Figure 38.

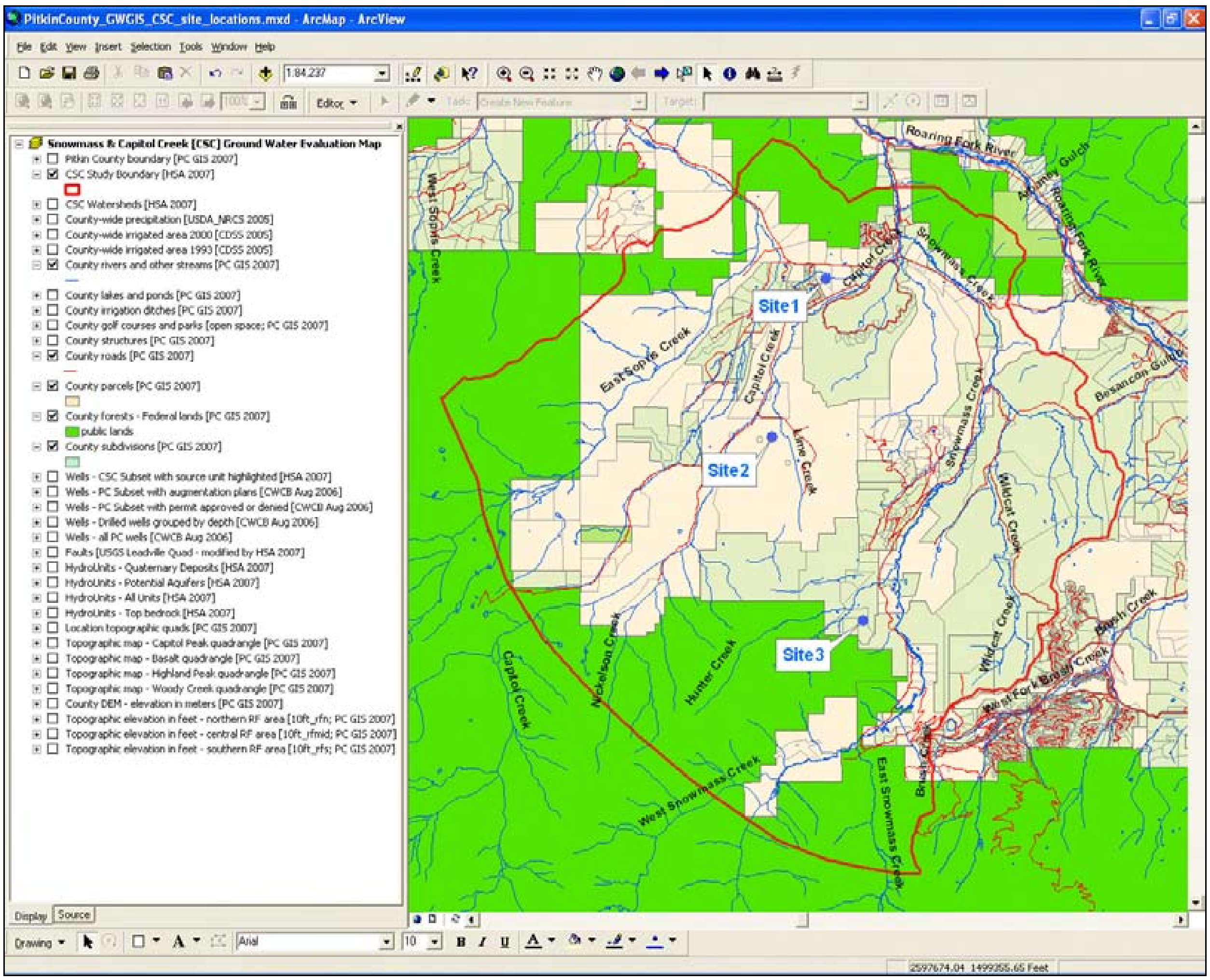

Figure 39. Location of Example Sites.

5.1 Example 1 in Lower Capitol Creek Valley

5.1.1 Identify Location on GIS Map

Example 1 is a site located on parcel #264504200004 [at about (Colorado State Plane, Central Zone NAD 83) coordinate 2575210, 1538460], just east of Little Elk Creek subdivision (blue marker dot; Figures 39 and 40). Parcel and subdivision details are found by using the *Identify* function on the menu bar and selecting the *County parcels* or *County subdivisions* layer from the layers list at the top of the *Identify Results* window (layers 13 and 15, respectively; Figure 40). The coordinates of the site can be found near the lower right hand corner of the map while moving the mouse to the location of the site (Figure 40). The streams layer and the roads layer are shown for orientation. The label feature of the subdivision layer and the streams layer are turned on. The site is located in the valley section of the FDB hydrologic subsystem, and the hydrogeologic conceptual model for this area is shown in Figure 16 (unconsolidated materials located on top of Mancos Shale).

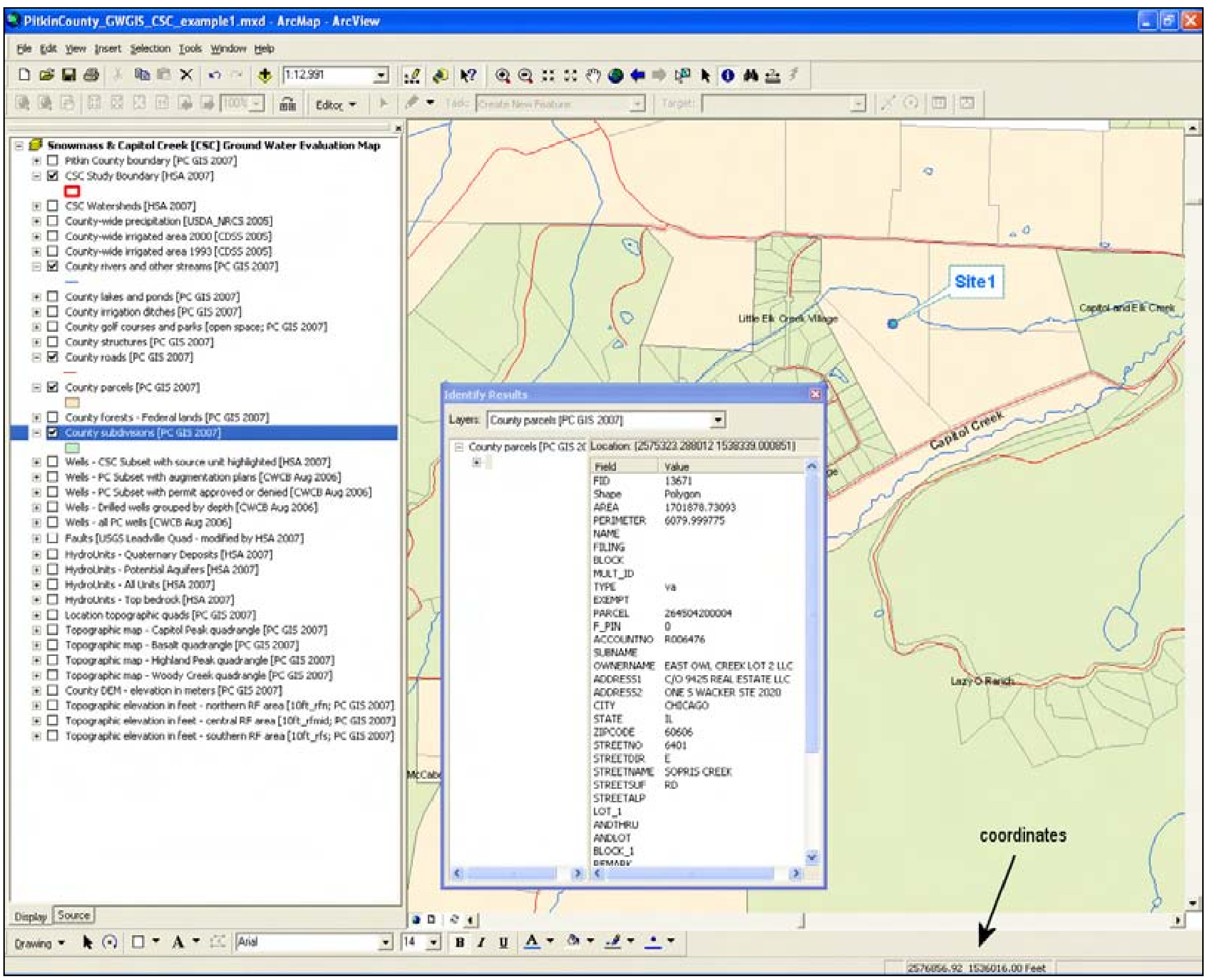

Figure 40. Locate Site 1 Using GIS Layers 13 and 15

(layers 07 [streams] and 12 [roads] are used for orientation).

5.1.2 Determine Ground Water Availability

Using the *Identify* function on the menu bar and turning on the *Hydrounits - Potential aquifers* layer (layer 23) from the GIS map's table of contents, it is determined that the potential aquifer material is Qal (alluvium), possibly on top of Qgf (Figures 16 and 41). From using the *Identify* function for the *Hydrounits - Top bedrock* layer (layer 25), the underlying bedrock unit is determined to be Km (Mancos Shale). From the discussion of the FDB subsystem in chapter 2, it is concluded that there may be a water resource in the Kdb unit at the site (Figure 16). However, the absence of the Kdb unit in the *Hydrounits - Top Bedrock* layer in the vicinity of the site indicates that there is no alluvium-bedrock aquifer connectivity (figure 42). This means that the surficial aquifer is not connected to or sustained by an underlying bedrock aquifer and that aquifer sustainability is determined solely by surface processes related to nearby streams, ditches, irrigation, and precipitation. Near the site, the Kdb unit is a confined aquifer. The use of the Kdb unit for water supply depends on its thickness and depth, the thickness of the overlying Mancos shale, and the recharge mechanism and rate.

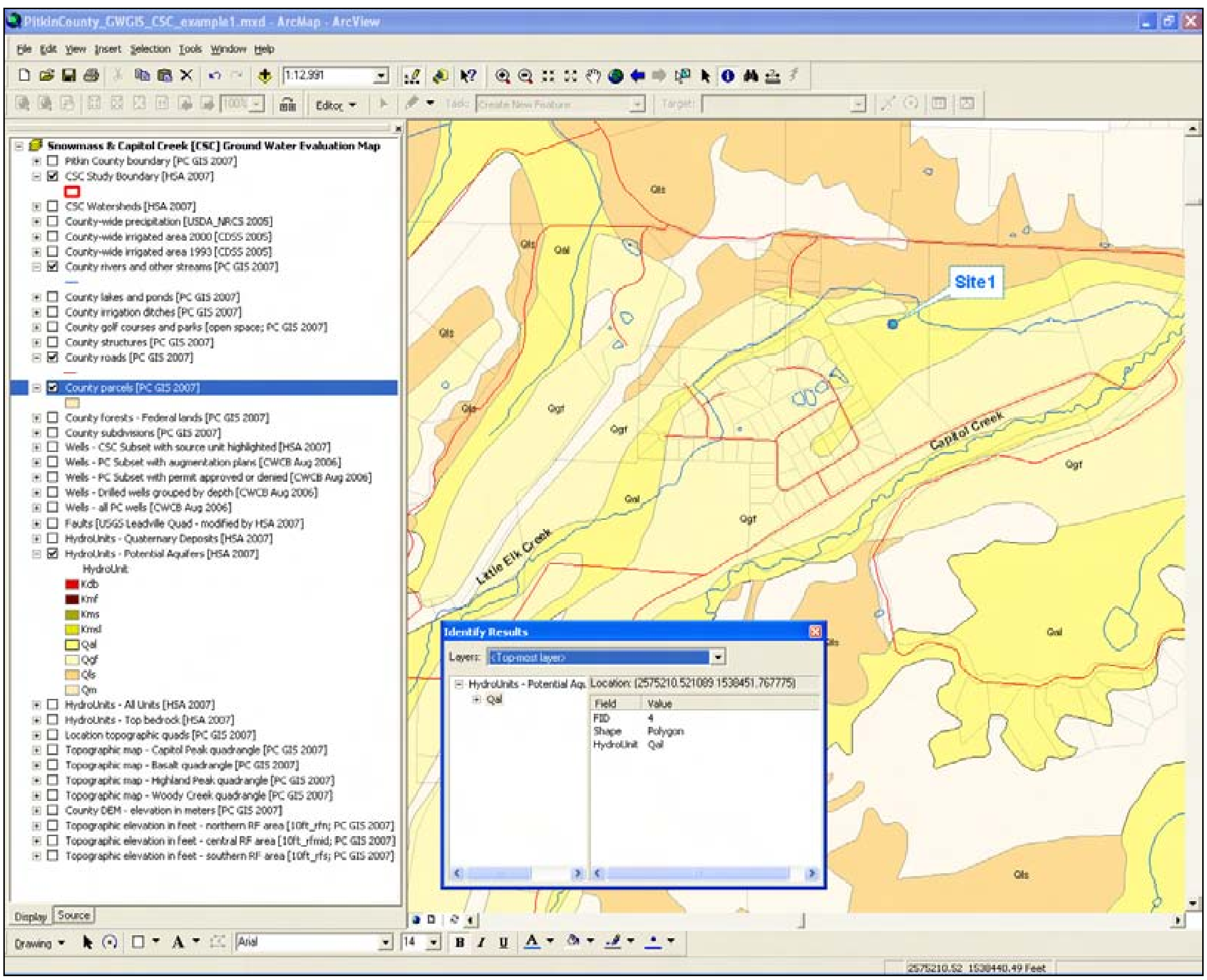

Figure 41. Determine the Potential Presence of an Unconsolidated Aquifer at Site 1 Using GIS Layer 23.

The next step is to determine if the alluvial material is saturated or unsaturated. This determination is made on the basis of information from nearby wells and, because the aquifer is an alluvial unit, the water levels in nearby streams in conjunction with ground elevation at the site.

Layer 19 (*drilled wells grouped by depth*) is turned on to identify relevant nearby wells. There are 9 wells identified that may provide information (Figure 43). The wells can be selected using the *Select Tool* from the Tools Toolbar (Figure 43). From the attribute table of layer 19, well depth, depth to static water level at time of drilling, well production (gallon per minute yield), and time of year of drilling can be evaluated with respect to pre-development saturated thickness (Figure 44; see Appendix 2 for explanation of field names). To display only the subset of selected wells, use the *Selected* button next to the *Show 'All' Records* button at the bottom of the attribute table (see inserted window in Figure 46). It appears that most wells near site 1 are not drilled to bedrock. Note, that the information available in the attribute table is insufficient to determine bottom elevation and saturated thickness of the potential aquifer.

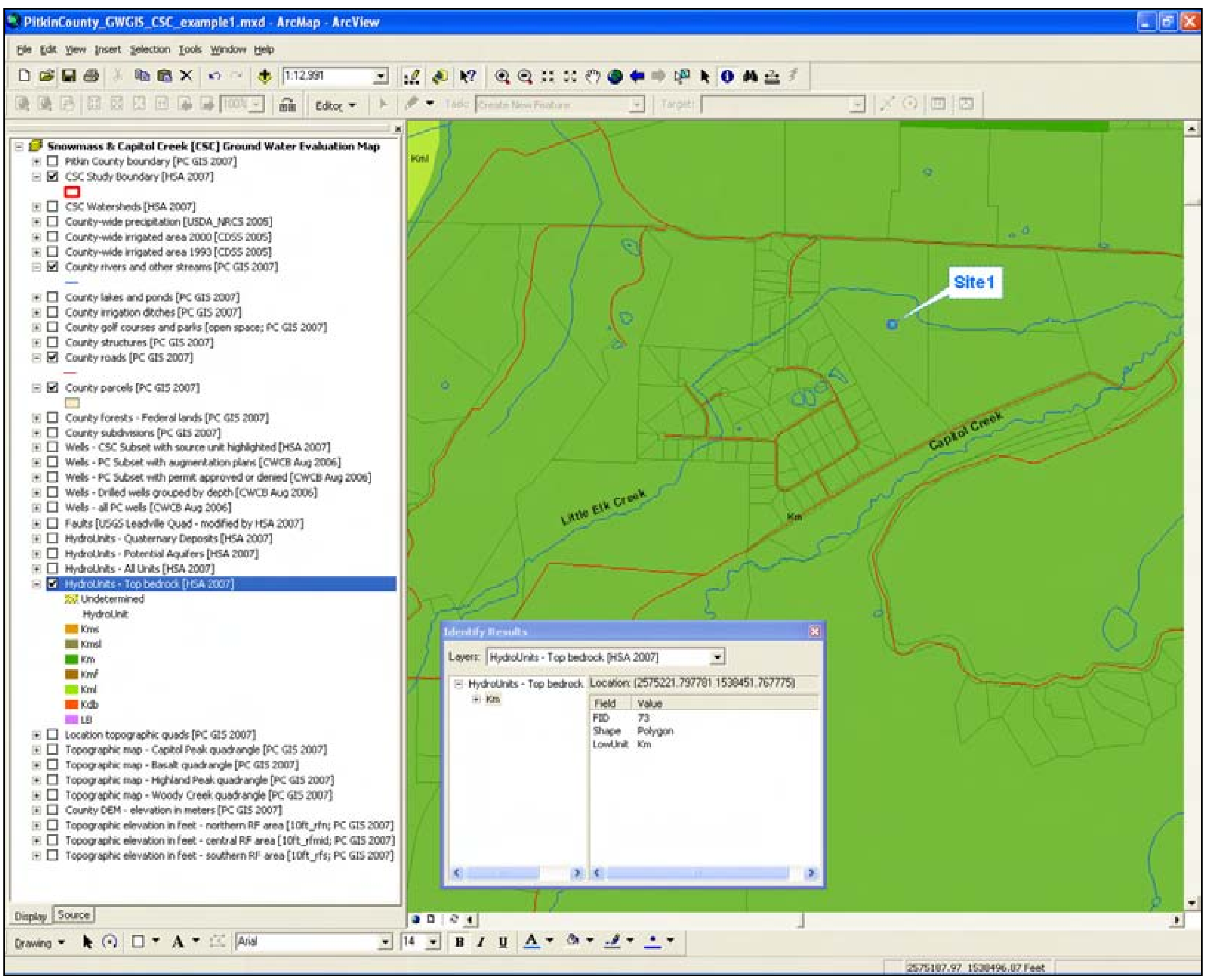

Figure 42. Determine the Hydrogeological Unit Underlying the Unconsolidated Aquifer at Site 1 Using GIS Layer 25.

Most nearby wells are shallow (less than 50ft deep), with a water table ranging from 3 to 24ft below ground surface, and a yield from 10 to15gpm. (Note, that 15gpm is the maximum permitted yield for household wells and that higher yields are possible). The deep well (permit # 221921) shows a depth to water of 86ft. Pre-pumping saturated thickness ranges from a minimum of 11 to 25ft (i.e., difference between water level and screen bottom). The shallow wells have short screens (2-6ft). Figure 43 shows that 1 well is located in the Qal hydrological unit (14261), 5 wells are located in the Qgf unit (22444, 44396, 56891, 221920, 221921), and 3 wells are located on the border between the two units (37254, 43151, 43152). It appears that shallow well 221920 was drilled and completed (≥15gpm yield), but not screened, and that about nine months later (according to the information in the *WCDATE* field in the attribute table) the deep well (221921) was drilled at or near the same location and screened at 120-245ft (12gpm yield). The deep well may have reached the Kmf unit and obtained a water supply from that unit.

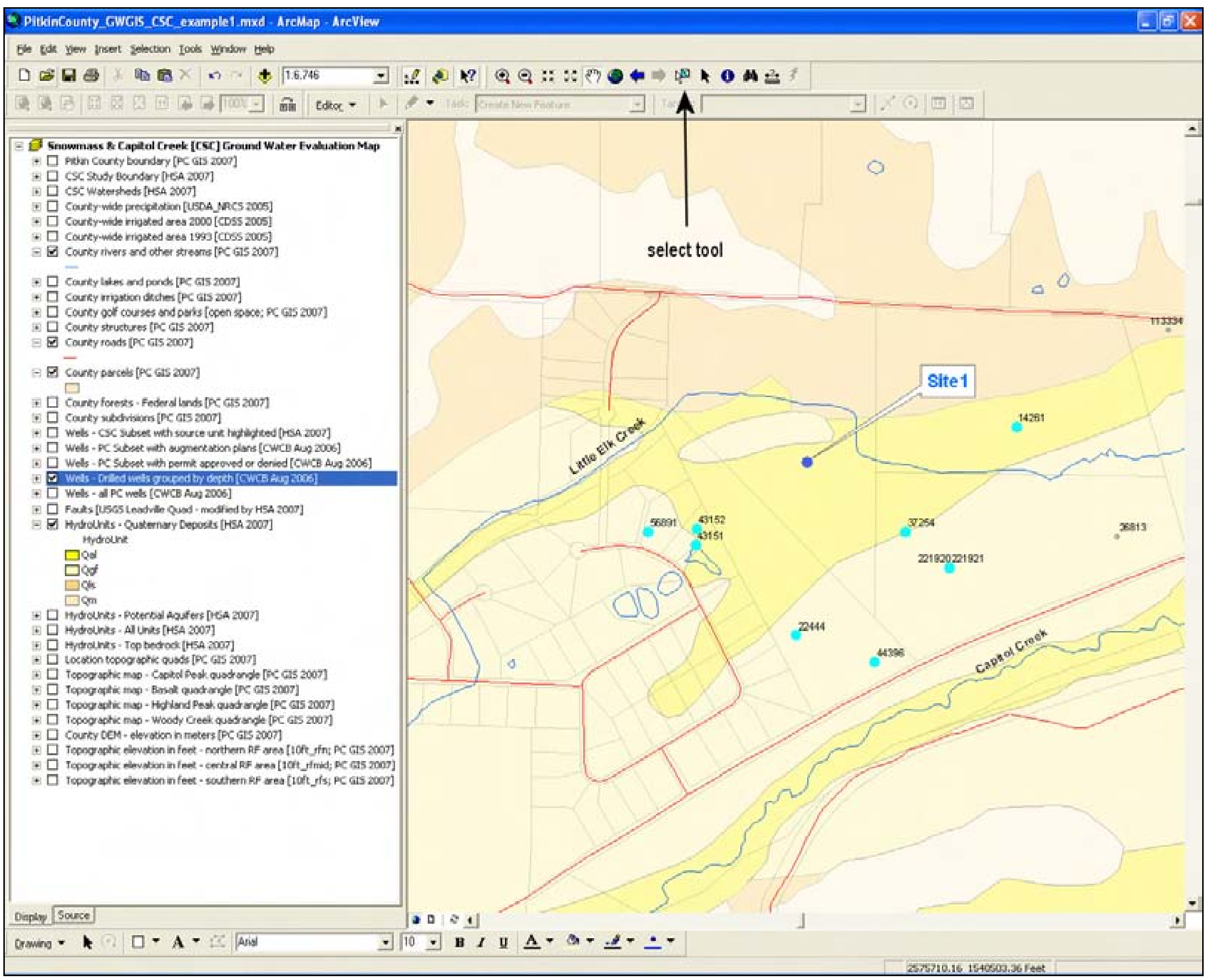

Figure 43. Identify Relevant Wells in the Vicinity of Site 1 Using GIS Layer 19.

Selected Attributes of Wells - Drilled wells grouped by depth [CWCB Aug 20...

OID	RECEIPT	DIVISION	COUNTY	PERMITNO	PERMITSUF	PERMITRPL	ACTDATE	ACREFT	TPERF	BPERF	CASENO	YIELD	DEPTH	LEVEL	ELEV
100	0014261	5	49	14261	MH		8/4/1988	0	0000	0000		0	30	0	0
336	0022444	5	49	22444	MH		3/3/1994	0	0031	0037		15	37	24	0
593	0037254	5	49	37254	MH		10/25/1999	0	0035	0040		15	41	15	0
1688	0360355A	5	49	43151	F		9/20/1993	0	0022	0024	84CW 285	15	27	12	0
1689	0360355B	5	49	43152	F		9/20/1993	0	0018	0020	84CW 285	15	26	3	0
1742	0370952A	5	49	44396	F		11/18/1994	0	0031	0037	94CW25	15	37	24	0
2338	0483874D	5	49	56891	F		11/1/2001	0	0014	0019	84CW285	10	23	8	0
2209	0454005	5	49	221920			10/5/1999	0	0000	0000		15	41	13	0
2210	0454024	5	49	221921			10/18/1999	0	0120	0245		12	245	86	0

Figure 44. Selected Fields of the Attribute Table for Layer 19 (drilled wells) with Relevant Information Regarding Wells in the Vicinity of Site 1.

5.1.3 Determine Ground Water Sustainability

The precipitation layer (layer 4) is turned on to assess the recharge potential from precipitation in the vicinity of the site. The site is located in an area that receives an average of about 17 inches of precipitation per year, or an estimate of 1.7 inches of recharge per year (Figure 45). Calculation of actual recharge amounts (a fraction of precipitation) requires professional judgment using standard practices.

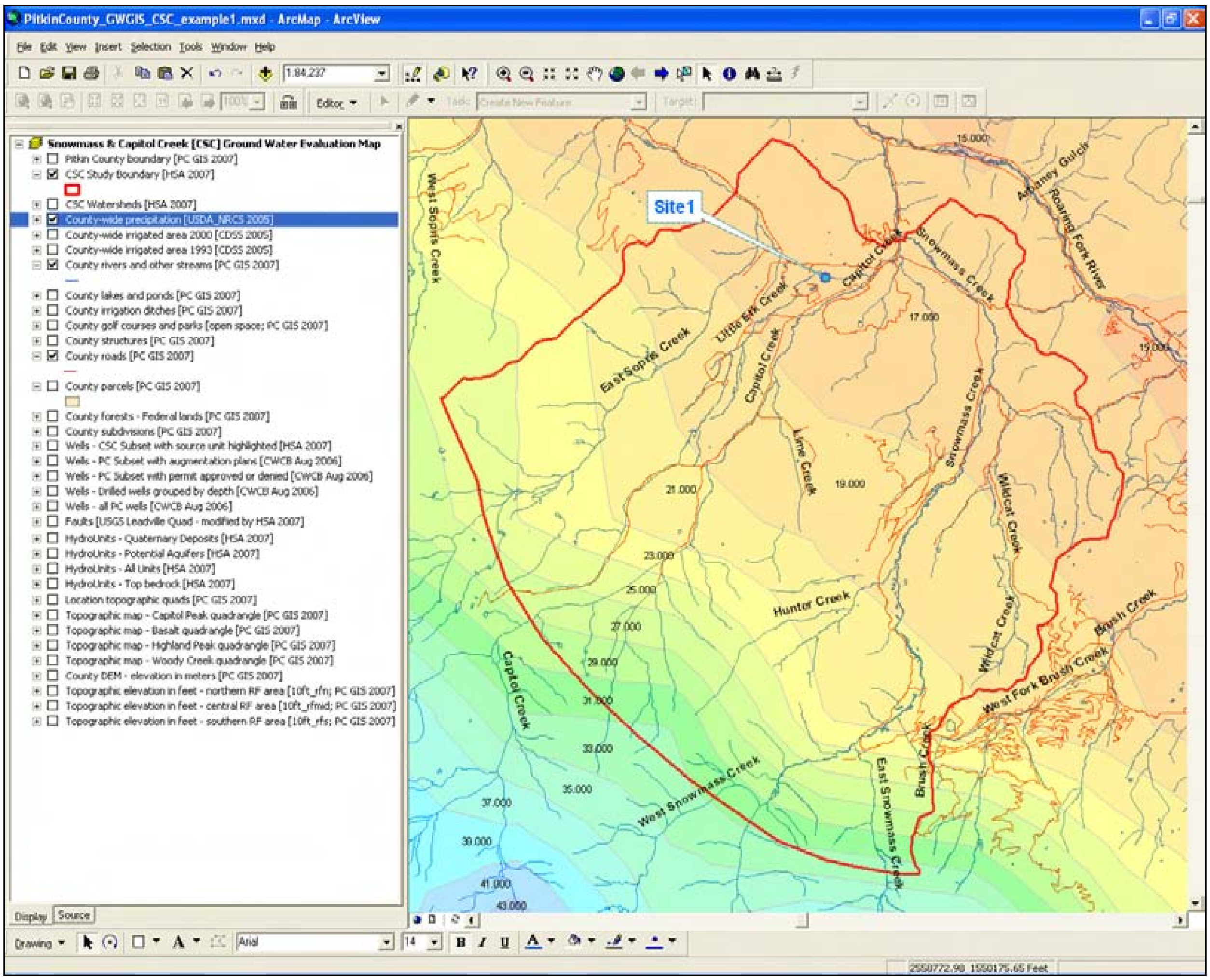

Figure 45. Determine Recharge from Precipitation in the Vicinity of Site 1 Using GIS Layer 4.

The next step is to determine if the shallow aquifer is hydraulically connected or not-connected with a perennial stream. This step is performed to determine the potential for recharge to the aquifer from a nearby stream. First, layer 7 (streams) and layer 8 (ponds) are turned on (Figure 46). The attribute table of layer 7 contains, among others, a field in the attribute table indicating intermittent stream flow (ephemeral stream) or continuous stream flow (perennial stream) (Figure 46). By analyzing hydrogeologic information from the potential aquifer layer (layer 23) and the county's streams layer as shown in Figure 46 in the context of the conceptual model of the LCC subsystem, it appears that a hydraulic connection between the unconsolidated aquifer and both Little Elk Creek and Capitol Creek exists. This hydraulic connection may be directly with the alluvium (Qal) or indirectly through the Qgf unit.

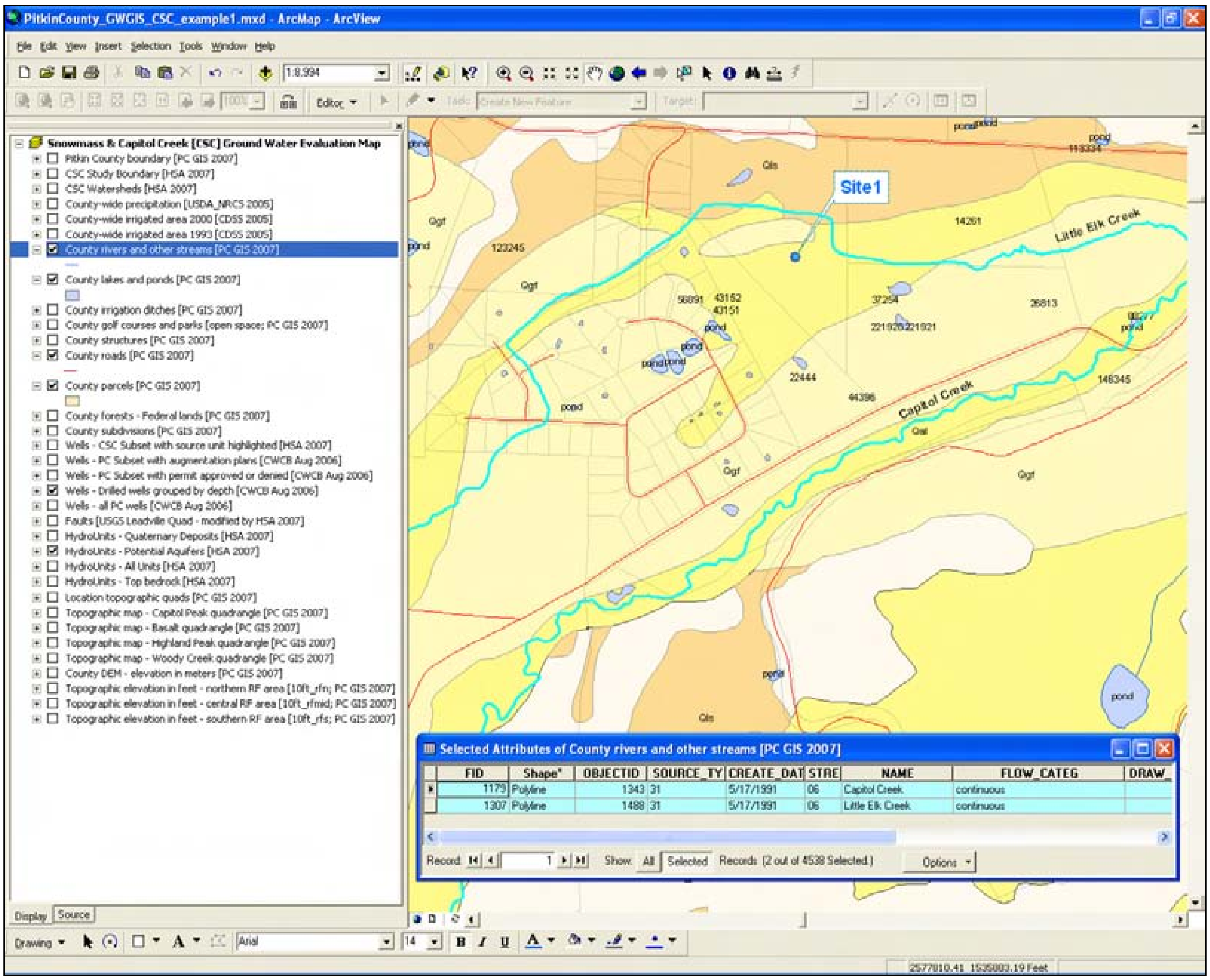

Figure 46. Determine the Presence of a Hydraulic Connection between the Aquifer at Site 1 and Nearby Streams Using GIS Layers 7 and 23.

Although little information is available with respect to ground water levels and flow, topography, and location and elevation of streams (layer 32) indicate that the ground water generally discharges to both Little Elk Creek and Capitol Creek (Figure 47). During spring runoff, Little Elk Creek may become an effluent stream recharging the shallow aquifer in the vicinity of the site. Pumping at the site may reverse local discharge to the stream and the stream may become effluent for most of the year.

Layers 5, 6, 9 are used in conjunction with layer 22 to determine if the shallow aquifer near site 1 is recharged by irrigation practices, which may not sustain a ground water supply if water uses and water-rights ownership change. Figure 48 shows that the site is surrounded by irrigated acreage, although the development of the Little Elk Village subdivision has removed some irrigated acreage to the west of the site. Figure 49 shows the network of ditches in the vicinity of the site. As the irrigated acreage and the ditches in the vicinity of the site are located directly above the unconsolidated sediments, it is expected that irrigation return flow and ditch leakage recharge the underlying aquifer. Note, that the ditch layer includes active and non-active ditches, but the distinction between active and inactive ditches, as well as size of the ditches, cannot be determined using this GIS layer. Note, also, that calculation of actual recharge amounts requires professional judgment using standard practices.

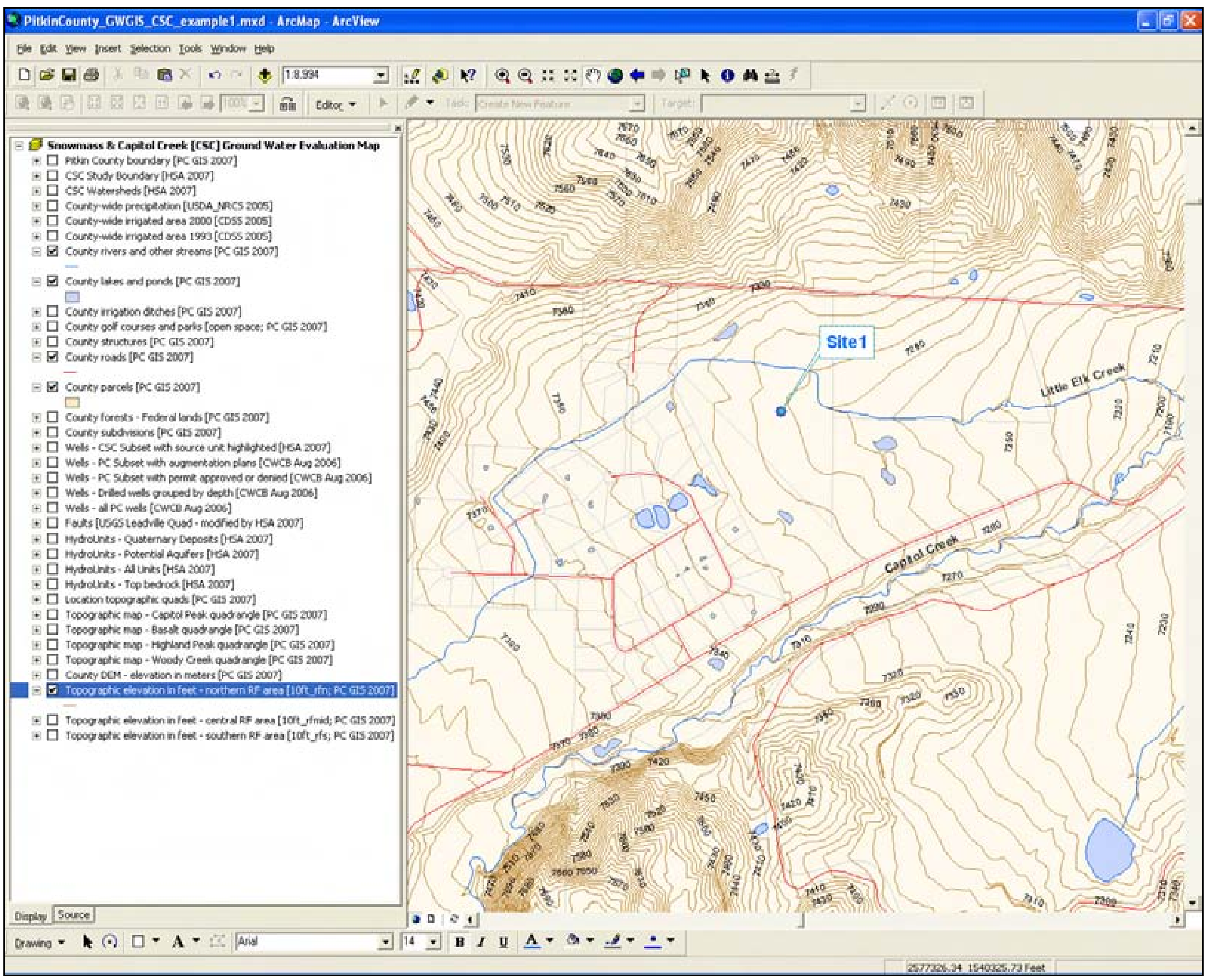

Figure 47. Determine Potential Recharge from Nearby Stream(s) Using GIS Layers 7 and 32.

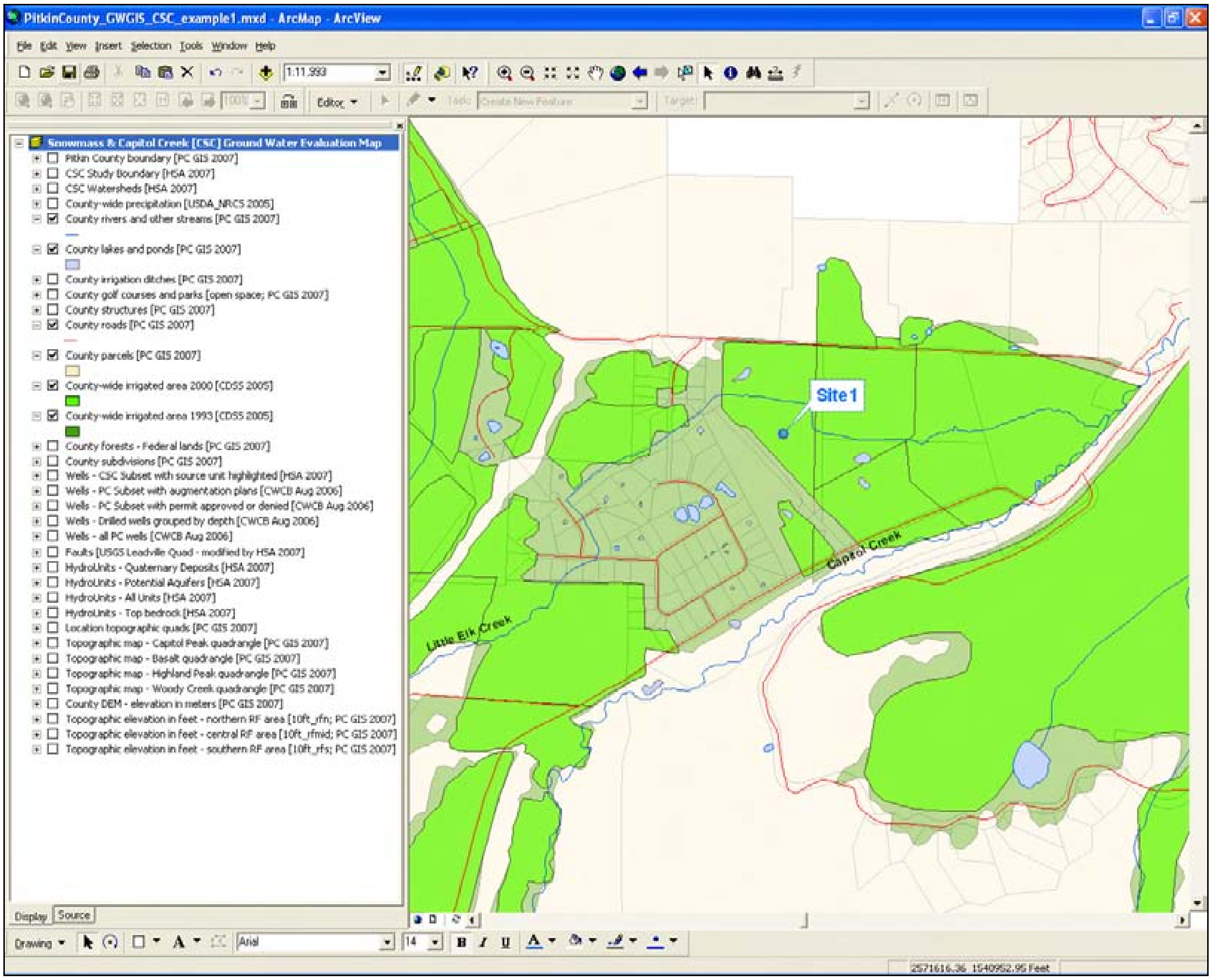

Figure 48. Determine Potential Recharge from Irrigation Return Flow in the Vicinity of Site 1 Using GIS Layers 5 and 6.

(Note, layers 5 and 6 have been moved down in the Table of Contents for improved legibility of Figure).

5.1.4 Determine Ground Water Vulnerability

Natural protection from overlying confining units, such as the Mancos Shale, is important for maintaining natural water quality. However, all ground water in the area with unconsolidated sediments, and bedrock aquifer outcrops or subcrops, is vulnerable to contamination from the land surface. Because the surficial aquifer and the shallow water table near site 1 is unprotected by a natural barrier, the ground water vulnerability in the area is considered high. Calculation of actual risk (both qualitatively and quantitatively) requires professional judgment using standard practices.

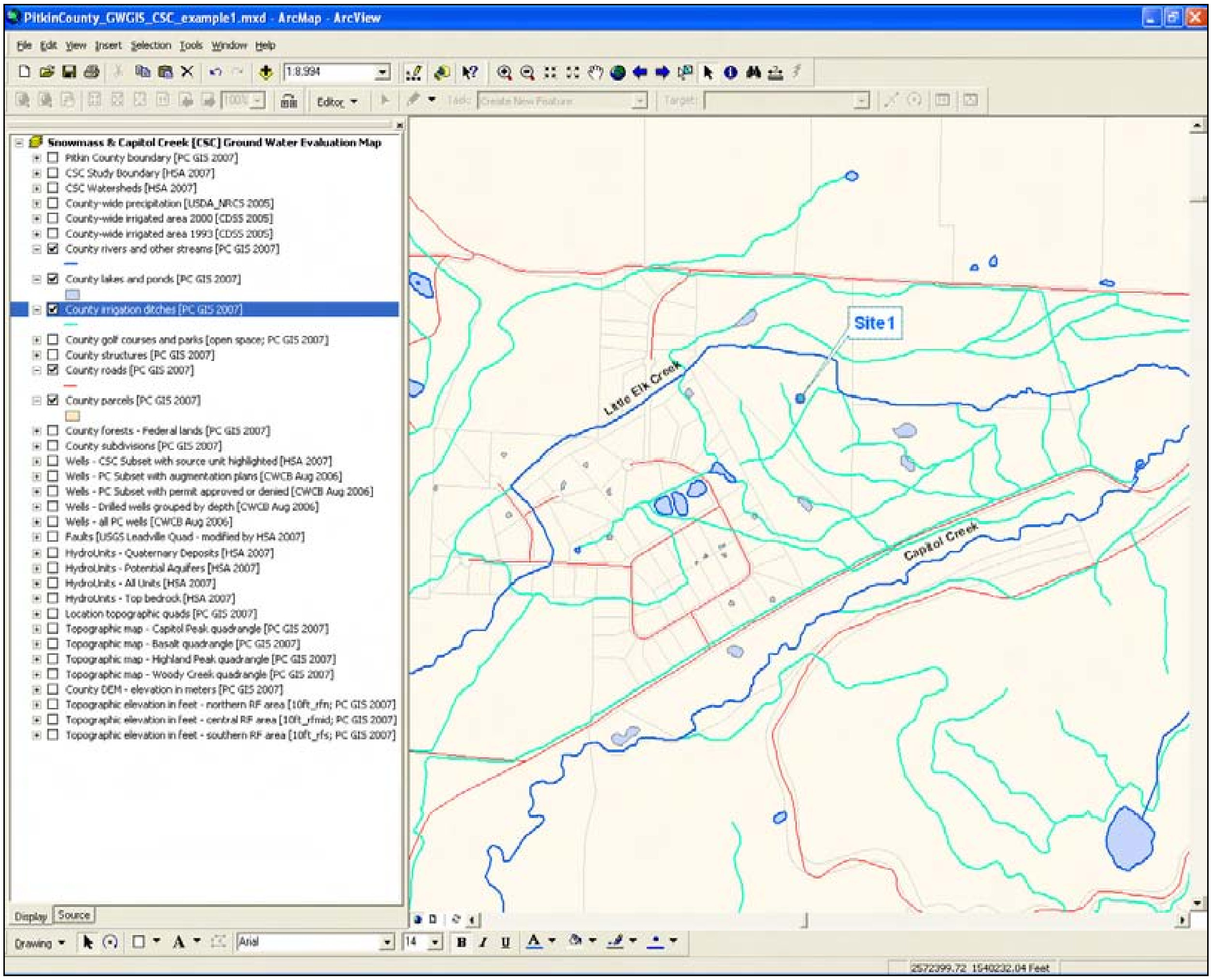

Figure 49. Determine Potential Recharge from Leaking Irrigation Ditches in the Vicinity of Site 1 Using GIS Layer 9.

5.2 Example 2 in Lime Creek Area of Upper Capitol Creek Valley

5.2.1 Identify Location on GIS Map

Example 2 is a site located on parcel #264517400001 [at about (Colorado State Plane, Central Zone NAD 83) coordinate 2571035, 1526125], near St Benedicts Monastery (blue marker dot; Figures 39 and 50). The coordinate location can be found near the lower right hand corner of the data frame. Parcel and subdivision details are found by using the *Identify* function on the menu bar and selecting the *County parcels* or *County subdivisions* layer from the layers list at the top of the *Identify Results* window (layers 13 and 15, respectively; Figure 50). The coordinates of the site can be found near the lower right hand corner of the map while moving the mouse to the location of the site (Figure 50). The streams layer and the roads layer are shown for orientation. The label feature of the subdivision layer and the streams layer are turned on. The site is located in the valley section of the UCC hydrologic subsystem, and the hydrogeologic conceptual model for this area is shown in Figure 11 (unconsolidated materials located on top of Mancos Shale).

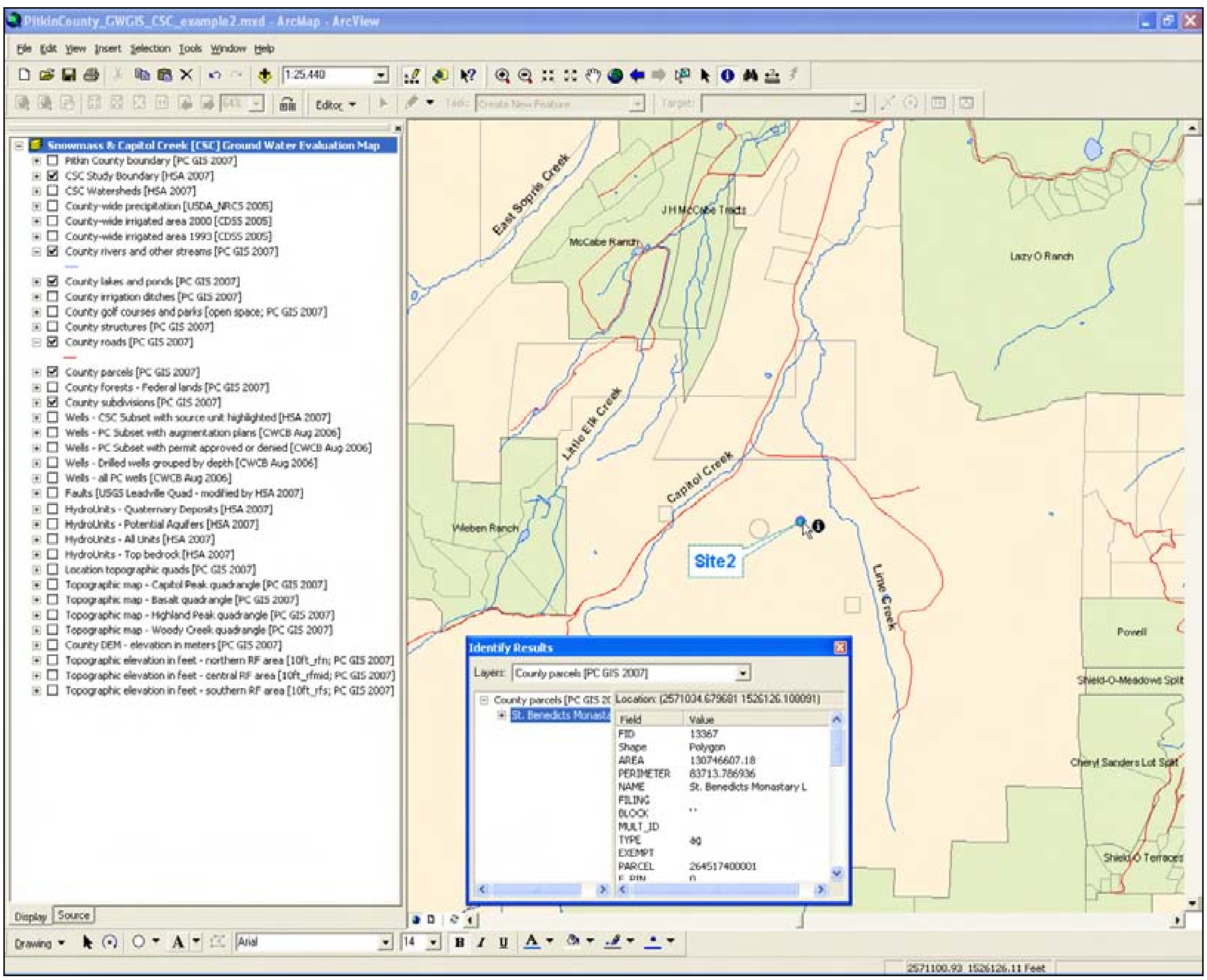

Figure 50. Locate Site 2 Using GIS Layers 13 and 15

(layers 7 [streams] and 12 [roads] are used for orientation).

5.2.2 Determine Ground Water Availability

Using the *Identify* function on the menu bar and selecting the *Hydrounits - Potential aquifers* layer (layer 23) from the layers list, it is determined that the potential aquifer material is Qal (alluvium), possibly on top of Qgf (Figures 11 and 51). From using the *Identify* function for the *Hydrounits - Top bedrock* layer (layer 25), the underlying bedrock unit is determined to be Km (Mancos Shale) (Figure 52). From the discussion of the UCC subsystem in chapter 2, it is concluded that there is no water resource in the bedrock at the site (Figure 11). Thus, there is no alluvium-bedrock aquifer connectivity. This means that the surficial aquifer is not connected to or sustained by an underlying bedrock aquifer and that aquifer sustainability is determined solely by surface processes related to nearby streams, ditches, irrigation, hillslope runoff, and precipitation.

The next step is to determine if the alluvial material is saturated or unsaturated. This determination is made on the basis of information from nearby wells and, because the aquifer is an alluvial unit, the water levels in nearby streams in conjunction with ground elevation at the site.

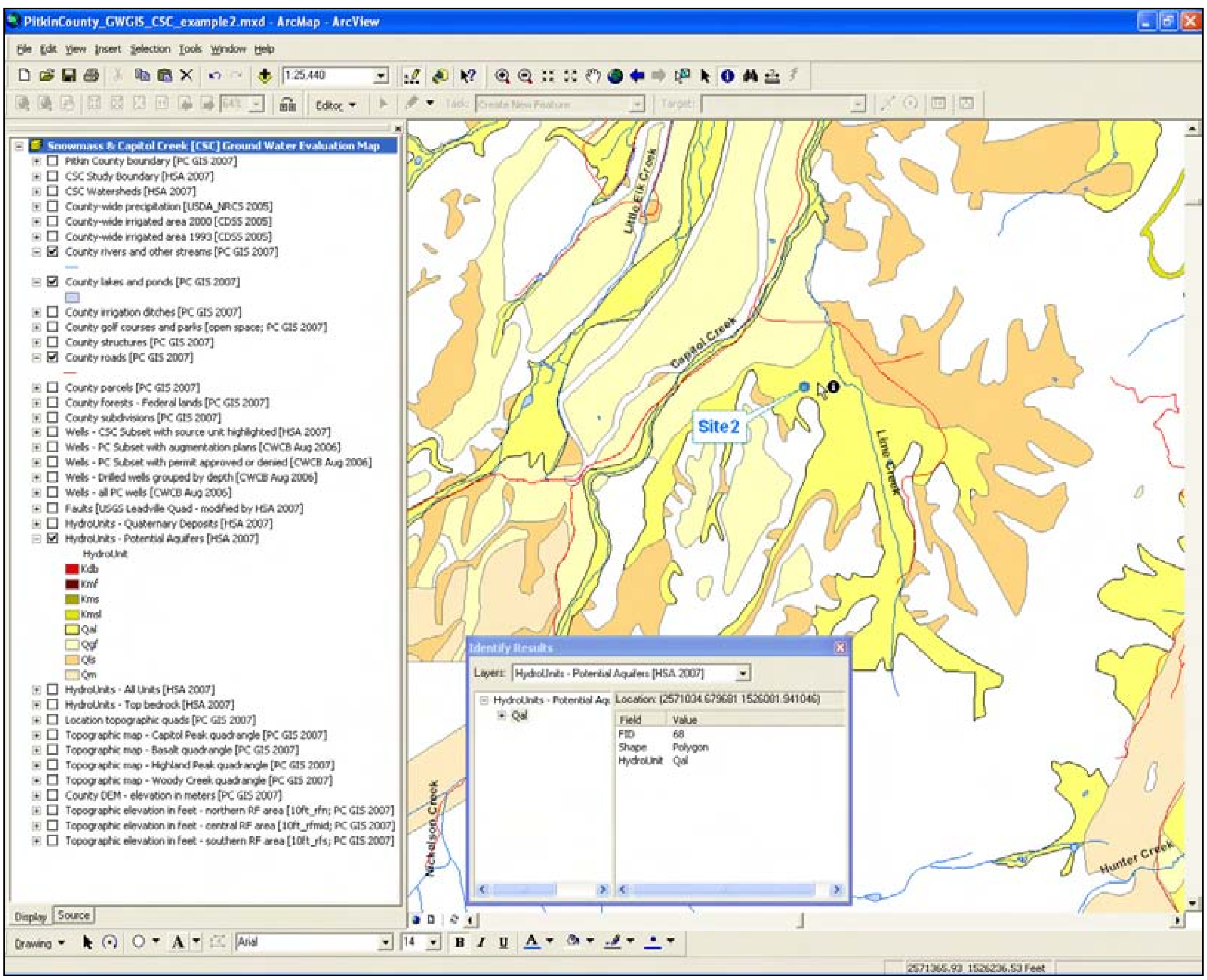

Figure 51. Determine the Potential Presence of an Unconsolidated Aquifer at Site 2 Using GIS Layer 23.

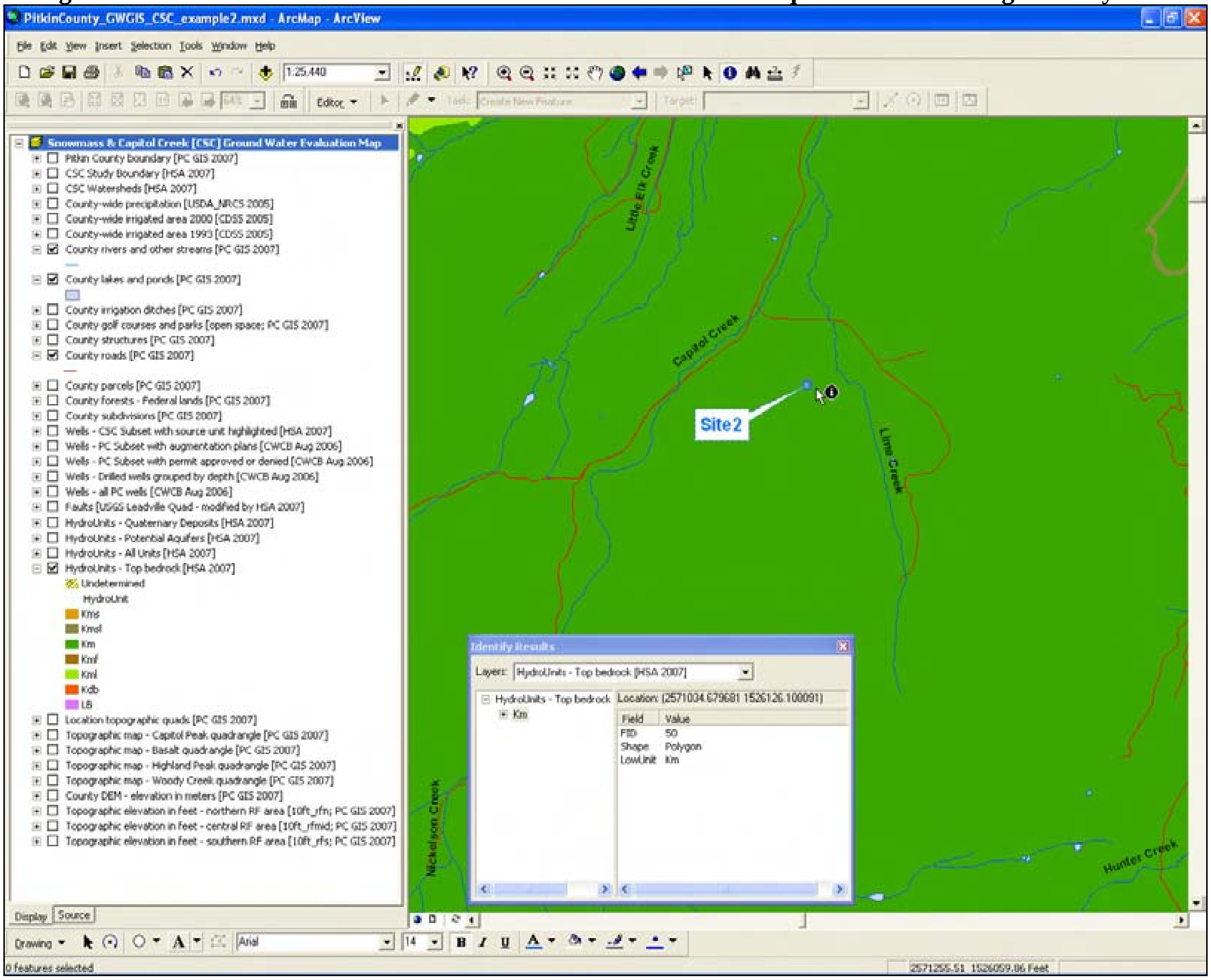

Figure 52. Determine the Hydrogeological Unit Underlying the Unconsolidated Aquifer at Site 2 Using GIS Layer 25.

Layer 19 (drilled wells grouped by depth) is turned on to identify relevant nearby wells (Figure 53). The nearest well that may provide information is well # 580 located 3300ft SSE of the site (Figure 53). This shallow well (50ft deep) is in the alluvium near the boundary between outcropping bedrock and the alluvium. The well may have been drilled to bedrock. In the absence of depth to static water level information, no judgment can be made with respect to pre-development saturated thickness based on this well. The site is about 800ft from Lime Creek, an intermittent stream. Site elevation is about 15ft higher than streambed elevation. Because the stream is not perennial, this information is not sufficient to assess saturated thickness at the site.

In conclusion, there are 2, possibly 3, potential aquifer units near the site: 1) alluvium, 2) gravels, and 3) landslide deposits. It is unknown if these units are saturated, and the saturated thickness can not be determined with the available information. Thus, the availability of a ground water resource is not determined. However, for the discussion in the next section, it is assumed that there is a ground water resource available.

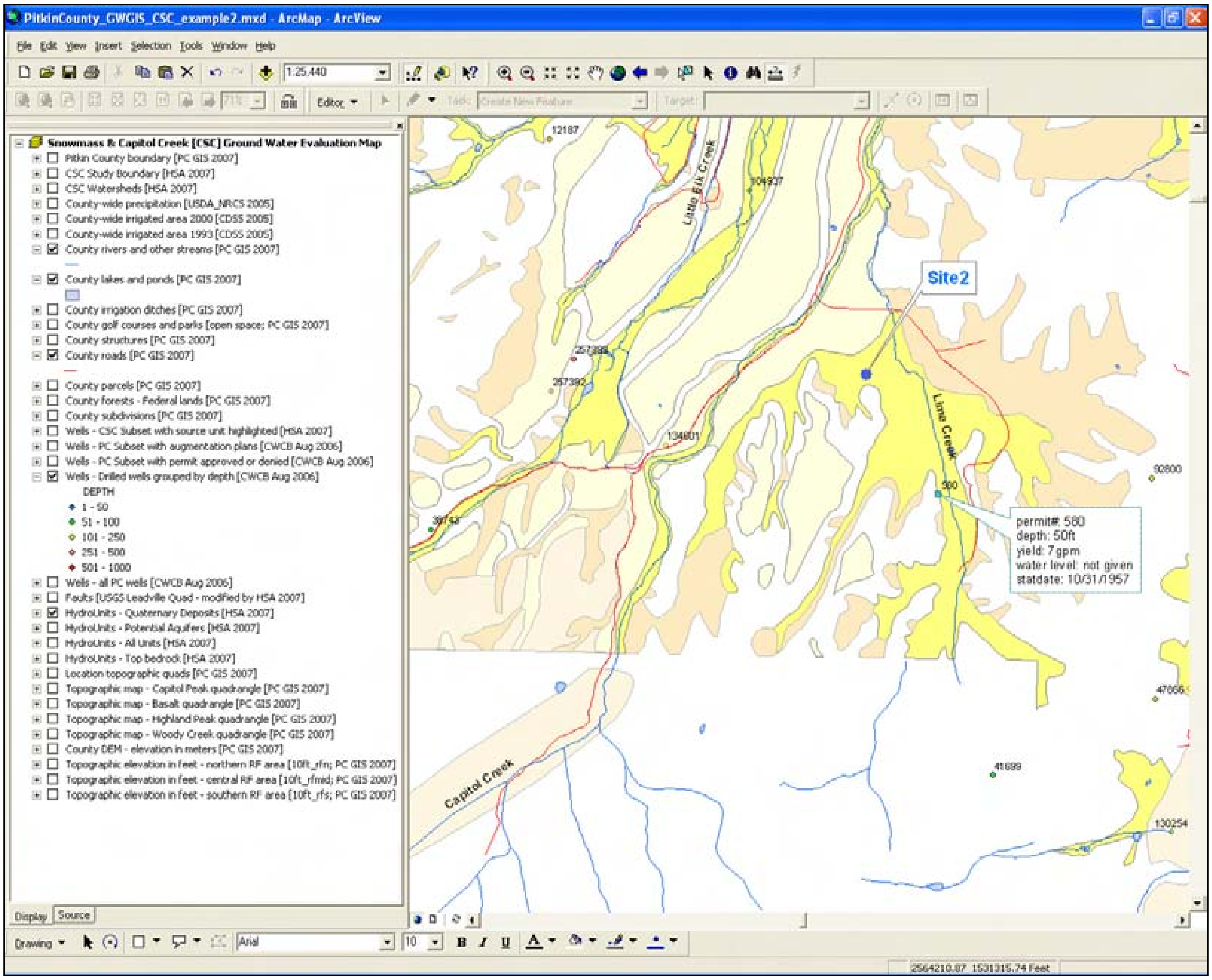

Figure 53. Determine Relevant Nearby Wells at Site 2 Using GIS Layer 19.

5.2.3 Determine Ground Water Sustainability

The precipitation layer (layer 4) is turned on to assess the recharge potential from precipitation in the vicinity of the site. The site is located in an area that receives an average of about 19 inches of precipitation per year, or an estimate of 1.9 inches of recharge per year (Figure 54). Calculation of actual recharge amounts (a fraction of precipitation) requires professional judgment using standard practices.

The next step is to determine if the aquifer is recharged from a nearby stream. First, a determination is made if the shallow aquifer near the site is hydraulically connected or not-connected with a perennial stream, or a stream that carries water almost continuously. By combining hydrogeologic information from the potential aquifer layer (layer 23) with the county's streams layer (layer 7), as shown in Figure 51, and checking creek elevations and site elevation (layer 33; Figure 55), it appears that a hydraulic connection exists between the unconsolidated aquifer and Lime Creek. The distance between the site and Capitol Creek is about 2100ft and the elevation difference is about 150ft. Therefore, although Capitol Creek appears to have a hydraulic connection with the alluvium (Qal) and/or the Qgf unit, the stream only drains the area around site 2, and cannot be a source of recharge.

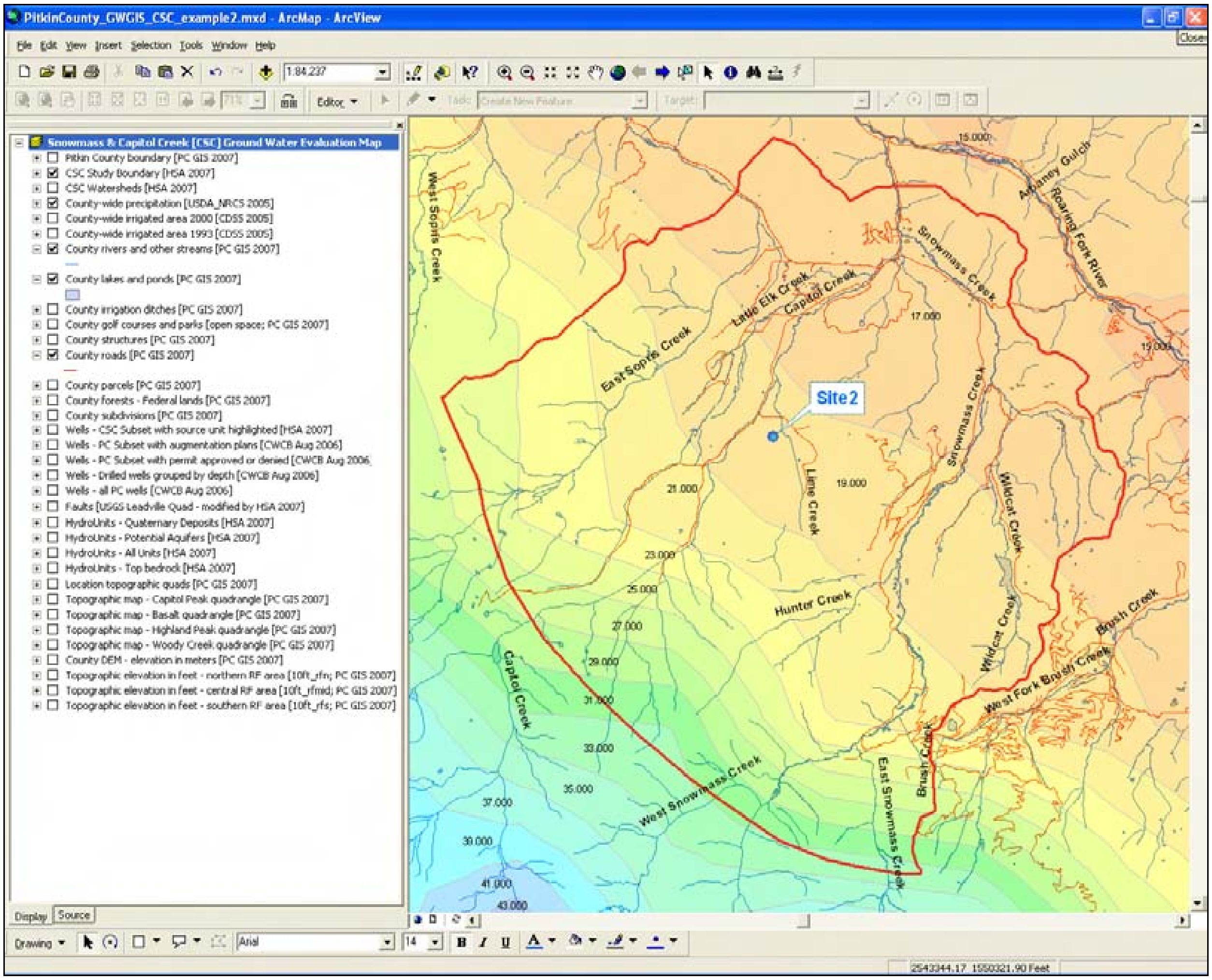

Figure 54. Determine Recharge from Precipitation at Site 2 Using GIS Layer 4.

Although little information is available with respect to ground water levels and flow, the locally rather flat topography, and the location and elevation of nearby streams (layer 33) indicate that the water table at site 2 is shallow, and that ground water generally discharges to both Little Elk Creek and Capitol Creek (Figure 55). During spring runoff, Little Elk Creek may become an effluent stream recharging the shallow aquifer in the vicinity of the site. Pumping at site 2 may reverse local discharge to the stream, and the stream may become effluent and more intermittent.

Layers 5, 6, 9 are used in conjunction with layer 22 to determine if the shallow aquifer near site 2 is recharged by irrigation practices, which may not sustain a ground water supply if water uses and water-rights ownership change. Figure 56 shows an extensive irrigated acreage and a dense network of ditches in the vicinity of the site. As irrigated acreage and the ditches are situated directly above the unconsolidated sediments, irrigation return flow and ditch leakage recharge the underlying aquifer. Note, that the ditch layer includes active and non-active ditches, but the distinction between active and inactive ditches, as well as size of the ditches, cannot be determined using this GIS layer. Note, also, that the determination of the sustainability of the ground water resources in this area is a quantitative problem that requires professional judgment using standard practices.

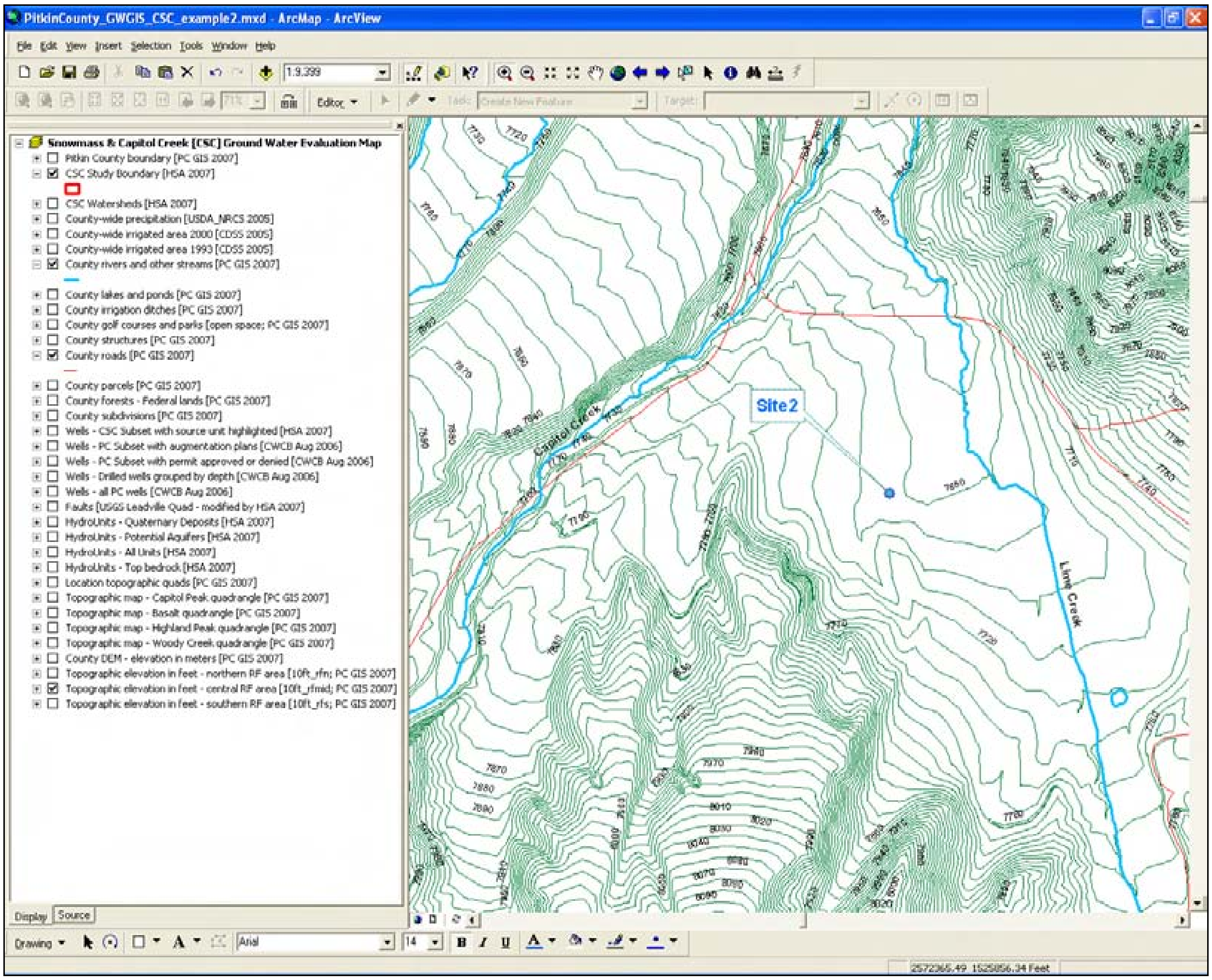

Figure 55. Determine Potential Recharge from Nearby Streams at Site 2 Using GIS Layers 7 and 33.

5.2.4 Determine Ground Water Vulnerability

Natural protection from overlying confining units, such as the Mancos Shale, is important for maintaining natural water quality. However, all ground water in the area with unconsolidated sediments, and bedrock aquifer outcrops or subcrops, is vulnerable to contamination from the land surface. Because the surficial aquifer and the shallow water table near site 2 is unprotected by a natural barrier, the ground water vulnerability in the area is considered high. Calculation of actual risk (both qualitatively and quantitatively) requires professional judgment using standard practices.

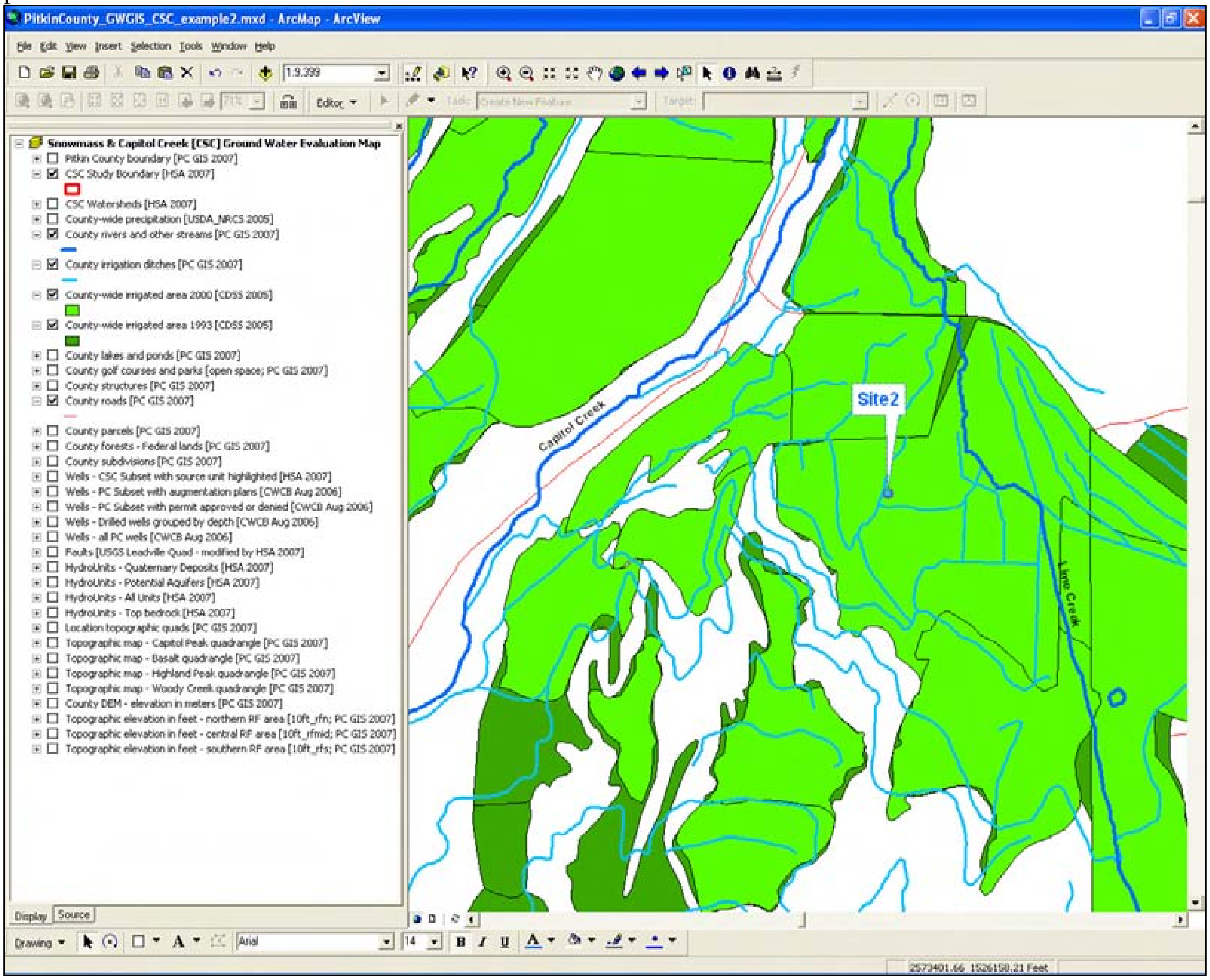

Figure 56. Determine Potential Recharge from Irrigation Return Flow and Leaking Ditches at Site 2 Using GIS Layers 5, 6 and 9.

(Note, layers 5 and 6 have been moved down in the Table of Contents for improved legibility of Figure).

5.3 Example 3 on Ridge Separating Upper Snowmass and Upper Capitol Creek Valleys

5.3.1 Identify Location on GIS Map

Example 3 is a site located on parcel # 26453201001 [at about (Colorado State Plane, Central Zone NAD 83) coordinate 2578150, 1511933], in the Harvey Snowmass Creek Ranch subdivision on the ridge between Snowmass Creek and Hunter Creek (blue marker dot; Figures 39 and 57). Parcel and subdivision details are found by using the *Identify* function on the menu bar and selecting the *County-Parcels* or *County-Subdivisions* layer from the layers list at the top of the *Identify Results* window (layers 13 and 15, respectively; Figure 57). The coordinates of the site can be found near the lower right hand corner of the map while moving the mouse to the location of the site (Figure 57). The streams layer and the roads layer are shown for orientation. The label feature of the subdivision layer and the streams layer are turned on. The site is located in the western hillslope section of the USC hydrologic subsystem, and the hydrogeologic conceptual model for this area is shown in Figure 7 (gravels on top of Mancos Shale).

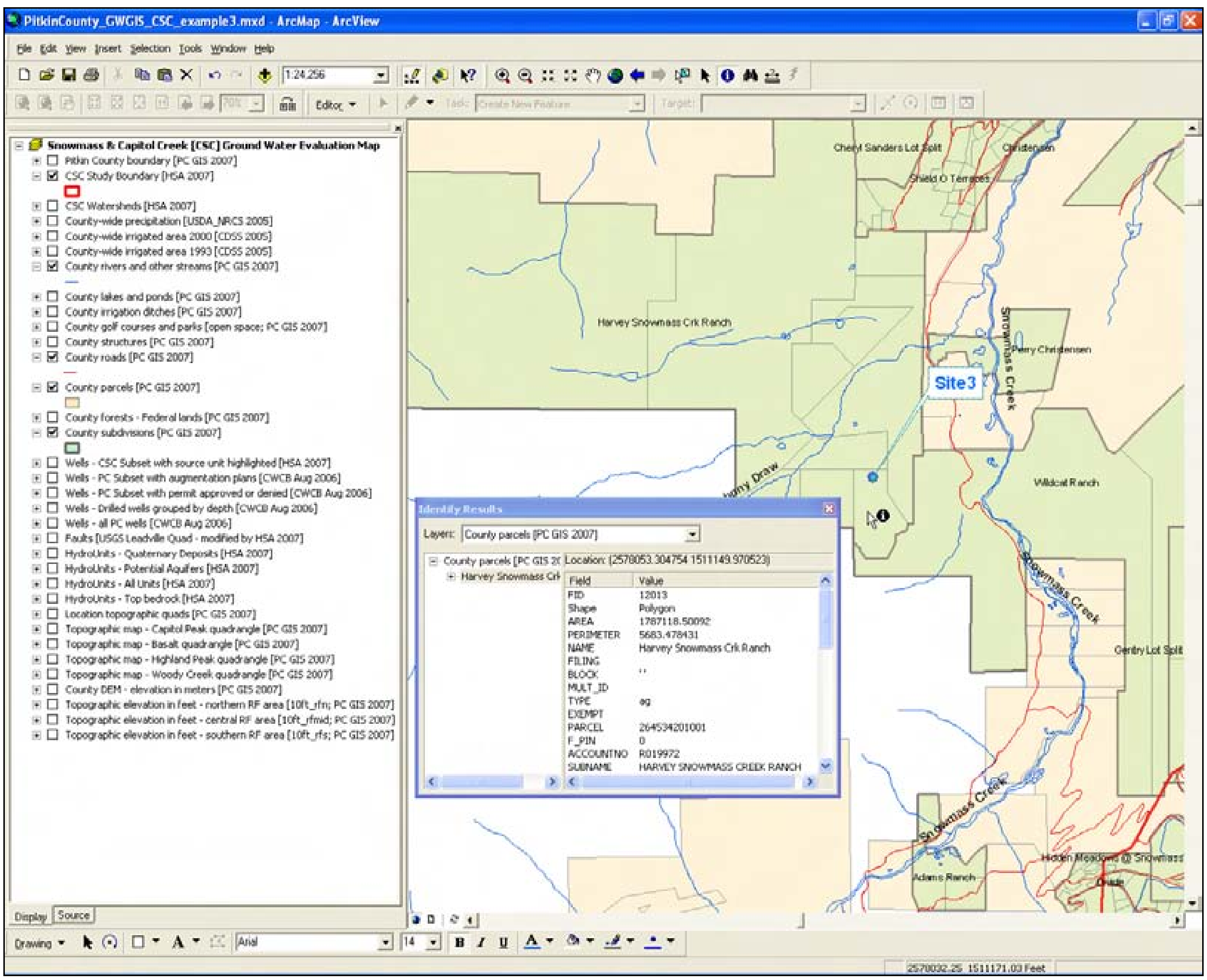

Figure 57. Locate Site 3 Using GIS Layers 13 and 15

(layers 7 [streams] and 12 [roads] are used for orientation).

5.3.2 Determine Ground Water Availability

Using the *Identify* function on the menu bar and selecting the *Hydrounits-Potential aquifers* layer (layer 23) from the layers list, it is determined that the potential aquifer material is Qgf (unconsolidated gravels), and is in direct contact with the adjacent Qgf unit (landslide materials; Figures 7 and 58). From using the *Identify* function for the *Hydrounits-Top bedrock* layer (layer 25), it follows that the underlying unit is Km (Mancos Shale) (Figure 59). From the discussion of the USC subsystem in chapter 2 it is concluded that there may be a water resource in the Kmf (Fort Hays Limestone) unit near the site (Figure 7). However, the Kmf unit is steeply dipping down to the synclinal axis located to the north of the site, away from the outcrop located 2000ft south of the site. (Figure 59; see also cross-section C-C' on the Highland Peak Geologic Quadrangle map; Bryant, 1972). According to the Bryant's cross-section, the thickness of the Mancos Shale above the Kmf at site 3 is at least 2000ft. Note, that by turning on the *Faults* layer (layer 21), the location of the synclinal axis north of the site becomes visible.

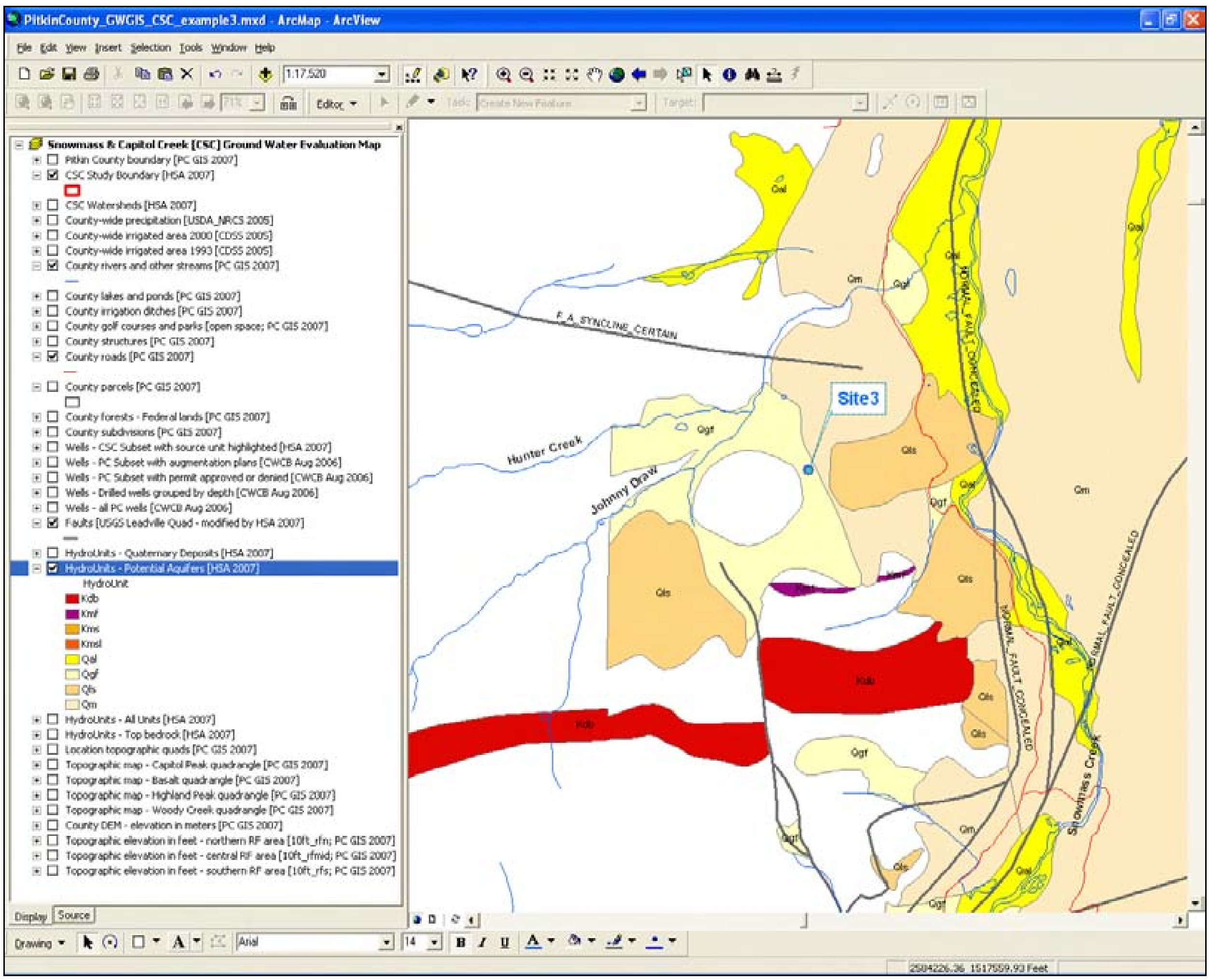

Figure 58. Determine the Potential Presence of an Unconsolidated Aquifer at Site 3 Using GIS Layer 23.
(Layer 21 is also turned on).

From the presence of the thick Mancos shale unit underneath the surficial aquifer materials at the site, and the location of the Mancos Shale outcrops directly west of the site as well as between the site and the Kmf outcrop, it is suggested that there is no surficial aquifer-bedrock aquifer connectivity (Figure 7). This means that the surficial aquifer at the site, if saturated, is not connected to or sustained by an underlying bedrock aquifer and that the sustainability of the surficial aquifer as a water supply is determined solely by surface processes.

In the direct vicinity of the site, the Kmf and Kdb units are under confined conditions. The relevance of these units as a water resource depends on unit thickness and depth, the thickness of the overlying Mancos shale units, and the recharge mechanism and rate. These units may have some local significance in the direct vicinity of the outcrops south of site 3.

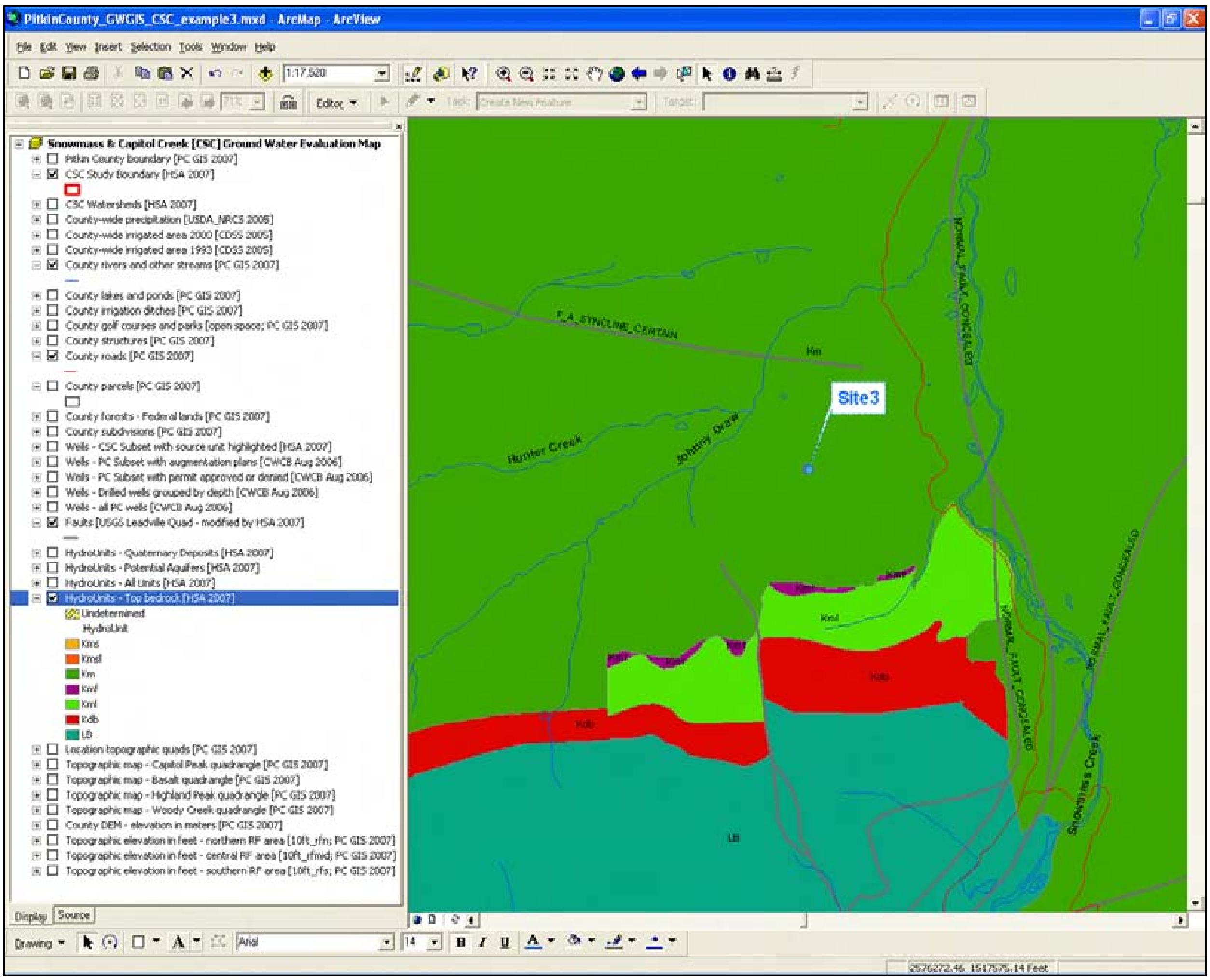

Figure 59. Determine the Hydrogeological Unit Underlying the Unconsolidated Aquifer at Site 3 Using GIS Layer 25.

The next step is to determine if the alluvial material is saturated or unsaturated. This determination is made on the basis of information from nearby wells and, if applicable, the water levels in nearby streams in conjunction with surface elevation at the site.

To identify relevant nearby wells, layer 19 (drilled wells grouped by depth) is turned on (Figure 60). The wells can be selected using the *Select Tool* from the Tools Toolbar (Figure 60). To display only the subset of selected wells, use the *Selected* button next to the *Show "All" Records* button at the bottom of the attribute table (see insert in Figure 60). The nearest well that may provide information is well # 78772 located about 2500ft east of the site (Figure 60). This well is one of a cluster of shallow wells (<50ft deep) in the Qls located near the boundary with the Snowmass Creek alluvium. Depth to static water level in these wells range from 12 to 17ft; pre-development saturated thickness ranges from at least 20ft to at least 23ft, based on the depth of the wells. However, the elevation at the site is 8610ft, while the surface elevations at the existing wells are at least 550 ft lower (Figure 61). Therefore, these wells can not be used to determine hydrologic conditions at the site. Using a similar analysis, it is concluded that Snowmass Creek with an elevation near the site of about 8040ft, and the confluence of Johnny Draw and Hunter Creek near the site at an elevation of about 8480ft cannot be used to determine hydrologic conditions at the site (Figure 61).

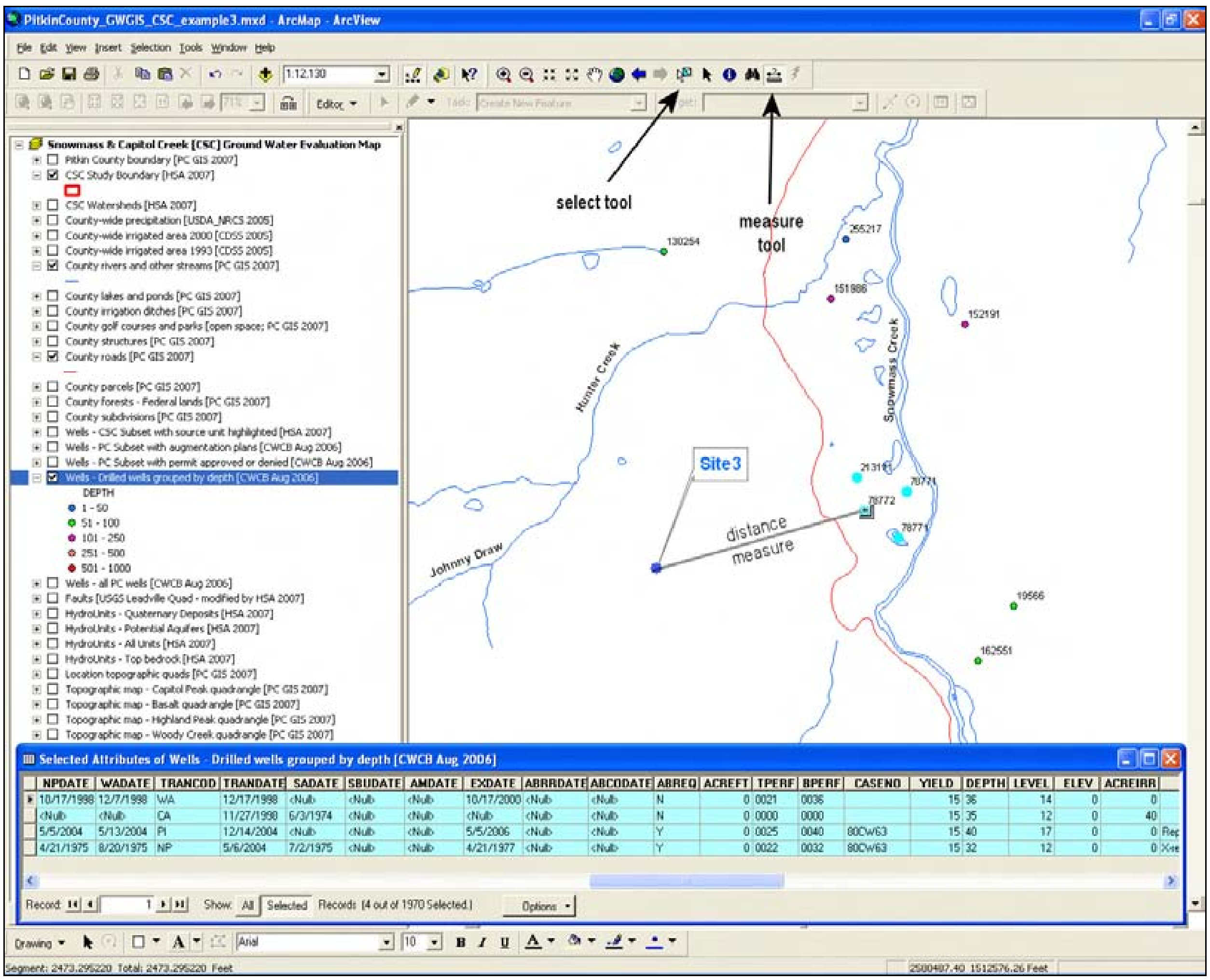

Figure 60. Identify Relevant Wells in the Vicinity of Site 3 Using GIS Layer 19.

In conclusion, there is a potential shallow aquifer in the Quarternary gravels. It is unknown if this unit is saturated at the site, and the potential saturated thickness has not been determined. Thus, the availability of a ground water resource is not determined. However, for the discussion in the next section, it is assumed that there is a ground water resource available.

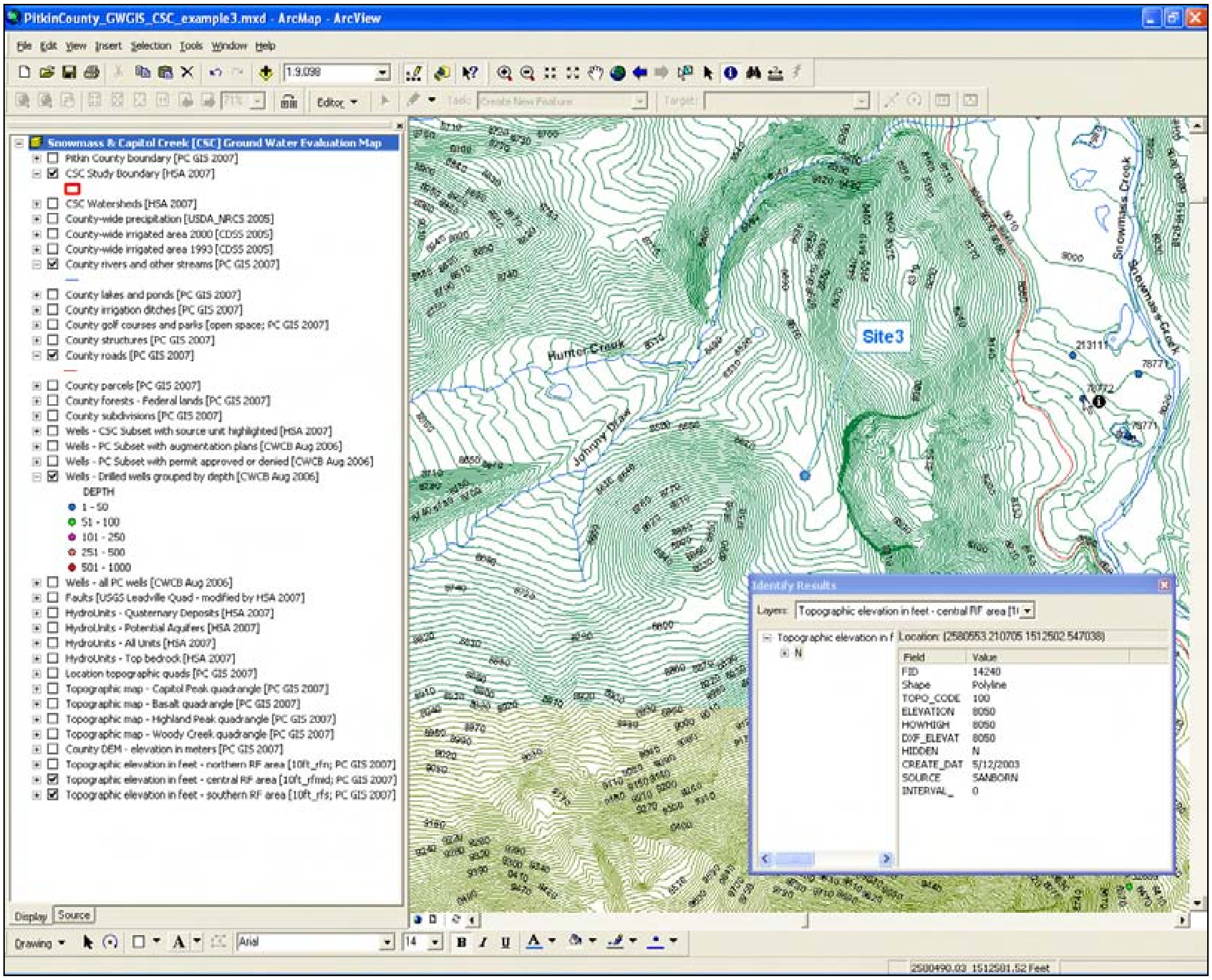

Figure 61. Identify Surface Elevation of Nearby Wells and Streams at Site 3 Using GIS Layers 33 and 34.

5.3.3 Determine Ground Water Sustainability

The precipitation layer is turned on (layer 4) to assess the recharge potential from precipitation in the vicinity of the site. The site is located in an area that receives an average of about 21 inches of precipitation per year, or an estimate of 2.1 inches of recharge per year (Figure 62). Calculation of actual recharge amounts (a fraction of precipitation) requires professional judgment using standard practices.

The next step is to determine if the aquifer may be recharged from a nearby stream. First, a determination is made if the shallow aquifer near the site is hydraulically connected or not-connected with a perennial, or a stream that carries water almost continuously. By analyzing hydrogeologic information from the potential aquifer layer (layer 23) and the county's streams layer (layer 7) as shown in Figure 58, and checking creek elevations and site elevation (layers 33 and 34; Figure 61), it is concluded that the lower lying Snowmass Creek, Hunter Creek, and Johnny Draw can only drain the area around site 3 and cannot be a source of recharge to the surrounding alluvial units.

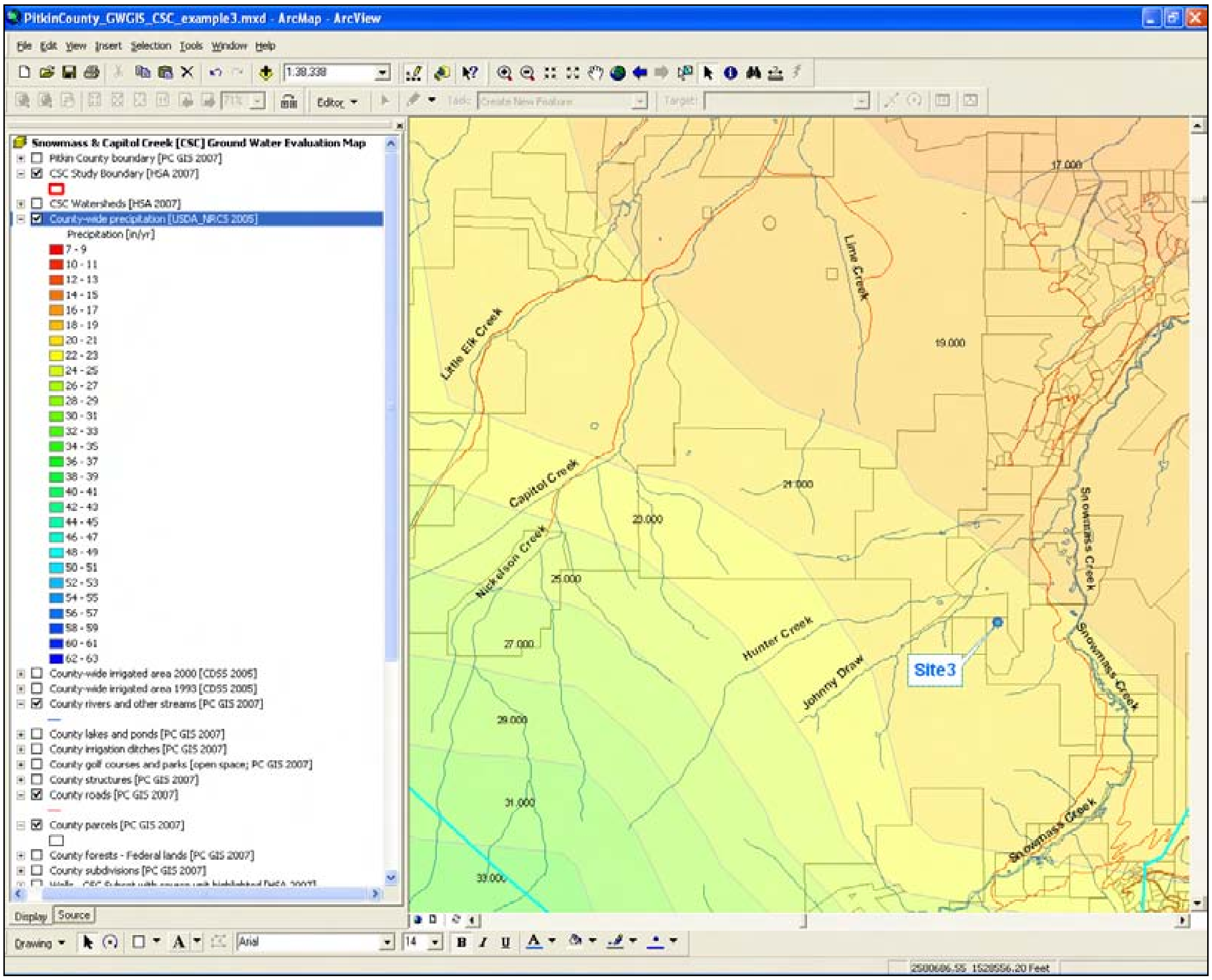

Figure 62. Determine Recharge from Precipitation at Site 3 Using GIS Layer 4

Although little information is available with respect to ground water levels and flow, topography and location and elevation of streams (layers 33 and 34; Figure 61) indicate that ground water generally discharges to the surrounding streams. Pumping at site 3 will have minimum influence on stream flows.

Layers 5, 6, 9 are used in conjunction with layer 22 to determine if the shallow aquifer near site 3 is recharged by irrigation practices, which may not sustain a ground water supply if water uses and water-rights ownership change. Figure 63 shows an extensive irrigated acreage supplied by an irrigation ditch in the vicinity of the site. The ditch brings water from the streams located west of the site to the irrigated area on the flat ridge top near the site. As irrigated acreage and the ditches are situated directly above the unconsolidated sediments, irrigation return flow and ditch leakage recharge the underlying aquifer. Note, that the ditch layer includes active and non-active ditches, but the distinction between active and inactive ditches, as well as size of the ditches, cannot be determined within this GIS layer.

In conclusion, if a ground water resource exists at site 3, it is only locally recharged by precipitation (rain and snow melt), irrigation return flow, and leaking ditches. Determination of the sustainability of a potential ground water resource in this area is a quantitative problem that requires professional judgment using standard practices.

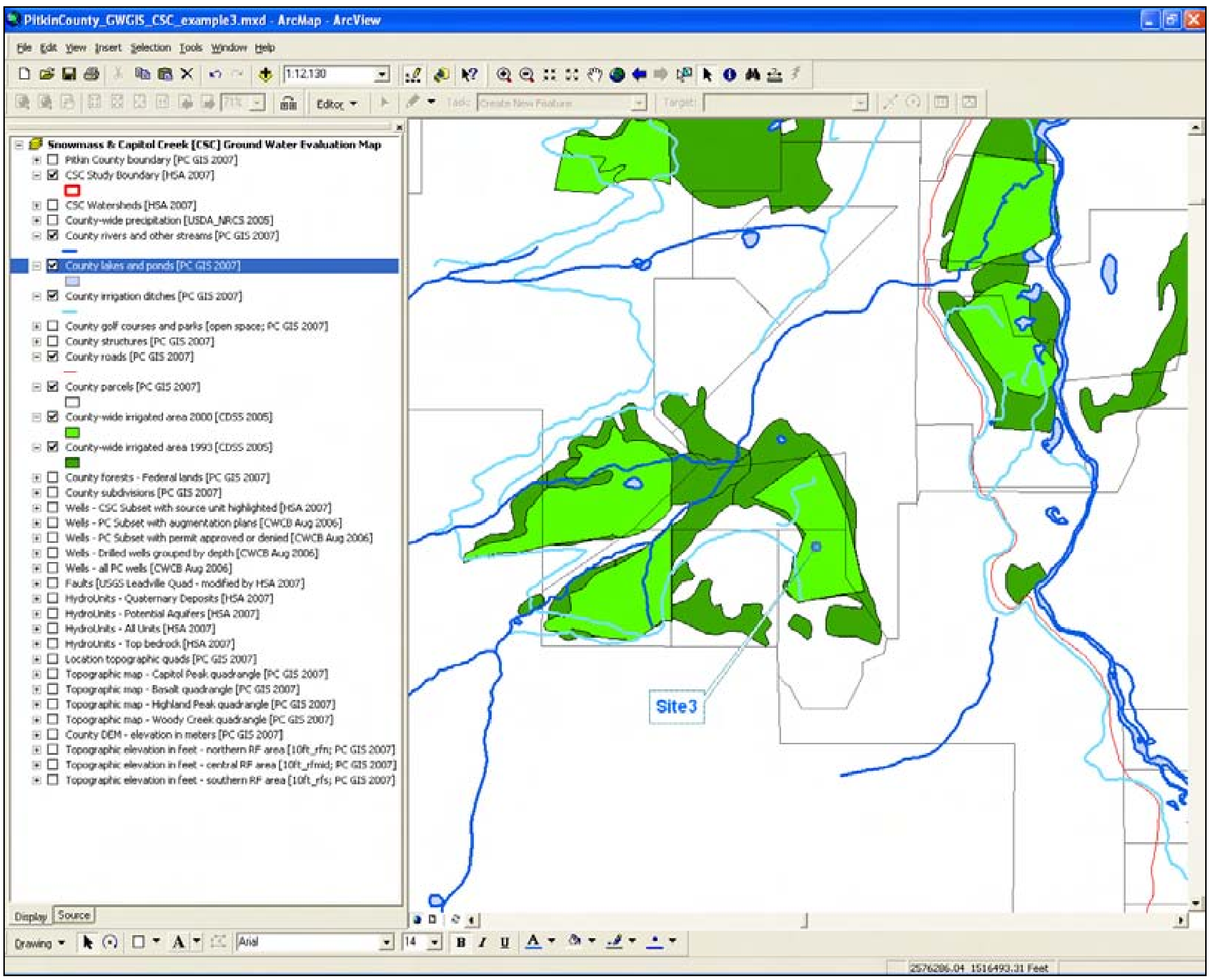

Figure 63. Determine Potential Recharge from Irrigation Return Flow and Leaking Ditches at Site 3 Using GIS Layers 5, 6 and 9.

(Note, layers 5 and 6 have been moved down in the Table of Contents for improved legibility of Figure).

5.3.4 Determine Ground Water Vulnerability

Natural protection from overlying confining units, such as the Mancos Shale, is important for maintaining natural water quality. However, all ground water in the area with unconsolidated sediments, and bedrock aquifer outcrops or subcrops is vulnerable to contamination from the surface. Because the presence of the unprotected surficial aquifer materials near site 3, the vulnerability of a ground water resource in this area is considered high. Calculation of actual risk (both qualitatively and quantitatively) requires professional judgment using standard practices.

6.0 Conclusions and Recommendations

6.1 Conclusions

Under an agreement with Pitkin County, Hydrologic Systems Analysis, LLC (HSA) of Golden, Colorado, in cooperation with Heath Hydrology, Inc. (HHI) of Boulder, Colorado, created a GIS-based, step-wise, ground water resources evaluation procedure for use as decision/land use management tools by Pitkin County. The procedure, supported by a GIS map and supporting databases, guides the site-specific analysis with respect to: 1) ground water resources availability in terms of sufficient quantities for the purpose of its usage, and economical exploitability (e.g., at reasonable depth and with sufficient permeability); 2) long-term sustainability of the utilization of the resources for water supply (i.e., presence of long term continuous recharge mechanisms, and absence of excessive water table fluctuations, for example, due to spring runoff, upland flood irrigation, and drought); and 3) the vulnerability of the resources to contamination. In addition, the GIS map provides information with respect to wells for which augmentation is required, and shows well applications approved (i.e., permitted wells, drilled or not drilled) or denied, and wells actually drilled. Note, that availability and sustainability should be judged in relation to yield requirements, presence of other resource usages, ecological requirements, water right issues, and physical constraints, such as limitations on drawdown.

Key elements in this project are the adaptation of the step-wise ground water resources evaluation procedure developed in a previous HSA/HHI study for Pitkin County, as well as the hydrologic systems analysis and the formulation of conceptual models for the study area. The GIS map and supporting databases focus the non-public lands area of the Capitol Creek, Snowmass Creek, and East Sopris Creek watersheds. The incorporated databases include delineated hydrogeological units created by HSA/HHI by combining published hydrogeologic information with the results of the hydrologic systems analysis, as well as databases from Pitkin County, the Colorado Division of Water Resources/Colorado Water Conservation Board, and the Natural Resources Conservation Survey (USDA).

Based on field work and hydrologic systems analysis, five general conceptual models are identified within the regional scale context of the CSC area: 1) Upper Snowmass Creek (USC) Subsystem near the White River National Forest boundary; 2) Lower Snowmass Creek (Watson Divide area) (LSC) Subsystem; 3) Upper Capitol Creek (UCC) Subsystem; 4) Lower Capitol Creek (LCC) Subsystem; and 5) Ft. Hays/Dakota-Burro Canyon Bedrock (FDB) Subsystem. Each of the five subsystems has a unique set of natural system parameters defining recharge and discharge, ground water levels and fluctuations, ground water flow velocities and direction, and ground water storage. In addition, each of these subsystems have important anthropogenic hydrologic system parameters, including ground water recharge from irrigation and irrigation ditches, and ground water discharge from wells. If water rights and allocations should change for these ditches, the hydrodynamics of the Quaternary glacial and alluvial aquifers would change, and water supplies from ground water may decline or vanish.

Three case history examples are presented to illustrate the analysis procedure, using the GIS map and databases provided with this report. Site 1 is located in the lower Capitol Creek valley; site 2 is located in the Lime Creek area, and site 3 is located on the ridge between Upper Snowmass Creek and Upper Capitol Creek near Hunter Creek. The examples show the existing uncertainties in evaluating local ground water resources due to data limitations, and illustrate the variability of drinking water supplies, both in availability and sustainability, dependent on the local hydrogeology and hydrological system. All three sites are vulnerable to ground water pollution. The examples demonstrate the utility and advantages of the GIS-based analysis procedure and its advantages over simple, one-layer paper maps showing, for example, some general ground water characteristics, and demonstrate the need for site-specific hydrogeologic investigation to obtain quantitative resource management answers and well design parameters.

6.2 Discussion

Pitkin County has six regions that contain parcels of potentially developable land: 1) Upper Roaring Fork Drainage; 2) Town of Aspen; 3) Middle Roaring Fork Drainage; 4) Castle, Maroon, and Woody Creeks, and Frying Pan River; 5) Snowmass and Capitol Creek Drainage; and 6) Crystal River Drainage. Three levels of information are required in order to fully understand the ground water-derived drinking water availability, sustainability, and vulnerability in these areas: 1) Hydrologic Systems Analysis (HSA); 2) Database and GIS development; and 3) Acquisition of site-specific hydrologic parameters. The hydrogeologic information processing and analysis begins at the conceptual level integrating regional, subregional, and local information, followed by database development and GIS evaluation. Finally, hydrologic parameters are needed at each specific site based on due diligence.

Examples of Hydrologic Systems Analysis are found in chapter 2 of this report, as well as in the MRF and URF reports by Kolm and van der Heijde (2006), Kolm and Gillson (2002) and Kolm and others (1998). The ultimate goal of this analysis is a conceptual model describing how the hydrogeologic framework and hydrologic system functions. Such a conceptual model forms the basis for the preparation of hydrogeological and hydrological GIS layers. Database development and GIS Evaluation are described in this report.

Hydrologic parameters, including quantitative measures of aquifer thickness, water table levels (depth to water table), hydraulic conductivity, recharge amounts and ground-water flow paths, are the result of in-depth site analysis and testing. The goal of the third aspect of this analysis is site-specific drinking water well yields and water quality, and the impact of the drinking water well on surrounding wells and ecosystems. The existing data could be analyzed for specific sites and generalized to hydrogeologic regions. However, each new site will need due diligence by the land owner, and the results of their studies can be integrated into the existing data and each hydrogeologic region can be updated continuously.

6.3 Recommendations

The Upper Roaring Fork Drainage area has a complete HSA, but lacks the delineation and digitalization of hydrogeologic units. The hydrogeologic data layers could be improved upon by separating the potential unconsolidated aquifers from the bedrock aquifer. The hydrologic parameters for the State Route 82 corridor would need to be evaluated as these were not assessed as part of the North Star study. The priority for this work is low compared with the assessment needs of other areas.

The Town of Aspen area has no formal HSA completed, and the region is complex due to urbanization, shallow aquifers of various types (moraines, outwash plains, alluvium), and a complex, faulted bedrock system (Leadville Limestone). Some of the GIS database development is completed, but additional data layers and evaluation are needed – particularly with respect to the hydrogeologic database. The hydrologic parameters for the Town of Aspen area would need to be evaluated as these were not assessed as part of any of the previous studies. The priority for this work is high compared with the assessment needs of other areas.

The Middle Roaring Fork Drainage area has a complete HSA, and most of the GIS database development and evaluation is completed. The hydrologic parameters for the Middle Roaring Fork Drainage area would need to be evaluated as these were not assessed in-depth as part of the current study. The priority for this work is low compared with the assessment needs of other areas.

The Castle, Maroon, Woody Creeks, and Frying Pan River areas have no formal HSA completed, and the region is complex due to some urbanization, shallow aquifers of various types (moraines, outwash plains, alluvium), and a complex, faulted bedrock system (including the Leadville Limestone and the Dakota Fm., and Tertiary intrusive rocks). Some of the GIS database development is completed, but additional data layers and evaluation are needed – particularly with respect to the hydrogeologic database. The hydrologic parameters for the Castle, Maroon, Woody Creeks, and Frying Pan River areas would need to be evaluated as these were not assessed as part of any of the previous studies. The priority for this work is moderate (Castle and Maroon Creek, and Frying Pan River areas) and high (Woody Creek area) compared with the assessment needs of other areas.

The Snowmass and Capitol Creek areas has a complete HSA, and most of the GIS database development and evaluation is completed. The region is complex due to the presence of shallow aquifers of various types (moraines, landslide deposits, outwash plains, alluvium), and a complex, faulted bedrock system. The hydrologic parameters for the Snowmass and Capitol Creek areas would need to be evaluated as these were not assessed in-depth as part of the present study. The priority for this work is low compared with the assessment needs of other areas.

The Crystal River area has no formal HSA completed, and the region is complex due to some urbanization, shallow aquifers of various types (moraines, outwash plains, alluvium), and a complex, faulted bedrock system (possibly including the Leadville Limestone, the Dakota Fm., and Tertiary intrusive bedrock). Some of the GIS database development is completed, but additional data layers and evaluation are needed – particularly with respect to the hydrogeologic database. The hydrologic parameters for the Crystal River area would need to be evaluated as these were not assessed as part of any of the previous studies. The priority for this work is high compared with the assessment needs of other areas.

In all of these areas, the completion of HSA and GIS database and evaluation should be concurrent and of higher priority before the hydrologic parameters analysis being undertaken. The higher priority areas are based on the rate at which urbanization is occurring and corresponding demand for permits.

The GIS-based ground water resources assessment procedure can be enhanced by unifying the existing and future ground water GIS maps, and the development of custom tools in ArcToolbox. These tools will facilitate consistent and complete execution of the assessment procedure and eliminate the extensive use of the information toolbar.

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Appendix A1

State of Colorado Division of Water Resources
DWR Wells Database

(http://www.water.state.co.us/pubs/welldata.asp).

Well System Data Fields

WELL SYSTEM DATA FIELDS

Field Header	Definition
receipt	The receipt number is the number assigned when the fee is paid. The entire receipt number is eight numeric characters followed by one alphabetic character (if required).
div (Division)	Numeric identifier for Water Division (1-8) in which the well is located.
cty (County)	Numeric identifier for Colorado counties (1-63) in which the well is located:

COLORADO COUNTIES NUMERICAL CODE:

ADAMS	01
ALAMOSA	02
ARAPAHOE	03
ARCHULETA	04
BACA	05
BENT	06
BOULDER	07
CHAFFEE	08
CHEYENNE	09
CLEAR CREEK	10
CONEJOS	11
COSTILLA	12
CROWLEY	13
CUSTER	14
DELTA	15
DENVER	16
DOLORES	17
DOUGLAS	18
EAGLE	19
ELBERT	20
EL PASO	21
FREMONT	22
GARFIELD	23
GILPIN	24
GRAND	25
GUNNISON	26
HINSDALE	27
HUERFANO	28
JACKSON	29
JEFFERSON	30
KIOWA	31
KIT CARSON	32
LAKE	33
LA PLATA	34
LARIMER	35
LAS ANIMAS	36
LINCOLN	37
LOGAN	38
MESA	39
MINERAL	40
MOFFAT	41
MONTEZUMA	42
MONTROSE	43
MORGAN	44
OTERO	45
OURAY	46
PARK	47
PHILLIPS	48
PITKIN	49
PROWERS	50
PUEBLO	51
RIO BLANCO	52
RIO GRANDE	53
ROUTT	54
SAGUACHE	55
SAN JUAN	56
SAN MIGUEL	57
SEDGWICK	58
SUMMIT	59
TELLER	60
WASHINGTON	61
WELD	62
YUMA	63

permitno (Permit Number)	The well permit number (numeric).
permitsuf (Permit Suffix)	A character field for the well suffix code that follows the permit number.
Permitrpl	Identifier indicating a well’s replacement.

actdate	Date well permit application received.
actcode	The activity code states status of permit application file:

Code	*Desc*
AP =	New application received.
AD =	Application denied. Denial number entered in permit number field and date entered in permit issued date field.
AW =	Application for a permit is withdrawn. Code and date also entered to status code and date fields.
AV =	Verbal approval granted to well construction contractor to construct a well without a permit in place (emergency only).
CA =	Canceled well permit. Code and date also entered to status code and date fields.
CD =	Change description of acres irrigated (designated basins). Entered to status and date fields of existing record upon receipt of application.
CO =	Application to commingle wells (designated basins). Entered to status and date fields of existing record upon receipt of application.
CP =	Amended household use permit to allow watering of user's noncommercial domestic animals.
EX =	Well permit expiration date extended.
MH =	Monitoring hole notice of construction. MH file number and date entered in permit number and permit date fields.
NP =	Well permit issued. Permit number and issue date entered in permit number and permit date fields.
TH =	Test hole notice. Replaced by MH notice in 1988.
TW =	Test well. Replaced by MH notice in 1988.

wd A character field which indicates the Water District in which the well is located (1-80). Defined as a basin on minor drainage within the Water Division.

basin When applicable, a character field indicating the Designated Groundwater Basin Number (1-8):

<u>DESIGNATED BASINS</u>

NORTHERN HIGH PLAINS	01
KIOWA-BIJOU	02
SOUTHERN HIGH PLAINS	03
UPPER BLACK SQUIRREL CREEK	04
LOST CREEK	05
CAMP CREEK	06
UPPER BIG SANDY	07
UPPER CROW CREEK	08

md A character field indicating the Designated Groundwater Basin Management District Number (1-13):

<u>MANAGEMENT DISTRICTS (BASINS)</u>

PLAINS	01
SAND HILLS	02
ARIKAREE	03
FRENCHMAN	04
CENTRAL YUMA	05
W – Y	06
NORTH KIOWA-BIJOU	07
EASTERN CHEYENNE	08
LOST CREEK	09
SOUTHERH HIGH PLAINS	10
MARKS BUTTE	11
UPPER BLACK SQUIRREL	12
UPPER BIG SANDY	13

full name	Applicant name (character field).
address1	A character field for the street portion of the primary mailing address of the permit holder.
address2	A character field for the street portion of a secondary mailing address if submitted.
city	A character field for the City of the primary mailing address.
state	A character field for the State of the primary mailing address
zip1	A character field for the primary zip code.
zip2	A character field for a secondary zip code, if provided.
phone_number	A character field for Applicant's phone number.
pm	Principal Meridian in which well is located (S = Sixth, N = New Mexico, U = Ute, C = Costilla, B = Baca).
rng (Range)	Numeric field for the Range in which well is located.
Rnga	Identifies half ranges ("H")
Rdir	Identifies direction (E, W)
ts (Township)	Numeric field for Township in which well is located.
Tsa	Identifies half ranges ("H")
Tdir	Identifies direction (N, S)
sec (Section)	Numeric field for Section in which well is located (1-36).
Seca	Reserved for locations containing a U in the section number.
QTR160	Character field for quarter section (160 acre quarter) in which well is located.
QTR40	Character field for the quarter-quarter section (40 acre quarter of 160 acre quarter) in which well is located.
QTR10	Character field for the quarter-quarter section (10 acre quarter of 40 acre quarter) in which well is located.
coordsns	Distance (feet) from the north or south section line to the well location.
coordsns_dir	Identifies which section line (N,S) from which distance is measured.
coordsew	Distance (feet) from the east or west section line to the well location.

coordsew_dir Identifies which section line (E,W) from which distance is measured.

AQUIFER1 Aquifer in which well is located.

AQUIFER CODES:

GW	ALL UNNAMED AQUIFERS	
KA	ARAPAHOE	
UKA	UPPER ARAPAHOE	
LKA	LOWER ARAPAHOE	
JMB	BRUSHY BASIN	
KDB	BURRO CANYON	
KCH	CHEYENNE	
CON	CONFINED	SAN LUIS VALLEY
KD	DAKOTA	
TDW	DAWSON	
UTDW	UPPER DAWSON	
LTDW	LOWER DAWSON	
TKD	DENVER	
JE	ENTRADA	
TG	GREEN RIVER	
PH	HERMOSA	
KI	ILES	
KL	LARAMIE	
KLF	LARAMIE FOX HILLS	
ML	LEADVILLE LIMESTONE	
KM	MANCOS	
KMV	MESA VERDE GROUP	
JM	MORRISON	
TO	OGALLALA	
KP	PIERRE SHALE	
KPU	PURGATOIRE	
JMS	SALT WASH	
UNC	UNCONFINED	SAN LUIS VALLEY
TW	WASATCH	
TW	WHITE RIVER	
KW	WILLIAMS FORK	

AQUIFER2 name of second aquifer if well is known to be multiply completed.

subdiv_name Subdivision name.

lot Lot number in subdivision.

block Block number in subdivision.

filing Filing number.

engineer Engineer who approved permit.

well_name Owners's well designation number or name.

Use1 & Use2 Codes for well Uses:

Data Code	Use Description
1	Crop Irrigation
2	Municipal
3	COMMERCIAL
4	INDUSTRIAL
5	RECREATION
6	FISHERY
7	FIRE
8	DOMESTIC
9	LIVESTOCK
G	GEOTHERMAL
H	HOUSEHOLD USE ONLY

K	SNOWMAKING
O	OTHER
O	MONITORING HOLE/WELL
R	RECHARGE
E	EXCHANGE AND AUGMENTATION
Q	=O (Other, or Monitoring Hole/Well)

Use3

CODE	TYPE
A	AUGMENTATION. All wells in augmentation plans are coded with an "A" in the last position. First position is the actual use of the well.
M	MONITORING WELL (PERMITTED). The first position is "O" followed by "M" in the last position.
Z	HOUSEHOLD USE WELLS ISSUED PRIOR TO HB1111 THAT HAVE BEEN AMENDED PURSUANT TO (3)(b)(II)(b) BY $25.00 APPLICATION. First position code is "H" followed by "Z" in the last position.
L	PERMIT ISSUED UNDER PRESUMPTION (3)(b)(II)(A) FOR DOMESTIC/LIVESTOCK USES AS THE ONLY WELL ON 35 ACRES. First position is either "8" domestic or "9" livestock", or both 1st and 2nd followed by "L" in the last position.
	PERMITS ISSUED UNDER (3)(b)(I) WHERE WATER IS AVAILABLE ARE CODED FIRST POSITIONS AS NECESSARY WITH THE ACTUAL USE. HB1111 does not apply to these wells.
G	GRAVEL PIT WELL PERMIT. This application (PERMIT) is coded as "O" in the first position with "G" in the last position.
C	CLOSED LOOP GEOTHERMAL WELL. First position is codes as "G" for geothermal. Last position is "C".
P	GEOTHERMAL PRODUCTION WELL. First position is coded "G" for geothermal. Last position is "P".
S	OTHER TYPES OF HOLES CONSTRUCTED-ESPECIALLY FOR CATHODIC PROTECTION.
	IDENTIFIES THAT THE PERMIT WAS ISSUED PURSUANT TO SENATE BILL 5 (137 (4). First positions are for the actual use(s) of the well.

driller_lic Water well contractor's license number.

pump_lic Pump installation contractor's license number.

pidate Date the pump installation report is received by DWR.

statute Statute under which the permit was issued using the last four numbers of chapter and paragraph, i.e. 37-92-602(3)..602(3). (see www.intellinetusa.com/statmgr.htm)

statcode Interim status of the application or permit:

Code	*Desc*
AB =	Abandoned well.
AR =	Date application for permit resubmitted to DWR.
AU =	Date application returned to applicant for correction or additional information.
EP =	Expired well permit.
NS =	Exempt wells where no statement of use is required (no longer used).
PI =	Pump Installation Report received (no longer used).
PU =	Pump Installation Report returned to responsible party for correction.
RC =	Record change. A portion of the file was modified.
SA =	Statement of beneficial use accepted (no longer used in statute code).
SP =	Statement of beneficial use received (no longer used in statute code).
SR =	Statement of beneficial use resubmitted to DWR.
SU =	Statement of beneficial use returned to owner for correction.
WA =	Well construction report received (no longer used).

WU = Well construction report returned to responsible party for correction.
WR = Well construction report resubmitted to DWR.
ZZ = Transaction code indicates a portion of the file was updated with general review and update of records.

statdate	Date of the above status code action.
npdate	Date the permit, denial (AD) or monitoring hole was issued.
wadate	Date the Well Construction and Test Report was received in DWR.
trancode	Activity or status code. Last action updated.
trandate	Computer machine date of last update to the record.
sadate	Date of first beneficial use.
sbudate	Date statement of use received.
exdate	Expiration date of well permit.
abrdate	Date abandonment report received.
abcodate	Date well plugged and abandoned.
abreq	Flag if the well requires plugging and sealing upon construction of new well
acreft	Annual appropriation in acre feet.
tperf	Depth to top of first perforated casing.
bperf	Depth to base of last perforated casing.
case_no	Water court case number.
yield	Yield in gallons per minute.
depth	Total depth of well.
level	Depth to static water level.
elev	Ground surface elevation.
area_irr	Acres irrigated.
Irr_meas	Acre irrigated units
comment	Comment field
meter	Totalizing flow meter reqd., installed.
wellxno	Cross reference to another well or record.
Wellxsuf	Cross reference character field for well suffix code (follows the permit number).

Wellxrpl Cross reference identifier indicates well replacement.

Nwcdate Notice of Well Construction Report received (Statewide nontributary rules).

Nbudate Notice of Commencement of Beneficial Use received (Statewide nontributary rules).

wcdate Date well construction completed.

pcdate Date pump installation completed

log Flag to indicate if a geophysical is required and received.

qual Water quality information available, y or n.

user1 Initials of last staff member to update file.

pyield Proposed yield of well in gpm.

pdepth Proposed depth of well.

pacreft Proposed annual appropriation.

well_type Calculated value to determine if record is exempt, non exempt or georthermal.

valid_permit Calculated value to determine if a well permit is valid. (must be verified)

parcel_no Parcel identifier

parcel_size Parcel size in acres. Number of acres on well site.

noticedate Notice sent to owner indicating permit about to expire. (Not yet used)

utm_x A numeric field for the UTM-X coordinate. Note some UTM values are calculated from legal description. All UTM values are Zone 13 based on NAD 27 and Clark 1866 projections.

utm_x A numeric field for the UTM-X coordinate. Note some UTM values are calculated from legal description. All UTM values are Zone 13 based on NAD 27 and Clark 1866 projections.

utm_y A numeric field for the UTM-X coordinate. Note some UTM values are calculated from legal description. All UTM values are Zone 13 based on NAD 27 and Clark 1866 projections.

loc_source Identifies source of UTM coordinates. If blank, the applicant provided the coordinates otherwise the version of the program used to determine the coordinates is given.

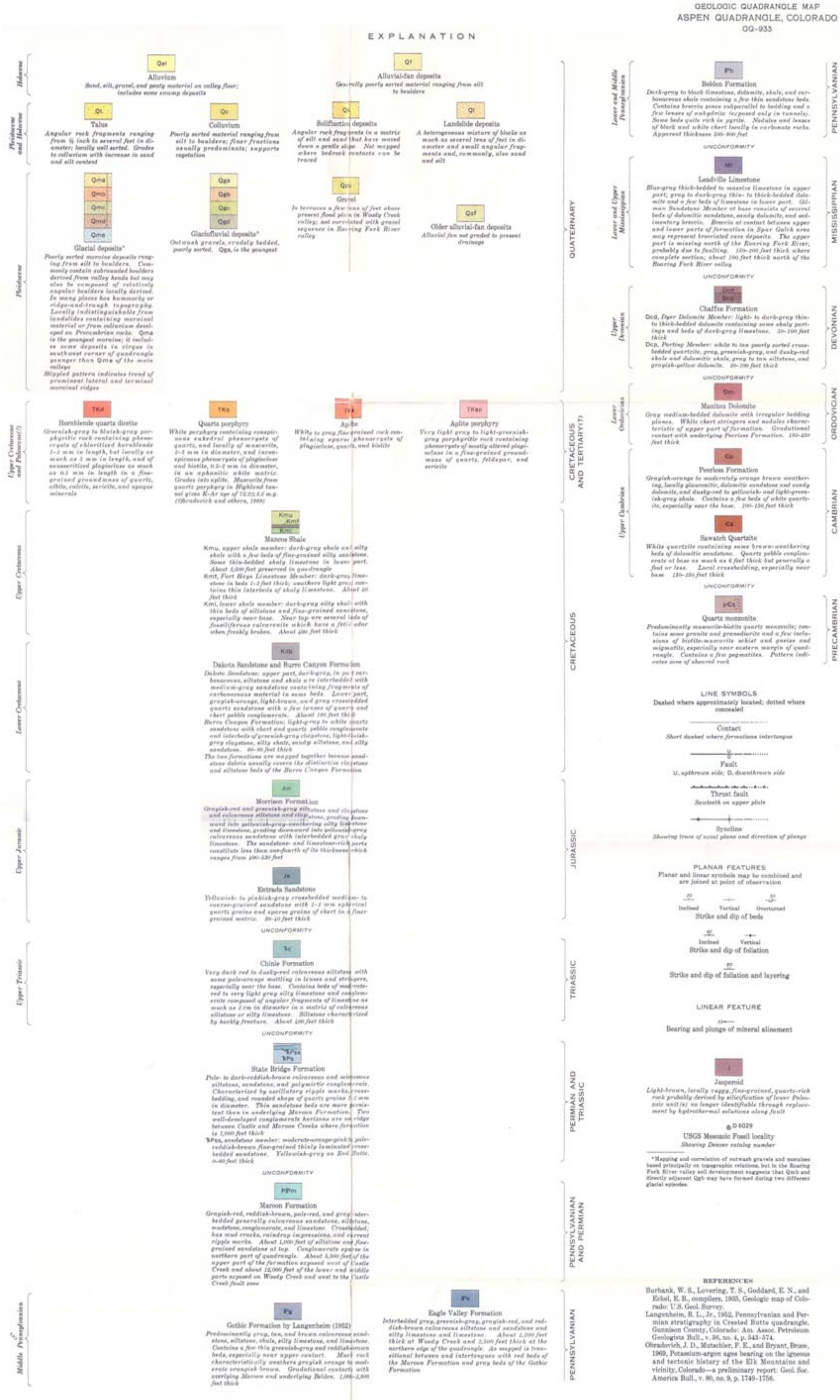
d:documents/word.Well_data fields.doc (6/25/01, ebt)
Modified from wellsys.doc 1/27/97 rab.
`c:officedoc.wellsys.doc`

Appendix A2

Geologic Quadrangle Map
Aspen Quadrangle
Colorado

U.S. Geological Survey
GQ-933

Legend


GEOLOGIC QUADRANGLE MAP
ASPEN QUADRANGLE, COLORADO
GQ-933
EXPLANATION
Alluvium
Alluvial-fan deposits
Talus
Colluvium
Solifluction deposits
Landslide deposits
Gravel
Older alluvial-fan deposits
Glacial deposits
Glaciofluvial deposits
Hornblende quartz diorite
Quartz porphyry
Aplite
Aplite porphyry
Mancos Shale
Dakota Sandstone and Burro Canyon Formation
Morrison Formation
Entrada Sandstone
Chinle Formation
State Bridge Formation
Maroon Formation
Gothic Formation by Langenheim (1952)
Eagle Valley Formation
Belden Formation
Leadville Limestone
Chaffee Formation
Manitou Dolomite
Peerless Formation
Sawatch Quartzite
Quartz monzonite
QUATERNARY
CRETACEOUS AND TERTIARY(?)
CRETACEOUS
JURASSIC
TRIASSIC
PERMIAN AND TRIASSIC
PENNSYLVANIAN AND PERMIAN
PENNSYLVANIAN
MISSISSIPPIAN
DEVONIAN
ORDOVICIAN
CAMBRIAN
PRECAMBRIAN
UNCONFORMITY
LINE SYMBOLS
Contact
Fault
Thrust fault
Syncline
PLANAR FEATURES
Strike and dip of beds
Strike and dip of foliation
Strike and dip of foliation and layering
LINEAR FEATURE
Bearing and plunge of mineral alinement
Jasperoid
USGS Mesozoic Fossil locality
REFERENCES

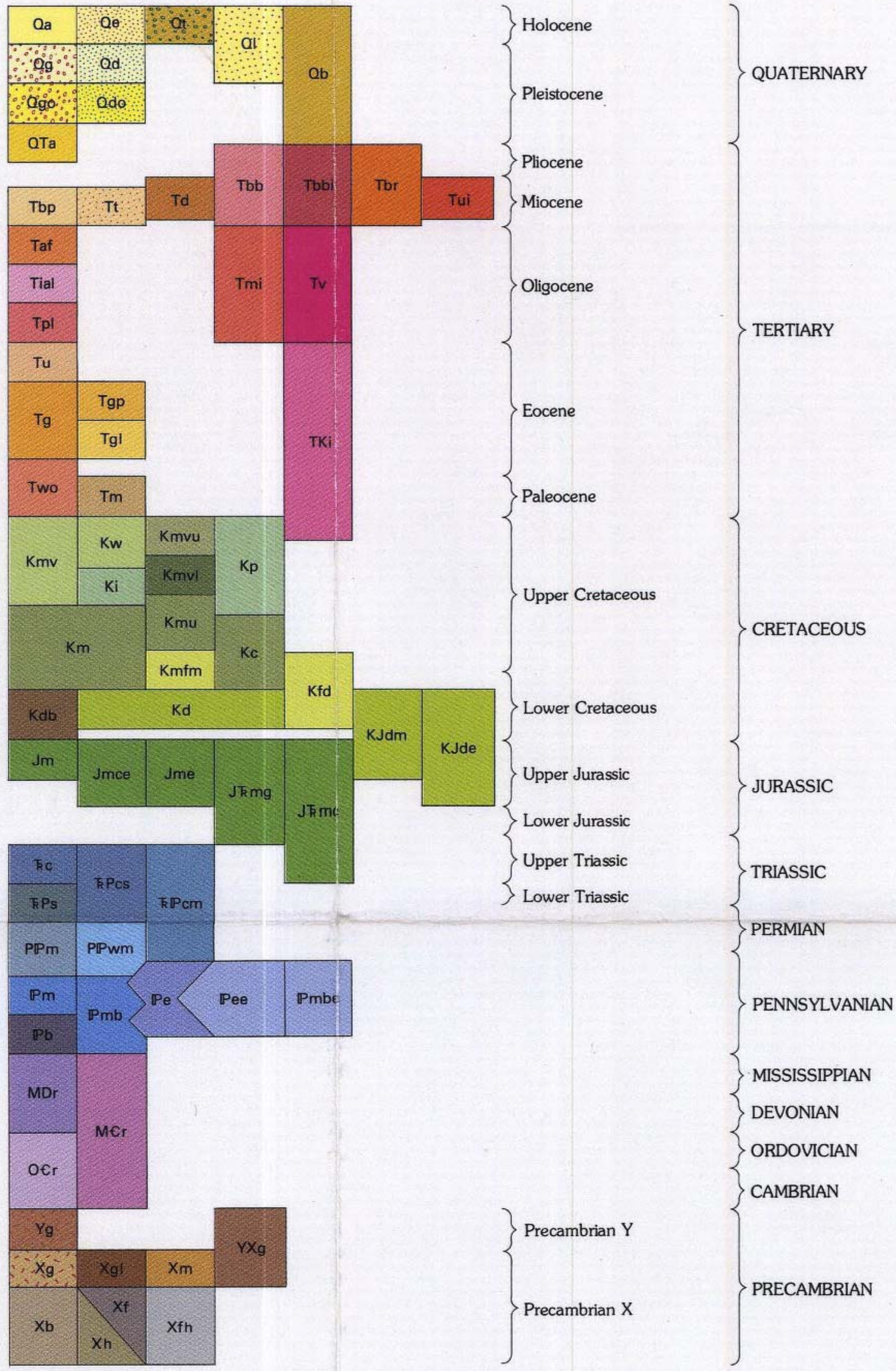
Appendix A3

Geologic Map
Leadville 1^o x 2^o Quadrangle
Colorado

U.S. Geological Survey
Miscellaneous Investigations Series Map I-999

Legend

CORRELATION OF MAP UNITS



DESCRIPTION OF MAP UNITS

Formations for which no map symbol is shown are grouped with other stratigraphic units to form map units

UNCONSOLIDATED DEPOSITS (HOLOCENE):

Qa — Alluvium—Gravel, sand, and silt in stream valleys and alluvial fans

Qe — Eolian deposits—Windblown sand and silt

Qt — Talus deposits and rock glaciers

Ql — LANDSLIDE DEPOSITS (HOLOCENE AND PLEISTOCENE)—On Grand and Battlement Mesas (southwestern corner of quadrangle), consist principally of large slump blocks of basalt irregularly veneered with young (Pinedale) glacial drift. Elsewhere, include mudflow and some talus deposits. Many small bodies not mapped

Qb — YOUNG BASALT (HOLOCENE AND PLEISTOCENE)—In Roaring Fork valley north of Aspen, 1.5 m.y. (million years) old; along Rock Creek north of McCoy, 0.64 m.y. old (Larson and others, 1975, p. 166). Near Dotsero, 4,150 years old (Giegengack, 1962)

* — Volcanic cinder cone or crater

UNCONSOLIDATED DEPOSITS (PLEISTOCENE):

Qg — Young gravels (Bull Lake and younger)—Stream, terrace, and outwash gravels

Qd — Young glacial drift (Bull Lake and younger)—Unsorted bouldery glacial deposits (till) and associated sand and gravel deposits

Qgo — Old gravels and alluviums (pre-Bull Lake)—Terrace, outwash, and pediment gravels

Qdo — Old glacial drift (pre-Bull Lake)—Unsorted bouldery glacial deposits (till); morainal form subdued or lacking

QTa — HIGH-LEVEL ALLUVIUM (PLEISTOCENE AND/OR PLIOCENE)—Fine-grained to bouldery alluvial deposits and gravels; preserved mainly on ridge tops; may not all be of same age; in southwest part of quadrangle, characterized by abundant basalt boulders and in places has been mapped previously as basalt

Tbp — BROWNS PARK FORMATION (MIOCENE)—Fluvial ashy siltstone, claystone, sandstone, conglomerate, and thin beds of air-fall ash; loosely consolidated; conglomerate at base. Locally interbedded with basalt (Tbb unit). Thickness >1,000 ft (305 m) south of State Bridge

Tt — TROUBLESOME FORMATION (MIOCENE)—Chiefly siltstone; contains many beds of volcanic ash and some of sandstone and conglomerate. Thickness >500 ft (152 m) in Williams Fork valley. Term is used in Middle Park for Miocene rocks largely equivalent to Browns Park Formation west of the Gore Range

Td — DRY UNION FORMATION (PLIOCENE AND MIOCENE)—Light-brown sandy siltstone and interbedded friable sandstone, conglomerate, and volcanic ash. Thickness >3,000 ft (915 m) in Arkansas River valley southwest of Leadville

Tbb — BASALT OF BIMODAL SUITE (PLIOCENE AND MIOCENE)—Dense black resistant alkali basalt in lava-flow layers 5–200 ft (1.6–61 m) thick, and interbedded tuffs and volcanic conglomerates. Greatest preserved thicknesses are 900 ft (275 m) on White River Plateau and 800 ft (244 m) on Grand Mesa. Ages determined from several localities range from 8 to 23 m.y. (Larson and others, 1975)

Tbbi — BASALTIC DIKES AND PLUGS (PLIOCENE AND MIOCENE)—Probable feeders of basalt flows of Tbb unit; also intrusive into the flows

Tbbi — Dike

Tbr — RHYOLITIC ROCKS OF BIMODAL SUITE (PLIOCENE AND MIOCENE)—In plugs, dikes, and small flows

Tbr — Dike

Tui — UPPER TERTIARY INTRUSIVE ROCKS (MIOCENE)—Sodic granite of Treasure Mountain south of Marble, and satellitic plugs and dikes. About 12.5 m.y. in age (Obradovich and others, 1969)

Taf — ASH-FLOW TUFF (OLIGOCENE)—Dense silicic welded tuff and vitrophyre; principally in Grizzly caldera south of Independence Pass in Sawatch Range

Tial — INTER-ASH FLOW ANDESITIC LAVAS AND BRECCIAS (OLIGOCENE)—Mapped only at Buffalo Peaks in southeast corner of quadrangle

Tpl — PRE-ASH FLOW ANDESITIC LAVAS AND BRECCIAS (OLIGOCENE)—Mapped only in Grizzly caldera area south of Independence Pass in Sawatch Range

Tmi — MIDDLE TERTIARY INTRUSIVE ROCKS (OLIGOCENE; 26-38 m.y.)—Granodiorite and quartz monzonite; generally porphyritic but equigranular in some large bodies; in stocks, dikes, sills, and irregular bodies

Tmi — Dike or sill

Tv — VOLCANIC ROCKS OF GREEN MOUNTAIN AREA (OLIGOCENE)—Trachytic lavas related to Green Mountain intrusive and volcanic center in Blue River valley.dated by fission-track method at 30 m.y. (Naeser and others, 1973)

Tu — UINTA FORMATION (EOCENE)—Siltstone, sandstone, and marlstone. Maximum preserved thickness on Battlement Mesa about 1,000 ft (305 m)

Tg — GREEN RIVER FORMATION (EOCENE)—Marlstone, oil shale, siltstone, and sandstone. Undivided unit mapped only at depositional edge of formation in southwest corner of quadrangle

Tgp — Parachute Creek Member—Oil shale and marlstone. Thickness 1,200 ft (365 m) on Roan Plateau northwest of Rifle; thins southward to wedge edge near south boundary of quadrangle

Tgl — Lower part of Green River Formation—Shale, sandstone, and marlstone in the Anvil Points, Garden Gulch, and Douglas Creek Members. Thickness >2,000 ft (610 m) on Roan Plateau northwest of Rifle; thins southward to wedge edge near south boundary of quadrangle

Two — WASATCH AND OHIO CREEK FORMATIONS:

Wasatch Formation (Eocene and Paleocene)—Variegated claystone, siltstone, sandstone, and conglomerate; carbonaceous shale and lignite near base. Maximum thickness about 5,800 ft (1,770 m)

Ohio Creek Formation (Paleocene)—Sandstone and conglomerate. Thickness 400 ft (122 m) near south boundary of quadrangle; thins northward to about 50 ft (15 m) along Grand Hogback north of Rifle

Tm — MIDDLE PARK FORMATION-UPPER PART (PALEOCENE)—Arkosic grit, conglomerate, sandstone, and mudstone; contains abundant volcanic detritus. Preserved thickness at northeast corner of quadrangle >2,000 ft (610 m)

TKi — LARAMIDE INTRUSIVE ROCKS (EOCENE, PALEOCENE, AND UPPER CRETACEOUS; 40–72(?) m.y.)—Quartz monzonite, granodiorite, and quartz diorite porphyries in stocks, sills, and dikes

TKi — Dike or sill

Kmv — MESAVERDE GROUP UNDIVIDED OR MESAVERDE FORMATION (UPPER CRETACEOUS)

Kw — Williams Fork Formation—Light-brown to white sandstone, gray to black shale, and coal beds. Maximum thickness along Grand Hogback north of Rifle is 4,500 ft (1,372 m)

Ki — Iles Formation—Massive beds of light-brown to white sandstone and interbedded shale and coal. Trout Creek Sandstone Member at top. Maximum thickness along Grand Hogback north of Rifle is 1,600 ft (488 m)

Kmvu — Upper part of Mesaverde Formation—Sandstone, shale, and minor coal beds. Maximum thickness along Grand Hogback south of Colorado River is 2,700 ft (823 m)

Kmvl — Lower part of Mesaverde Formation—Sandstone, shale, and coal. Unit thins southward by wedging of lower sandstone beds into Mancos Shale. Thickness near Colorado River is 2,400 ft (732 m); near Carbondale, where Rollins Sandstone Member is at base, 1,400 ft (427 m)

Kp — PIERRE SHALE (UPPER CRETACEOUS)—Dark-gray marine shale containing a few thick beds of fine-grained sandstone. Maximum preserved thickness 5,000–6,000 ft (1,525–1,830 m)

CONTACT

FAULT—Dotted where concealed. Bar and ball on downthrown side

THRUST FAULT—Dotted where concealed. Sawteeth on upper plate

INFERRED FAULT IN VALLEY-FILL DEPOSITS—Largely concealed; location approximate or conjectural. Bar and ball on downthrown side

PRECAMBRIAN SHEAR ZONE—Dotted where concealed

ANTICLINE—Showing crestline; dotted where concealed

SYNCLINE—Showing troughline; dotted where concealed

MONOCLINE—Showing anticlinal crestline of steep dip; dotted where concealed

Km — MANCOS SHALE (UPPER AND LOWER CRETACEOUS)—Gray to dark-gray marine shale. Sandstone beds near the top. Calcareous sandstone of Upper Cretaceous Frontier Sandstone Member 300–400 ft (90–122 m) above base, overlain by calcareous shale zone equivalent to Niobrara Formation. Silver-gray siliceous shale of Lower Cretaceous Mowry Shale Member at base. Thickness north of Colorado River about 5,000 ft (1,525 m); south of river, >6,000 ft (1,820 m)

Kmu — Upper unit of Mancos Shale (Upper Cretaceous)—Mancos Shale above the Frontier Sandstone Member

Kmfm — Frontier Sandstone and Mowry Shale Members and intervening shale zone (Upper and Lower Cretaceous)—Thickness about 500 ft (152 m)

Kc — COLORADO GROUP (UPPER AND LOWER CRETACEOUS)—Consists of Upper Cretaceous Niobrara Formation (calcareous shale and marly limestone) and Upper and Lower Cretaceous Benton Shale, which has calcareous sandstone equivalent to Frontier Sandstone Member of Mancos Shale at top and siliceous shale equivalent to Mowry Shale Member at base. Thickness 800–1,000 ft (244–305 m)

Kd — DAKOTA SANDSTONE (LOWER CRETACEOUS)—Light-gray and tan sandstone or quartzite; some interbedded dark shale and shaly sandstone. Resistant, widely exposed unit but too thin to show separately at map scale in many areas. Thickness 125–225 ft (37–68 m)

Kdb — DAKOTA SANDSTONE AND BURRO CANYON FORMATION (LOWER CRETACEOUS)—Mapped only in Aspen-Basalt area

Burro Canyon Formation—Yellow sandstone and green claystone. Maximum thickness 225 ft (68 m)

Kfd — FRONTIER SANDSTONE AND MOWRY SHALE MEMBERS OF MANCOS SHALE AND DAKOTA SANDSTONE

Jm — MORRISON FORMATION (UPPER JURASSIC)—Variegated shale and mudstone, light-gray sandstone, and local beds of gray and green-gray limestone. Locally conglomeratic near base. Thickness about 500 ft (152 m) along Grand Hogback and along Colorado River near Burns; thins eastward and southeastward to <200 ft (60 m) in Blue River valley

CURTIS FORMATION (UPPER JURASSIC)—Yellowish-gray to pale-green glauconitic sandstone and oolitic limestone. Thickness <100 ft (30 m)

ENTRADA SANDSTONE (UPPER JURASSIC)—Light-gray to orange crossbedded sandstone. Thickness 75–150 ft (23–46 m) in northwest and central parts of quadrangle; wedges out southward in Aspen area and eastward at Gore Range

KJdm — DAKOTA FORMATION AND MORRISON FORMATION

KJde — DAKOTA, MORRISON, CURTIS, AND ENTRADA FORMATIONS ALONG COLORADO RIVER NEAR BURNS AND STATE BRIDGE; ELSEWHERE, DAKOTA, MORRISON, AND ENTRADA FORMATIONS

Jmce — MORRISON, CURTIS, AND ENTRADA FORMATIONS

Jme — MORRISON AND ENTRADA FORMATIONS

GLEN CANYON SANDSTONE (LOWER JURASSIC AND UPPER TRIASSIC)—Light-brown to light-gray crossbedded sandstone that closely resembles the overlying Entrada Sandstone, from which it is separated by a subtle unconformity. Maximum thickness 75 ft (23 m)

J₮mg — MORRISON, ENTRADA, AND GLEN CANYON FORMATIONS

₮c — CHINLE FORMATION (UPPER TRIASSIC)—Brownish- and purplish-red calcareous siltstone, mudstone, and sandstone; limestone-pellet conglomerate in lower part; Gartra Sandstone Member at base (pale-purple to white pebbly sandstone 25 ft or 8 m thick). Thickness 1,200 ft (365 m) near Brush Creek south of Eagle; thins from there in all directions; wedges out beneath pre-Entrada unconformity along west side of Gore Range and in Elk Mountains southwest of Aspen

J₮mc — MORRISON, ENTRADA, AND CHINLE FORMATIONS—Along Grand Hogback south of T. 6 S., Chinle is represented only by the Gartra Member

₮Ps — STATE BRIDGE FORMATION (LOWER TRIASSIC AND PERMIAN)—Orange-red to red-brown siltstone and sandstone. Thickness at least 5,000 ft (1,525 m) in local depositional basin in Hardscrabble Mountain area south of Eagle. To the north, unit is 500 ft (152 m) thick and thins eastward to wedge out along west flank of Gore Range. To the southwest, unit is 2,400 ft (732 m) thick along Fryingpan River east of Basalt but absent beneath pre-Chinle and pre-Entrada unconformities at Grand Hogback and in Elk Mountains

₮Pcs — CHINLE AND STATE BRIDGE FORMATIONS

PPm — MAROON FORMATION (PERMIAN AND PENNSYLVANIAN)—Maroon and grayish-red sandstone, conglomerate, and mudstone; lower part intertongues with Eagle Valley Formation or Evaporite which underlies the Maroon in places. Thickness >9,500 ft (2,900 m) in area southwest of Aspen; thins northeastward to depositional margin along west flank of Gore Range; thinning also due to pre-State Bridge unconformity

WEBER SANDSTONE (PERMIAN AND PENNSYLVANIAN)—Yellow-gray sandstone. Thickness about 100 ft (30 m) near northwest corner of quadrangle; thins toward depositional margin to south and east; present margin south of Glenwood Springs, east of Eagle, and east of Burns results in part from truncation beneath pre-State Bridge unconformity

PPwm — WEBER SANDSTONE AND MAROON FORMATION

₮Pcm — CHINLE, STATE BRIDGE, AND MAROON FORMATIONS

Pm — MINTURN FORMATION (PENNSYLVANIAN)—Gray, pale-yellow, and red sandstone, grit, conglomerate, and shale, and scattered beds and reefs of carbonate rocks. Includes rocks of Gothic Formation of Langenheim (1952). Thickness near Minturn >6,000 ft (1,830 m); thins abruptly eastward toward depositional margin along west flank of Gore Range and at Breckenridge. Thins westward and intertongues with Eagle Valley Evaporite in Eagle basin. Thickness on western side of basin, in Elk Mountains, about 3,000 ft (915 m). East and north of Sawatch Range, contact with overlying Maroon Formation is placed at top of highest marine limestone; west of Sawatch Range and White River Plateau, contact is at color change from predominantly gray (Minturn) below to predominantly red (Maroon) above

Pb — BELDEN FORMATION (PENNSYLVANIAN)—Dark-gray to black shale, carbonate rocks, and sandstone. Map unit includes local thin lenses of Molas Formation (Pennsylvanian) at base. Maximum thickness in Elk Mountains and White River Plateau area about 900 ft (275 m); thins eastward to depositional margin along Gore Range and near Hoosier Pass

Pmb — MINTURN AND BELDEN FORMATIONS

Pmbe — Evaporite-bearing facies of Minturn and Belden Formations—Mapped only in South Park, in southeast corner of quadrangle

Pe — EAGLE VALLEY FORMATION (PENNSYLVANIAN)—Gray and reddish-gray siltstone, shale, sandstone, carbonate rocks, and local lenses of gypsum. Unit is transitional between the coarse clastic rocks of the Minturn and Maroon Formations and purely evaporitic rocks. Thickness variable, depending on intertonguing relations

Pee — EAGLE VALLEY EVAPORITE (PENNSYLVANIAN)—Gypsum, anhydrite, and interbedded siltstone and minor dolomite; contains thick salt at depth in some places, as shown by wells drilled for oil and gas. Intertongues with Minturn, Belden, and Maroon Formations and grades into fine-grained clastic rocks of Eagle Valley Formation. Diapiric in structural configuration in many places, especially in large area in central part of quadrangle. Thickness indeterminate

MDr — MISSISSIPPIAN AND DEVONIAN ROCKS—Includes rocks of, Leadville Limestone (or Dolomite) (Mississippian) and Chaffee Group (Mississippian? and Devonian). Leadville thickness variable beneath pre-Belden unconformity; maximum of about 275 ft (84 m) in Elk Mountains; truncated eastward along west flank of Gore Range and near Hoosier Pass. Chaffee Group consists of Gilman Sandstone (Mississippian or Devonian), Dyer Dolomite (Mississippian? and Devonian) and Parting Formation (Devonian). Maximum thickness of Chaffee Group 250 ft (76 m) in White River Plateau area; truncated beneath pre-Belden unconformity along west flank of Gore Range and near Hoosier Pass

OCr — ORDOVICIAN AND CAMBRIAN ROCKS—Includes various combinations of: Fremont Limestone (Ordovician), Harding Sandstone (Ordovician), Manitou Dolomite (Ordovician), Dotsero Formation (Cambrian), Peerless Formation (Cambrian), and Sawatch Quartzite (Cambrian). Fremont is present beneath pre-Parting unconformity only in western Elk Mountains. Harding is present beneath pre-Parting and pre-Fremont unconformities only in western Elk Mountains and along Eagle River from Minturn area to Tennessee Pass. Manitou is widespread but in eastern part of quadrangle is absent beneath pre-Harding and younger unconformities from Pando and Breckenridge northward. Dotsero is mapped only in White River Plateau area. Peerless and Sawatch are widespread but are truncated beneath various unconformities along Gore Range and near Breckenridge. Maximum thickness of Ordovician and Cambrian rocks about 750 ft (230 m) in White River Plateau area

MCr — MISSISSIPPIAN, DEVONIAN, ORDOVICIAN, AND CAMBRIAN ROCKS

Yg — GRANITIC ROCKS (PRECAMBRIAN Y— 1,400 m.y. AGE GROUP)—Includes Silver Plume and St. Kevin Granites and equivalents

Xg — GRANITIC ROCKS (PRECAMBRIAN X— 1,700 m.y. AGE GROUP)—Includes Cross Creek Granite of Gore and northern Sawatch Ranges, Denny Creek Granodiorite of central Sawatch Range, and equivalent rocks

Xgl — LEUCOCRATIC GRANITIC ROCKS (PRECAMBRIAN X)—Includes trondhjemitic Kroenke Granodiorite in Sawatch Range, and granite at Taylor Pass southeast of Ashcroft Mountain in the Elk Mountains

YXg — GRANITIC ROCKS UNDIVIDED (PRECAMBRIAN Y AND X)

Xm — MAFIC INTRUSIVE ROCKS (PRECAMBRIAN X)—Noritic gabbro

Xb — BIOTITIC GNEISSES AND MIGMATITE (PRECAMBRIAN X)—Unit contains minor interlayered hornblende gneiss and calc-silicate rocks. Parent materials mainly graywacke and shale

Xf — FELSIC GNEISSES (PRECAMBRIAN X)—Parent materials probably igneous rocks of intermediate compositions

Xh — HORNBLENDIC GNEISSES (PRECAMBRIAN X)—Parent materials probably mainly basaltic and andesitic igneous rocks; some of gneiss is closely associated with calc-silicate rocks and minor marble and probably is metasedimentary

Xfh — INTERLAYERED FELSIC AND HORNBLENDIC GNEISSES (PRECAMBRIAN X)

Appendix A4

Summary of Hydrogeologic Units in Upper and Middle Roaring Fork Study Area
Pitkin County, Colorado

Hydrogeological Units in Upper and Middle Roaring Fork Study Area Pitkin County, Colorado

Hydrologic Systems Analysis, LLC., Golden, Colorado

1. Surficial Aquifer Materials

Modern Alluvium *(Qal; alluvium)*. Sand, silt, gravel and peaty material on valley floor [USGS GQ-933, 1971]. This material is primarily located along the modern streams, such as Owl Creek and Brush Creek, and rivers, such as the Roaring Fork. These materials usually are natural aquifers that have direct connection to and are sustained by the nearby surface water bodies, and are most likely vulnerable due to being prone to seasonal fluctuations and changes in surface water body use (withdrawal for irrigation, for example).

Terrace Gravels *(Q, Qg, Qf, and Qc; young terrace gravels, fans, colluvium)*. Combination of primarily glaciofluvial deposits (Qg, outwash gravels, crudely bedded, poorly sorted), and some alluvial fan deposits (Qf, poorly sorted material ranging from silt to boulders), and colluvium (Qc, poorly sorted material ranging from silt to boulders; finer fraction usually dominates) [USGS GQ-933, 1971]. This material is primarily located above the modern stream levels on the hillslopes. These materials usually are dry, or can be aquifers created and sustained by anthropogenic activity, such as irrigation ditches or irrigation return flow.

Moraines *(Qm; terminal and lateral moraines)*. Poorly sorted glacial deposits ranging from silt to boulders; locally indistinguishable from landslide deposits or colluvium [USGS GQ-933, 1971]. This material is primarily located at mountain canyon mouths, such as the Roaring Fork River, and Castle and Maroon Creek canyons, or along the higher hillslope locations near the high glacially carved hanging valleys and cirques, such as the slopes along Burnt Mountain near Snowmass Village. The moraines of the Roaring Fork River and Castle and Maroon Creeks are dry near the surface, but frequently contain natural ground water at depth. The moraines and associated mass wasting deposits of the Owl and Brush Creek areas also contain natural ground water at depth, and are sustained by natural climate and underlying Dakota Formation in some locations.

Landslides *(Ql, Qls, landslide deposits)*. A heterogeneous mixture of blocks as much as several tens of feet in diameter and smaller angular fragments and , commonly also sand and silt [USGS GQ-933, 1971]. This material is primarily located along the hillslopes surrounding the populated areas of Pitkin County. These materials are mostly dry, but in areas of irrigation ditches and other anthropogenic activity, may become aquifers.

Older terrace gravels and fans *(Ts, Qof; Tertiary/Pleistocene(?) deposits; see terrace gravels and fans)*. This material is primarily located along the hillslopes. These materials usually are dry, or can be aquifers created and sustained by anthropogenic activity, such as irrigation ditches or irrigation return flow.

These surficial materials, when saturated, will be primarily unconfined or water table systems. Therefore, the water table will fluctuate naturally with climate input (seasonal rainfall and snowmelt). In addition, these aquifers, in the absence of overlying low-

permeability units, will be vulnerable to contamination from land surface activity, such as irrigation, industrial, or urban uses.

2. Bedrock Aquifer Material

Dakota Sandstone *(Kd, Lower Cretaceous)*. This unit is primarily a sandstone that may have either matrix or fracture permeability. Aquifer conditions may be unconfined or confined dependent on overlying geologic unit. Given the age of the unit, fracture permeability is likely to be most significant for water supply. Typically, this unit is located at a depth greater than 200 feet under most of the study area west of the City of Aspen.

Leadville Limestone *(Ml, Mississippian; Carbonates)* This unit is primarily a limestone that has mostly fracture and karst permeability. Aquifer conditions may be unconfined or confined dependent on overlying geologic unit. The unit is located a depths greater than 1,000 feet under most of the study area west of the City of Aspen.

Fractured Crystalline Material *(Granite, Gneiss, etc)*. This unit is primarily igneous or metamorphic crystalline rocks that have mostly fracture permeability. The unit has vast thicknesses, however, the depth to which saturated thickness of this (mostly unconfined) unit is maintained is usually not greater than 500 feet. Note that the fractured crystalline material is found primarily beneath BLM and U.S. Forest Service lands, and is located in the upper Roaring Fork Drainage and North Star area.

For the current study area, only the surficial material, the Dakota Sandstone, and the fractured crystalline rocks are of interest. The Leadville Limestone is of interest when the study is extended to Aspen and nearby areas.

3. Bedrock Aquitard Material

Mancos Shale *(Km, Upper Cretaceous)*. This unit consists of an upper and lower shale member of significant thickness, separated by an up to 40 ft thick limestone member (Fort Hays Limestone). This very low-permeability unit serves as a confining layer when present, primarily in the western half of the Middle Roaring Fork study area.

Appendix A5

Stepwise Approach to Assessing Ground Water Availability, Sustainability, and Vulnerability in Upper and Middle Roaring Fork Study Area, Pitkin County, Colorado

Stepwise Approach to Assessing Ground Water Availability, Sustainability, and Vulnerability in Upper and Middle Roaring Fork Study Area, Pitkin County, Colorado

Hydrologic Systems Analysis, LLC., Golden, Colorado

Steps 1 – 2 prompt the user to initiate the GIS and locate the site being evaluated.

Step 1. Start ARCMAP™ Version 8.3 (ESRI®, Redlands, California) or higher and load the Middle Roaring Fork (MRF) or Upper Roaring Fork (URF) annotated map dependent on the location of the site [*file: PitkinCounty_GWGIS_MRFannotated.mxd or PitkinCounty_GWGIS_URFannotated.mxd*].

Step 2. The precise location or platting of the permit site (PS) should be plotted on the URF or MRF map using the appropriate layers in the GIS (e.g., using site coordinates or location information on existing wells, roads, parcels, etc.). This location is used in conjunction with the hydrology and hydrogeology GIS layers to determine the presence of ground water (Steps 3 - 6). The succeeding tasks include determining the level of ground water sustainability as a resource at the site (Steps 7-9), and its vulnerability to contamination and subsequent loss of supply (Step 10). It should be noted that due to limitations in data availability and quality, this analysis is primarily qualitative in nature. It does not replace due diligence on the side of the permit applicant.

Steps 3 – 6 allow the user to determine the potential availability of ground water for water supply at the site by identifying the areas covered by hydrogeologic formations that may be an aquifer (either unconsolidated surficial materials or bedrock) and evaluating the presence or absence of ground water in these formations (see document *HSA_Hydrogeology_Legend.pdf* for descriptions of hydrogeological units).

Step 3. Determine the potential unconfined surficial aquifer material at the site. Check to see if the site is located in one of the following units:

> For Unit 1: Modern Alluvium (Qal; alluvium). *In the MRF GIS map, switch on layer S; in the URF GIS map, switch on layer Q or layer R.*
>
> For Unit 2: Terrace Gravels (Q or Qg; young terrace gravels, fans, colluvium). *In the MRF GIS map, switch on layer T; in the URF GIS map, switch on layer Q or layer R.*
>
> For Unit 3: Moraines (Qm; moraines). *In the MRF GIS map, switch on layer U; in the URF GIS map, switch on layer Q or layer R.*
>
> For Unit 4: Landslides (Qls). *In the MRF GIS map, switch on layer V; in the URF GIS map, switch on layer Q or layer R.*
>
> For Unit 5: Older terrace gravels and fans (Ts). *In the MRF GIS map, switch on layer W; in the URF GIS map, switch on layer Q or layer R.*

Step 4. Determine potential unconfined and confined bedrock aquifer material at site. Check to see if the site is located in one of the following units:

For Unit 7: Dakota Sandstone (unconfined or confined). *In the MRF GIS map, switch on layers Y and/or BB; in the URF GIS map, switch on layer Q or layer R.*

For Unit 8a: Leadville Limestone (Carbonates) (unconfined or confined). *In the MRF GIS map, switch on layers Y and/or BB; in the URF GIS map, switch on layer Q or layer R.*

For Unit 8b: Fractured Crystalline Material (Granite, Gneiss, etc) (unconfined). *In the MRF GIS map, switch on layers Y and/or BB; in the URF GIS map, switch on layer Q or layer R.*

Note that Hydrogeologic Unit 6 is Mancos Shale, a potential aquitard.

Alternatively, step 3 and 4 combined (MRF only); use: 1) Locate the site in a set of layers showing the outcrops of all hydrogeologic units combined: *switch on MRF layers R and EE together*; or 2) Locate site with respect to each of the unconsolidated hydrogeologic units (*switch on MRF layers S, T, U, V and W, separately)* and each of the potential bedrock aquifers (switch on *MRF layers BB and CC, separately).*

Step 5. Determine if the potential alluvial/colluvial aquifer is connected/not connected with a bedrock aquifer. This step determines if the alluvial/colluvial aquifer is sustained by a bedrock aquifer, or sustained solely by surface processes, such as a nearby river. For the MRF, presence of Mancos Shale indicates absence of connectivity; for the URF, additional professional judgment may be needed to interpret geologic map. Overlay the surficial layers over the bedrock layers to determine connectivity: *in the MRF GIS map, switch on layers R and EE and check presence of unit 6 (Mancos Shale); in the URF GIS map, switch on layer Q or layer R, determine geologic stack, and check for connectivity.*

Step 6. Determine if the alluvial/colluvial material is saturated or unsaturated. This step shows the availability of ground water for the site. Identify one or more relevant wells based on distance to PS and comparable hydrogeology (*switch on layer GG and combine with layers identified as relevant in steps 3-5).* Using the accompanying attribute table in layer GG, well depth, depth to encountered water below the surface (and calculated saturated thickness, and well production (gal per minute yield) may be determined. This step could be used to quantitatively determine the amount of ground water available, but requires professional judgment using standard practices.

Steps 7 – 10 allow the user to determine the potential sustainability and vulnerability of ground water for use as a water supply for the site.

Step 7. Determine amount of direct infiltration of precipitation into the alluvial/colluvial aquifer or the bedrock aquifer. This step is performed to determine recharge to the aquifer from precipitation. To assess the recharge potential from precipitation in the vicinity of the site, a precipitation layer is included in the GIS maps *(layer C in both MRF and URF GIS maps)*. Calculation of actual recharge amounts (a fraction of precipitation) requires professional judgment using standard practices.

Step 8. Determine if the alluvial/colluvial aquifer is connected/not connected with a perennial stream. This step is performed to determine recharge to the aquifer from any nearby surface water system. The attribute table of Pitkin County's water GIS layer *(GIS layer F in both MRF and URF GIS maps)* contains, among others, a field in the attribute table indicating intermittent stream flow (ephemeral stream) or continuous stream flow (perennial stream). By combining hydrogeologic information from the alluvial aquifer layer (*layer O in both MRF and URF GIS maps*), or the information resulting from steps 3-6, with the county's streams layer F, the existence of a hydraulic connection can be established. Calculation of actual recharge amounts and effect of new well on stream requires professional judgment using standard practices.

Step 9. Determine if the saturated alluvial/colluvial aquifer is connected with an irrigation ditch or return flow of irrigation water. This step is performed to determine recharge to the aquifer from any irrigation practices, which may not sustain a ground water supply if water uses and water rights ownership change. In order to establish if the saturated portion of the potential aquifer of interest is connected with an irrigation ditch, hydrogeologic information from the alluvial aquifer layer (*layer O in both MRF and URF GIS maps*), or the information resulting from steps 3-6, is combined with the county's ditches layer (*layer H in both MRF and URF GIS maps*). The potential effect of the return flow of irrigated acreage on recharge can be evaluated by plotting the PS on the 2000 or 1993 irrigated acreage layer (*layer D and E, respectively*). Calculation of actual recharge amounts requires professional judgment using standard practices.

Step 10. Determine the vulnerability of ground water supplies to contamination from the surface for the site. Natural protection from overlying confining units, such as the Mancos Shale, is important for maintaining natural water quality, However, all ground water in the area shown in the MRF layers R (unconsolidated sediments), Y (Dakota Sandstone outcrops) & Z (Lower Bedrock outcrops) is vulnerable; natural protection is only available in areas shown by the MRF layer DD (extent Mancos Shale) for ground water in the Dakota Sandstone underneath the Mancos Shale. *In the MRF GIS map, switch on layer EE and check presence of unit 6 (Mancos Shale) at PS; in the URF GIS map, switch on layer Q or layer R and check geologic stack for presence of Mancos Shale (or other potentially confining layers).* If the Mancos Shale is present, determine if there is an underlying aquifer (Dakota) that may be a source of ground water: *in the MRF GIS map, switch on layer FF and check presence of unit 7 (Dakota Sandstone) at PS; in the URF GIS map, switch on layer Q or layer R and check geologic stack for presence of Dakota Sandstone underneath Mancos Shale.* Calculation of actual risk (both qualitatively and quantitatively) requires professional judgment using standard practices.