4. Ground Water Resources Evaluation Procedure

The complexity of the hydrogeology in CRWS 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, formation depth and thickness, aquifer matrix and fracture 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 (Kolm and van der Heijde, 2006; Kolm and Others, 2007). This stepwise procedure facilitates the evaluation of ground water availability, sustainability, and vulnerability on a site-specific base. The following text segment is largely taken from Kolm and others (2007). A summary of this procedure is included in an Appendix to this report.

At each step of the assessment procedure, notes refer to individual layers in the CRWS GIS map. For ease of reference in this chapter, each layer in the Table of Contents of the GIS map has been numbered as shown in Figure 52. To view a referenced layer in ArcMap, place a check mark in the layer’s checkbox in the Table of Contents; these user-placed check marks should be removed when moving to the next step in the procedure.

It is assumed that the starting point of the assessment procedure is a permit application for development of one or more parcels in the CRWS study area. Note, that the stepwise procedure may also be used for other planning or permitting 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; see Chapter 1). The succeeding tasks include determining the level of ground water availability (Objective 1b; see Chapter 1), sustainability as a resource at the site (Objective 2; see Chapter 1), and vulnerability to contamination and subsequent loss of supply (Objective 3; see Chapter 1). 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 or other users.

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 other low-permeability bedrock. Such potential aquifers may be in surficial material or bedrock formations. It should be noted
Table of Contents

Figure 52. Annotated Table of Contents for the CRWS GIS Map.
that even in low-permeability bedrock, a source of water can be found for individual users when
the presence of hydro structures, such as fracture zones in the Maroon Formation, has resulted in
locally increased permeability.

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., the Crystal River, Prince Creek, West Sopris and Sopris Creeks, and along
some intermittent streams near the northern county line. 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 characteristics
and use, such as spring runoff and withdrawal for irrigation. They may be recharged from
seepage from higher terraces or leaking ditches, and/or from irrigation return flow. (GIS
layer 29 in Figure 52; Figure 53).

Terrace Gravels and Fans (Qgf). This material is located above the modern stream levels on
the hillslopes. Extensive areas of this material can be found in the lower Crystal River valley
up to Avalanche Creek, and in the upper sections of the Thompson Creek watershed. Due to
the extent of these materials in some parts of the study area and the drainage patterns present
in these materials, they may provide a permanent source of water sustained by natural
recharge. When present as stand-alone terraces, these materials usually are dry, but can be
aquifers created and sustained by anthropogenic activity, such as leaking irrigation ditches or
irrigation return flow. (GIS layer 29 in Figure 52; Figure 53).

Landslides (Qls). This material can be found in many places along the hillslopes in the
northeast quadrant of the CRWS study area and along North Thompson Creek. These
materials are primarily dry, but in areas of irrigation ditches and other anthropogenic activity,
may become aquifers. They also may be seasonally of importance as a source of water. (GIS
layer 29 in Figure 52; Figure 53).

Moraines (Qm). This material is primarily located at the northern and eastern flanks of
Mount Sopris, and along the middle reach of Avalanche Creek. The moraines of the CRWS
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 29 in Figure 52; Figure 53).

Tertiary Sedimentary Deposits (Ts). This material can be found in the northern and
northeastern sections of the study area. The weakly indurated to unconsolidated fluvial
deposits (pebbles and cobbles in a matrix of silty sand) have a major presence in the
Carbondale evaporite collapse area near the northern county line where they are partially
covered by Quarternary sediments. This unit is potentially a good local or subregional
aquifer of variable thickness with significant matrix based permeability and may act in
conjunction with overlying sediments as a source of water. (GIS layer 30 in Figure 52;
Figure 54).
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 constitute aquifers in the study area (GIS layer 30 in Figure 52; Figure 54):

**Mount Sopris Granodiorite** (Tgs). These Upper Tertiary intrusive rocks are found in the vicinity of Mount Sopris and in the Elk Mountains near the upper reaches of Avalanche Creek. This unit may locally act as an unconfined, moderately permeable, fractured crystalline aquifer with local recharge.

**Wasatch and Ohio Creek Formation** (Tw). This unit consists of channel sandstones, conglomerates, overbank siltstones, claystones and shales. The conglomerates and sandstones are potentially good aquifers, both on a regional scale with matrix-based permeability and on
a local scale with fracture-based permeability. The siltstones, claystones and shales may form internal, potentially discontinuous confining layers. This unit is primarily located near the North and Middle Forks of Thompson Creek in the northwestern section of the study area.

**Mesa Verde Formation (Kmv).** This unit consists of interbedded sandstones and siltstones, shales, carbonaceous shales and coals and is potentially a complex of good aquifers with both matrix- (regional scale) and fracture-based (local scale) permeability. This unit is at or near the surface in a north-south stretching zone just west of the Crystal River, dipping down to the west underneath the Wasatch and Ohio Creek Formation. In the study area, this unit is a recharge zone for the regional system, and it is likely that in the outcrop area the unit contains a deep water table. Further to the west Kmv becomes a part of a confined aquifer system.

**Fort Hays Member of Mancos Shale (Km).** This unit consists of thick-bedded, coarse-grained limestone and may be a good local or regional fractured-flow aquifer when present. Its extent in the study area is not very well known. As it is part of the larger Mancos Shale formation, the Ft Hays unit is probably at or near the surface in a north-south stretching zone just west of the Crystal River, dipping down to the west underneath the Mesa Verde Formation. If present here, its outcrop/subcrop is a recharge zone with a deep water table. The unit may be also present in the Mancos shales directly north and northeast of Mount Sopris as it is discussed in the Basalt geological map (Streufert and Others, 1998). If present, its extent is more localized as the Mancos Shale in this area is disconnected from the Mancos Shale to the west. The unit is mostly confined except in the outcrop zones.

**Dakota-Burro Canyon Sandstone (Kdb).** This unit consists of sandstone layers 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 northeastern and eastern sections of the study area, and a small outcrop band west of the Crystal River. The (north-)eastern segment may provide a source of water although its orientation and elevation in the landscape indicates that it can only be recharged locally from precipitation. The outcrop of this unit west of the Crystal River is a recharge zone for a regional system and has a deep water table. This unit is primarily confined except in the outcrop/subcrop areas.

**Morrison and Entrada Sandstones (Jme).** This unit consists of poorly indurated, fine grained, well sorted sandstones, siltstones and claystones. The Entrada sandstones form a very good regional aquifer with matrix and fracture permeability. The Morrison shales are confining layers, while the lower Morrison sandstones perform as aquifers. This unit is mostly covered by the Dakota-Burro Canyon Formation and Mancos shales and thus confined, except in a small outcrop band west of the Crystal River, and in the hills east of Mount Sopris. The outcrop of this unit west of the Crystal River is a recharge zone for a regional system and has a deep water table.

**Maroon and Minturn Sandstones (PPmm).** This unit is characterized by grayish-red to pale-red arkosic sandstones, silt- and mudstones, and conglomerates. In the Minturn Formation these materials are interbedded with shale and limestone. Where metamorphosed and well
cemented, this unit acts as crystalline rock with only local potential for significant fracture permeability. This is the situation in the study area where significant fracturing occurs along the north-south trending fault and fracture zone of the Crystal River providing increased permeability beneath and along the river. Significant secondary fracturing occurs in the surrounding hills steering ground water flow towards the river valley. In the central Crystal River area, these fractured aquifer conditions are further enhanced by the additional fracturing related to the synclinal trough. Most of the area with Maroon/Minturn sub- or outcropping is considered a recharge zone, except for stream valleys where it is in the discharge zone. The recharge zone at the higher elevations have a deep water table, while in the discharge zones the water table may reach into the sediments above it.

Note that, in general, the Mancos Shale (Km), the Morrison shales (Upper Morrison; Jme), Chinle and State Bridge Formations (TrCSb), the Eagle Valley Formation, and the Eagle Valley Evaporite are mostly low permeability units and are considered in the study area to be confining layers. The State Bridge Formation in the eastern section of the study area may contain some discontinuous sandstones providing a highly localized fractured aquifer.
4.1.3 *Is the Potential Surficial 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 shales of the Mancos, Morrison, Chinle or State-Bridge Formations, or the Eagle Valley Formation or Eagle Valley Evaporite are areas where connectivity is not likely. Areas where landslide and alluvial material overlie the Tertiary sediment deposits, the Mt Sopris Granodiorite, the Wasatch and Ohio Creek Formation, the Mesa Verde Formation, the Fort Hays Limestone, the Dakota-Burro Canyon Sandstone, the Morrison and Entrada Sandstones, or the Maroon and Minturn Sandstones may 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 19-23 (Figure 52) 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 40 in Figure 52), the 50ft elevation contours layer (GIS layer 41 in Figure 52), or the topographic map layers (GIS layers 33-39 in Figure 52). Note, that in absence of sufficient well data, analysis of topography, vegetation, and nearby stream elevations may provide some insights with respect to nearby water table elevations.

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 16 in Figure 52). 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 and that overall precipitation increases from the north end of the study area towards the south end (see Figure 6).

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 is flowing for most of the year in the stretch across the aquifer, and the water table near the stream should be below stream level. GIS layers 11 and 12 (Figure 52) are based on Pitkin County’s waterline layer which contains, among others, a field indicating intermittent stream flow (ephemeral stream) or continuous stream flow (perennial stream). By comparing hydrogeologic unit information from layer 29 with the streams layers 11 and 12, the existence of a hydraulic connection may be assessed. When the stream is rated intermittent, additional information from filed observations may be required. There is no hydraulic connection between a stream and the aquifer when 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 simultaneously 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 29 is 
compared with the county’s ditches layer (GIS layer 13 in Figure 52). 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 (Figure 52, GIS layers 17 
and 18, 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 bedrock aquifers are overlain 
by confining units (see section 4.1.2).

All potential sedimentary aquifers shown in GIS layers 29 (Qa, Qgf, Qls, Qm) and 30 
(Ts) (Figure 52) are vulnerable; natural protection is only available for bedrock aquifers 
underneath confining layers.

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.