SECTION 7

7.0 INTERRELATIONSHIP BETWEEN SURFACE WATER AND GROUND-WATER IN STUDY AREA

The purpose of Section 7 is to provide more detailed discussion regarding the interrelationship between surface water and groundwater in the study area.

There are many facets to surface water/groundwater interaction that have been described in Sections 1 through 6 such as: stream gains/losses; groundwater recharge mechanisms; nature of alluvial, colluvial and bedrock springs; importance of surface irrigation as a recharge source; and the critically important hydrologic role that unconsolidated surficial deposits play, among other topics. Section 7 elaborates on these and other factors, and provides an integrated analysis of surface water/groundwater interactions.

The major subjects in Section 7 include:

- 7.1—Dominance of Surface and Near-Surface Flow Regimes
- 7.2—Significance of Unconsolidated Surficial Deposits, and Surface Irrigation, Stream Gains and Losses
- 7.3—Effectiveness of Recharge into Bedrock Formations (Hydraulic Properties of Bedrock)
- 7.4—Nature of Alluvial, Colluvial and Bedrock Springs and Seeps
- 7.5—Faults and Fractures as Recharge Mechanisms

7.1 Dominance of Surface and Near-Surface Flow Regimes

Perhaps the most important finding that emerges from the information and data assembled herein is that the study area is dominated by surface and near-surface flow regimes. Consider the following representative quotations regarding the significance of surface and near-surface flows in the study area:

- A similar fresh water flow mechanism occurs along the steeper flanks of the Grand Mesa as does nearer the Gunnison Valley floor. A mechanism that allows the bulk of the water in near-surface flows to be directly tied with meteoric surface flows moving down along the side of Grand Mesa in a 300-1,000 foot zone paralleling the side slopes of the Mesa… The surface waters and springs along the upper flanks of the Mesa are obviously fresh. The waters near the outcrop and exposed coal interval are mineralized but potable enough for irrigation and, with some care and treatment, are usable for domestic water. The opposite would probably be true in the coal interval if the near-coal surface waters came from deep inside the Mesa after flowing through and dissolving the available salts and minerals associated with the thick intervening sequence of sands and shales (Bertram 2002).

- Most all of the water wells drilled into, through and just below the surface alluvium are less than 300 feet deep; there are 2-4 wells that exceed 500 feet. Most of the water wells drilled are less than 200 feet deep. The proximity of the shallower water wells that produce from the subcrop of different formations including the overlying alluvium would easily allow them to be influenced by near-surface flows. Most, if not all of the near-surface characteristics associated with near-surface water flow discussed earlier in this paper apply to these shallow water wells. The cases mentioned earlier and the application of reason support the conclusion that these water well fluid levels are greatly influenced, if not entirely influenced, by near-surface flow regimes. If any conclusion can be drawn from the apparent continuity of water in these shallow water wells to the surface, it is just that: continuity of the shallow (within 600 feet of the surface) weathered, disturbed, fractured and continuous zone conforming to and paralleling the surface topography (Bertram 2002).

- Recharge of the water-bearing zones is by seepage from area streams, direct infiltration of precipitation and snowmelt. Alluvial water-bearing zones are hydraulically connected with adjacent bedrock and inter-mixing of the two units with groundwater is likely (Ackerman and Brooks 1985).

- Unconsolidated Quaternary deposits locally recharge and discharge in the North Fork of the Gunnison River Valley, ultimately contributing water to the river. These deposits comprise the more productive aquifers in the Delta-Paonia area. This is especially true in the Paonia area where most water supplies are developed from valley alluvium along the North Fork of the Gunnison River. Valley-slope deposits consist of landslide deposits and other unconsolidated Quaternary deposits which receive recharge on the higher slopes and discharge water from the lower slopes. All springs inventoried in the Paonia study area originate from unconsolidated deposits, which in many places are underlain by the less permeable Mesaverde Formation… The Mesaverde Formation transmits little water. Water within the Mesaverde Formation normally is limited to relatively small and isolated lenticular sandstones… Small transmissivity values and small storage coefficients are characteristic of the Mesaverde Formation in the Delta-Paonia area (Brooks 1983).

- Unconsolidated alluvial deposits found in stream valleys contain the best producing aquifers… Wells completed in alluvial deposits were reported to yield from 1 to 750 gallons/minute (Brooks and Ackerman 1985).
- The primary groundwater-bearing zones in the North Fork of the Gunnison River Basin occur in Quaternary alluvial, colluvial, glacial and eolian deposits and Cretaceous bedrock. Alluvial deposits along the North Fork of the Gunnison River represent a major aquifer… Colluvial water-bearing units located on valley slopes are generally isolated and are limited in extent. These units are normally saturated seasonally and have a low storage capacity and yield. Most springs and seeps in the region issue from colluvial deposits underlain by less permeable bedrock… Minor groundwater occurrence is reported in the late cretaceous Mancos Shale, Mesaverde Formation and Tertiary Wasatch Formation (BLM and USFS 2000).

These quotations are supported by other data gathered in the course of preparing this report. For example:

1. Review of Division 4, District 40 decreed water rights within the study area showed that 97 percent of the decreed absolute flow rights are associated with surface diversions (ditches). (The nature of the remaining 3 percent of the decreed rights is explained in Section 5.3.)
2. About 71 percent of water wells in the study area are located in unconsolidated deposits. About 15 percent of wells receive water from a combination of bedrock and unconsolidated deposits, while the remaining 14 percent receive water from bedrock only. (See Section 6.2 for additional discussion.)
3. Observed water production rates from the seven oil and gas wells in the study area with such data are considerably less than the flow of a garden hose. (See Sections 6.4.2 and 6.4.3 for additional discussion.)
4. In general, coal mines throughout the entire study area have experienced only small groundwater inflows. Where inflows have been encountered, they typically

are associated with shallow overburden depths and are in the proximity of surface drainages. Occasionally, such as at the West Elk Mine, a significant water-bearing fault has been encountered. Special circumstances are usually associated with these cases, as described herein. Coal mine groundwater inflows normally decline with time and are seasonally related. (See Section 6.5 for additional discussion.)

5. The quantities of precipitation over the study area (See Figure 6) and streamflow (see Section 5.1) are orders of magnitude larger than the current bedrock groundwater use in the study area. As discussed in Section 6.2.3.3, a rough estimate for average annual Mesaverde Formation groundwater use is about 20 acre-feet, whereas in an average year, total precipitation on the study area is about 1 million acre-feet and cumulative streamflows off the south side of the Grand Mesa exceed 150,000 acre-feet/year in the study area.

6. Municipal water supplies are dominated by surface water and alluvial groundwater sources, as discussed in Section 5.4. No Mesaverde Formation wells are used in municipal systems in the study area, based on the records that were reviewed, mainly from CDPHE.

7. The conceptual water balance for Surface Creek presented in Section 5.5 demonstrates the importance of surface irrigation relative to groundwater recharge.

8. The literature reviewed and interviews conducted consistently show that surface and near-surface water resources predominate in the study area, with bedrock groundwater uses very small by comparison.

7.2 Significance of Unconsolidated Surficial Deposits, Surface Irrigation and Stream Gains and Losses

The west side of the study area is characterized by extensive unconsolidated surficial deposits; in contrast, the east side generally lacks such deposits, primarily due to steep slopes and stream gradients (see Section 4.1). The hydrology of both the west and east sides of the study area, including the interaction of surface water and groundwater, is strongly influenced by the extent and nature of these surficial deposits. Closely related are the factors of stream gains and losses and the groundwater recharge role that surface irrigation plays. All of these factors are discussed in this section.

As presented in Section 4.1, a USGS survey high-altitude color relief photograph of the study area provided in Figure 4 clearly illustrates the massive surficial deposits on the west side of the study area, and also shows the general lack of such deposits on the east side. This distinction, and its hydrogeologic significance, were described by Brooks (1983) and Brooks and Ackerman (1985) and Bertram (2002). Basically, alluvium/colluvium (also referred to as unconsolidated surficial deposits) overlies the less permeable bedrock formations on the western side of the study area. In places, the bedrock can be weathered and cracked near the interface of the overlying deposits and bedrock. Thus, water that infiltrates into the surficial deposits can also infiltrate into the bedrock. Bertram (2002) states:

> Theoretically, a series of shallow water wells drilled in that area would produce little from the alluvium, but if drilled into the interface between the alluvium and the bedrock or into the bedrock just below that interface would produce higher volumes of water. The water would also “take on” some of the chemical nature of the bedrock, resulting in water having a different composition than waters found nearer to the ground surface.

This process would be limited to areas where the unconsolidated surficial deposits exhibit relatively high permeability due to having been reworked by water, layered, stratified and sorted. Many deposits around Cedaredge exhibit these characteristics. In contrast, as discussed in Section 6, not all of the unconsolidated surficial deposits in the study area have relatively high permeability. For example, debris flows derived primarily from the Wasatch Formation would exhibit low permeability.

Review of well logs from the west side of the study area in the vicinity of Cedaredge (as described in Section 6.2) shows that many domestic wells are drilled into the alluvial/outwash deposits and into the upper portion of the Mesaverde Formation. Well logs indicate that the casing is typically perforated in both the unconsolidated overlying deposits and the bedrock formation. The unconsolidated, reworked and stratified surficial deposits overlying the bedrock can be envisioned as a "sponge" over much of the west side of the study area. The "sponge" absorbs rainfall, snow melt, initial applications of irrigation water, and irrigation return flows. That portion of the water which is not "lost" through evapotranspiration or direct runoff percolates downward and either emerges downgradient in the form of alluvial-colluvial spring/seeps or continues downward and enters the bedrock formations. Entry into the bedrock (Mesaverde Formation) is facilitated by the presence of localized secondary permeability, which can be caused by weathering, coal burning and faults/fractures (see Sections 4.4 and 4.11). In some locations, the Mesaverde Formation has accumulated sufficient water to create springs/seeps.

Field observations, interviews and the literature reviewed emphasize the importance of surface irrigation in this process. On the west side of the study area, tens of thousands of acre-feet are applied for irrigation each year (see Sections 5.3 and 5.5). As stated by Bertram (2002):

> Old timers relate that very few if any of the side slopes springs and seeps now present on the exposed flanks of these terraces existed prior to irrigation for crops on the terrace surfaces, beginning in the late 1890s and early 1900s. The alluvium providing the soils for the crops does not retain the excess water placed on them, but allows that water to percolate down to the underlying Mancos Shale where the water finds and flows along near-surface fractures and pre-alluvium weathered terrain (ridges and gulleys) to the sides and bottoms of the surrounding terrace slopes.

Mr. Bertram's characterization of excess irrigation water migrating through the alluvial outwash until it encounters the Mancos Shale (an impermeable boundary) also applies where the alluvial outwash overlies the Mesaverde Formation, except that the Mesaverde contains some localized areas of enhanced permeability, as discussed in Sections 4.4, 4.11 and Section 6. In these limited areas, the water can enter the formation.

Consistent with the observations of WWE and Bertram, Brooks (1983) described the hydrologic and hydrogeologic significance of the unconsolidated surficial deposits as follows:

> The saturated thickness of the Mesaverde Formation differs in the Paonia and Cedaredge study areas because the topography and geology of the two areas are different. There is less opportunity in the Paonia study area for precipitation and runoff to infiltrate into the exposed areas of the Mesaverde Formation because the terrain is very steep and ravines are numerous. Limited infiltration results in limited groundwater recharge and ravines also allow rapid drainage of infiltration water. The slopes in the Cedaredge study area are less steep, and the area has sufficient unconsolidated cover to allow more time for water to infiltrate into the Mesaverde Formation… Transmissivity values and storage coefficients reported for unconsolidated Quaternary deposits are greater than those reported for the Mesaverde Formation. Unconsolidated Quaternary deposits can transmit a significant quantity of water. The more extensive the unconsolidated deposit, the more potential there is for groundwater recharge, discharge and storage for long periods… The Mesaverde Formation and overlying unconsolidated Quaternary deposits are more saturated in the Cedaredge study area than in the Paonia study area. An estimated inflow of 7 to 12 gallons/minute (December 1982) enters the Red Canyon Mine, about three miles northwest of Cedaredge. Few faults were reported, but the overburden consists of saturated Mesaverde Formation overlain by saturated unconsolidated Quaternary deposits (L.M. Reschke, Grand Mesa Coal Company, Oral Communication 1982). An abandoned mine adjacent to the Red Canyon Mine requires an estimated pumping rate of 16 gallons/minute to keep pace with the inflow… Greater coal mine inflows would be expected in the Cedaredge study area than in the Paonia study area because alluvial aquifers are thicker, more extensive and saturated to a greater thickness.

The *North Fork Coal Environmental Impact Statement Delta and Gunnison Counties, Colorado* (BLM and USFS 2000) states that “recharge of the water-bearing zones is by seepage from area streams, direct infiltration of precipitation and snow melt.” The same report notes that: 1) alluvial water-bearing zones are hydraulically connected with adjacent bedrock and intermixing of the two units with groundwater is likely, 2) the shallow alluvial and colluvial groundwater flow follows local topography, and 3) bedrock groundwater flowpaths follow topography and are affected by numerous drainages bisecting the region.

Few stream gain/loss studies have been conducted in the study area, and those that have been conducted suggest that gains and losses are site-specific, preventing generalizations regarding this phenomenon. For example, Brooks (1983) provides the following summary of streamflow gain and loss measurements conducted by the USGS at that time:

> Measurements were made on Terror Creek in the Paonia study area and on Oak Creek in the Cedaredge study area. No surface inflows or outflows were found between measurement sites. The reach on Terror Creek was chosen because it crosses the lower part of the Mesaverde Formation and has overlying alluvium… A 0.59 cfs loss was measured along this approximately 1.5 mile reach, indicating that the lower part of the Mesaverde Formation receives recharge in the Paonia study area. Streamflow gain and loss measurements on Oak Creek in the Cedaredge study area indicate a hydraulic connection between water in the alluvium and the stream. Oak Creek gained 0.92 cfs along about a 1.5 mile reach of alluvial streambed, indicating the alluvium contributes base flow.

WWE's gain/loss measurements on Surface Creek near Cedaredge in December 2002 identified no discernable gain or loss, as discussed in Section 5.5.2. In the fall of 2002, WWE also conducted a gain-loss study on Anthracite Creek and the North Fork of the Gunnison River for a consortium of industrial clients along the North Fork. The purpose of this study was to evaluate the magnitude of channel losses when augmentation water is released from the East Beckwith Reservoir. The study reach between the reservoir and the USGS gauge near Somerset encompassed approximately 23 miles of stream channel. Although the work is still in progress, preliminary results indicate channel losses on the order of 10 percent.

In summary, the presence of unconsolidated alluvial deposits and irrigation, particularly on the western portion of the study area near Cedaredge, play key roles in recharging the Mesaverde Formation in limited areas. The role of stream channel gains/losses is less clear, based on the available data, but is likely quite variable and highly site-specific.

7.3 Effectiveness of Recharge Into Bedrock Formations (Hydraulic Properties of Bedrock)

As discussed in Section 7.2, the unconsolidated surficial deposits which blanket the west side of the study area and less extensive deposits on the east side of the study area provide a recharge source to the Mesaverde Formation. However, in general, the Mesaverde Formation in the study area has limited permeability, and this limits the amount of recharge that can occur. The Mesaverde Formation in the study area transmits little groundwater because of the negligible transmissivity of the 1,300 feet of fine-grained sandstone, coal and shale comprising the formation (Brooks 1983). Water within the Mesaverde Formation normally is limited to relatively small and isolated lenticular sandstones (Brooks 1983). The primary hydraulic conductivity of the Mesaverde Formation is small (Brooks 1983).

The potential for any given formation to yield water can be measured by the transmissivity and storage coefficient values of the formation. Transmissivity is the rate at which water is transmitted through an aquifer under specified conditions. Transmissivity is directly related to permeability and thickness. The storage coefficient, in simple terms, is the amount of water, as a percentage of the total rock volume, that can be drained by gravity. The transmissivity and storage coefficients of alluvial/colluvial deposits in the study area are orders of magnitude higher than those for the Mesaverde Formation. For example, coalbed transmissivities in the study area are reported to range from 1.5 to 16.7 ft^2/day and storage coefficients range from 0.00004 to 0.097 (Brooks 1983). Brooks stated that these values indicate that the coalbeds have little potential for supplying water for domestic use. (It should be noted that under these conditions, the coal beds can yield some water, but only if there is a large piezometric head drop.) Brooks (1983) also indicated that the transmissivity of the Barren Member of the Mesaverde Formation is 0.33 ft^2/day and stated that "results of aquifer tests indicate that the Mesaverde Formation transmits little water where undisturbed, although significant quantities of water can be transmitted where the Mesaverde Formation is fractured." For purposes of comparison, Brooks noted the much higher transmissivity values for the unconsolidated Quaternary deposits at Stevens Gulch near Paonia of 187 to 230 ft^2/day and 1,900 ft^2/day at a location six miles east of the Cedaredge area. Storage coefficients for alluvial and colluvial deposits are often about 0.2 to 0.3, which is far higher than the ranges reported for the Mesaverde Formation.

Mayo and Koontz (2000) reached similar conclusions regarding Mesaverde Formation permeability. They found that matrix permeability data from samples of the Rollins Sandstone collected in the West Elk Mine indicated that:

> …the unfractured rock has very little ability to transmit groundwater… Several of the cores analyzed are nearly incapable of vertically transmitting groundwater

> (i.e., permeability of less than 10^{-4} Darcy) and most samples have a matrix permeability of less than 10^{-3} Darcy.[6]

In field work conducted during June 2002 in the study area, Cordilleran reached similar conclusions regarding the low permeability of the Mesaverde Formation. Cordilleran obtained permeability values for the lower and upper coal members ranging from less than 0.1 Darcy to 0.022 Darcy, and stated that much of the original porosity was reduced by compaction during burial (Pittman, et al. 1996). Regarding the Barren Member, Cordilleran found that most porosity is secondary in origin and that conventional core-measured permeability resulted in values of less than 0.001 to 0.01 Darcy. Cordilleran also noted that permeabilities are highest in sandstones containing abundant open vertical fractures and lowest in areas where the fractures are cemented by carbonate. Regarding the Ohio Creek Member, Cordilleran reported that conventionally measured core permeability varied from less than 0.0001 to 0.01 Darcy (Cordilleran Compliance Services 2002a).

The general lack of permeability in the Mesaverde Formation was also noted in many of the coal mine hydrologic reports that were reviewed at the offices of the CDMG. The following quotation, taken from the *Cumulative Hydrologic Impact Study of the Tongue Creek Watershed* (CDMG 1991) is representative:

> The Mesaverde does not typically have productive aquifers in this area due to the poor lateral continuity, inappropriate petrology or poor recharge topography. The Rollins Sandstone Regional Aquifer is rather dry in this area as the seam is a cliff former and little recharge is possible. No impacts are predicted for this aquifer as the discontinuous sandstones, siltstones, shales and coals between the mining zones and Rollins preclude migration of water.

Adding to this lack of permeability is the fact that calcareous and siliceous cement and clay commonly fill the space among sand grains in the lower part of the formation (Dunrud 1989a). This observation was corroborated by Bertram (2002): “The Rollins Sandstone contains visible clay and calcareous matrix cementation of varying amounts throughout the western area.”

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[6] A Darcy is a standard unit of permeability, equivalent to the passage of one cubic centimeter of water of one centipoise viscosity flowing in one second under a pressure differential of one atmosphere through a porous

Although there is usually little primary permeability in the Mesaverde Formation, there are small, localized areas where significant secondary permeability is present, generally from the outcrop downdip (inward) a distance of a few hundred up to 1,500 ft (Dunrud 1976). The causes of the relatively high secondary permeability include weathered and burned zones in the Coal-Bearing Member, discussed in Section 4.4.3.3, and faults and fractures, discussed in Sections 4.4 and 4.11. In certain locations, such as in the vicinity of Cedaredge, these factors have been sufficient to enable about two dozen permitted wells to draw exclusively from the Mesaverde Formation. As discussed above, in the Cedaredge area, much of the overlying unconsolidated surficial deposits act as a “sponge” which provides a constant source of near-surface water to the underlying Mesaverde Formation.

The Coal-Bearing Member above the Rollins Sandstone can conduct some water through secondary hydraulic conductivity features such as fractures; however, core drilling indicates that fracture zones probably are not areally extensive (Brooks 1983).

It is also noteworthy that during geologic mapping, Dunrud observed no large flows of water during core drilling and rotary drilling operations. He recalls that it was necessary to haul water to the core-drilling sites and that foam was used in most rotary drilling operations, indicating that very little groundwater was encountered. Foam could not have been used if significant flows of water had been encountered.

In summary, recharge of the Mesaverde Formation is limited to localized areas near outcrops where weathered or burned zones occur, or in some cases, areas where fractures occur.

7.4 Nature of Alluvial, Colluvial and Bedrock Springs and Seeps

An important manifestation of surface water/groundwater interaction is springs. Precipitation, snowmelt, streamflow, and overland flow infiltrate into either unconsolidated material or

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medium having a cross-sectional area of one square centimeter and a length of one centimeter (Jackson 1997).

bedrock formations, move downgradient and eventually emerge as springs or seeps. Springs are found throughout the study area from either alluvial, colluvial or bedrock sources.

In addition to water quality data presented in Sections 5 and 6, many of the references reviewed in the course of preparing this report discuss spring flows. For example, the 1999 *North Fork Coal Environmental Impact Statement, Delta and Gunnison Counties, Colorado* (BLM and USFS 2000) states:

> Colluvial water-bearing units located on valley side slopes are generally isolated and are limited in extent. These units are normally seasonally saturated and have a low storage capacity and yield. Most springs and seeps in the region issue from colluvial deposits underlain by less permeable bedrock… Numerous seasonal springs and seeps issuing from these zones have been developed for livestock watering and support wildlife.

Brooks (1983) also provided these observations regarding springs:

- Valley-slope deposits consist of landslide deposits and other unconsolidated Quaternary deposits which receive recharge on the higher slopes and discharge water from the lower slopes. All springs inventoried in the Paonia study area originate from unconsolidated deposits, which in many places are underlain by the less permeable Mesaverde Formation.

- All perennial springs in the coal-lease tract area[7] overlie a minimum of 1,500 feet of overburden… Springs supplying domestic water to Oak Mesa are just outside the Paonia proposed lease tract… The saturated unconsolidated deposits from which these springs issue are west of east Roatcap Creek drainage area.

- Sixteen springs, all issuing from unconsolidated Quaternary deposits, were inventoried in the Paonia study area during the late summer of 1982. Other springs may have existed, but had ceased flowing by late summer. Discharge was measured for 15 springs and water quality samples were obtained for 14 springs. Discharge ranged from 0.02 to 8.41 gpm, specific conductance ranged from 242 to 678 umhos and pH ranged from 5.5 to 8.1. The spring waters were a calcium sodium bicarbonate type.

Brooks and Ackerman (1985) reported the following regarding bedrock springs:

> Specific conductance values for water samples from 43 springs issuing from consolidated sedimentary rock formations other than the Mancos Shale ranged from 42 to 18,500 µS/cm with a median of 932 µS/cm. Specific conductance valves for groundwater in this formation range from 325 to 5,390 µS/cm. Two samples from springs issuing from the Mancos Shale had specific conductance values of 110 and 7,540 µS/cm. Two (Mancos) wells had specific conductance values of 629 and 1,900 µS/cm.[8]

Brooks and Ackerman (1985) made the following observations regarding alluvial springs:

- Springs are common at higher elevations, wells are generally located in the valleys.
- Salinity and water chemistry indicate that flow paths and residence times are longer for most well waters than for spring waters.
- Spring waters predominately originate from precipitation and snowmelt infiltration. Alluvium, glacial drift and landslide deposits on steep slopes may be saturated only seasonally and are intermittent sources for springs. Some valley springs issue from the base extensive terrace gravels overlying bedrock and have a large continuous discharge. These springs are less saline than most well waters and probably derive much water from the infiltration of stream flow and irrigation water on the terraces.
- Specific conductance for samples from ten wells ranged from 80 to 32,000 µS/cm with a median of 1,750 µS/cm. Specific conductance values for 16 of 18 sampled springs were less than 500 µS/cm.[6] Most spring waters are a calcium sulfate bicarbonate type, but some are of a calcium magnesium bicarbonate sulfate type.

WWE used the data from Brooks and Ackerman (1985) described above to compare the water quality of wells completed in the Mesaverde Formation with that of wells and springs fed from alluvial and glacial deposits. TDS in 19 Mesaverde Formation wells varied between 180 and 3,400 mg/L, with an average of 812 mg/L. TDS in six alluvial and one glacial deposit wells and in eight alluvial springs varied between 49 and 22,000 mg/L. Closer examination of the three

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[7] The author examined two coal-lease tract areas, one of which was referred to as the Cedaredge tract study area and the other as the Paonia tract study area. Both of these tracts lie within the study area that is delineated in Figure 1 of this report.

[8] To convert µS/cm to mg/L of TDS, it is necessary to multiply the µS/cm values by 0.55 to 0.75, as discussed in Section 5.2.6.

alluvial water sources with very high TDS levels (above 2,000 mg/L) showed that they all were wells; two contained high levels of sulfate (1,600 and 1,800 mg/L) and one contained a high concentration of chloride (12,500 mg/L), indicating that they were likely influenced by old mine workings. When these three wells were not counted, TDS in the remaining alluvial wells and springs varied between 49 and 300 mg/L, with an average of 174 mg/L.

Typically, the springs and wells in the unconsolidated materials or the weathered zone of Mesaverde bedrock and old mines producing water show seasonal variations in water production. Their peak flows occur in the spring and during the irrigation seasons and flows decrease in the fall and dry times of the year (personal communications between John Rold and Messrs. Loucks and Bertram 2002).

In summary, numerous springs exist in the study area. Although the majority of these emanate from the unconsolidated deposits, bedrock springs also exist. Water quality of the springs varies widely based on their origin. Flow rates also vary significantly and typically show seasonal variation.

7.5 Faults and Fractures as Recharge Mechanisms

Another important element of surface water/groundwater interaction is the recharge role played by faults and fractures. The nature of faults and fractures in the study area is presented in Section 4.11. For example, faults exist under some of the major drainages in this study area, such as Surface Creek, Leroux Creek, Hubbard Creek and Terror Creek. When assessing the study area as a whole, the available evidence suggests that faults and fractures do not play a significant recharge role. However, in localized areas, they can be a factor.

As discussed in Section 4.11, in general, water and gas may be present in some of the faults that cut the rocks of the Mesaverde Formation—water and gas that has accumulated from within these rocks over centuries. However, as structural conduits for the transfer of water, the significance of these faults is estimated to be very low, for the following reasons:

- The faults (of late Cretaceous age) most likely do not transect the clays, silts and marlstones of the Wasatch, Green River and Uinta Formations (of Tertiary age).
- In many locations, the faults are covered by a low permeability blanket of Wasatch debris flows.
- The faults in the Cedaredge area, in particular, project northward to abundant lakes and reservoirs on Grand Mesa; if there were a hydraulic connection between these water bodies and the faults in the Mesaverde Formation, a significant amount of the water stored in the lakes would leak out and be the source of high pressure, high volume springs in the Cedaredge area, yet springs of this nature are not apparent.

Many of these observations hold true for fractures, as well. For example, debris flows with large amounts of clay and silt from the Wasatch and Green River Formations and basalts that cap the Grand Mesa are found in many locations in the study area. Vertical and horizontal permeabilities of these debris flows are low to very low. These debris flows are commonly associated with channels which also contain fractures. Consequently, the probability of "sealing" of faults and fractures by debris flows is high. Just as thousands of years of erosion of fine-grained material from the Wasatch Formation has tended to seal fractures, fractures tend to "heal" from within, as formations expand and swell, in the same way that clays expand due to water additions. As noted by Brooks (1983): "Alluvial deposits contain fine siltstone and clay sediments derived from the Wasatch Formation. This silt and clay could seal subsidence cracks."

Mudstones and claystones in the Mesaverde Formation may expand when in contact with water and seal fractures in bedrock overburden (DeGraff and Romesburg 1982). The Colorado Mined Land Reclamation Division (1981) report on the Blue Ribbon Mine, two miles east of the USGS Paonia study area, noted that cracks in competent rocks, such as sandstone, tend to remain open while cracks in incompetent rocks, such as mudstone and claystone, and soils are likely to fill (Brooks 1983). Brooks (1983) also notes that alluvial deposits contain fine silts and clay sediments derived from the Wasatch Formation which can seal subsidence cracks associated with coal mines. Brooks also states that greater overburden thicknesses decrease the potential for coal mine subsidence fractures to extend from the mine to the surface, and that a thick overburden may prevent or decrease losses of water from streams, surface impoundments, springs and seeps into fractures. Brooks (1983) expressed the concern that surface or groundwater might recharge the overburden and drain into underground coal mine workings, where cracks occur and interconnect them with the mine. However, the research of Dunrud at coal mines in the study area (Dunrud 2000), and the experiences of coal mine operators throughout the study area, indicate that the probability of surface cracking in response to coal mining is small, and that the relatively small number of cracks that are observed tend to heal and seal with time, as discussed above.

The probability of a continuous vertical connection between the surface of the Grand Mesa and the Mesaverde Formation via fractures and faults is insignificant. As stated by Bertram (2002):

> If an entirely porous and vertically connected model of the 3,000-8,000 foot sequence of rocks all containing fresh water under Grand Mesa (advocated by others) is used to design and test the proposed CBM project wells, the physical separation and protection of this resource is severely compromised. I believe such a model does not explain all of the dynamics controlling water flows through, down and below the Grand Mesa.

Cordilleran (2002a) reached a similar conclusion:

> Based on the hydrostatic pressures observed in previous test wells at depth and the pressures observed within water-bearing intervals, the Mesaverde Formation does not appear to be in communication from top to bottom. In other words, if there were natural fractures that connected the shallow, potable water-bearing units to the water contained within the target coal zone, the methane would be leaking out naturally. Evidence of natural methane seeps is not widely or readily apparent in the project area.

It is important to understand that many of the faults and fractures mapped in the study area occurred during the period of mountain building called the Laramide Orogeny. This process occurred some 60 to 70 million years ago and formed the major structural uplifts or mountain ranges and basins that are apparent today. At that time, the Mesaverde and older formations would have been faulted and folded. Younger formations such as the Green River Formation and Upper Wasatch Formation did not exist at the time of the Laramide Orogeny and, therefore, would not be faulted, except for minor faulting that may have occurred later. As would be expected, few of the faults shown in the Mesaverde rocks by Ellis, Gaskill and Dunrud (1987) extend into the Wasatch and younger rocks.

Experience of those mining in the study area further confirms that fracture zones are not extensive in the study area. For example, the Bowie #2 coal mine permit document (Bowie Resources, Limited 1996) states:

> The primary permeability is low due to the lithologic composition of the sandstone and the secondary (fracture) permeability is not well developed. Extensive core drilling within these strata shows that fracture zones are not well developed. Similar observations were made in the Orchard Valley underground mine. Fracture zones or zones of lost circulation during drilling do not appear to extend from hole to hole. Fracture and fault zones, although encountered, are not well developed.

Furthermore, the CDMG (2001) *Cumulative Hydrologic Impact Study – North Fork of the Gunnison River* states that some fractures and faults transect the Mesaverde Formation and extend vertically to the surface, but that such faults and fractures produce no bands of secondary porosity within the rock strata.

In summary, although faults and fractures exist in the study area, they serve a very limited, localized role in recharging the bedrock formations. Clays in the Wasatch and Green River Formations help to seal these cracks and limit their role as conduits for surface flows to recharge the bedrock formations. Faults and fractures in incompetent rocks such as mudstone and claystone also tend to heal over time.

Review of the available geologic and hydrogeologic data for the study area indicates that there is not continuous groundwater flow from the top of the Grand Mesa down to the base of the Mesaverde Formation, a distance of roughly 4,000 to 6,000 feet. To the contrary, groundwater within the bedrock is generally limited to discontinuous lenses of limited volume.