# HYDROGEOLOGY OF THE SOUTH FLANK OF THE GRAND MESA
# IN THE VICINITY OF CEDAREDGE AND PAONIA
# DELTA COUNTY, COLORADO

**Prepared For:**

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**June 10, 2002**

# EXECUTIVE SUMMARY

Gunnison Energy Corporation (GEC) has applied to Delta County, Colorado for special use agreements for five natural gas exploration wells and is proposing to drill four of the wells in the summer of 2002. GEC will use the test wells to evaluate the economic viability of natural production from several target horizons in the Mesaverde Formation in these areas. An important goal of the test wells is to demonstrate the economic viability of coal bed methane (CBM) production from the Cameo Coal.

GEC retained Cordilleran Compliance Services, Inc. (Cordilleran) to prepare a preliminary hydrogeologic investigation of the south flank of the Grand Mesa in the exploration area. This investigation includes evaluation of surface water and groundwater resources, principally in the upper Cretaceous Mesaverde Formation, to estimate, based on available information, the potential for the natural gas exploration and for the testing project to impact these resources. In support of this evaluation, Cordilleran is in the process of conducting groundwater monitoring and sampling throughout the proposed test area in order to assemble a representative baseline database of water quality.

Based on GEC's exploration and testing plans and the information obtained from public sources, the proposed testing of natural gas and coal bed methane resources in the Mesaverde Formation in Delta County, Colorado is not expected to adversely impact surface water or groundwater resources for the following reasons.

- The GEC test wells will be completed and constructed in accordance with current COGCC regulations and current industry standards to preclude impacts to surface water and direct impacts from drilling or the completed wells to the adjacent aquifers. The test wells are remote from each other precluding any cumulative effect from simultaneous testing.
- The wells will be completed and tested within a short time period.
- The test wells will not be located in areas that are obviously faulted and fractured.
- If economic natural gas resources, other than CBM, are identified within sandstone units within the Mesaverde Formation, GEC will ensure the proper completion of the

gas well and will follow all applicable COGCC guidelines for completing a natural gas well.

- For a positive CBM test result, the prospect coal interval must be confined to the extent that the hydraulic pressure in the coal can be reduced to the point that CBM can be produced. If the coal is not confined and pressure cannot be reduced the test would be terminated. If the coal is confined and hydraulic pressure can be successfully reduced, it is axiomatic that the CBM test interval is not well interconnected with adjacent aquifers.
- The fine-grained sandstone, siltstone, and claystone strata, characteristic of the Mesaverde Formation, transmit little water to wells and springs due to low permeabilities and low transmissivities.
- In the areas of the proposed test wells, most seeps and springs occur at the contact between bedrock and alluvial deposits on the mesa rather than at bedrock outcrops. Within the test areas, upper strata of the Mesaverde Formation may be essentially drained adjacent to the deep canyons that are eroded into the Grand Mesa.
- Groundwater for potable use is currently produced primarily from wells completed in shallow, discontinuous lenses of sandstone.
- The total depths of the water supply wells are typically less than 350 feet bgs while the proposed total depths of the test wells range 2,800 feet to 4,000 feet. The lithologies of the Mesaverde Formation between the coal beds and the water bearing units are very fine-grained and of low permeability.
- The nearest a known water supply well to any of the coal bed methane test wells is 1,300 feet. However, most locations are typically more than 1-mile away.
- 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 in the project area is not apparent.

- The Groundwater Protection Council, a national association of federal and state regulators and professionals, conducted a 1998 survey that revealed no incidents of groundwater contamination from hydraulic fracturing associated with coal bed methane operations. The results indicate that there is little evidence that adverse impacts to drinking water resources have occurred due to coal bed methane exploration and production activities; and

In, addition, the coal zones that GEC plans to test for CBM potential have been mined for over 100 years. There are numerous abandoned and active coal mines in the region. Although dewatering is and continues to be a common component of coal mining, groundwater resources do not appear to have been adversely impacted. Based on this observation, shallow groundwater resources do not appear to be interconnected with the coal bearing members of the Mesaverde Formation.

Cordilleran is currently sampling surface water and groundwater from project area water supply wells, seeps, and springs that will be combined with other available information in a preliminary, representative, base line hydrogeologic and hydrochemical database. Concurrently, Cordilleran is continuing to compile and review existing relevant research and other available data in order to prepare a work plan to conduct a subsurface investigation. The subsurface investigation work plan will be implemented in conjunction with the drilling of the proposed test wells. Site specific data will be combined withal available research information to compile a conceptual model of the site to guide environmental assessment, including computer modeling of potential long term impacts resulting from natural gas and CBM production.

# 1.0 Introduction

Gunnison Energy Corporation (GEC) has applied to Delta County, Colorado for special use agreements for five natural gas exploration wells. GEC is proposing to drill four of the wells in the summer of 2002. The proposed wells are spaced at intervals of approximately six miles across the south flank of the Grand Mesa. GEC will use the test wells to evaluate the economic viability of natural production from several target horizons in the Mesaverde Formation in these areas. An important goal of the test wells is to demonstrate the economic viability of coal bed methane (CBM) production from the Cameo Coal. A General Site Location Map showing the locations of the proposed test well locations is included as Figure 1.

GEC retained Cordilleran Compliance Services, Inc. (Cordilleran) to prepare a preliminary hydrogeologic investigation of the south flank of the Grand Mesa in the exploration area. This investigation includes evaluation of surface water and groundwater resources, principally in the upper Cretaceous Mesaverde Formation, to estimate, based on available information, the potential for the natural gas exploration and testing project to impact these resources. In support of this evaluation, Cordilleran is in the process of conducting groundwater monitoring and sampling throughout the proposed test area.

Cordilleran's scope of work consists of the following activities:

- A review of geologic and hydrogeologic papers, maps, and cross-sections prepared by the United States Geologic Survey (USGS) and the Colorado Geologic Survey (CGS), and other available sources that describe groundwater resources in the proposed test well locations;
- A review of water well permit records at the Colorado Office of the State Engineer, Division of Water Resources for wells in the areas of the proposed test well locations;
- Identification of groundwater and surface water resources that could potentially be impacted by the exploration project;

- Collection of groundwater samples from water wells, springs, and seeps prior to the test well drilling activities to establish a representative baseline database for water quality in the test well areas; and
- Designing a groundwater monitoring program, to generate site specific data during the test project that can be used to evaluate the long term impacts of natural gas (including CBM) development on groundwater and surface water resources; and
- Development of a Work Plan for additional and ongoing activities once the test project is initiated.

This document summarizes readily available information used to evaluate potential impacts to groundwater and surface water from the limited testing project proposed by GEC. The conceptual hydrogeologic model for the exploration and testing area based on available information believed to be adequate to estimate potential impacts to groundwater resources. Evaluation of the potential impacts of full-scale development will require significant additional data collection, research, and computer modeling based on the results of the exploration and testing project.

## 1.1 Exploration Plan

GEC has stated that it plans to conduct its operations in the following manner to minimize potential adverse impacts to the environment:

- The drilling locations will be designed by a professional engineer.
- Existing roads will be used where possible to minimize impacts to the land surface, and the "footprint" of each well pad will be as small as possible.
- GEC intends to drill the test wells using compressed air and fresh water mist. If drilling with fluid is required, fresh water will be used, amended as required with standard drilling additives. GEC does not intend to introduce diesel or diesel derivatives into the subsurface in conjunction with the use of drilling muds or

hydraulic fracturing agents. Potentially harmful chemicals used by drilling equipment, such as oils and grease, will be properly stored within secondary containment.

- Surface casing will be installed and cemented through 500 feet to 1,000 feet of the uppermost strata at all locations precluding any direct impacts from the boreholes to shallow groundwater intervals. After the surface casing has been installed, the well will be drilled and casing will be cemented in place to the lowest prospective interval. Pressure testing of the casing and cement bond logs will confirm the integrity of the casing. In addition, a pressure sensor will be installed behind the surface casing to assure the integrity of the well.
- GEC will use plastic lined ponds during the drilling, and that these ponds will be filled and reclaimed consistent with COGCC guidelines as soon as drilling and testing activities are completed.
- A storm water management plan will be prepared and implemented to prevent runoff and sediment from the test well sites from impacting surface waters.

## 1.2 Project Location

GEC proposes drilling up to five exploratory test wells in four areas to evaluate the potential development of natural gas resources at four locations in Delta County, Colorado. The Spaulding Peak #1, Dever Creek #1, Stevens Gulch #1, and Lone Pine #1 are the four primary locations scheduled for completion in 2002. The Keep & Son Cattle Company #1 well located near the Spaulding Peak #1 would be an alternate location for 2002 drilling. The proposed well locations are shown in Figure 1 – General Site Location Map, and on the Cedaredge, Bowie, Dry Creek, Leon Peak, and Gray Reservoir, USGS 7.5-minute series topographic quadrangle maps.

The proposed test well locations are as follows:

- Dever Creek #1 - Section 12, Township 13 South, Range 93 West;
- Spaulding Peak #1 - Section 24, Township 12 South, Range 94 West;

- Stevens Gulch #1 - Section 1, Township 13 South, Range 92 West;
- Lone Pine #1 - Section 25, Township 12 South, Range 91 West; and
- Keep & Son Cattle Company #1 - Section 27, Township 12 South, Range 94 West of the Sixth Principal Meridian.

### 1.3 Drilling and Test Well Completion Information

GEC plans to use compressed air and fresh water mist for drilling the test wells to depths ranging from 2,821 feet to 4,915 feet below ground surface (bgs). All test wells will penetrate the coal seams within the Lower Coal Member (Cameo Coal) of the Mesaverde Formation and reach total depth (TD) in the Mancos Shale.

The testing program will include extensive wireline logging and coring of several intervals. The test wells will be lined with double casing and cemented to the surface in accordance with Colorado Oil and Gas Conservation Commission (COGCC) requirements. The outer casing will be set at depths ranging from 500 feet to 1,000 feet bgs. The inner casing will extend down into the prospective zones. The upper intervals of the test wells will be cased and grouted to the surface prior to the drilling and completion of the prospective zones. After the inner casing is installed and grouted the well casing will be perforated within the prospective intervals at depths ranging from approximately 1,800 feet bgs to 3,200 feet bgs (6,200 feet to 5,400 feet above sea level).

# 2.0 Background Research - Geology and Hydrogeology

The following sections describe the hydrogeology of the project area. For this document, Cordilleran researched available public information on the geology and hydrogeology in the project area, primarily in regard to the Mesaverde Formation. Most information was acquired through the United States Geological Survey (USGS) and the Colorado Department of Natural Resources, Geological Survey Division (CGS) and Division of Minerals and Geology. Cordilleran also obtained summary and detail reports from computer databases maintained by the Office of the State Engineer, Division of Water Resources for permitted water wells in the vicinities of the proposed well locations.

## 2.1 Bedrock Geology

The Grand Mesa is capped with a thick, erosion resistant lava. Approximately ten million years ago, lava flows filled ancient stream valleys. Since the lava rock was resistant to weathering, the soft, older sedimentary rocks that formed the walls of the ancient stream valley eroded away leaving the Grand Mesa exposed as a high elevated plateau. There are no volcanic deposits in the immediate areas of the well locations.

The bedrock geology of the exploration area consists of the upper Cretaceous age Mesaverde Formation and Tertiary age Wasatch Formation (Ellis, Gaskill, and Dunrud, 1987). The lower-most part of the Mesaverde Formation was deposited in a transitional zone of blanket, regressive marginal marine sandstones that intertongue with the Mancos Shale. The Mancos Shale is a regional confining unit that was deposited in a marine environment. The upper part of the Mesaverde Formation was deposited in a river delta and marginal marine environment. The resulting sedimentary sequence consists of 4,600 feet to 6,500 feet of discontinuous sandstone lenses, conglomerate, silty sandstone, siltstone, coal, shale, claystone, and mudstone (Tremain, 1983). Lithology varies vertically and laterally, and intertonguing is common among the various members and strata that make up the Mesaverde aquifer (Robson and Banta, 1995). The Wasatch Formation unconformably overlies the Mesaverde Formation in some of the proposed test well areas. The Wasatch Formation consists of sandstone, siltstone, mudstone, claystone, shale, and localized conglomerate.

## 2.2 Stratigraphy of the Mesaverde Formation

- The Rollins Sandstone Member is named for the Rollins Mine that was located north of the town of Delta. The Rollins Sandstone has been interpreted as being deposited as a river channel and delta sediments in offshore, tidal, and backshore environments (Nowak, 1991). The Rollins Sandstone consists of fine-grained to very fine-grained, tan to light gray, quartz sand in the upper part, locally containing rock fragments or feldspathic intervals, or containing elongate iron concretions, and having a gradational contact with the Mancos Shale. Siliceous or calcareous cement is common between sand grains, but locally, the Rollins Sandstone may be uncemented (Ellis, Gaskill, Dunrud, 1987).
- The Lower Coal Member overlies the Rollins Sandstone. GEC proposes to test the potential for development of methane gas contained within the Lower Coal Member, also known as the Bowie Shale Member in some references (Nowak, 1991). The Bowie Shale Member was named after the former coal mining village of Bowie in Delta County. It is composed of coal, fine-grained sandstone, siltstone, and shale, and contains three coal beds, the A seam (also known as either the Cameo Coal or Old King), the B Seam (also known as the Somerset), and the C Seam (or Bear).
- There are also coal seams in the overlying Upper Coal Member, also referred to as the Paonia Shale Member. In the Somerset coal field the Paonia Shale Member contains two historic economically important coal zones, the “D” or “Oliver” coal bed, and the “F” or Hawksnest coal bed.
- The Barren Member is composed of interbedded sandstone, mudstone, and shale, and uneconomic coal seams (Dunrud, 1989). Sandstone is fine to very fine-grained; beds are lenticular and commonly range from a few feet to about 100 feet thick. The Barren Member separates the deeply buried coal bearing sequences from the Ohio Creek Member that is exposed at the surface in some parts of the area.

- The upper part of the Ohio Creek Member consists of lenticular sandstones, local conglomerates, kaolinite clay, siltstone, and mudstone. The Ohio Creek Member is gradational with the Barren Member at its base (Ellis, Gaskill, Dunrud, 1987).

## 2.3 Hydrostratigraphy

A generalized hydrostratigraphic column that summarizes important hydrogeologic characteristics of the prospective intervals and the underlying and overlying strata is presented as Figure 2.

The Mancos Shale is a regional confining unit that limits the evaluation of potential impacts to overlying aquifers. The overlying Mesaverde Formation is composed of five major members that include, from the oldest to youngest, the Rollins Sandstone member (80 feet to 200 feet thick), the Lower Coal Member or "Bowie Shale" (330 feet to 260 feet thick), the Upper Coal Member or "Paonia Shale" (approximately 180 feet to 270 feet thick), the Barren Member (750 to 1,000 feet thick), and the Ohio Creek Member (approximately 500 feet to 900 feet thick) (Dunrud, 1989)(Brooks, 1983). In some of the proposed test well areas, the Ohio Creek Member is covered by the Tertiary aged, Wasatch Formation, or Quaternary aged alluvial gravels or Quaternary aged colluvium. (Ellis, Gaskill, Dunrud, 1987).

The following hydrostratigraphic details concerning the Mesaverde Formation are the primary basis of the conceptual model for evaluating potential impacts to groundwater resources from the GEC's exploration and testing project.

<u>Rollins Sandstone Member:</u>

Given its position at the base of the upper and lower coal members, the Rollins would be the focus of concern if CBM production proves to be feasible. Matrix porosity test hole data in the West Elk Mine indicate that porosity within each interval (of the Rollins Sandstone) is relatively constant, but that the porosity of the intervals decreases with depth. Porosities range from 0 % to 16 %, and the porosity data indicate that the aquifer matrix is capable of storing appreciable quantities of groundwater (Mayo and Koontz, 2000). Matrix permeability data from samples of the Rollins Sandstone collected in the West Elk mine indicate that “the unfractured rock has very little ability to transmit groundwater. A Darcy is a standard unit of permeability, equivalent to the passage of one cubic centimeter of fluid of one centipose viscosity flowing in one second under a pressure differential of one atmosphere through a porous medium having an area of cross-section of one square centimeter and a length of one centimeter (Jackson, 1997). Several of the cores analyzed are nearly incapable of vertically transmitting groundwater (i.e., permeability $< 10^{-4}$ Darcy), and most samples have a matrix permeability of $< 10^{-3}$ Darcy” (Mayo and Koontz, 2000).

The highest groundwater yields to water supply wells from the Rollins are expected to be most productive closest to the outcrop, both in terms of water quality and accessibility. The outcrop is an area of recharge with potential for infiltration from local overlying clinker zones and/or alluvial cover and interconnection with surface waters. Near the outcrop groundwater resources will be enhanced by natural fractures. The recharge area will be unconfined for some distance downdip from the outcrop. Springs in the Rollins, adjacent intervals, and overlying alluvial deposits may be rejected recharge from shallow circulation systems.

Behind the outcrop on the south side of Grand Mesa, the Rollins Member descends and is progressively buried as it dips to the north into the Piceance Basin. At some distance behind the outcrop groundwater will begin to flow down-dip and an increasing potion of recharge is probably from infiltration from overlying units with the ultimate source of recharge being precipitation on top of the Grand Mesa. At depth, the Rollins Sandstone is expected to be confined, and characterized by higher total dissolved solids (TDS) concentrations (Mayo and Koontz, 2000).

The Lower and Upper Coal Members

Porosity and permeability in the coal bearing sequences are variable with porosities ranging from less than 4% to greater than 12 %, and permeabilities ranging from less than 0.001

Darcy to 0.022 Darcy. Much of the original porosity was reduced by compaction during burial (Pitman et al, 1996). Except for near the outcrop, the presence of methane and other water quality issues would preclude the coal bearing members of the Mesaverde Formation as a viable source of groundwater.

## The Barren Member

The sandstones and mudstones comprising the Barren Member were deposited in a river, or fluvial environment. Porosity in the sandstones ranges from less than 1.0 percent to 11.1 percent. Most porosity is secondary in origin and is the result of carbonate dissolution. Conventional core-measured permeability is from less than 0.001 to 0.01 Darcy and is best developed in sandstones containing abundant open vertical fractures. In areas where the fractures are cemented by carbonate, the carbonate may act as a barrier to fluid flow and greatly reduce permeability (Pitman et al, 1996). The Barren Member is probably the most impermeable interval of the Mesaverde Formation (Brooks, 1983). The Barren Member ranges in thickness from 750 feet to 1,000 feet, commonly thickens westward (Dunrud, 1989).

## The Ohio Creek Member

The Ohio Creek Member is separated from the overlying Wasatch Formation by an unconformity, and in many locations is characterized by a white kaolinite clay rich layer that is about 300 feet thick. Conglomeratic lenses are scattered throughout the upper 375 feet of the Mesaverde Formation (Johnson, 1989). Porosity in the Ohio Creek zone is highly variable and ranges from 0.7 percent to 9.7 percent. Conventionally measured core permeability in the Ohio Creek Member varies from less than 0.0001 to 0.01 Darcy (Pitman et al, 1996). It appears that most of the groundwater supply wells nearest the proposed test wells are completed within the Ohio Creek Member. Deep erosion that is characteristic of the south flank of the Grand Mesa has probably drained water bearing zones in this member where exposed in the sides of deep canyons.

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 nor readily apparent in the project area.

## 2.4 Occurrence of Groundwater

Hydrogeologic studies of the project area indicate that the Mesaverde Formation transmits little water due to the overall low permeability and transmissivity of the formation. Most producible groundwater occurs in three circumstances: 1) within pore spaces in the lenticular sandstones, 2) within the coal beds, and 3) within fractures and faults. Within the sandstone units groundwater occurs primarily in the pore spaces between sand grains. The coal seams and fault and fracture systems may locally yield moderate to large quantities of water. Natural fractures will enhance the permeability of coals to both gas and water (Tremain, 1983).

Wells completed in the Mesaverde Formation within the greater project area generally yield less than 10 gallons of water per minute (Ackerman and Brooks, 1986). Water may be present in fractured sandstones and within burned coal zones, known as "clinker", where these units crop out. The Wasatch Formation is not known to yield water to wells in the project area, however, some wells in the Wasatch in surrounding areas yield as much as 25 gallons per minute (gpm) from sandstone and conglomerate. Wells completed in alluvial aquifers along the stream drainages yield from 2 gpm to 40 gpm (Ackerman and Brooks, 1986). Thicker alluvial deposits yield water to wells in the project area. Groundwater in the alluvium is unconfined and is commonly hydraulically connected with surface water.

Spring discharges from the Mancos Shale, Mesaverde Formation, and Wasatch Formations were measured in 1986. The discharge rates for four springs in the Mancos ranged from 1 gpm to 30 gpm. Discharges from three springs in the fractured Mesaverde Formation ranged from 5 gpm to 25 gpm. Discharges from three springs in the Wasatch Formation ranged from 1 gpm to 20 gpm (Ackerman and Brooks, 1986). Discharges from springs are within the upper, fractured portion of the Mesaverde Formation, and not at the depths associated with natural gas or CBM testing or development.

## 2.5 Recharge, Discharge, and Groundwater Flow

The saturated thickness of the Mesaverde Formation differs in the Paonia and Cedaredge areas due to differences in the topography and geology of these areas. 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 dissected by numerous ravines. Limited infiltration results in limited groundwater recharge and rapid drainage of infiltrated groundwater through the ravines resulting in a large number of natural seeps and springs. Wells completed in the Mesaverde Formation in the Paonia area do not produce sufficient water quantity for any beneficial use (Brooks, 1983).

The slopes in the Cedaredge area are less steep, and the area has sufficient unconsolidated cover to allow more time for water to infiltrate into the Mesaverde Formation. Domestic wells completed in the Mesaverde Formation in the Cedaredge area have been used for many years. Water contained in the upper units of the Mesaverde Formation discharges to surface water at seeps and springs in areas where the water bearing members of the Mesaverde Formation are exposed in ravines or gulches.

## 2.6 Structural Geology

The project area is located on the southern rim of the Piceance Basin, a structural depression in the earth's crust associated with the uplift of the Colorado Rocky Mountains. The Piceance Basin has a highly asymmetrical surface expression and is bound to the northeast by the Grand Hogback Monocline and the White River Plateau, the Douglas Creek Arch to the west, by the Uncompahgre Plateau to the southwest, and by the San Juan Volcanic Field to the south. In the project area the Mesaverde Formation dips 3° to 5° to the north and northeast into the Basin.

Faults have been mapped in the Mesaverde Formation north of Paonia. The extent of faulting and fracturing in the Paonia area is not known; however, many of the stream valleys appear to follow linear fracture zones. Based on drill hole information, mine workings, and outcrop data, subsurface faults at the stratigraphic interval of the Rollins Sandstone Member have been mapped north of Paonia and northeast of Cedaredge (Ellis, Gaskill, Dunrud, 1987). Surficial faults have been mapped in the area around the proposed Lone Pine #1 test well location (Dunrud, 1989). Limited information exists on faulting and fracturing in the Cedaredge area (T. Brooks, 1983). Undiscovered faults and fractures may exist in the project area. Additional research and examination of aerial photographs will be conducted to evaluate this possibility.

## 2.7 Groundwater Quality

The water quality in the Mesaverde Formation is highly variable and commonly contains naturally high concentrations of TDS, metals, and salts. The lower members of the Mesaverde contain methane and petroleum hydrocarbons. Groundwater analytical results indicate elevated concentrations of bicarbonate (Brooks, 1983). Groundwater quality is directly influenced by the lithologies and chemical composition of the Mesaverde Formation, by depth, residence time, and proximity to recharge areas. Groundwater quality generally diminishes with depth as longer residence time results in higher TDS concentrations.

Due to the variable quality and unreliable groundwater resources, water source supply companies provide drinking water for the towns of Cedaredge, Paonia, Redlands Mesa, and Hotchkiss. Terror Creek and springs provide water to the town of Paonia through an aqueduct. The groundwater sources of the water for the creek and springs are of different hydrostratigraphic intervals than the proposed test wells. Cedaredge also receives water from surface waters located to the north and northeast at higher elevations than the proposed test wells. These water supplies are transported to the towns via aqueducts.

Groundwater quality data is available for some wells, springs, and seeps in the Paonia area for sampling activities conducted in the 1980s and more recently associated with coal mines in the area (Brooks, 1983) (Ackerman and Brooks, 1986), (Mayo and Koontz, 2000). Cordilleran is currently sampling surface water, wells, springs, and seeps throughout the project area to significantly expand the available water quality database.

## 3.0 State Engineers Office Water Well Permit Records

Cordilleran obtained summary information on water wells permitted by the Office of the State Engineer, Division of Water Resources. Table 1 summarizes information about water wells nearest to the proposed test well locations, including completion information that allows comparison with the supply wells and the proposed test wells.

Most water supply wells within a 2-mile radius of the project areas have total depths typically ranging from 200 feet to 300 feet bgs. Although the COGCC requires water wells within a ½ mile radius be identified, GEC requested that Cordilleran identify and sample water wells in a 1-mile radius from the test wells; and up to a 5-mile radius if domestic water wells were identified. Some of the water wells were shallow with total depths ranging from 10 feet to less than 100 feet bgs. Static water levels range from 12 feet bgs to more than 100 feet bgs. A specific aquifer was not named for any of the wells; instead, the provided code was for "All Unnamed Aquifers." With additional research and inspection of geologic mapping of the area, it may be possible to correlate well depths with stratigraphic intervals.

Five permitted water wells were identified to the southwest of the proposed GEC Spaulding Peak #1 test well. The closest water well was located approximately ¾ of a mile from the Spaulding Peak location. These water wells had total depths ranging from 157 feet to 328 feet bgs and static water levels ranging from 12 feet to 91 feet bgs. The proposed GEC Spaulding Peak #1 test well would be completed with a total depth of 4,065 feet bgs. The top of the Cameo coals is expected to be at 3,200 feet bgs.

Three permitted water wells were identified in the area of proposed GEC Dever Creek #1, and the nearest well was located more than ¾ of a mile to the east - northeast. All three wells were identified as "monitoring holes". The closest permitted monitoring hole (Permit #29517) had a total depth of 45 feet bgs; however, the well was not located during a search of the area.  The well may be incorrectly located in the well records due to a typographical error. The proposed total depth of the GEC Dever Creek #1 is 3,125 feet bgs.  The top of the Cameo Coals in the Dever Creek #1 is expected to be at 2,250 feet bgs.

Two permitted water wells were identified more than 1-mile to the south of the proposed GEC Stevens Gulch #1 test well location.  The closer of the two wells (Permit #213508) was identified as a domestic water well with a total depth of 270 feet bgs and a static water level of 130 feet bgs.  The other well was identified as a monitoring hole with a total depth of 30 feet bgs.  Seven other monitoring wells were located in sections further south and southwest of the test well.  A spring was identified on the topographic map approximately 1,300 feet to the southeast of the proposed GEC Stevens Gulch #1 site.  The proposed GEC Stevens Gulch #1 test well is expected to be completed with a total depth of 2,821 feet bgs.  The top of the Cameo Coals is expected at 2,053 feet bgs.

No permitted water wells were identified in the adjoining sections adjacent to the proposed GEC Lone Pine #1 test well.  The Lone Pine #1 test well is proposed to be completed at a depth of 3,780 feet bgs.  The top of the Cameo Coals is expected at 2,670 feet bgs in the Lone Pine #1 test well.

The closest permitted water well to the proposed GEC Keep & Son Cattle Co. #1 is a domestic water well located within ½ mile (approximately 1,200 feet) to the northeast of the test well.  The domestic water well (Permit #212743) reportedly was completed at a total depth of 203 feet bgs and has a static water level of 168 feet bgs.  There are three wells located approximately 1 mile south, and six other domestic water wells at lower elevations located more than 1 mile south of the GEC Keep & Son Cattle Co. #1 proposed location.  The water wells had total depths ranging from 133 feet bgs to 315 feet bgs, and static water levels ranging from 15 feet to 189 feet bgs.  Approximately six other water wells were located to the north of the GEC Keep & Son Cattle Co. #1 location at distances of ¾-mile to 1 mile away; however, all of these water wells were at a higher elevation than the proposed coal bed methane well.  The GEC Keep & Son Cattle Co. #1 test well is to be completed at a depth of 3,625 feet bgs.  The expected zone to be fractured is at 2,760 feet bgs and the top of the perforated casing would also be set at this depth.

Cordilleran has prepared conceptualized geologic cross-sections for the Spaulding Peak #1 and the Keep & Son Cattle Company #1 test wells with the existing Leon Lake test well data. These test wells show the relationship between the proposed natural gas wells and the nearest water wells.  These conceptualized geologic cross-sections were prepared with data provided by GEC for the projected tops of formations or individual members.  Additionally, Cordilleran used information from the Colorado State Engineers Office.  The COGCC recommends identifying all water wells within ½ mile radius of a proposed natural gas well site, prior to drilling.  Cordilleran identified only one well within the ½ mile radius of the Keep & Son well, and Cordilleran has made an effort to identify domestic water wells up to 5 miles from the proposed test wells.  The conceptualized geologic cross-sections are presented as Figure 3 and Figure 4.  A map showing the lines of these cross-sections is presented as Figure 5.

## Potential Impacts to Surface Water and Groundwater

Potential impacts to surface water and groundwater resources during proposed testing would be from drilling operations and changes in aquifer pressures as groundwater is withdrawn from the prospect coal interval to test the potential for development. In some cases potential impacts are mitigated by natural circumstances. In other cases, potential impacts will be addressed through appropriate operational procedures.

### 4.1 Potential Impacts to Surface Water

The following issues will be addressed by GEC to prevent impacts to surface waters:

- Increased sediment load from road and drilling location construction;
  - GEC plans to use existing roads and utilize best management practices to minimize the footprint of the drilling locations.
  - A storm water management plan for the project will be prepared and implemented.
- Drilling fluid, amendments, and produced water;
  - GEC plans to drill with air and fresh water mist. If drilling with fluid is required fresh water will be used, amended as required with standard drilling additives. If drilling additives are required they will be properly managed.
  - All drilling fluid will be contained and recirculated during drilling operations and subsequently stored in plastic lined and fenced production pits. These materials will either be evaporated or hauled offsite to a licensed disposal facility.
  - All produced water will be appropriately treated and/or disposed. No water will be discharged unless it meets applicable surface water/air quality standards. This will necessitate the collection and analysis of samples of the produced water.

## 4.2 Potential for Impacts to Groundwater

The following issues will be addressed by GEC to prevent impacts to groundwater:

- Infiltration of drilling fluid or hydraulic fracturing solutions into permeable formations during drilling;
  - GEC plans to drill with air and fresh water mist. Pressure distributions in this situation are called under-balanced, meaning that the hydrostatic pressure in the strata adjacent to the borehole will be higher than the pressure in the borehole, precluding infiltration into the formation. If drilling with fluid is required fresh water will be used, amended as required with standard drilling additives. When drilling with fluid, pressure is commonly higher in the borehole than within the adjacent formation. Drilling fluid additives are designed to stabilize the borehole in part by minimizing infiltration into the adjacent formation. Significant losses of drilling fluid into the formation will occur only under lost circulation drilling conditions. In these cases drilling additives are specifically designed to plug the open zones and prevent the loss of drilling fluid. If drilling fluid additives are required they will be managed appropriately.
  - Hydraulic fracturing will only be used after careful evaluation of the well data and will be restricted to the target coal intervals. Only fresh water based hydraulic fracturing agents will be used. According to an article dated September 18, 2001, in the Bureau of National Affairs' Daily Environment, The United States Environmental Protection Agency (USEPA) conducted an assessment of coal bed methane fracturing with the final report to be issued soon. The information collected by individual states reportedly found little evidence of contamination of underground drinking water supplies resulting from hydraulic fracturing of coal beds. Hydraulic fracturing is a process in which mixtures of water and sand are forced underground at high pressures to break up coal beds and stimulate the release of natural gas. Environmentalists contend that the fluids used during hydraulic fracturing contaminates underground drinking water supplies and that such operations should be classified as Class Two underground injection wells. The Groundwater Protection Council conducted a 1998 survey that revealed no incidents of groundwater contamination from hydraulic

fracturing. The Groundwater Protection Council is a national association that includes federal and state regulators who oversee oil and gas wells, underground injection wells, and drinking water. In 1997, the Groundwater Protection Council filed a friend-of-the-court brief, arguing that hydraulic fracturing should not be regulated as part of the underground injection program (M. Ferullo, 2001).

  - Drilling and completion of the test wells are expected to be of short duration (13 – 17 days), and all proposed test wells are remote from any existing water wells. No environmental impacts are expected from infiltration of drilling or hydraulic fracturing fluid during the proposed exploration and testing project.

- Recharge of shallow aquifers by fugitive drilling fluid or produced water from testing.
  - Any drilling fluid will be contained and recirculated during drilling operations and subsequently stored in plastic lined production pits pending appropriate disposal.
  - All produced water will be treated or appropriately disposed. No water will be discharged unless it meets applicable surface water quality standards.
- Leakage of produced water from the well casing;
  - GEC planned well completion methods will preclude any leakage from the well casing.
- Interconnection of separate saturated zones caused by fracturing of the coal.
  - Excursions of energy from fracturing operations should only be of concern in areas that are naturally fractured and/or faulted. In these cases hydraulic fracturing is usually not necessary and difficult to implement due to the loss of fluids through the natural fracture network.
- Interconnection of separate saturated zones caused by changes in aquifer pressure may be induced by pump testing during evaluation of economic CBM production.
  - The prospective coal interval must be confined to the extent that the hydraulic pressure in the coal can be reduced to the point that CBM can be produced. If the coal is unconfined and well connected to other saturated zones it is unlikely that CBM production could be economically achieved. If the coal is confined, any pressure

changes in adjacent saturated intervals as the hydraulic system re-equilibrates would be buffered by the low permeability conditions that confine the coal. Propagation of the induced pressure difference to more distant saturated intervals would be spread over increasingly long time intervals. Re-equilibration of hydrostatic pressures across unsaturated intervals would be locally precluded dependent on the lateral extent of the unsaturated interval. To the extent that strata enveloping the coals are interconnected, pressure changes would be distributed over a larger volume, minimizing the impact on any specific interval. Based on the expected short duration of the proposed CBM testing project, induced interconnection of different saturated intervals is not anticipated, and recharge might obscure any water level declines in the enveloping strata that would result from the testing.

- Release of methane to wells and springs from reduced pressure in the coal intervals.
  - Permeability to gas in the Mesaverde is generally low (< 0.1 millidarcy) because the sandstones have complex pore geometries resulting from extensive authigenic clay mineral formation in secondary pores (Pitman et.al, 1996). Except along fault and fracture zones, permeability will be much lower vertically (transverse to layering) than parallel to layering.
  - Existing wells and springs are remote and stratigraphically separated from the proposed test wells by fine-grained, strata with low permeability. Outcrops of the coal zones are several miles to the south of the proposed well locations.
  - It is unlikely that any significant excursions of methane would occur over the short time period of the proposed exploration and testing project. Aquifer pressures should quickly equilibrate after testing is complete. The potential of CBM excursions related to full-scale production may need to be evaluated by computer modeling.

### 4.3 Potential for Impacts to Groundwater – Water Levels

The most observable effect of testing and development would probably be seen in a decline in aquifer pressures (water levels) primarily in the coal from which water is being withdrawn and to a progressively declining extent in saturated intervals farther from the area of maximum drawdown in the coal.

The prospect coal interval must be confined to the extent that the hydraulic pressure in the coal can be reduced to the point that CBM can be produced. If the coal is unconfined and well connected to other saturated zones it is unlikely that CBM production could be economically achieved. If the coal is confined, any pressure changes in adjacent saturated intervals as the hydraulic system re-equilibrates would be buffered by the low permeability conditions that confine the coal. Propagation of the induced pressure difference to more distant saturated intervals would be spread over increasingly long time intervals. Re-equilibration of hydrostatic pressures across unsaturated intervals would be locally precluded dependent on the lateral extent of the unsaturated interval. To the extent that strata enveloping the coals are interconnected, pressure changes would be distributed over a larger volume, minimizing the impact on any specific interval. Based on the expected short duration of the proposed testing project, induced interconnection of different saturated intervals is not anticipated, and recharge might conceal any water level declines in the enveloping strata that would result from testing.

Based on the expected short duration of the proposed testing project, observable declines of hydrostatic pressure in saturated zones other than the prospect coal are not expected. The hydrogeologic characteristics of the Mesaverde Formation should mitigate any observable water level declines during the planned test project. Prediction of water level declines during production would require computer modeling based on the results of the proposed testing project.

# 5.0 Conclusions

Based on GEC's exploration and testing plans and the information obtained from public sources, the proposed testing of natural gas and coal bed methane resources in the Mesaverde Formation in Delta County, Colorado is not expected to adversely impact surface water or groundwater resources for the following reasons.

- The GEC test wells will be completed and constructed in accordance with current COGCC regulations and current industry standards to preclude impacts to surface water and direct impacts from drilling or the completed wells to the adjacent aquifers. The test wells are remote from each other precluding any cumulative effect from simultaneous testing.
- The wells will be completed and tested within a short time period.
- The test wells will not be located in areas that are obviously faulted and fractured.
- If economic natural gas resources, other than CBM, are identified within sandstone units within the Mesaverde Formation, GEC will ensure the proper completion of the gas well and will follow all applicable COGCC guidelines for completing a natural gas well.
- For a positive CBM test result, the prospect coal interval must be confined to the extent that the hydraulic pressure in the coal can be reduced to the point that CBM can be produced. If the coal is not confined and pressure cannot be reduced the test would be terminated. If the coal is confined and hydraulic pressure can be successfully reduced, it is axiomatic that the CBM test interval is not well interconnected with adjacent aquifers.
- The fine-grained sandstone, siltstone, and claystone strata, characteristic of the Mesaverde Formation, transmit little water to wells and springs due to low permeabilities and low transmissivities.
- In the areas of the proposed test wells, most seeps and springs occur at the contact between bedrock and alluvial deposits on the mesa rather than at bedrock outcrops.

Within the test areas, upper strata of the Mesaverde Formation may be essentially drained adjacent to the deep canyons that are eroded into the Grand Mesa.

- Groundwater for potable use is currently produced primarily from wells completed in shallow, discontinuous lenses of sandstone.
- The total depths of the water supply wells are typically less than 350 feet bgs while the proposed total depths of the test wells range 2,800 feet to 4,000 feet. The lithologies of the Mesaverde Formation between the coal beds and the water bearing units are very fine-grained and of low permeability.
- The nearest a known water supply well to any of the coal bed methane test wells is 1,300 feet. However, most locations are typically more than 1-mile away.
- 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 in the project area is not apparent.
- The Groundwater Protection Council, a national association of federal and state regulators and professionals, conducted a 1998 survey that revealed no incidents of groundwater contamination from hydraulic fracturing associated with coal bed methane operations. The results indicate that there is little evidence that adverse impacts to drinking water resources have occurred due to coal bed methane exploration and production activities; and

In, addition, the coal zones that GEC plans to test for CBM potential have been mined for over 100 years. There are numerous abandoned and active coal mines in the region. Although dewatering is and continues to be a common component of coal mining, groundwater resources do not appear to have been adversely impacted. Based on this observation, shallow groundwater resources do not appear to be interconnected with the coal bearing members of the Mesaverde Formation.

Cordilleran is currently sampling surface water and groundwater from project area water supply wells, seeps, and springs that will be combined with other available information in a preliminary, representative baseline hydrogeologic and hydrochemical database. Concurrently, Cordilleran is continuing to compile and review existing relevant research and other available data in order to prepare a work plan to conduct a subsurface investigation. The subsurface investigation work plan will be implemented in conjunction with the drilling of the proposed test wells. Site specific data will be combined withal available research information to compile a conceptual model of the site to guide environmental assessment, including computer modeling of potential long term impacts resulting from natural gas and CBM production.

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