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Crestone CDP and Risks to Water Resources

1. **Qualifications to comment on groundwater and surface water impacts related to oil and gas development**

My qualifications for reviewing the Crestone comprehensive development plan (CDP) stem from my work with USGS and USEPA. While at USGS I was charged with collecting groundwater and surface water samples for various investigations related to ambient water quality. In addition, I was also collecting field data such as surface water stream flow, temperature, pH and conductivity. I also collected groundwater field data such as depth to water, as well as groundwater quality information. I was also responsible for designing and implementing aquifer pump tests to collect information related to determining aquifer characteristics, such as transmissivity and hydraulic conductivity.

With USEPA I have written permits for Class II produced water disposal wells and enhanced recovery wells used in oil and gas production. Additional duties encompassed groundwater and surface water cleanup activities at military base closure sites and at private NPL sites. Primarily this work focused on designing remedial investigations that included collecting groundwater and surface water information to be used for feasibility studies and risk assessments. I also conducted NEPA reviews of proposed oil and gas projects. My last 10 years at EPA focused on groundwater impacts related to oil and gas developments in Colorado and Wyoming including managing two national study sites related to **EPA's Study of Hydraulic Fracturing for Oil and Gas and Its Potential Impact on Drinking Water Resources.** I conducted work on this project as a staff member with the Office of Research and Development working on field data collection projects and as a contributing author and editor for the national study document. My tenure ended at EPA Region 8 as the Advisor on Water Issues related to oil and gas development.

Materials relied on

- GEOLOGIC MAP OF THE BOULDER—FORT COLLINS—GREELEY AREA, COLORADO By Roger B. Colton
- COGCC Data Viewer/DataBase https://cogcc.state.co.us/data.html
- COGCC Interactive Map https://cogcc.state.co.us/maps.html - /gisonline
- GROUND WATER ATLAS of the UNITED STATES Arizona, Colorado, New Mexico, Utah HA 730-C DENVER BASIN AQUIFER SYSTEM
- State of the Watershed: Water Quality of Boulder Creek, Colorado by Sheila F. Murphy
- Hydrologic Assessment of a Riparian Section Along Boulder Creek Near Boulder Colorado, Water Resources Investigations Report 94-4111
- Upper Pierre Aquifer Water Quality Study, COGCC Project Number 2141
- Quality of Groundwater in the Denver Basin Aquifer System, Colorado, 2003–5 Scientific Investigations Report 2014–5051 U.S. Geological Survey
- **The Pawnee Aquifer, Denver-Julesburg Basin, Northeastern Colorado,** Theresa Jehn-Dellaport and Tammi Renninger, The Mountain Geologist, Rocky Mountain Association of Geologists
- FracFocus – Online database http://fracfocus.org

2. Potential impacts to groundwater and wells

Groundwater Resources Located in Eastern Boulder County

General geology/hydrogeology of the area

The major bedrock aquifer system within the Denver Basin is part of the upper Cretaceous sediments known as the Denver Basin Aquifer System. This system covers approximately 7,000 square miles and extends from Greeley to just north of Colorado Springs and from the east flank of the Front Range eastward to Limon, Colorado. The aquifer system includes Cretaceous and Paleocene/Eocene (Tertiary) age sandstone, conglomerate and some shale. The upper formations of the aquifer system include the Dawson arkose, Denver, Arapahoe and Laramie. In the vicinity of Crestone's proposed well pads, those upper formations are absent due to the location on the western margin of the basin.

Fox Hills Sandstone

As a result of the location on the western boundary of the geologic basin, the primary formation of the Denver Aquifer System is the Fox Hills Sandstone. In most areas in eastern Boulder County and in the CDP well pad area, the Fox Hills Sandstone is covered with a thin veneer of quaternary wind blown and alluvial deposits. Below the Fox Hills Sandstone is 6,000 feet of Cretaceous Pierre Shale. It is important to note that this shale provides a natural barrier between the Denver Basin Aquifer and the lower formations, which are the production formations, including the Niobrara and other even deeper formations that have historically produced for oil and gas. It should be noted also that in the CDP application area that the Fox Hills Sandstone is very near the surface in upland areas and is in contact with the alluvial deposits, which are located along the floodplain of South Boulder Creek. In addition, geologic maps depict outcrops of Fox Hills Sandstone in the CDP area.

As a result of the thin deposits in upland areas, and the direct contact with South Boulder Creek saturated alluvium and outcrop locations, it is likely that this area is a recharge area for the Fox Hills Sandstone and ultimately contributes to recharge for the Denver Basin Aquifer System. These recharge areas are also unconfined. The only recognized confining unit within the Denver Basin Aquifer System is located in the upper portion of the Laramie Formation – a formation which does not exist in the Crestone CDP area. The thickness of the Fox Hills Sandstone ranges from 0-300 feet. The Fox Hills aquifer matrix is made up of sandstone and siltstones and in some areas thin layers of shale exist. Transmissivity for the Laramie Fox Hills aquifer in the northwest margin of the basin can be expected to be about 5 feet squared per day; in the southern area of the Basin it reaches 600 feet squared per day. Water quality in the Laramie Fox Hills aquifer ranges from 200 to 2,000 mg/l TDS.

Pierre Shale

The Pierre shale, located below the Fox Hills Sandstone, provides a natural barrier for protecting the overlying Fox Hills Sandstone. However, it should be recognized that the upper portion of the Pierre shale is a known transition zone that may include some sandy zones. COGCC has also recognized that a sandstone aquifer exists in the upper portion of the Pierre shale. The aquifer is referred to as the Upper Pierre Aquifer or the Pawnee aquifer. In a recent Rocky Mountain Association of Geologist report, the aquifer thickness is up to 1000 feet thick and is separated from the lower Fox Hills aquifer by a laterally extensive 125-250 foot shale zone.

Boulder Creek Alluvial deposits

The saturated alluvium next to South Boulder Creek is expected to be similar to other riverine systems found along the Front Range. For the most part during spring snow melt, the alluvial sediments will be recharged and the river will be determined to be losing flow to the alluvium. Later in the summer and particularly during fall and winter months, the flow in these streams will be groundwater dependent. Water flow within the alluvium trends in the same direction as flow in the Boulder Creek channel. As one moves farther away from the channel, groundwater movement is less influenced by flow in Boulder Creek. However, water levels in most wells in the USGS WRI Report 94-4111 responded to stream stage height. One anomaly to high flow during snow melt (May-June) was spikes in flow observed to be the result of periodic ice damning during winter months

created by high flow releases upstream to generate power. The thickness of the alluvium in the study area averaged 5 feet.

3. Sources of impacts to water

COGCC database records list twenty-one spill reports submitted over the past five years in Boulder County. Four spills were from flowline leaks, sixteen from tank batteries and one was unknown. Currently there are 266 producing wells and 158 plugged and abandoned wells in Boulder County. In addition, there are 37 shut in wells for a total of 461 wells. Hydrocarbon production in Boulder County in 2017 totaled 91,000 barrels of oil, 1.5 million MCF of gas, and 28,000 barrels of produced water. Boulder County does not have any produced water injection facilities. The Crestone CDP proposes 140 new wells located on 3 pad sites in eastern Boulder County, a more than 50% increase in the number of currently producing wells in Boulder County.

Twenty-one spills over five years at 461 well sites results in 5% of all production sites having a spill within every five years. Increasing the number of wells will increase the number of spills that occur in Boulder County. Increasing the total number of wells by 30% in Boulder County could potentially increase the number of spills by 30%.

Spills from pipelines

Examples of pipeline spills exist in Boulder County. There were 4 pipeline/flowline spills reported during the last 5 years. One reported spill at the well site THRONDSON-61N69W 2SWSW (API# 013-06353) indicated a leak in a flowline that was discovered by a Boulder County inspection using infrared photography. Although it was not revealed how the volume of fluid was determined, the estimation was set between 0 and 1 barrel (42gal). Groundwater was encountered during the excavation; however, there are no records in the remediation file indicating that groundwater was sampled nor were there sampling results for the soil.

Spills from tank storage

Examples of spills from tank storage also exist within Boulder County. One example - Remediation Project #11218 located at the Dawson 2-10 (API# 05-013-06087) well site - is within the floodplain of Boulder Creek less than 300 feet from the stream channel. Groundwater was determined to be 7 feet below ground surface. The amount of fluid loss from the storage structure was listed as unknown. No information about the results of a remedial investigation are available. It appears that there were no soil samples or groundwater samples collected to determine the extent of this spill. The site is listed as resolved in reference to remediation. A map of the location of the site is located in Appendix 3.

Spills from trucking

Examples of spills of product or produced water are difficult to determine as a spill website does not exist for these records.

Leakage Due to Defective Well Casing/Cement

Leakage from wells through casing and cement can occur a number of ways. It should be recognized that the well needs to be designed and constructed in such a manner as to prevent migration of fluids between zones of different water quality and subsurface pressure. If constructed properly there is still a chance that channeling in cement and losses can affect the ability of the well construction to protect groundwater. Designing and constructing a well to protect groundwater resources requires an understanding of shallow groundwater quality, shallow geology (above the production zones) and how groundwater moves within the subsurface that is in contact with the drill hole prior to installing casing and cement and ultimately after the well has been constructed. It should also be recognized that there is very little direct groundwater monitoring within the vicinity of the well bore prior to, during and after the well is constructed. Direct monitoring would include monitoring water quality and water levels at various depths to determine if the

hydrocarbon well has impacted water quality or movement of groundwater or fluids between subsurface zones.

The design and construction of an oil or gas well that is protective of groundwater resources is very dependent on local conditions. In some locations there are natural geologic barriers that prevent migration of fluids from production zones to zones with useable groundwater resources. In the vicinity of the proposed pad locations of the Crestone CDP the deepest aquifer that is used would be the Fox Hills Sandstone mentioned above. This aquifer is just below the Quaternary surface deposits and resides on top of the Pierre Shale and deserves protection from migrating fluids moving to shallow zones from the production zone. The Pierre shale below the Pierre aquifer (or Pawnee aquifer) can be up to 6,000 feet thick and provides a natural barrier to migration of fluids from deeper hydrocarbon bearing zones. However, when constructing a well that penetrates this protective barrier, if casing and cement placement are not done correctly, the well can provide a migration pathway for fluids (liquid and gas) from deeper zones to enter shallower zones. Current producing, shut-in and plugged and abandoned oil and gas wells in Boulder County penetrate the Pierre shale in order to produce oil and gas from hydrocarbon bearing zones below the Pierre shale. In addition, the wells proposed by the Crestone CDP would also completely penetrate the Pierre shale.

The Pierre shale is a very good natural hydro-geologic barrier and wells that penetrate this barrier, if constructed properly, can maintain the integrity of the barrier characteristics. However, certain design and construction items need to be incorporated into the construction and tested to determine whether these protection goals have been sufficiently addressed. Two very important well design goals for groundwater protection is providing adequate casing and cement across the all aquifers that are drilled through and sufficient integrity of cement and casing at the casing shoe within the Pierre shale that will withstand high pressures. In some cases this can be established through surface casing and cement. At the Crestone proposed locations, the top of the Fox Hills aquifer is just below the surface and is at most 300 feet thick, while just below the Fox Hills aquifer is a shale unit in the upper Pierre shale up to 250 feet thick and below that is the Pierre aquifer that can be up to 1000 feet thick. The total thickness of this aquifer sequence that requires protection is approximately 1,500 feet below the ground surface. The use of surface casing should be more than adequate for groundwater protection and to provide safety while drilling deeper production casing strings. If drilling requires setting shallower surface casing for blowout prevention, then an intermediate casing must be set below the bottom of the Pierre aquifer at approximately 1500 feet or deeper. The remaining question then is how well is the surface or intermediate casing anchored into the upper Pierre shale. This can be determined by requiring a formation integrity test and reporting the results prior to allowing any deeper drilling. It is necessary for the formation integrity test to test for pressures that are expected during the drilling of the hole for production casing.

As mentioned earlier, the upper part of the Pierre shale contains the Pierre aquifer which will require a determination during the drilling of the surface casing hole of how deep the surface casing (or intermediate casing) shoe should be placed in order to provide adequate groundwater protection during the drilling of the production casing hole. As wells in the Crestone CPD are located essentially in 3 locations, adequate surface casing depth information should be developed during the first well drills at each location in order to ensure setting the surface casing shoe deep enough to avoid any sandy zones in the upper Pierre shale.

Over 450 oil and gas wells have already been drilled in Boulder County. There are a number of important questions that should be addressed concerning these existing wells. First, what were the design and construction requirements for these wells and were adequate tests performed to determine if groundwater protection goals were met. Second, for the existing wells, is there adequate casing and cement in zones that the new wells will be producing from to prevent fluid movement into zones above the Pierre shale. Both of these questions require that the well records be robust enough to provide that information. It is not enough to just recite the requirement to protect groundwater with surface casing and cement without the actual drilling and construction records providing information that assists in determining that that goal was achieved. The COGCC Rule 317 language concerning groundwater protection in the Denver Basin specifically

addresses specific requirements by setting surface casing depth requirements. If there is no documentation to determine if protection measures such as sufficient surface casing depth or cement quantity and quality for the Fox Hills aquifer have been achieved then statements by the operator or COGCC regarding groundwater protection cannot be substantiated.

Answering the first question requires a review of the existing well drilling/construction records to determine if COGCC Conditions of Approval (COAs) sufficiently required surface casing, cement and formation tests for each well to specifically protect groundwater. Not all well files will provide this information. Without this information in the well file additional testing such as running a cement bond log and remedial cementing of the production casing would be a minimum requirement. For example, a well file may provide the depth of surface casing and the volume of cement that was set but does not include information related to the formation integrity test (if required) and the depth to the top of the Pierre shale. Lacking this information makes it impossible to determine if the Fox Hills and more recently identified Upper Pierre aquifers have been adequately protected. One very problematic issue related to existing well construction requirements relates to the aquifer located in the upper portion of the Pawnee or Upper Pierre shale that has been discussed above. Since this is recently published information, COGGC and operators may not have considered this groundwater resource when designing groundwater protection measures for existing wells. And Rule 317 still does not require protection of the Pawnee or Upper Pierre shale aquifer. In many cases prior to understanding the existence of the Pierre aquifer, surface casing would not be required to extend to depths beyond the Fox Hills aquifer at the bottom of the Denver Basin aquifer system which was described earlier and did not recognize the Pierre aquifer. This can lead to inadequate protection of this aquifer under current conditions but could be in further jeopardy if the Niobrara shale is target of the Crestone CDP wells.

For example records for State 5 (API# 123-08185) well just east of the Boulder County line, which was plugged and abandoned in 1993, are rudimentary. A cement bond log was not in the file for either surface casing or production casing making it difficult to establish if cement quality prevented fluid migration among zones of different water quality. There is no information on the bottom location of the Fox Hills aquifer making it impossible to determine if the surface casing was deep enough to protect aquifers of the Denver Basin aquifer system. In addition, the approval of a plugging and abandonment plan without this information is basically a “shot in the dark” as to whether the plugging and abandonment cement placement prevents fluid movement between zones or into the Denver Basin Aquifer system. For wells in eastern Boulder County, it appears that in most cases surface casing may be set deep enough to protect the Fox Hills aquifer; however, since recent information regarding the Pawnee/Upper Pierre shale aquifer has been established, it is very likely that surface casing has not be set deep enough to protect this resource.

Leakage Due to Defective Pit Liners

CDP indicates that no pits will be used at no time during drilling, hydraulic fracturing, and production stages of development.

Types of Fluids

Drilling Fluids

The significant type of drilling fluid that will be used at these sites are “oil based muds” or OBM. As the name implies, Crestone intends to be using hydrocarbon-based fluids for various reasons during the drilling processes. However, it should be noted that only freshwater drilling fluids should be used when drilling the surface casing in order to protect groundwater resources. Although this is a standard practice, unfortunately the Crestone CDP does not mention specific items including depths or types of drilling fluids related to drilling surface casing.

It was however mentioned that no drilling fluid pits either for cuttings or for storing circulated fluid or for reserve fluids with be used on site. Therefore, Crestone must intend to use closed loop drilling and tanks.

Hydraulic Fracturing Fluids (including flowback fluids)

The Crestone CDP states that water and sand will be used for hydraulic fracturing fluid. This statement is misleading on many fronts. It leads one to believe that the fluids used during fracturing will only be water and sand, when in fact, this is not in anyway representative of the fluids currently being used by industry and by Crestone for Niobrara production wells located in Weld County. A review of Crestone wells on the FracFocus website reveals additional chemicals are being used during the hydraulic fracturing process. One example of a frac job completed as recently as June 5, 2018 is provided below. In addition to water and sand, FracFocus lists these categories of chemicals used recently by Crestone in Weld County:

- Friction Reducers
- Solvents
- Biocides
- Corrosion Inhibitors
- Nonionic Non-emulsifier

Friction reducers include petroleum distillates, which are primarily a mixture of hydrocarbon referred to usually as kerosene. Solvents in this case are water and hydrochloric acid. Biocides are used to reduce slim build up in the casing and formation being fractured. As the name implies, biocides are extremely toxic to the aquatic environment. And under corrosion inhibitors are listed a number of chemicals including one proprietary chemical listed as ethoxylated alcohol.

Production Fluids

Hydrocarbons in the form of gas and oil are produced from the well, in addition to condensate. Condensate can be separated out of the fluids at the well head and diverted to tanks or pipelined to off-site facilities. The Crestone CDP proposes to use pipelines to offsite facilities for the oil and gas.

Produced water is also proposed to be moved by pipeline to offsite facilities. The composition of chemical compounds dissolved in produced fluids is unknown at this time but examination of analytical data from other producing wells nearby would remove questions regarding the chemical constituents found in produced water.

Summary of potential spills or leakage

Spills related to pipeline accidents have been documented in Boulder County (21 in five years). Weld County with many more wells has experienced 1,788 spills, primarily from tank batteries and flowlines or pipelines. Trucking accidents resulting in spills are not tracked or recorded by COGCC and online searches did not provide information that would be helpful resolving this information.

Leakage from wells is also not easily recorded as it is assumed that unless some visual evidence is noted, then there is no leakage. There are monitoring tests that help assess the potential for leakage either between casing strings or from inside casing to the formations surrounding casing. Tests such as bradenhead, acoustic logs, or mechanical integrity tests can be performed during the production phase to determine the integrity of the well's casing and cement. As mentioned earlier, formation integrity tests can be performed after the surface casing and cement have been installed in the well. This test needs to be performed prior to drilling the production hole and therefore cannot be monitored during the production phase.

The important tests related to well integrity regarding protection of groundwater resources are: the surface casing formation integrity test and an acoustic log to determine the effectiveness of the cement seal around the surface casing.

4. Potential surface water impacts from oil and gas impacts

From the information above in Section 3, spills from oil and gas production facilities have occurred in Boulder County. Placing a pad and/or the pipelines for 56 wells into floodplain/riparian zones increases the risk for impacts to surface water resources. As noted above, some of the fluids, such as biocides, used for hydraulic fracturing pose a serious risk to aquatic life if released into surface water resources such as Boulder Creek. Other fluids including solvents like hydrochloric acid – which can also be a hydraulic fracturing chemical - can affect the pH of aquatic environments. There is also simply the large volume of oil that will be produced from 56 wells located on DSU#1 that will flow from the site through 1 or more pipelines. Even a short-lived spill or leak from a pipeline(s) with this much product flow would have large negative impacts on Boulder Creek.

The Crestone CDP follows the general format of COGCC's Form 2A. However, information related to water resources is not included. For example the following general or approximate information is not included in the CDP:

Is the area potentially a "sensitive area" defined under rule 901.e.?
What is the approximate distance to surface water from disturbed surface areas?
What are depths to groundwater?
What is the distance to any nearby water wells?
Are any of the locations within a Rule 317B Surface Water Supply Area buffer zone?

As the approval of the Crestone CDP may replace the need for completion of Form 2A and there is no specific language in the CDP stating if this is the intention, then the CDP should be at least as thorough as Form 2A. As stated by COGCC, "Elimination of site-specific permitting requirements. In certain circumstances, an approved CDP will eliminate the need to obtain approval for individual oil and gas locations covered by the Plan. Where the CDP contains information and undergoes procedures substantially equivalent to that which would be required for an individual Form 2A, then a Form 2A will not be required for a location covered by the CDP. Where the CDP does not contain information or undergo procedures substantially equivalent to that needed for a Form 2A, or where the operator seeks a variance from the CDP or a rule not addressed in the Plan, then a Form 2A will be required for a new oil and gas location covered by the Plan. However, in such instances the informational and procedural requirements for a Form 2A will be modified to take into account information included in and procedures used to approve the CDP."

In addition, under Section 11 of the Crestone CDP, the only mitigation or best management practice related to surface water resources was a commitment to minimize flood impacts with nothing specifically mentioned. It would be expected that specific activities related to mitigating surface water impacts to Boulder Creek would be spelled out in detail.

5. Potential impacts to aquifers

The aquifers of the Denver Basin Aquifer system and the Pawnee or Upper Pierre Aquifer meet COGCC's definition of "known or reasonably estimated utilizable domestic fresh water". Reference below is to COGCC's Rule 317A that sets specific requirements for drilling and setting surface casing in the Denver Basin for the purpose of safety and aquifer protection. The recently implemented rule would apply to all wells in the Denver Basin. The first part responds to the need for safe drilling operations. The second part attempts to provide protection of freshwater zones within the Denver Basin. The Crestone CDP area is not included in the specifically listed township and range sections requiring all wells to be surface cased through the Fox Hills aquifer and set the casing depth to 50ft below the bottom of the aquifer 50 feet into the Pierre shale. Conversely, all wells outside the specifically listed areas are only required to set surface casing to a depth below the deepest aquifer that a nearby well (less than one mile) is screened into.

In the area of the Crestone CDP that would more than likely mean setting surface casing through the Fox Hills aquifer and 50 feet into the top of the Pierre shale formation. Rule 317 only recognizes areas of the Fox Hills aquifer currently used as sources, as needing protection. Since groundwater moves according to regional flow directions, the rule relies on dilution and degradation of fluids which leak into the aquifer from uncemented sections well casing prior to reaching a nearby water well or in cases where new water wells are permitted and drilled within 1 mile of the production well.

This specific approach under Rule 317, while better than the 'rule of thumb' used in other locations in Colorado, still falls short on two accounts. First, this specific rule only recognizes currently used sources of groundwater as needing protection. In the face of a rapidly rising Front Range population, this limited protection seems to be extremely short sighted. COGCC should evaluate the Crestone CDP against a best management practice of protecting the entire Denver Basin aquifer system. Secondly, recent publication of a study in the Mountain Geologist, and recognition in an additional report authored by COGCC, of the Pawnee or Upper Pierre shale aquifer demonstrates a good quality aquifer of sufficient quantity to also be a valuable resource. This aquifer also meets the definition of "known or reasonably estimated utilizable domestic fresh water" according to COGCC requirements. Therefore, for the Crestone CDP, and for the entire extent of the Pawnee aquifer, all surface casing should extend though the Pawnee/Upper Pierre Shale aquifer and at least 50 feet into the underlying Pierre shale. The Mountain Geologist report provides adequate methods to identify the contact zone at the bottom of the Pawnee aquifer and the extensive Pierre shale below.

The suggestion above for setting surface casing depths below the Pawnee aquifer is precisely the type of mitigation measure that should be discussed and implemented under the Crestone CDP in order to protect currently used and future use of groundwater in eastern Boulder County.

6. Approval of the Crestone CDP would not be consistent with protection of the water, the environment, and fish and wildlife.

First, as the Crestone CDP currently is written, one significant surface water resource issue that needs to be addressed prior to approval of the CDP is the potential for large volumes of hydrocarbons and/or production fluids to reach Boulder Creek in a very short amount of time. Other than moving DSU#1 out of the riparian/floodplain, there really is no other feasible mitigation that would prevent a potential disaster that could occur, for example, due to a pipeline break next to Boulder Creek. Additionaly, biocides trucked in, stored and used during the hydraulic fracturing process within a few hundred feet of water resources found at DSU#1 and DSU#2 is not recommended.

Second, requiring adequate surface casing depths along with good quality cement placement are critical to protecting aquifers. The Crestone CDP, as written, does not address groundwater resources that are known to exist in the area. The may be an unstated reliance in the CDP on Rule 317 as a protective measure; however, as discussed above, Rule 317 falls short of adequate aquifer protection due to not anticipating future use for domestic, municipal and agricultural purposes. The Crestone CDP and Rule 317 do not recognize the Pawnee aquifer as a substantial groundwater resource, and therefore no surface casing requirements for protecting this aquifer have been anticipated and stated in the CDP.