SBS LLC

Review of Phase II Hydrogeologic Study

Prepared for Garfield County

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Evaluation of Phase II Hydrogeologic Study for Garfield County

Executive Summary

This report reviews and integrates the results of the Garfield County Phase I and II hydrogeological investigations performed by URS and S. S. Papadopulos & Associates, respectively. The main findings can be summarized as follows:

1 – The water quality data is sufficient to establish the range of natural background chemistry and delineate the impact of petroleum activities. Impacts from petroleum activity are not currently present at levels that exceed regulatory limits. The impacts are mainly elevated methane and chloride in groundwater wells.

2 - There is a temporal trend of increasing methane in groundwater samples over the last seven years that is coincident with the increased number of gas wells installed in the Mamm Creek Field. Pre-drilling values of methane in groundwater establish natural background was less than 1ppm, except in cases of biogenic methane that is confined to pond and stream bottoms. The cases of biogenic methane can be readily identified by stale isotopic characterization of the methane. The isotopic data for the methane samples show the most of the samples with elevated methane are thermogenic in origin.

3 - Concurrent with the increasing methane concentration there has been an increase in groundwater wells with elevated chloride that can be correlated to the number of gas wells. Chloride is derived from produced water.

4 - The increasing methane and chloride will not trigger regulatory action since there is no regulated limit on methane and the majority of chloride values are below regulatory limits, however, as more gas wells are drilled the chloride value may reach the regulatory limit.

5 - Currently the only monitoring mechanism to evaluate the impact of gas well drilling and gas production to groundwater quality is the existing domestic water wells and surface water bodies.

The number of water wells (<200) and their spatial distribution is inadequate to monitor and locate potential source of contamination from the more than 1400 potential point sources (gas wells and produced water pits). There are only a few cases where COGCC has been able to identify gas wells as point sources of the observed more widespread increase in impact (West Divide Creek seep and the Amos well).

Introduction

The purpose of this report is to perform an evaluation of water and geologic data collected in an area south of Silt, Colorado by S.S. Papadopulos Associates. The data was analyzed in view of data from past studies undertaken by the County, specifically that conducted by URS in 2006. This report will describe the nature of the geochemical conditions of the study area, including the chemistry of the groundwater in the Wasatch Formation, influences of lithology on the water chemistry, any indications of the hydraulic relationship between the Wasatch and the underlying Mesa Verde Group, the orientation and extent of fractures and structural features, any potential influences on water chemistry from natural gas wells or gas development activities such as fracing and well construction, and potential influences from other anthropomorphic activities such as land cultivation.

Figure 1 shows the study area which is slightly larger than the Mamm Creek Field. The map also shows the mapped major structural features including shallow, intermediate and deep (basement) faults that can serve as vertical conduits for gas and fluid movement. There are likely additional faults and fractures not mapped as yet except by operators. The COGCC Mamm Creek Field Special Drilling Zone is also shown. This area was the subject of a Notice to Operators (NTO effective July 23, 2004) that established special drilling and completion procedures due to repeated reports of problems drilling and completing wells including lost circulation and pressure bumps during drilling, loss of cement during completion activities and persistent elevated bradenhead pressures.

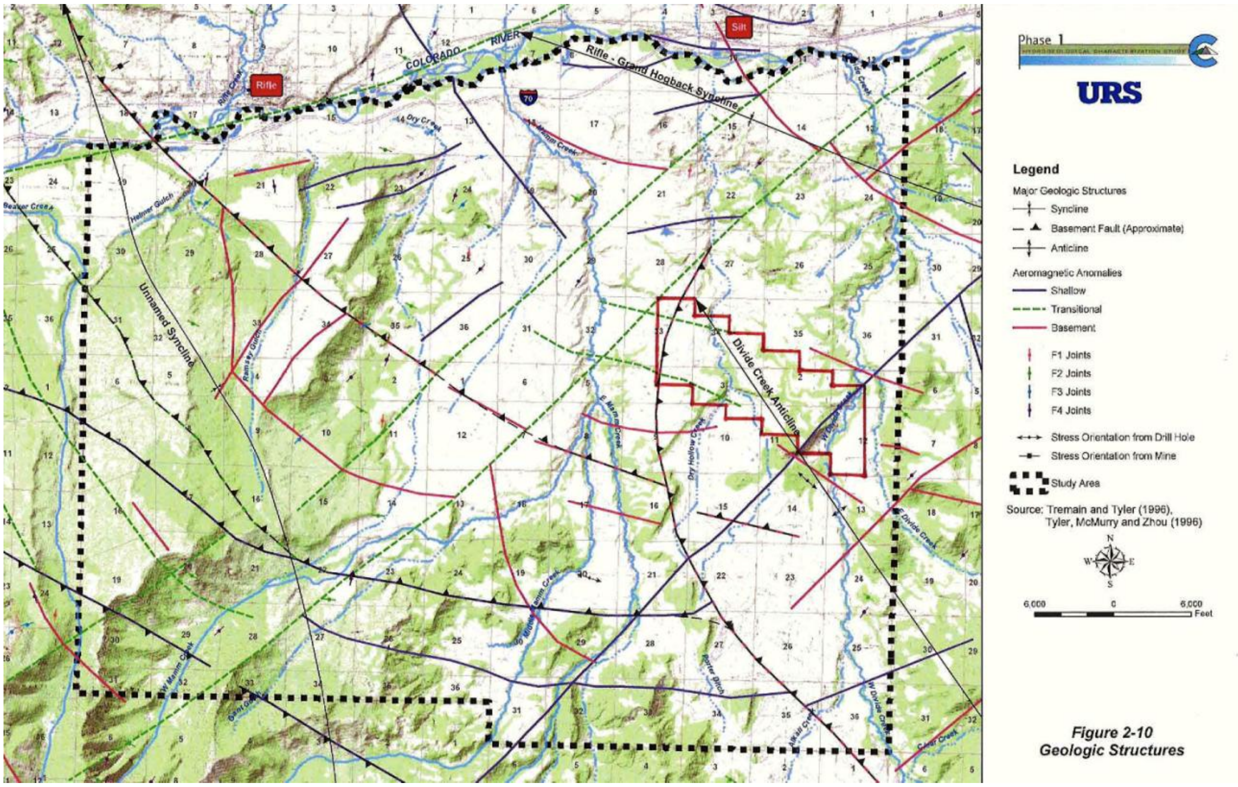

Figure 1. Phase I and II study area with major structural elements and COGCC special drilling zone outlined in red (from URS 2006).

Data Sources

The data sources used for this report include the Phase I study by URS Corporation, the Phase II study by S.S. Papadopulos and Associates, COGGC documentation and a Colorado School of Mines thesis by Tamee Albrecht entitled " Using sequential hydrochemical analyses to characterize water quality variability at Mamm Creek field area, Southeast Piceance Basin, Colorado". This produced a total of 704 samples from 292 locations including 18 samples from production (gas) wells, 46 samples from springs, 68 from streams, 26 from irrigation ditches and cisterns, 27 from ponds, 96 from monitoring wells at the West Divide Creek seep and 394 from domestic wells. Twenty-nine samples are currently unidentified as to location. The fundamental purposes of the first study were to establish the hydrologic and geologic framework in the study area, establish the pre-development baseline water quality, compile and evaluate post-development water quality data and identify impacts to water resources from petroleum activity. The Phase II study was focused on sampling of water wells that yielded elevated inorganic and organic parameters in Phase I, sampling of adjacent gas wells and sampling of water wells with elevated methane that lacked isotopic analyses (Papadopulos 2008).

Drilling and Production Activity

The COGCC database provides a record of the number of well and gas, oil and water production for the Mamm Creek Field. Figure 2 shows the increase in number of wells and produced fluids including gas. The number of wells in the last eight years has increased from about 200 to more than 1300 wells. During the last four years gas production has remained constant at approximately 80 million MCF/year with current plans to continue development based on ten acre well spacing, which would be about 7000 total wells. During this period the production of water from the gas-bearing interval has increased from 130,939 barrels to 2,513,980 barrels per year (5,499,438 to 105,587,160 gallons per year).

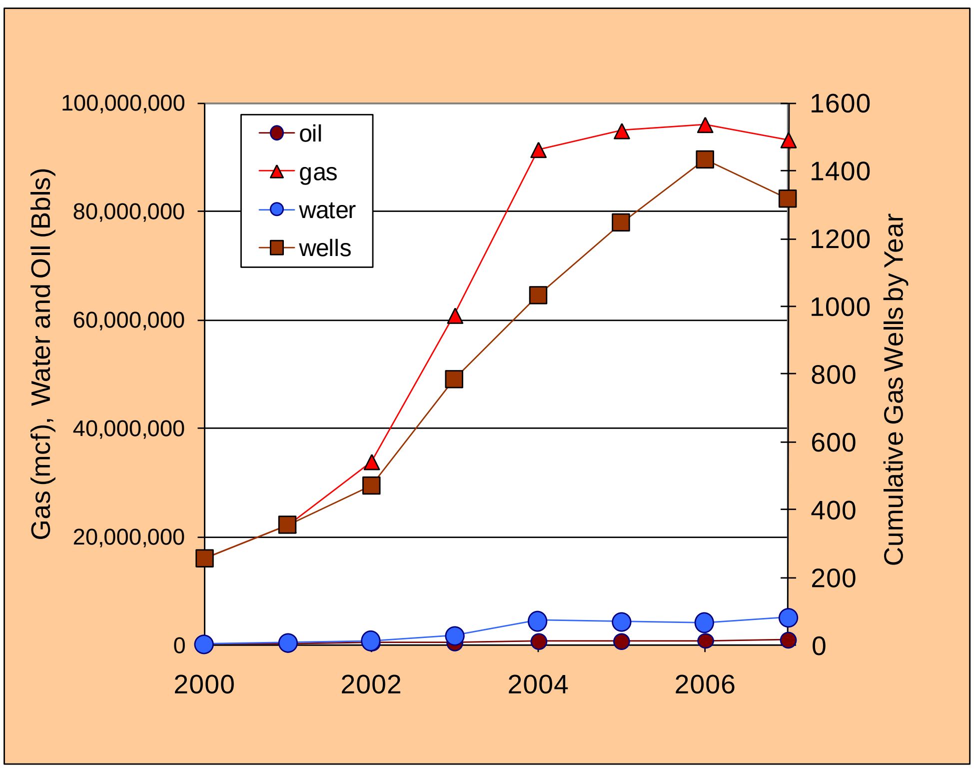

Figure 2. Number of wells and gas, oil and water production from the Mamm Creek Field for 2000 through 2007 (from COGCC website).

Bradendhead Pressures

One of measures used by COGCC to indicate well drilling problems is bradenhead pressure. In the Mamm Creek Field the regulations require wells to set and cement surface casing to below local water well intervals to protect the drinking water quality. This standard has variations in depth of cemented interval with some cases of as much as 800 feet of cemented surface casing with depths of 300- 800 feet more common. In addition the regulations require cementation of most wells to be cased and cemented to 500 feet above the top of gas. The top of gas is defined by geophysical well logs. The drill hole between the bottom of surface casing and top of gas casing in the Wasatch Formation is uncased. Typically this uncased length is 3000 to 6000 feet. Thus, the bradenhead casing collects any gas from leaks in the production tubing, cemented intervals and from gas discharge into the uncased interval. Figure 3 shows a schematic diagram of a well with bradenhead to help visualize the installation.

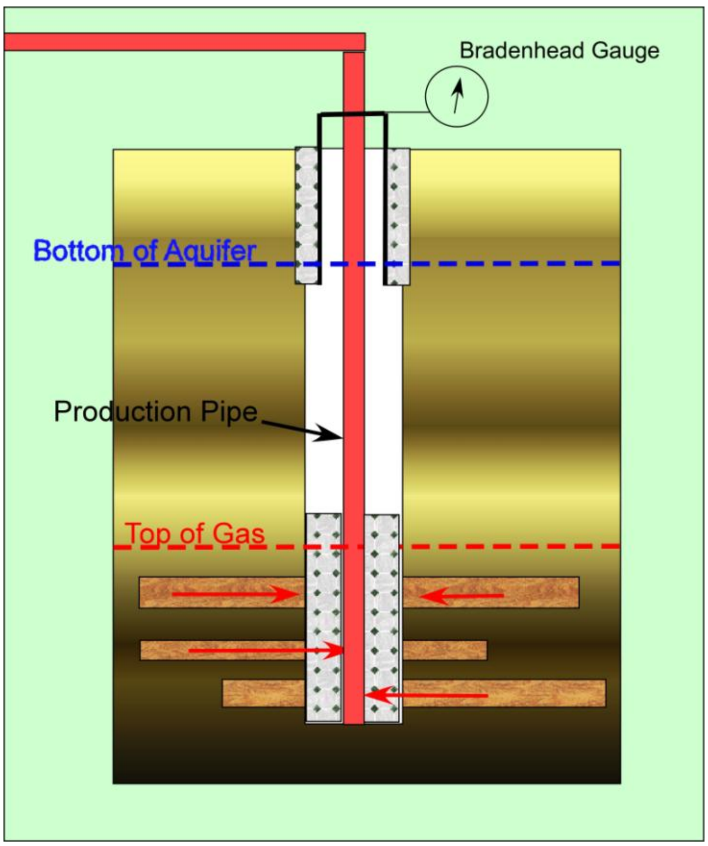

Figure 3. Schematic diagram of gas well completion and bradenhead, not to scale.

COGCC regulations require the initial bradenhead pressures be reported to the State, although only a limited number of well pressures were available for this analysis (Albrecht, 2007). The more stringent regulations for the Special Drilling Zone require repeated measurements to be reported. Normally, bradenhead pressures are elevated (100-800psi) for a month or two after completion of the wells as non-economic gas from the Wasatch Formation discharges into the well bore. The gas in the bradenhead is vented to atmosphere or collected for sale at the discretion of the operator. However, some well exhibit persistent elevated pressures (100-400 psi) that do not decline when vented or build back up on a monthly basis. These locations indicate horizontal and vertical gas, and potentially water mobility from the uncased interval in the Wasatch. Bradenhead pressure builds up in the well annulus either due to leaking gas from the well casing and production tubing, or infiltration of gas from uncased subsurface units. Wells with high or persistent bradenhead pressures generally indicating completion or cementation problems (URS, 2006), or sufficient production from the uncased intervals (Wasatch Formation).

Figure 4 shows the initial bradenhead pressure recorded. The distribution of these wells is related to the recognized geologic faults and fractures.

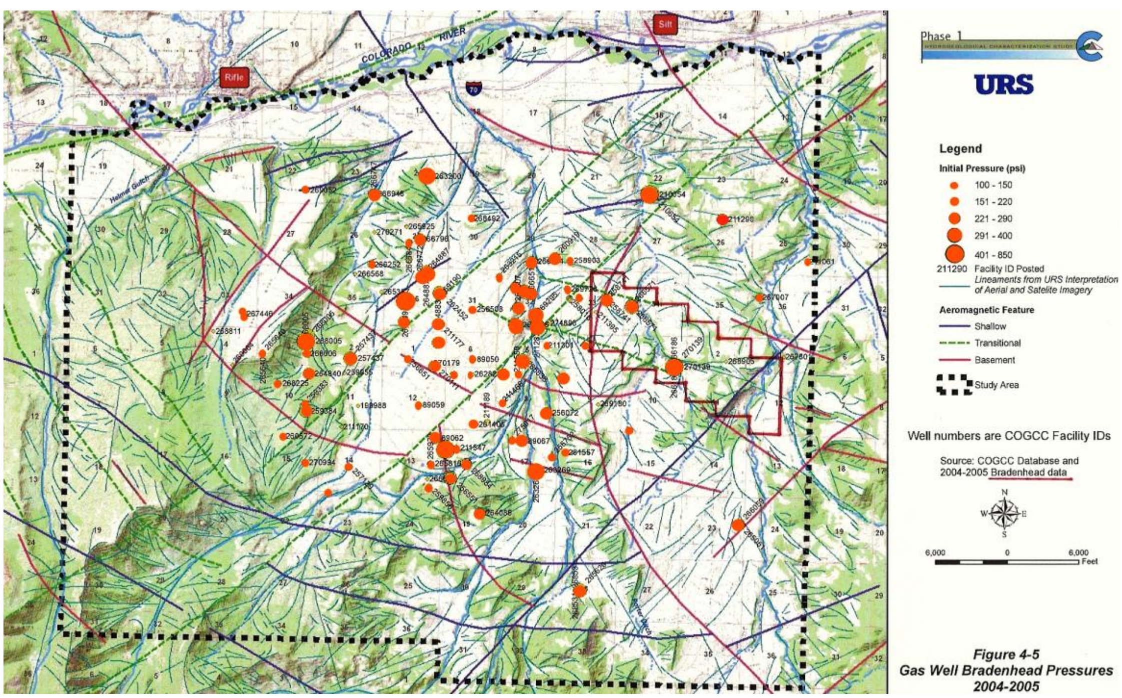

Figure 4. Map of distribution of reported initial bradenhead pressures of gas wells, mapped structural features and Mamm Creek Field Special Drilling Zone. Modified from URS (2006).

Persistent bradenhead pressures are indications of significant vertical mobility of gas. Figure 5 shows the location of wells identified as "problem wells" that exhibit persistent bradenhead pressures (>100 psi) that could not be lowered, or wells which regained pressures of at least 100 psi within 4 months of successful release. Most problem wells occur near the eastern portion of the study area coincident with the Divide Creek anticline. Increased fracturing near the anticline may cause a higher incidence of well drilling and completion problems, which in turn may affect water resources in this area by allowing introduction of gas or other fluids into the groundwater aquifer.

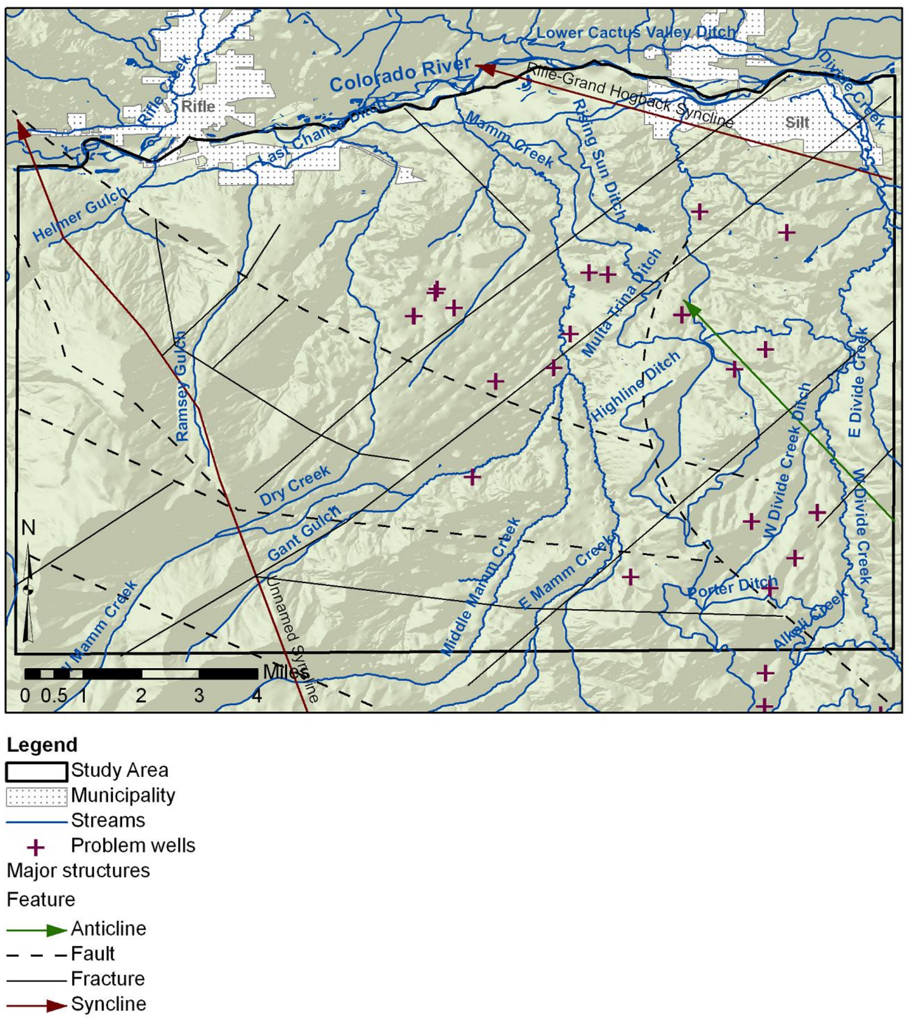

Figure 5. Location of gas wells with persistent or reoccurring bradenhead pressures greater than 100psi, from Albrecht (2007).

Distribution of Dissolved Methane

Pre-drilling methane values in water wells did not exceed 1ppm and were often much lower. Therefore, values above 1ppm dissolved methane are assumed to indicate impact to groundwater with the most likely source being produced gas from the Williams Fork Formation. There is also a trend of increasing dissolved methane with time that is positively correlated with the number of gas wells. Figure 6 and 7 show the increase in average methane with cumulative number of wells and the increase in samples with greater than 1ppm methane or more than 250ppm chloride (a major component of Williams Fork produced water) with time.

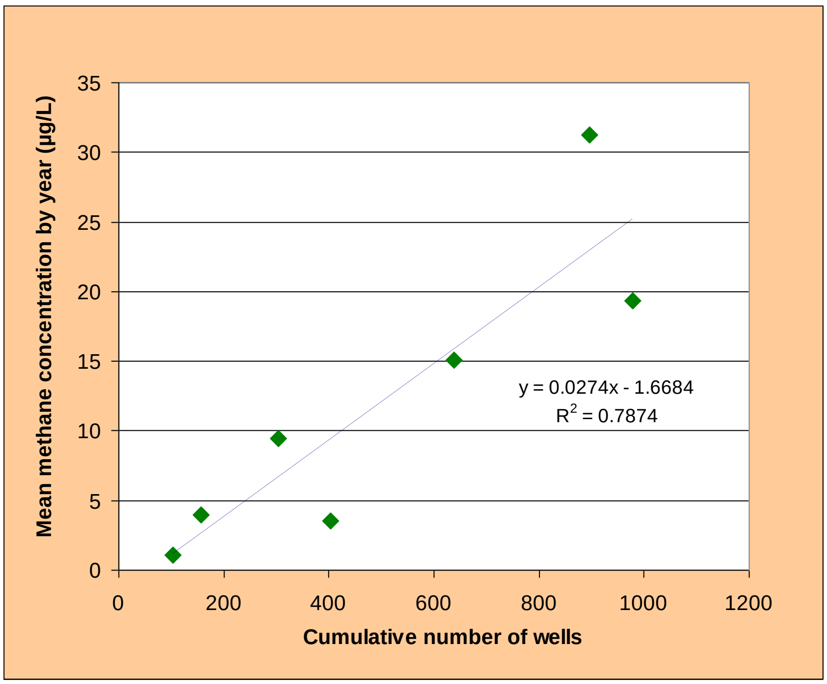

Figure 6. Average methane by year (2000-2007) versus cumulative number of gas wells in the Mamm Creek Field. R^2 is the squared correlation coefficient of determination for the linear regression. From Albrecht (2007).

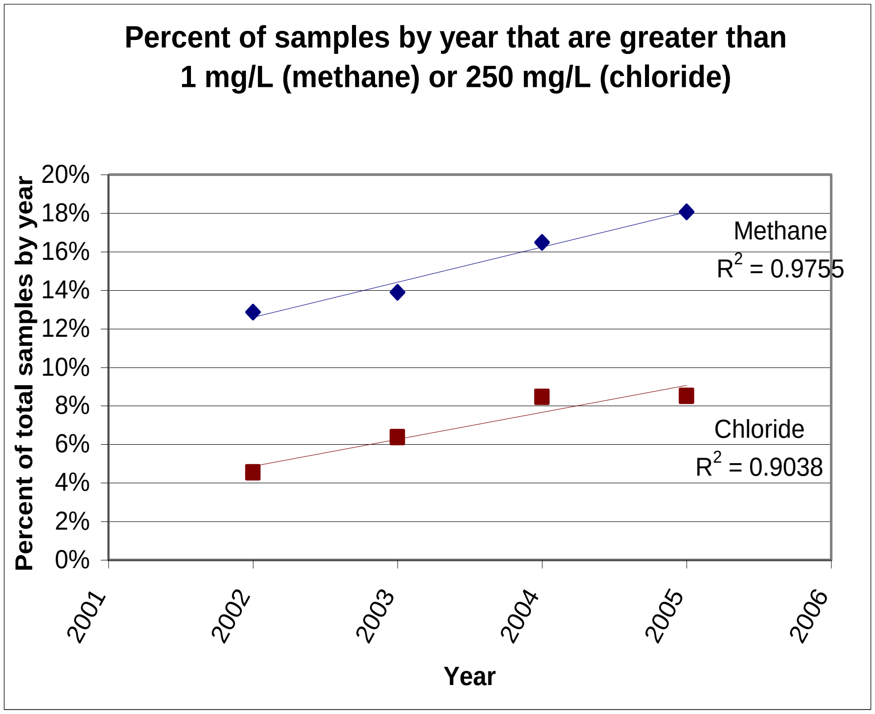

Figure 7. Percent of total sampled wells with methane >1ppm and chloride >250ppm by year for Mamm Creek Field. R^2 is the squared correlation coefficient of determination for the linear regression. From Albrecht (2007).

Methane Isotopic Data

SSPA sampled a total of seven domestic wells that had prior elevated methane content for isotopic analysis to determine the source of the methane. In all seven cases the isotopic values indicated thermogenic origin. As expected the gas from the four production wells show a tight cluster in the thermogenic field. Figure 8 is a plot of the stable isotopic values for hydrogen and carbon for 270 methane samples taken over the last four years, most from the West Divide Creek (WDC) seep.

It should be noted that all the groundwater samples except the WDC monitoring wells are taken from domestic wells. First, the number of domestic well sample points is far exceeded by the potential point sources (gas wells). Domestic wells are much less than ideal for sampling purposes. Domestic wells not placed to determine sources of contamination in groundwater. They are not evenly spaced around gas wells or within close enough proximity to determine the presence of chemicals associated with methane that degrade rapidly. Domestic wells are generally screened over large intervals making vertical spatial resolution for samples difficult nor are the wells are not constructed to facilitate measurement of water table elevation or downhole sampling. This forces sampling to occur at the surface after pumping raising the possibility of sampling artifacts. In addition, since domestic wells are the sole source of drinking water for individual properties, it is difficult to arrange access to take samples due to privacy issues, and the County may bear potential liability for damage during sampling and interruption of water supply.

The hydrogen and carbon isotopic values of methane are used to determine the origin of the gas (Schoell, 1980). Examination of the carbon and hydrogen isotopic values shows that there are three distinct clusters of samples with a few samples with intermediate values between the clusters. The first cluster is composed of most samples and plots in the thermogenic origin field. Samples in this group are from production well streams and bradenheads, as well as most of the SSPA domestic well samples. A smaller cluster of about 18 samples from the West Divide seep and surface ponds plots in the microbial fermentation field. Microbial fermentation is the process that occurs in many landfill, swamps and pond bottoms where natural accumulations of organic matter is converted into CO_2 and CH_4 in equal proportions. Methane produced by this process is often termed "swamp gas". The fermentation samples include many of the surface ponds as expected and a few samples from the WDC seep. The last cluster of samples consists of about 40 samples from a range of sources including the WDC seep and domestic wells that lie in the blue field in Figure 8, labeled microbial CO_2 reduction. Microbial CO_2-reduction is another process that produces methane wherein CO_2 is reduced to CH_4 by microbial processes (Botz et al., 1996). In this process the carbon isotopic value of the resulting methane becomes more negative than the parent CO_2 producing δD ratios between –250 and –170 per mil (Whiticar et al., 1986).

It is most likely that methane plotting in the microbial CO_2 reduction field is derived from the thermogenic CO_2 in the Williams Fork Formation and can be considered thermogenic. The Williams Fork Formation contains up to 22% by volume of CO_2 (Johnson and Rice, 1990) and this carbon dioxide is part of the normal production stream. The average value of 27 CO_2 samples from the Williams Fork Formation is –11.0 per mil (Albrecht, 2007). Methane produced by the CO_2-reduction of Williams Fork CO_2 gas would have a $\delta^{13}C$ value of –76.0 per mil (fractionation factor of approximately –65 per mil, Scott et al., 1994) similar to what is observed. Therefore, regardless if the CO_2-reduction process is occurring at depth in the Williams Fork Formation or in near surface environments, the original source of this methane is Williams Fork gas and all the samples that plot in the traditional thermogenic field and the microbial CO_2 reduction field are interpreted as indicating petroleum-related sources, not shallow natural methane.

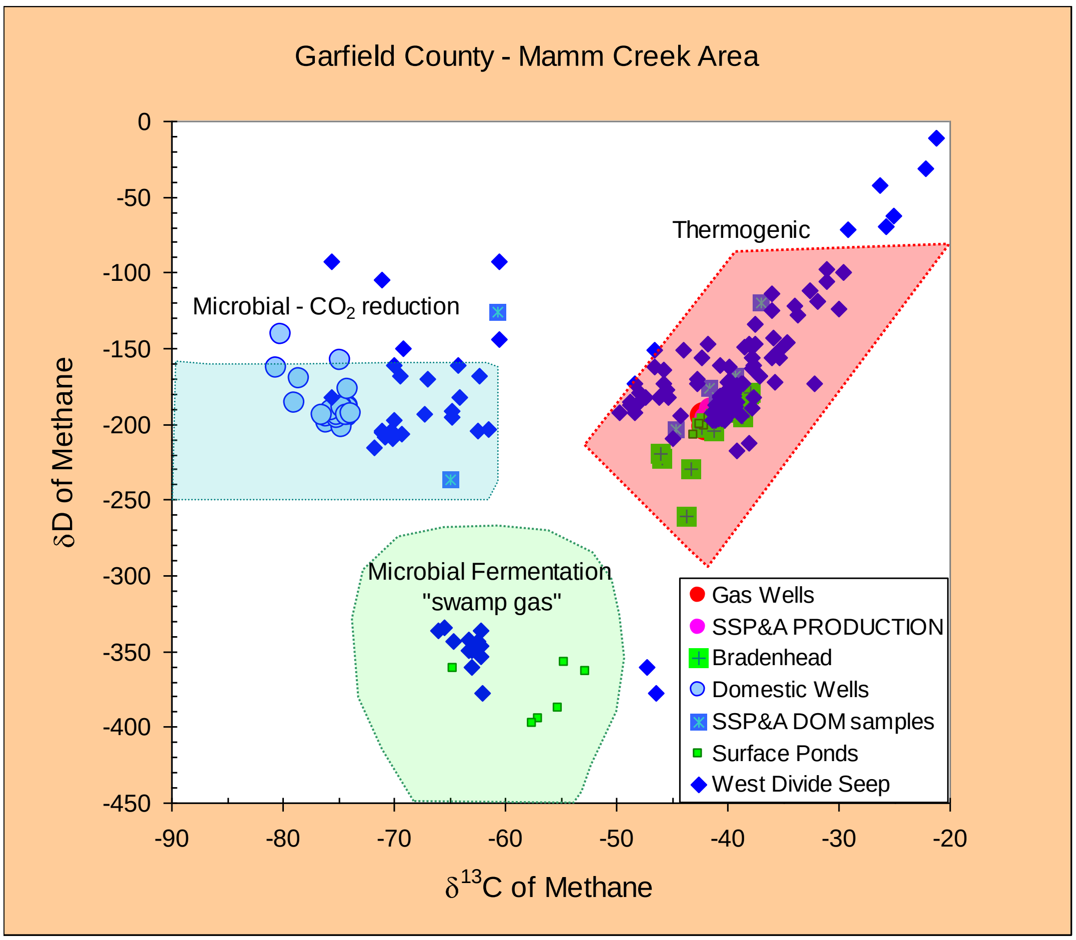

Figure 8. Plot of the carbon and hydrogen isotopic values for methane samples from a variety of sources in the Mamm Creek Field area.

An alternative interpretation for the theromogenic isotopic signatures is that the methane was originally fermentation gas and has been oxidized by microbial processes (CH_4 to CO_2) creating a "residual" methane that appears to be thermogenic (pg. 37, Papadopulos, 2007). In the oxidation process, the portion of the methane gas not converted to CO_2 becomes isotopically heavier as microbial processes selectively utilize the lighter isotope. However, the data in Figure 8 do not show any samples with intermediate values between the fermentation and thermogenic fields. Instead, the only samples with trends toward more positive values are found in the thermogenic and CO_2-reduction fields. Figure 9 is a plot of the isotopic composition of samples from the monitoring wells at the WDC seep with time. The figure shows that the isotopic composition of most samples remains constant during the eight month sampling period. However, there are three sample locations with thermogenic and one sample location with CO_2-reduction signatures that show a small trend of increase in more positive isotopic values indicating oxidation of methane, but this appears to be relatively rare. The current data do not support an interpretation of widespread “false positives” due to methane oxidation for the majority of the methane data.

The methane oxidation process also produces elevated dissolved bicarbonate (HCO_3^-), but none of the WDC seep samples show elevated bicarbonate. In conclusion, it appears that most of the methane samples from domestic wells, bradenheads and some surface ponds are thermogenic in origin, showing impact from produced Williams Fork gas on water resources. More conclusive evidence for the origin of the methane can be derived by measuring the carbon stable isotopic value of the dissolved bicarbonate from the same sample as the methane since each of the proposed sources for methane origin will generate bicarbonate with distinctly different values.

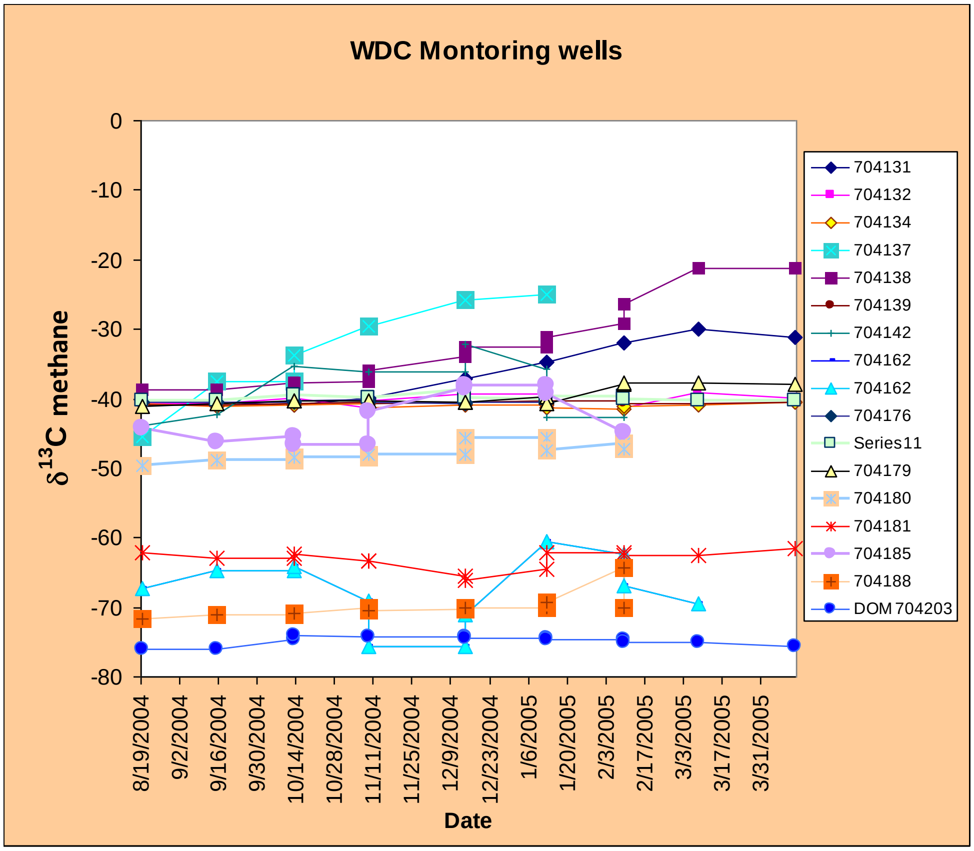

Figure 9. Plot of the carbon isotopic values for methane samples from the West Divide Creek seep versus time.

Water Quality

A total of 704 samples were analyzed for trends in water quality (chemistry). Figure 10 is a Piper plot of the samples showing the distribution of the major dissolved components and labeled by source in a manner analogous to the isotopic samples. The data show the majority of domestic wells and surface sources with low total dissolved solids (<1000ppm), while the gas well produced water samples have much higher total dissolved solids (TDS). There is a wide range of variation in the chemical composition of the samples.

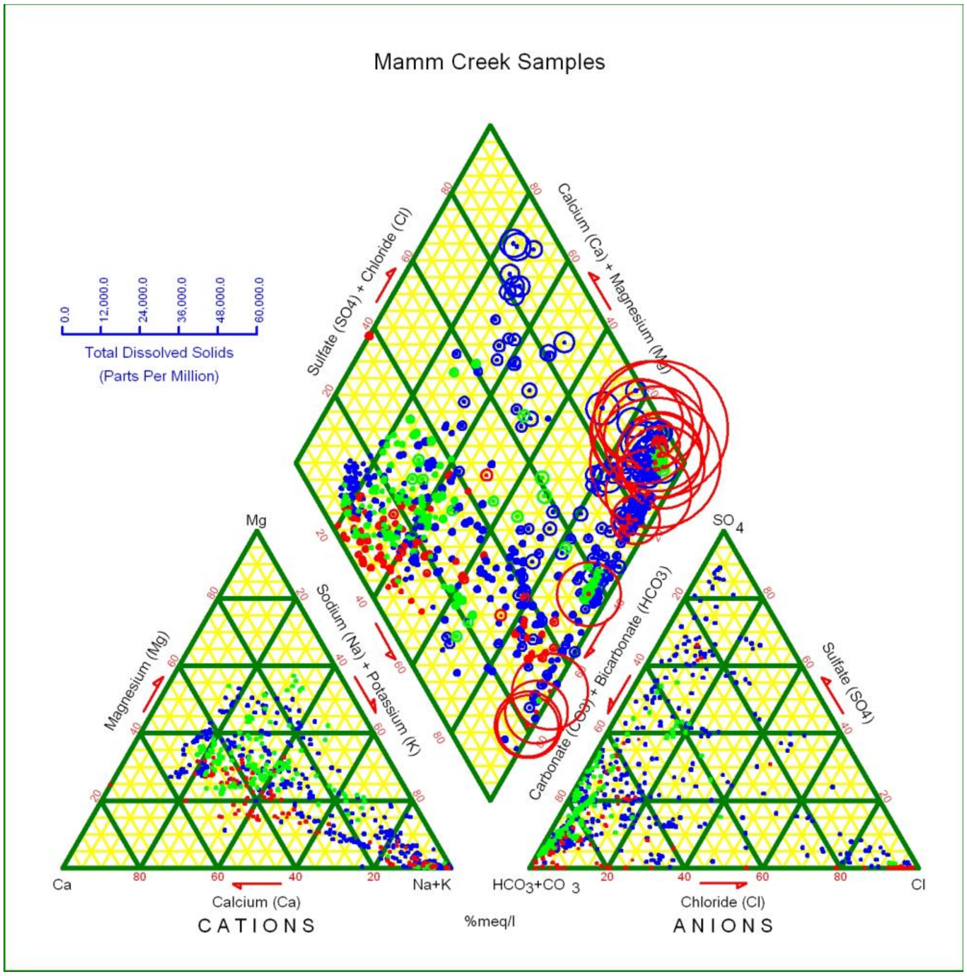

Figure 10. Piper diagram of 704 water samples from the Mamm Creek Field area, data from URS, 2006, Albrecht, 2007, and Papadopulos, 2008. Blue symbols are from domestic wells, red from gas wells and green from surface water samples. Size of circles in the diamond plot field indicates TDS value of sample.

Preliminary analysis of the water chemistry dataset shows the samples fall into three general categories: the first is low TDS, Ca-Na-Mg-HCO_3 water, the second is higher TDS Na-Ca-HCO_3-SO_4 water and the last is higher TDS with a distinctive Na-Cl component. The only source of Na-Cl in the study area is produced water from the Williams Fork Formation. Produced water is high salinity (up to 22,000ppm TDS), composed mostly of Na and Cl solutes. This distinctive water chemistry offers a natural tracer to evaluate the potential impact to groundwater quality. In the early stages of the development of the Mamm Creek Field the produced water was used to formulate drilling fluids for new wells. Since water production has exceeded drilling needs, the produced water is usually collected in unlined surface impoundments where it can re-infiltrate into the shallow aquifer, or is stored until treated and disposed. In 2007, 105,587,160 gallons of saline formation water was produced at the Mamm Creek Field.

Figure 11 shows the spatial distribution of the water chemistry in the study area. The size of the pie chart circle indicates the TDS, while the chemistry is shown by the distribution of the pie segments. Most of the samples have low TDS. The higher TDS samples are found in either the Special Drilling Area, especially near the nose of the Divide Creek Anticline, or near Grass Mesa. Comparison with Figure 1 shows the high TDS samples near Grass Mesa are associated with the intersection of mapped basement faults. These areas of intersecting deep faults are more likely to serve as hydraulic connections between the deeper formations and shallower aquifers.

Recognizing that elevated chloride content indicates the potential for produced water impact, statistical measures were employed in order to evaluate the potential effect. Figure 12 shows a cumulative frequency plot of chloride values. Cumulative frequency plots of specific solutes have been used to determine natural background in areas with anthropogenic impact. The breaks in slope of the curve represent a change in the population of samples. In this case the line shows a minor break at about 9ppm (about 30% of the total samples) and a sharper break at about 100ppm with a sharply increasing slope between 100 and 400ppm. All three groups of samples (<10, <100 and >400ppm) have a relatively unbiased mixture of sources (springs, ponds, and domestic wells). Since the domestic wells are not well constrained as to depth of sample, it is not possible to determine the relationship between chloride content and depth. The data is tentatively interpreted to indicate natural background for chloride is low (<10ppm), with a group of samples with moderate chloride (<100ppm) that are probably slightly impacted and a smaller set of samples (<20%) that have more significant impact (Cl > 400ppm). Figure 13 shows a plot of chloride versus TDS. The data show two distinct groups of samples, one with elevated chloride that lie along a mixing between normal groundwater and produced water and the other group where TDS and chloride are not related. The range of Cl and overall TDS in the samples from the gas wells has been interpreted brackish William's Fork Formation water (Papadapolus, 2007). However, it is likely the lower salinity samples represent dilution of saline formation water with condensed water formed during production-induced cooling. Future samples should be analyzed for silica content as well to quantify any potential dilution. This is a significant issue as accurate characterization of the Williams Fork Formation water will allow the degree of impact from produced water mixing with normal groundwater to be accurately calculated.

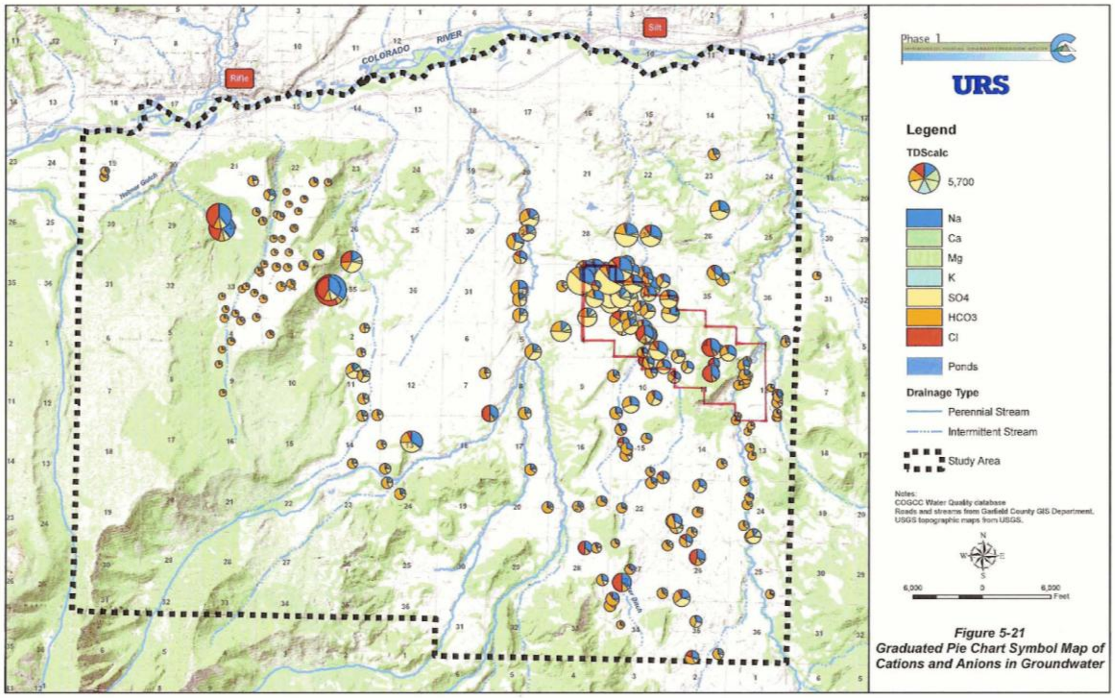

Figure 11. Map of groundwater quality using pie charts to show TDS and chemical composition of water samples from the Mamm Creek Field area (URS, 2006).

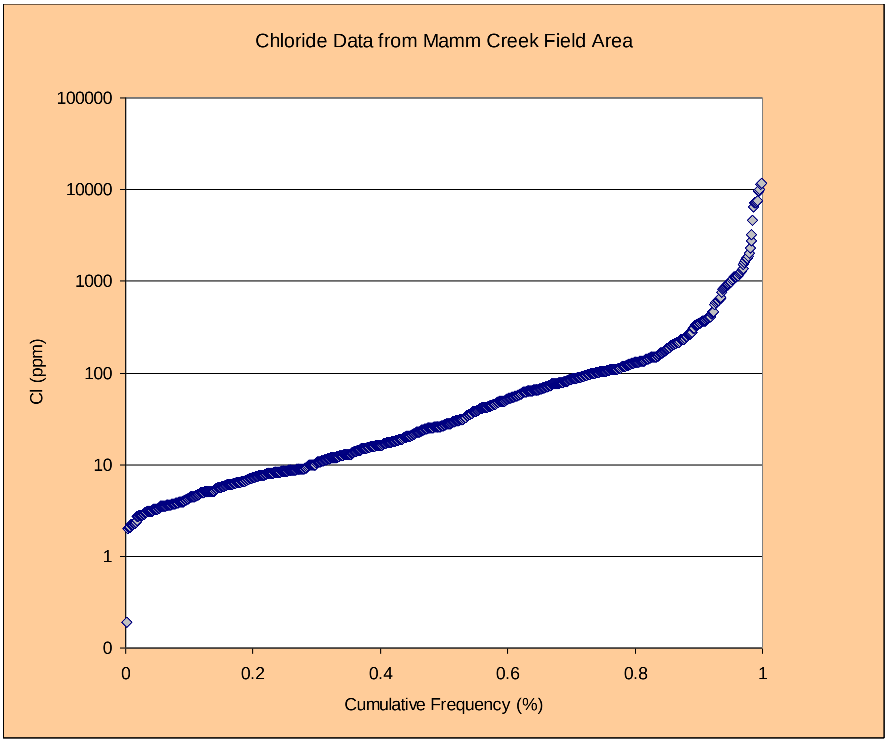

Figure 12. Cumulative frequency diagram for chloride content in water samples from the Mamm Creek Field area.

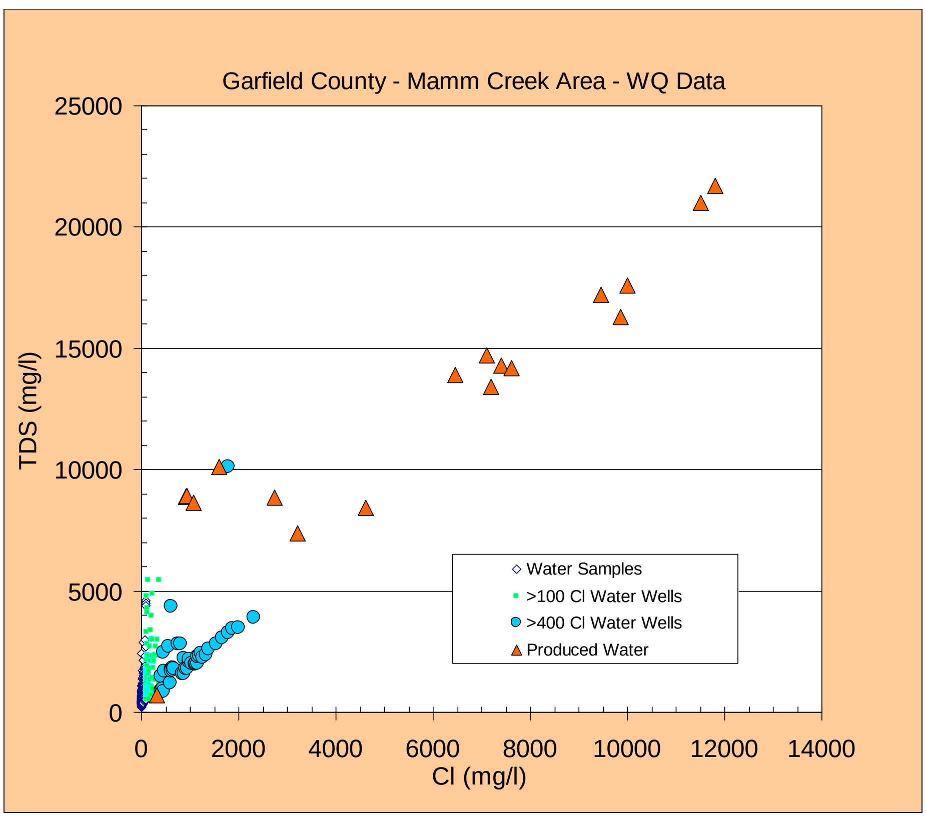

Figure 13. Plot of 704 surface and ground water samples from the Mamm Creek study area for chloride versus TDS.

A more rigorous statistical evaluation of the data was made using multivariate statistical methods using the data from the Phase I study by URS supplemented with additional water quality data from two surrounding areas without gas wells (Albrecht, 2007). The results of this study delineated two naturally-occurring water types, a low TDS Ca-Mg-HCO_3 water that occurs in streams and water wells near surface streams inside and outside the study area, and a higher Na-Ca-HCO_3-SO_4 water associated with water wells both inside and outside the study area that are either deeper or not near active discharge zones (streams). There were three other water types associated with groundwater samples from inside the study area that were impacted by petroleum activities. The first was associated with the WDC seep where low TDS background water had elevated methane, BTEX, Fe and Mn. The second impacted group of samples had higher TDS with elevated Na and Cl and methane. The third had high TDS and elevated Na, Cl and SO_4. Based on the spatial distribution of this water type and mixing models, samples from the third group were interpreted as being impacted by produced water. Figure 14 shows the spatial distribution of the statistically-derived clusters of water samples. The locations of the natural background and impacted samples locations are essentially the same as the Phase I URS map.

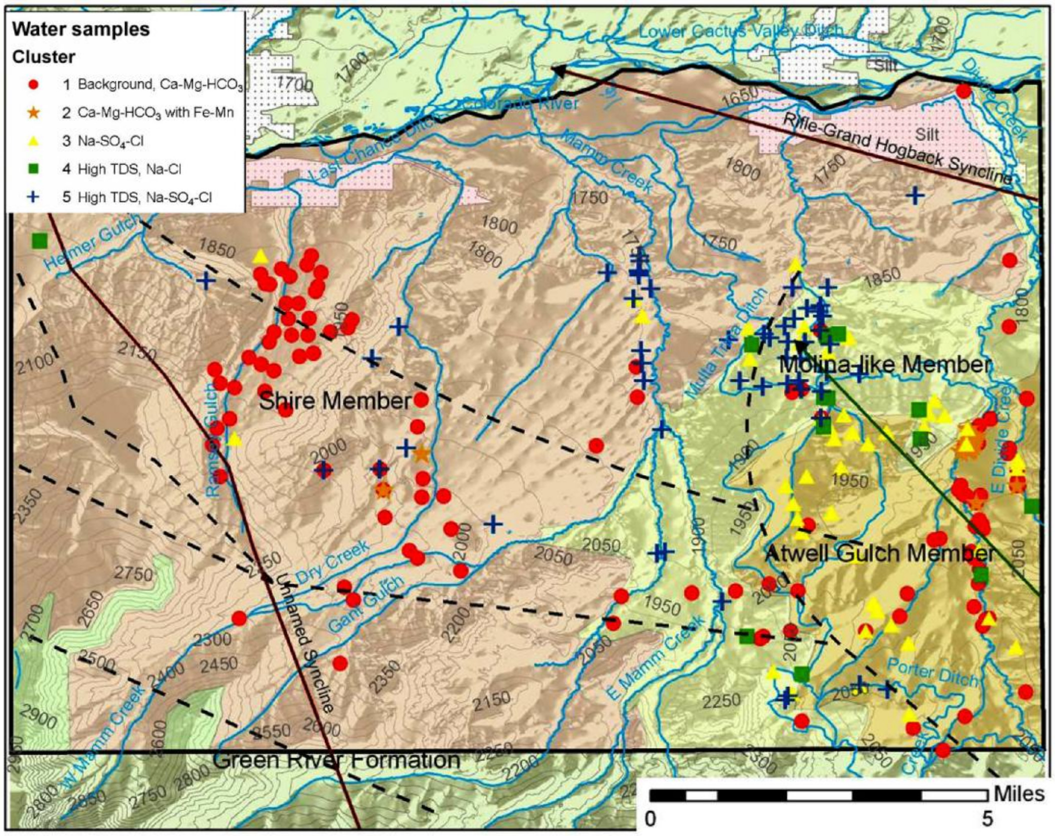

Figure 14. Map of locations of water samples divided into statistically-derived groups with three groups of samples showing impact from petroleum activities (modified from Albrecht, 2007).

Discussion

The Phase I and II reports noted the presence of some domestic wells with elevated concentrations of the inorganic components nitrate (NO_3), selenium (Se) and Fluoride (F). Domestic wells with elevated values (as defined by regulatory limits) were re-sampled during Phase II to confirm the elevated values and the well owners privately notified. None of these three inorganic contaminants appear related to petroleum activities at this time.

The issue of impact to water resources from petroleum activities can be viewed from two perspectives. One perspective is regulatory. In the case of regulatory action, the concentration of a regulated solute must exceed the standards for action to occur. This was the case in WDC seep for benzene, which allowed COGCC to take action. However, such situations have been rare in the study area. The other perspective is that of solutes in concentrations less than the regulatory limit, or solutes not regulated, but are above the natural background. The URS/SSPA data clearly provide evidence for solutes elevated above natural background in the study area. Currently, the trend of this sub-regulatory impact is best delineated by the increasing methane and chloride found in groundwater samples. The methane stable isotopic data show that almost all the samples are thermogenic in origin. While it is likely that some small amount of vertical migration of gas from the Wasatch Formation is naturally occurring, the low pre-drilling concentrations (<1ppm) and trend of increasing dissolved methane that is positively correlated to well numbers indicate that drilling and production activities are the cause. The locations of the most affected are near structural features where the faults and fractures maximize the vertical mobility of the gas, however it is not possible at this time to identify if leaking production tubing, leaking top-of-gas casing or un-cased Wasatch interval is the primary source of methane.

The trend and location of chloride, which is derived from Williams Fork production water shows similar trends of increasing concentration and locations near structural features. As was the case with methane the current data do not permit precise identification of the source. As with methane the total area impacted and identification of point sources is hindered by the low number of sample points (domestic water wells) compared to the number of potential point sources (gas wells).

Usually the identification of specific sources requires at least three monitoring points (wells) for each potential point source for determination of background and up-gradient water, and water down-gradient of potential sources. The Phase II report included an effort to identify gas wells as sources of impact by comparing samples from up-gradient gas wells adjacent to impacted domestic wells. The report concludes that samples from gas wells near two domestic wells with elevated methane (703996 and 704023) were not identical to the domestic well samples and therefore could not be positively identified as the source of the elevated methane. In both cases, the domestic well methane was depleted in ethane and propane. An additional five domestic wells with elevated methane had similar conditions. Finally, two more domestic wells with unusual water chemistry were ascribed to impact from sources other than the gas wells.

These conclusions highlight the difficulty of defining specific criteria for identifying gas well production impacts or assigning responsibility to specific gas wells. The case of the WDC is an excellent example of the difficulty. In that case the composition of gas at the seep was identical to the composition of the Swartz 2-15B well allowing positive identification. The site had over twenty monitoring wells in an area of 500 by 2000 feet, the amount of gas (>100 million cubic feet) was large, the leakage duration short (2 months) and the point source at the surface. These circumstances meant there was almost no degradation of the gas before sampling and the point source could be positively identified. Figure 15 shows the contours of methane concentration from the WDC seep December 2007 data.

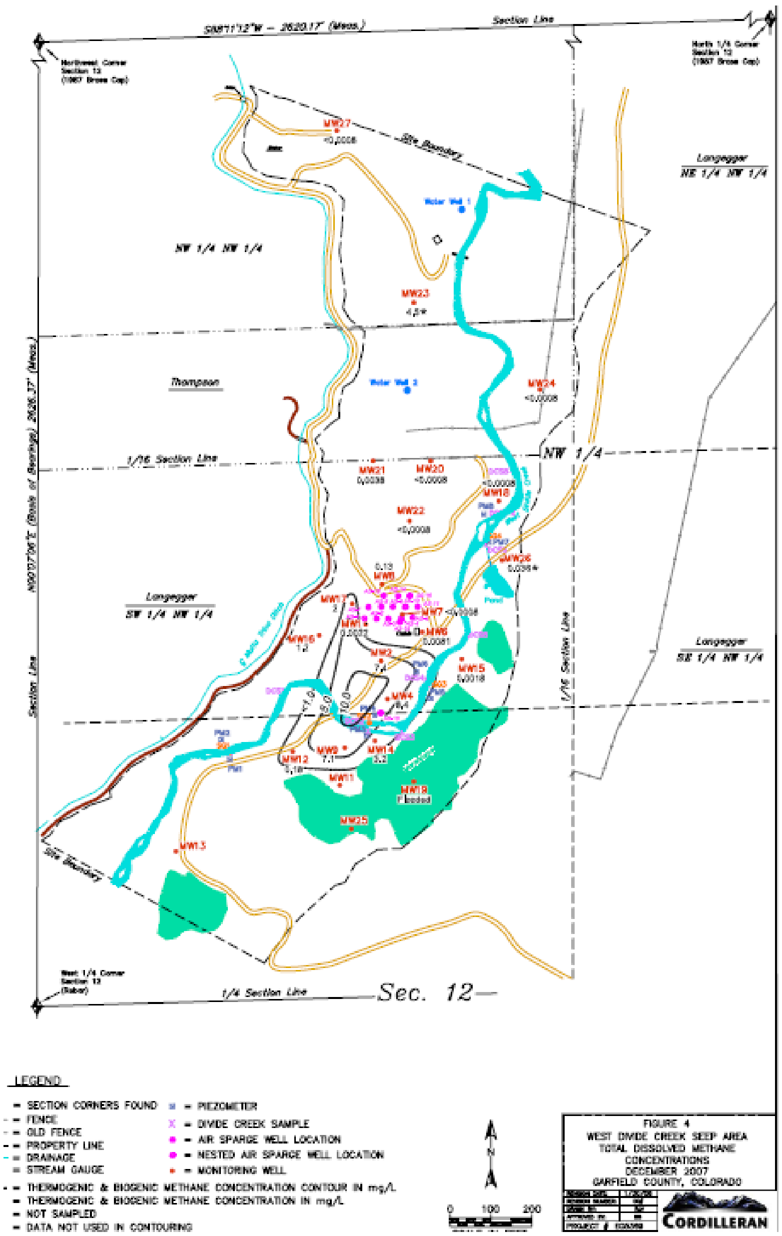

Figure 15. Contour of methane concentration from water samples at the West Divide Creek seep, from Cordilleran Compliance Service report, COGCC, 2008).

In contrast, the impact to domestic wells is likely to be from much smaller volumes of gas. The higher homologues (ethane, propane, butane) and other hydrocarbon components of the produced gas (i. e. BTEX) degrade rapidly during transport to by-products that are not analyzed in current sampling protocols after less than 400 feet transport (Albrecht, 2007). The WDC seep data (COGCC, West Divide Creek Seep Status, Dec. 2007) shows this pattern clearly as the monitoring wells 200-400 feet from the seep show no methane or BTEX as little as 200 feet from the point source. Samples from MW-12, only 200 feet from the seep, showed depleted ethane and propane. This means the current sampling and analysis program is unlikely to detect any but the largest volume leaks. Given the likely increase in number of gas wells and the inherent limitations of using domestic wells as monitoring wells, this inability to positively identify the point sources will continue.

Conclusions

The currently available water quality data is sufficient to establish the range of natural background water chemistry and delineate the impact of petroleum activities. Impacts from petroleum activity are not usually present at levels that exceed regulatory limits. The sub-regulatory impacts most clearly delineated are elevated methane and chloride in groundwater wells. There is a temporal trend of increasing methane in groundwater samples over the last seven years coincident with the increased number of gas wells installed in the study area. Pre-drilling values for methane in groundwater establish natural background was less than 1ppm, except in cases of biogenic methane that are confined to pond and stream bottoms. The cases of biogenic methane can be readily identified by stale isotopic values of the methane. The isotopic data for the methane samples show the most of the samples with elevated methane are thermogenic in origin. More conclusive identification of the origin of methane can be made by determination of the inorganic carbon isotopic value.

Concurrent with the increasing methane concentration there has been an increase in groundwater wells with elevated chloride that can be correlated to the number of gas wells. Chloride is derived from produced water. The increasing methane and chloride will not trigger regulatory action since there is no regulated limit on methane and the majority of chloride values are below regulatory limits, however, as more gas wells are drilled the chloride value may reach the regulatory limit.

Currently the only monitoring mechanism to evaluate the impact of gas well drilling and gas production to groundwater quality is the existing domestic water wells and surface water bodies. To date, there are only a few cases where COGCC has been able to identify wells as point sources. The number of water wells (<200) and their spatial distribution is inadequate to monitor and locate potential source of contamination from the more than 1400 potential point sources (gas wells and produced water pits). If future development continues the number of gas wells may reach 7000 assuming ten-acre spacing and the problem of determining sources will become more difficult.

Recommendations

The recommendations are based on the overview presented in this report and are directed to proactively manage the projected growth and continued operation of the tight gas resource. Based on the description of the scope of work were to be completed during the Phase II project, the most important shortcoming identified was the lack of specific locations, as either UTM or latitude-longitude, for nineteen reported chemical analyses from the 2007. The facility ID's for these samples are: 704151, 704158, 704228, 704320, 704327, 704392, 704423, 704434, 704444, 704545, 704660, 704475, 704477, 704479, 704500, 704501, 704516, 704526, and 704534. There should be locations on the well information form (Appendix A, Papadopulos, 2008).

In addition:

1. The County should secure GIS coverage of all water and gas wells, gas pipelines, produced water disposal pits and treatment facilities, mapped springs, streams and ponds that have been sampled or may be available for sampling. This GIS should be fully linked to a geodatabase that includes all chemical samples and can be updated as new information becomes available from basic monitoring activity by COGCC.
2. The County should design and contract the Phase III study to continue supplement basic monitoring activity by COGCC with targeted monitoring of sites with

increasing concentrations of parameters indicating impact. This Phase III study should ensure that the analyzed solutes are compatible with Phase I and II and not include parameters that are not common to both studies. This study should include a more rigorous examination of the limitations of domestic wells to identify leaking point sources (gas wells) and try and identify other methodologies. The WDC seep data may constitute a valuable source of information to delineate the extent and degree of impact from leaking gas wells and help define criteria for identifying impact of lower volumes and greater distance from other sources.

3. The County may wish to investigate regulatory guidelines and relevant examples of dealing with cumulative impacts to water quality in addition to traditional point source contamination that exceeds regulatory standards.

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