COGCC RATON BASIN BASELINE STUDY STAFF REPORT
October 27, 2003

The Colorado Oil and Gas Conservation Commission (COGCC) has completed the Raton Basin Baseline Study. The purpose of this study was to document existing conditions, to collect data that can be used to address future complaints, and to identify and monitor areas of concern within the Basin. The Baseline Study was conducted between 2000 and 2003. The data collected only represent the conditions that existed at that time; therefore, the results of the study are not intended to be a final answer, but the first step to systematically evaluating the interaction of coalbed methane (CBM) development and the environment. Additional data will continue to be collected across the Basin and evaluated as required to address important issues. The baseline data collected will be used to answer questions, and evaluate concerns and perceptions associated with CBM development including:

A. Does CBM development increase the methane levels at or near the ground surface?

B. Is there a relationship between methane in water wells and CBM methane?

C. Is there communication between shallow ground water aquifers and deeper CBM producing coal horizons?

These are difficult questions to answer because of the size of the Raton Basin and complexity of the stratigraphy of the coals in the area. Any scientific evaluation of these issues requires not only a large spatially distributed sample set, but also an analysis of changes over time. The COGCC baseline study provides a comprehensive initial data set that documents current conditions and will provide a basis for future evaluations.

The baseline study consisted of:

- A methane seep survey that covered 2,749 linear miles and documented 67 seep sites.
- The sampling of 100 water wells and 50 gas wells.
- The digitizing of 465 historic coal mine maps and the locations of 1141 coal exploration core holes.
- The compilation and incorporation of other data from operators and the USGS.

The following contractors were used to conduct the various phases of the study:

- Dr. Anthony Gorody, Universal Geoscience Consulting, Inc. performed a complete review and analysis of the data and prepared the Power Point overview of the study;
- Greg Lewicki, Lewicki & Associates digitized the mines and core holes;
- Apogee Scientific performed the gas seep survey;

- The Seacrest Group sampled the water wells;
- ESN Rocky Mountain sampled the gas wells and performed the wet chemistry on the water samples;
- Isotech Laboratory analyzed the gases and dissolved inorganic carbon of water.

A discussion of how these data are used by COGCC staff to address concerns and perceptions regarding impacts to the environment and ground water resources from CBM development follows:

A. Does CBM development increase the methane levels at or near the ground surface?

To begin to address this question Apogee Scientific was hired to locate areas where methane currently is seeping out of the ground. The methane survey identified 67 methane seeps. Most of the seeps are within an area of CBM production which is approximately twelve miles wide in an east-west direction parallel to and along the north and south sides of the Purgatoire River. Dr. Gorody noted that this area of gas seepage also corresponds to the outcrop and subcrop of the Raton Formation. Coals in the Raton Formation probably are the source of most of the seeps.

Because this was the first attempt by anyone to inventory and accurately locate the seeps, we do not yet know certain temporal aspects of their existence. That is, were the seeps present before CBM development, have they changed or will they change in response to CBM development, do they respond to barometric or climatic changes, or have they developed in response to other human activities such as mining? There are anecdotal reports from local residents indicating that some seeps were present before CBM development. When plotted on a map, some seeps correlate with historic mine locations. Other seeps seem to correlate with ground water discharge points along stream drainages.

Overall, the Apogee vehicle mounted, infrared gas seep detector was a good reconnaissance screening tool. However, further evaluation of each individual seep would be required to understand its origin. The COGCC will identify specific seeps that may require future monitoring.

The survey data with GPS locations is currently available on the COGCC website. These data have already been put to use by a major operator in the Basin who is using it for their own evaluation of gas gathering pipeline integrity.

B. Is there a relationship between methane in water wells and CBM methane?

To begin to answer this question, COGCC contractors collected samples for chemical and isotopic analysis from 100 water wells and 50 gas wells. In addition, analytical results from previous testing events were compiled. All of these data have been entered into and are managed with a COGCC database. The analytical results have been used to assess whether there is communication between the CBM producing zones of the Raton and

Vermejo Formations and the shallower formations or zones in which most water wells are completed.

Methane was detected in 114 of the 246 water well samples. Concentrations ranged from 0.00029 milligrams per liter (mg/l) to 38 mg/l. This confirms that methane is widely distributed in the shallow aquifers across the Basin. The question then becomes "What is the source of the methane?" Is it "biogenic" gas generated by methanogenic bacteria within the shallow water bearing zones, is it "thermogenic" gas that was generated in place or has it entered the shallow water bearing zones via man-made or natural conduits, or is it a mixture of methane from different sources?

A common method for "fingerprinting" and determining the origin of methane is an analysis of the stable isotopes of carbon and hydrogen in the methane, followed by a comparison of their ratios δC^{13} and δD, respectively. Stable isotope analysis has been performed on samples from some of the water wells and CBM wells completed in the Vermejo Formation.

By comparing the analytical results from the two sample sets, in most areas we found differences in δC^{13} values for the methane from the water wells and the methane from the gas wells. For example in one area the δC^{13} values for the water well samples ranged from -51.92 and -59.27 per mil. The δC^{13} for samples from nearby gas wells ranged from -38.02 to -43.53 per mil. Similar differences between the δC^{13} values for samples from water wells and samples from gas wells were observed in three other areas of the Basin. The water well values tend to indicate a biogenic or a less thermally mature source of methane, and the gas well values tend to indicate more thermogenic or a more thermally mature methane source. Although this small data set can not be extrapolated across the entire Basin, this study demonstrates that the results of stable isotope analyses can be used to investigate allegations that gas is migrating from CBM wells into water wells. As discussed by Dr. Gorody, in other areas where the isotopic signatures of the water well methane and the CBM methane are similar, we can further refine our analysis by comparing other stable isotopes such as deuterium of water and possibly CO_2.

In one area on the extreme eastern edge of the Basin, the water well samples and gas well samples have similar δC^{13}isotope signatures. The δC^{13} values range from -44.63 to -46.25 per mil. This area differs from most of the Basin because there is little or no vertical separation between the water wells and gas wells, since both are completed in the Vermejo Formation. We are continuing to monitor this area for indications of communication between the water wells and the CBM wells.

C. Is there ground water communication between shallow ground water aquifers and deeper coal horizons?

Our analysis of this concern involved a thorough review of geologic and hydrogeologic literature, information provided by operators, and analytical data from water well and gas well sampling events.

A review of the hydrogeology indicated that complex heterogeneous conditions exist throughout the Basin. At any location there is a large variation of lithology with numerous sands and thin coal seams interbedded with shale throughout the Raton and Vermejo Formations. Coals and sands typically are the water yielding strata, whereas the shales are the less permeable confining layers. The sands and coals tend to be lenticular and laterally discontinuous as demonstrated by lack of geologic correlation from one CBM well to another, and in outcrop. A good illustration of the stratigraphic heterogeneity is included in Dr. Gorody's slide presentation. Water movement through the Raton and Vermejo Formations, both horizontally and vertically is controlled not only by hydraulic gradients, but also by the lateral and vertical continuity of water bearing beds. Fracturing also plays a role in specific areas.

Water well depths are variable with most of the water wells completed at depths less than 300 feet below ground surface (bgs). Surface casing is used to protect the shallow aquifers. Gas well production is generally deeper, in the range of 600 to 2,500 feet bgs. Therefore on average, there is about a 1,000 ft vertical separation between the water well and gas wells. There are some exceptions to this on the eastern edge of the Basin and recently a 1,000 foot deep water well was drilled near the Golden Eagle Mine. This trend of land owners drilling deeper water wells is likely to increase in the future.

The heterogeneous nature of the coal beds, the vertical separation between shallow water well and producing gas wells, and the COGCC surface casing program should prevent vertical water communication. The COGCC is currently looking in more detail at the vertical separation of water wells and CBM producing zones by comparing the water well depths from the State Engineer records to the depths of perforations in nearby gas wells. Areas were small vertical separations exist may require a more detailed hydrogeologic analysis.

Baseline Water Quality Results

Another important part of the COGCC study was to document current water quality conditions. These data will be a critical part of any evaluation in the future. The water chemistry data will be used to respond to specific complaints and monitor areas of concern (e.g., areas with little vertical separation between the producing zones in water wells and gas wells). The data will also be distributed to operators and the public for use in their studies.

Dr. Gorody believes that water chemistry monitoring is a reliable and inexpensive tool that can be used for early detection of shallow ground water mixing with deeper coal zone waters. There may be some merit to this hypothesis, given that typically the shallow ground water and the produced water from the deeper coal zones are chemically different. The COGCC will continue to evaluate this idea. If changes in the chemistry of water wells or gas wells occur over time, then we will evaluate the need for further investigation, and sampling and analysis of additional water samples. Dr. Gorody's evaluation of the ground water chemistry data is summarized below:

1. There are four principal water types in the Raton Basin.
   - calcium and magnesium bicarbonate,
   - sodium sulfates with minor amounts of calcium sulfate;
   - sodium bicarbonate and;
   - sodium chloride.

2. The principal shallow ground water types are calcium bicarbonate and sodium sulfate. Intermediate and deep water types are sodium bicarbonate and sodium chloride.

3. Produced waters within the coal-bearing formations are predominately sodium bicarbonate, which is typical for coal seams. Sodium chloride forms a significant component of produced waters in the eastern half of the Purgatoire River ground water flow system.

4. Total dissolved solids (TDS) values in the Basin are variable, and exhibit a bimodal distribution. The first group is located in northwestern (Huerfano County) and southwestern portions of the study area and averages approximately 1,100 milligrams per liter (mg/l) TDS. The second group is located in the southeastern portion of the study area within the Purgatoire River drainage basin, just west of the Trinidad Reservoir. TDS in this area tends to be higher and averages approximately 4,600 mg/l.

Maps showing the distribution of several water quality parameters are included in Dr. Gorody's presentation.

Conclusions

By combining the COGCC data sets with those from operators and USGS studies, the Raton Basin Baseline Study presents a more complete picture of the Basin. These data will be a critical piece in any future assessments and in complaint response. Baseline data are necessary to evaluate changes in ground water that may or may not be associated with CBM development. The COGCC staff recognizes that this is just a starting point and will continue to collect data as issues warrant for further evaluations. The baseline study data and associated reports will be made available to the public via the internet. New data will be posted on the COGCC web site Library as it is acquired. Making these data publicly available to operators and other interested parties will assist them in making their own evaluations.

Recommendations

Based on the results of the Raton Basin Baseline Study, staff did not identify any issues that require immediate actions. Nonetheless, as CBM development in the Raton Basin continues, so too should monitoring gas seepage and ground water quality continue. The

Raton Basin Baseline Study covered the entire Basin. Future monitoring should focus on specific areas and issues. For example:

- Gas seepage near areas of high CBM well density, residential development, or the outcrop of the Vermejo Formation.

- Areas where vertical separation between water wells and CBM wells is small.

- Areas where specific complaints are made to the COGCC.

- Areas of potential future CBM development, where additional baseline data would be required to evaluate potential impacts.

It is also recommended that this network of water wells be resampled periodically to establish trends in ground water quality Basin wide.