Appendix D

Oil and Gas Methodology and Assumptions

1.0 Introduction

The following summarizes the basis and rationale for the assumptions used to analyze past, present, and reasonably foreseeable development (RFD) coal bed natural gas (CBNG) and conventional oil and gas activity in the Wyoming Powder River Basin (PRB) and the associated impact-causing parameters. The assumptions address segregation of past and present CBNG and conventional oil and gas wells from the IHS Inc. (IHS) data set, projection of RFD well numbers, lateral (east to west) migration of CBNG and conventional oil and gas wells over time, vertical allocation of CBNG wells within the three defined coal layers for the study (shallow, Wyodak, and deep), quantification of wells by subwatershed, production (hydrocarbon and water), groundwater discharge volumes by discharge method, and associated disturbance acreages.

Recently, the Wyoming Bureau of Land Management (BLM) State Office Reservoir Management Group (RMG) prepared updated oil and gas RFD projections for the Buffalo Field Office (FO) area (Stilwell et al. 2009) in support of the Buffalo Resource Management Plan (RMP) revision. The Stilwell et al. (2009) RFD projections contain more detail than earlier projections and include almost 10 additional years for CBNG activity in the Wyoming PRB. In addition, the number of CBNG and conventional oil and gas wells projected to be drilled in the Wyoming PRB was revised substantially. The Stilwell et al. (2009) data provide more accurate numbers of total conventional oil and gas wells drilled in the Buffalo FO portion of the PRB study area as well as better classification of currently active wells as summarized below.

- 13,250 total cumulative conventional oil and gas wells have been drilled as of March 2009;
- 4,146 active wells and wells that have not been classified as plugged and abandoned (P&A), including shut-in and idle wells. This category consists of wells of all types including producing wells and service wells (e.g., injectors, disposal wells, source water wells). Thirteen wells had an undetermined status due to confidentiality of reporting, so the number of wells not P&A but whose status could be defined is 4,133; and
- 9,104 P&A wells.

The Stilwell et al. (2009) data also provide the following numbers for CBNG development.

- 29,716 CBNG wells were drilled through 2008; and
- 26,064 “existing” CBNG wells as of January 2009.

Although not explicitly stated in the Stilwell et al. (2009) RFD projections, it can be deduced that 3,652 wells have been abandoned up to the end of 2008. Also, out of the “existing” well category, there is no breakdown of the number of producing wells, completed not yet producing wells, or wells that are shut-in and ready to be abandoned.

The assumptions and RFD well numbers developed by Stilwell et al. (2009) have been adopted for the PRB Coal Review, with minor modifications. The Stilwell et al. (2009) RFD projections used a planning period from 2009 to 2028. Since the time frame for the PRB Coal Review is to 2030, well numbers were adjusted to fit the time frame for this study. Because the difference is only 2 years, the incremental adjustments were minimal. Information from Crockett and Stilwell (2005) for the BLM Casper FO portion of the study area (northern Converse County) also has been used. (It should be noted that approximately 95 percent of the projected CBNG wells would be in the Buffalo FO area where the land use plan is not yet finalized. When finalized, the BLM anticipates the total projected number of CBNG wells would be lower than the current projections [BLM 2010c].)

Unconventional hydrocarbon resources are those oil and gas resources in accumulations "that historically have not been produced using traditional development practices including 'tight' sandstones, gas shales, and CBNG" (USGS National Resource Assessment Team 1995). A reasonable interpretation of this definition also would include oil and gas production from the Mowry, Niobrara, and other formations through the use of horizontal drilling techniques, plays that may constitute substantial conventional oil and gas exploration and production over the next 20 years in the Wyoming PRB. Unconventional hydrocarbon accumulations were included under "conventional" oil and gas in the Stilwell et al. (2009) RFD projections. For purposes of this study, the term "conventional" oil and gas has been used to refer to hydrocarbon resources that do not involve natural gas from coal seams.

The following sections summarize the assumptions used during Phase I of the study as documented in Appendix E of the Phase I update of the Task 2 report (AECOM 2009), the basis and rationale for development of new assumptions for Phase II of the study, and the Phase II assumptions.

2.0 Actual Active, New, and P&A Wells and Production Data Determination

The following assumption was used by the BLM for segregation of CBNG and conventional oil and gas wells in the IHS dataset during the Phase I update of the Task 2 report. This assumption has been retained for Phase II.

Assumptions in the Phase I Task 2 Report

1. Wells were categorized as CBNG or conventional based on their listed tax credit type. Those wells listed with a CBNG tax credit were categorized as such; remaining wells were categorized as conventional wells.

Phase II Assumptions and Methodology

For Phase II, the BLM used the following assumptions for sorting and categorizing the actual well data obtained from IHS and the WOGCC for years 2003 through 2009 (BLM 2011b). Assumptions relative to actual production and well locations also are included.

1. Wells were categorized as CBNG or conventional based on their listed tax credit type. Those wells listed with a CBNG tax credit were categorized as such; remaining wells were categorized as conventional wells.
2. Each well has only one type of status for the year, as follows:
   - If a well was reported as "Active" and "New" in the same year, it was counted as new only and the production deleted.
   - If a well was reported as "Active" and "P&A" in the same year, it was counted as P&A only and the production deleted.
   - If a well was reported as "Spud" and "P&A" in the same year, or "New" and "Inactive" and "P&A" in the same year, it was not included. (Note: Very few wells fell into these categories.)
   - If a well was reported as "New" and "Inactive" in the same year, it was counted as new only.
   - If a well was reported as "Inactive" and "P&A" in the same year, it was counted as P&A only.
3. If a well has a reported spud date for the year = new well.
4. If a well has any reported production (oil, gas, or water) for the year = active well.

5. If a well has a reported status of P&A for the year = P&A well.
6. If the WOGCC Land Type Code is: 10, 11, 12, 13, 14, 91, 93, 94 = federal well.
7. If the WOGCC Land Type Code is: 40, 41, 43, 46 = state well.
8. If the WOGCC Land Type Code is: 20, 23, 30, 31, 34, 36, 81, 83, 84 = fee well.
9. Production totals are as reported in IHS.
10. Reported well locations (latitudes and longitudes) are in NAD 27.

In addition, the following methodology and assumptions were used to determine the cumulative number of wells drilled, the cumulative number of wells P&A, and the number of inactive CBNG wells.

11. CBNG and conventional wells drilled prior to 2003 are reflected in the 2003 actual well numbers in the active or P&A categories or are assumed to have been P&A and successfully reclaimed prior to 2003.
12. Cumulative wells drilled and cumulative wells P&A were calculated as follow:
    - 2003 cumulative P&A = P&A for 2003
    - 2003 cumulative wells drilled = active + new + P&A for 2003
    - Cumulative P&A for subsequent years = previous year's cumulative P&A + P&A wells for year
    - Cumulative wells for subsequent years = previous year's cumulative wells drilled + new wells for year.
13. Inactive CBNG wells for year = calculated cumulative CBNG wells drilled for year – calculated cumulative CBNG wells P&A for year – CBNG wells reported as active for year – CBNG wells reported as new for year

3.0 Estimate of Future Conventional Oil and Gas Wells Drilled per Year

Assumptions in the Phase I Task 2 Report

The following assumptions were used during Phase I; they have been replaced with updated assumptions for Phase II.

1. Wells located in T34N through T58N are within the PRB study area.
2. The PRB would see a short-term increase in the number of operating wells in the region, followed by a slow decline.
3. Forty percent of wells drilled would be nonproductive and P&A within that year, and an additional 10 percent of active wells would be P&A each year.

Basis and Rationale for New Assumptions

The Stilwell et al. (2009) RFD projections provide an estimate of the number of conventional oil and gas wells that would be drilled over the period of 2009 to 2028, and imply P&A rates, as summarized below.

- 1,359 new wells would be drilled from 2009 through 2028, an average of 68 new wells per year.
- Twenty-five percent of the 1,359 new wells would be P&A from 2009 to the end of 2028, resulting in 340 P&A wells and 1,019 new wells for the planning period.

- Existing wells at the beginning of the RMP RFD planning period consisted of 4,146 currently active and non-active wells that have not been classified as P&A.
- The 4,146 existing wells include conventional oil and gas producers and service wells associated with conventional oil and gas production (injection, disposal, and source water wells).
- The existing 4,146 conventional oil and gas producers and service wells would decline to 2,524 wells by the end of 2028; a decline of approximately 40 percent or approximately 81 wells per year.
- There would be a total of 3,543 conventional oil and gas and associated service wells by the end of 2028.

Phase II Assumptions and Methodology

The following new assumptions are based on Stilwell et al. (2009) as discussed above and incrementally expanded to cover the PRB Coal Review's RFD time period (2009 through 2030) and to account for conventional oil and gas activity in the Casper FO portion of the study area. A new assumption also has been developed to provide a more precise description of the PRB study area.

1. All RFD wells would be located in the Wyoming PRB study area (see **Figure C-1** in **Appendix C** of this report). This area includes portions of Campbell, Converse, Johnson, and Sheridan counties.
2. An assumed 68 wells per year would be drilled in the Buffalo FO portion of the study area for a total of 1,496 new wells. The projection is assumed to be constant, with 68 new wells drilled each year.
3. In the Casper FO portion of the PRB study area, an assumed 313 conventional oil and gas wells would be drilled to 2030, and 25 percent of those wells would be directionally or horizontally drilled (see assumption Number 5 below). (The number of wells per year was based on the well density in Figure 22, Stilwell and Crockett [2005].)
4. The relative proportions of conventional oil and gas wells drilled on federal and state/fee acreage would be consistent throughout the study period.
5. Based on potential for shale gas development, continuous resource oil plays, and recovery of by-passed gas, assumed 25 percent of future conventional oil and gas wells would be directional or horizontal wells, and producers would have a nominal spacing of 320 acres (two wells per section).

4.0 Estimates of Future Active and P&A Conventional Oil and Gas Wells

Assumptions in the Phase 1 Task 2 Report

Based on the discussion above in Sections 2.0 and 3.0, the following Phase I assumptions have been replaced for Phase II.

1. Forty percent of new wells are unproductive and P&A within the first year after drilling.
2. Decline rates would be based on data provided by BLM RMG (2005).
3. The wells to be abandoned would not be dependent on geographic location.

4. Approximately 2,000 inactive (shut-in) wells exist within the PRB study area. Remaining wells designated as inactive in the IHS database are actually seasonally active. These wells were distributed proportionally to the active wells in the region.

Basis and Rationale for New Assumptions

See Section 3.0 relative to the active versus P&A allocation of newly drilled wells.

Phase II Assumptions and Methodology

1. Future active well numbers reflect actual 2009 conventional oil and gas wells with continuing production in future years in addition to new RFD wells. Actual 2009 wells with continuing production in future years include reported active wells as of 2009 (see Section 2.0).
2. Of the actual wells within the study area projected to have continuing production in future years, 81 wells per year would be assigned as P&A.
3. Twenty-five percent of newly drilled conventional oil and gas wells would be P&A the same year as drilled (17 wells per year in Buffalo FO portion of the study area and 4 wells per year in the Casper FO portion of the study area).
4. Assuming a constant P&A reduction of 25 percent per year for new wells, through 2030 there would be a total of 1,122 new active wells in the Buffalo FO area and approximately 235 new active wells in the Casper FO area. New active wells subsequently would be P&A based on an average well life of 9 years.

5.0 Estimate of the Number of Future Cumulative Conventional Oil and Gas Wells

Phase II Assumptions and Methodology

The following assumptions were used to calculate cumulative conventional oil and gas well numbers.

1. Cumulative wells drilled and cumulative wells P&A were calculated as follow:
   - Cumulative P&A wells for year = previous year's cumulative P&A + P&A wells for year
   - Cumulative wells for year = previous year's cumulative wells + new RFD wells for year

6.0 Allocation of Future Conventional Oil and Gas Wells by Subwatershed

Assumption in the Phase I Task 2 Report

The following assumption used during Phase I has been replaced with updated assumptions for Phase II.

1. The future distribution pattern of wells by subwatershed would be similar to distribution patterns through 2003.

Basis and Rationale for New Assumptions

Figure 58 in Stilwell et al. (2009) depicts the projected allocation of RFD conventional oil and gas well drilling activity. The well drilling density was broken down into categories ranging from very high (more than 30 wells from 2009 to 2028) to none.

The most recent RFD projections for the Casper FO portion of the study area are from Crockett and Stilwell (2005). The Casper FO portion of the PRB study area was predicted to have a conventional well drilling density characterized as low (2 to 20 additional wells per township) over the planning period of 2001 to 2020.

Phase II Assumptions and Methodology

1. The future distribution pattern of conventional oil and gas wells would reflect the drilling densities depicted in Figure 58 from Stilwell et al. (2009) and the drilling densities depicted in Figure 22 from Crockett and Stilwell (2005). Wells would be proportionately allocated into undrilled spacing units (e.g., 40, 80, or 160 acres depending on Wyoming Oil and Gas Conservation Commission [WOGCC] order) within the subwatersheds in the study area.
2. Projected conventional oil and gas wells proportionately would be distributed through 2030 based on available well locations, with 68 wells allocated per year in the Buffalo FO portion of the study area and 14 wells allocated per year in the Casper FO portion of the study area.
3. Abandonment would be allocated proportionately among the subwatersheds based on the number of active wells.
4. The density of projected new wells in the Buffalo FO portion of the study area was based on the projections shown in Figure 58 in Stilwell et al. (2009). The density of projected new wells in the Casper FO portion of the study area was based on the projections shown in Figure 22 in Crockett and Stilwell (2005).

7.0 Estimate of the Future Rate of CBNG Wells Drilled Per Subwatershed per Year

Assumptions in the Phase I Task 2 Report

The following assumptions were used during Phase I. Assumptions 1 and 2 have been replaced with updated assumptions, and assumptions 4 and 5 have been modified. Assumptions 3, 6, and 7 have been retained for Phase II.

1. The BLM Buffalo FO would issue 2,500 applications for permits to drill (APDs) per year through 2015. Starting in 2016, the number of federal permits issued per year would decline at a rate of 200 per year until 2020 to account for a tapering off of activity that is expected to occur after 25 years of activity in the play. The BLM Casper FO would issue 35 APDs per year through 2020. Of all federal APDs issued, 89.8 percent would be drilled (BLM RMG 2005).
2. The number of state/fee APDs that the WOGCC would issue would be proportional to the number of federal APDs issued by each BLM office, as well as to the amount of remaining available spacing for state/fee pads within the BLM field office boundaries. Of the state APDs issued, 72.4 percent would be drilled.
3. An average of 1.45 wells would be drilled per pad (BLM 2003).
4. Distribution of new wells in the PRB subwatersheds would be proportional to remaining available pads within the jurisdiction of each BLM office.

5. No significant CBNG development would occur outside of the Wasatch/Fort Union coal outcrop.
6. Technology used to extract CBNG would not change significantly during the time frame of this study.
7. Future wells will be drilled based on 80-acre spacing.

Basis and Rationale for New Assumptions

The well drilling and abandonment rates as depicted in Figure A1-8 in Stilwell et al. (2009) have been used for Phase II. Therefore, assumptions 1 and 2 above have been eliminated for Phase II. The CBNG development in the Casper FO portion of the study area is minor in comparison to the Buffalo FO, and the Casper FO RFD projections (Crockett and Stilwell 2005) show only a small area where CBNG drilling density could exceed 100 wells per township.

The potential for production in the Casper FO portion of the study area is mainly from Wyodak zone coals in the northernmost townships of Converse County. These coals pinch out to the south, and deep coals do not appear to have the potential for significant gas production in this area based on limited development in the Dry Fork Cheyenne River subwatershed. Therefore, it is estimated that approximately 700 conceptual wells through 2030 would be more likely in the Casper FO portion of the study area (BLM 2010c) than the approximately 900 conceptual wells previously projected in Crockett and Stilwell (2005).

The Buffalo FO RFD projections (Stilwell et al. 2009) estimate that 13,803 CBNG wells would be drilled from 2009 to 2028. Figure A1-9 in Stilwell et al. (2009) shows the development potential by township, ranging from very high (greater than 220 wells per township) to very low (less than 5 wells per township).

Recent WOGCC data provided by the BLM RMG indicate that the observed failure rate, or wells classified as “dry holes,” is approximately 0.9 percent. Incorporation of such a low failure rate would have little if any effect on projected well numbers; therefore, a failure rate has not been tracked in this study.

Retention of Phase I assumption 3 (1.45 wells per pad) is subject to revision if it is not reflective of current conditions. According to Stilwell et al. (2009), 9.18 percent of wells drilled before 2009 were on a pad with another well, and 18.96 percent of wells drilled after 2008 (between 2009 and 2028) would be on a well pad with another well (a ratio of 1.2 wells per pad for future wells). However, the PRB Coal Review differs slightly from Stilwell et al. (2009) in that: 1) the PRB Coal Review extends through 2030 (2 years longer); and 2) RFD wells are allocated vertically based on stratigraphy. Therefore, to ensure sufficient spacing for well allocations over time, the ratio of 1.45 wells per pad has been retained for this study.

Assumptions 4 and 5 have been retained with additional final densities as shown in Figure A1-9 in Stilwell et al. (2009).

Phase II Assumptions and Methodology

1. Future CBNG drilling rates per subwatershed would reflect the future drilling rates presented in Figure A1-8 in Stilwell et al. (2009) and in the maps and data provided by the BLM RMG (2010).
2. In the Casper FO portion of the study area, an assumed 32 wells would be drilled per year through 2030 (a total of approximately 700).
3. An average of 1.45 wells would be drilled per pad.
4. Distribution of new wells by subwatershed would be proportional to remaining available pad spacing within the jurisdiction of each BLM office. (Final densities shown in Figure A1-9 in Stilwell et al. [2009] would be incorporated.)

5. No significant CBNG development would occur outside of the Wasatch/Fort Union coal outcrop. (Final densities shown in Figure A1-9 in Stilwell et al. [2009] would be incorporated.)
6. Technology used to extract CBNG would not change significantly during the time frame of this study.
7. Future wells would be drilled based on an 80-acre spacing.
8. Based on the low observed failure rate (approximately 0.9 percent), a failure rate was not tracked.

8.0 Estimate of the Rate of P&A CBNG Wells per Subwatershed per Year

Assumptions in the Phase I Task 2 Report

The following assumptions were used during Phase I. Assumptions 1, 2, and 3 have been replaced, and assumption 4 has been retained for Phase II.

1. It is assumed that abandonment rates of new wells would be 4.1 percent (BLM RMG 2005).
2. Wells would be P&A between 8 and 12 years after they start producing, with the majority of wells abandoned after 10 years of operation (BLM RMG 2005). Wells with a first production year of 2003 or later were closed based on age according to Table E-2 (in Phase I Task 2 report update).
3. Rates of abandonment for wells active prior to 2003 with an untracked first production year would be similar to the average closure rate in each subwatershed between 2003 and 2008.
4. The distribution pattern of abandoned wells between subwatersheds would be proportional to the numbers of active wells in the subwatersheds.

Basis and Rationale for New Assumptions

Figure A1-8 in Stilwell et al. (2009) presents the annual historical and projected drilling and abandonment rates for CBNG wells. The projection of plugged wells goes to 2030.

Phase II Assumptions and Methodology

1. Future CBNG P&A rates per subwatershed reflect the future abandonment rates presented in Figure A1-8 in Stilwell et al. (2009).
2. The distribution pattern of abandoned wells between subwatersheds would be proportional to the number of active wells in the subwatersheds.
3. Approximately 11 percent of the actual 2009 inactive wells in each subwatershed would re-initiate production each year from 2010 through 2018 and, based on an average well life of 9 years, subsequently would be P&A from 2019 through 2027. (See Section 2.0 relative to actual 2009 P&A wells.)
4. Approximately 11 percent of the actual 2009 producing wells in each subwatershed would be P&A each year from 2010 through 2018, based on an average well life of 9 years.

9.0 Determination of Future Yearly Total Production of Oil, Natural Gas, and Water

Assumptions in the Phase I Task 2 Report

The following assumptions were used during Phase I. Assumption 1 has been retained for Phase II, and assumptions 2 and 3 have been modified. New assumptions also have been incorporated to reflect updated RFD projections from the BLM RMG.

1. While production from individual wells can vary greatly, because the number of wells is fairly large, the overall mean is representative of regional production.
2. The average rate of production per well would not change greatly over the period of this study.
3. Average annual production per subwatershed was based on the number of wells for each year divided into the total production each year, then averaged.

Basis and Rationale for New Assumptions

Two new assumptions have been added for Phase II to incorporate recent BLM information including: 1) production estimates in Crockett and Stilwell (2005) and Stilwell et al. (2009), and 2) projected CBNG groundwater production rates (Crockett 2011) based on the BLM RMG's CBNG groundwater production report (BLM 2011d, 2010e). The BLM RMG report was developed using historical information to determine the gas-to-water ratio and the application of the ratio to the RFD CBNG groundwater production projections. The report and the associated projected CBNG groundwater production rates are presented in **Appendix E** of this report.

CBNG production in the Buffalo FO portion of the study area was estimated based on the projected gas production in Figure A1-15 of Stilwell et al. (2009) and prorated among active wells in the respective subwatersheds. The Casper FO RFD (Crockett and Stillwell 2005) does not break out the estimated future CBNG production separate from overall future gas production. Therefore, CBNG production in the Casper FO portion of the study area also was based on the prorated annual production calculated from the Stilwell et al. (2009) estimates. Conventional oil and gas production for the study area was based on the average historic gas to oil ratio per subwatershed/well as calculated from IHS data, the projected oil and gas production rates per Stillwell et al. (2009), and the projected oil production rates per Crockett and Stillwell (2005). Conventional gas production in the Casper FO portion of the study area was estimated based on the projected oil production (Crockett and Stillwell 2005) and the average historic gas to oil ratios.

Phase II Assumptions and Methodology

1. While production from individual wells can vary greatly, because the number of wells is fairly large, the overall mean is representative of regional production.
2. The average rate of water production per CBNG well would not change greatly over the period of this study; however, gas production may vary.
3. Annual RFD conventional oil and gas production in the Buffalo FO portion of the study area was allocated on a subwatershed basis based on the projected number of active wells per subwatershed per year (see Section 3.0 above), the historic gas to oil ratio, and the projected annual oil and gas production provided in Table 5 from Stilwell et al. (2009). For the Casper FO portion of the study area, oil production rates was allocated on a subwatershed basis based on the projected number of active wells per subwatershed per year, the historic gas to oil ratio, and the projected annual oil production provided in Table 16 (Alternative E) from Crockett and

Stilwell (2005); gas production was estimated based on the per well oil production and the average historic gas to oil ratios.

4. Annual RFD CBNG production for the study area was allocated on a subwatershed basis based on the sum of: 1) the number of actual wells (active and idle wells) with production in the near-term RFD years (per Section 8.0) and the production decline rate provided in Stilwell et al. (2009), plus 2) the number of projected active wells per subwatershed per year (see Section 7.0 above) and the projected annual gas production provided in Stilwell et al. (2009).
5. Annual RFD CBNG groundwater production was allocated on a subwatershed basis (Crockett 2011) based on the projected number of active CBNG wells per subwatershed per year and the BLM RMG's CBNG groundwater production report (BLM 2011d, 2010e) (see **Appendix E**).
6. Annual RFD conventional groundwater production rates per Figure 32 in Stilwell et al. (2009) will be used. Produced groundwater will be allocated similarly to CBNG based on active wells per subwatershed per year.

10.0 Determination of Future Cumulative Values for Production of Oil, Natural Gas, and Water

Assumption in the Phase I Task 2 Report

Future cumulative production values were identified during Phase I by determining the estimated yearly production (products and water) for the yearly estimated number of wells and adding these to the previous year's cumulative estimate. The equation used is as follows:

Estimated cumulative production for given year = previous year estimated cumulative + current year estimated production

Basis and Rationale for New Assumptions

Conventional Production – Oil, Gas, and Water:

Table 5 from Stilwell et al. (2009) provides cumulative production estimates for conventional oil and gas wells. From 2009, oil is assumed to decline at a rate of 6.2 percent per year, for a total estimated cumulative production of 95,528,744 barrels by 2028. Conventional gas production is assumed to decline at a rate of 2.8 percent per year, for a total cumulative production of 183,837,588 thousand cubic feet (MCF) of gas by 2028. Using these decline rates, it is possible to extrapolate cumulative conventional oil and gas production to 2030 (99,929,832 barrels of oil and 197,105,606 Mcf gas).

Figure 32 in Stilwell et al. (2009) shows the actual cumulative water production to the end of 2008 of 3.5 billion barrels of water (BW). This figure shows cumulative and yearly conventional water production. The cumulative curve builds at a rate of approximately 100,000,000 BW per year over 35 years. Therefore, assuming water would be produced at a steady volume of 100,000,000 BW per year, cumulative water production would be 5.7 billion BW (approximately 735,000 acre-feet) by 2030.

CBNG Production – Gas and Water

Stilwell et al. (2009) estimated that cumulative CBNG production would be 8,671 billion cubic feet (Bcf) by 2028. Figure A1-15 in Stilwell et al. (2009) shows a production history with a peak in 2003-2004, a slight decline, and then another peak in 2009-2010; projected annual production then decreases steeply

to 2018, with another peak in 2026 to 2027 and a decline in 2028. The projected peak in 2026-2027 is slightly less than 300 Bcf per year.

The RFD projections in Stilwell et al. (2009) do not provide an estimated water production value with which to extrapolate cumulative water production from CBNG. Annual and cumulative water production was estimated by Bank and Kuuskraa (2006) based on water production data on historically-matched type wells from a variety of PRB CBNG developments. Cumulative gas production ranged from 0.08 to 0.66 Bcf and averaged 0.233 Bcf. Water production ranged from 75,000 to 1,400,000 barrels, with the average being approximately 370,000 barrels. The average gas production is remarkably close to the 0.223 Bcf of a "typical" well presented in the Stilwell et al. (2009) RFD projections; however, the water from a typical well in the RFD projections was 3.48 million barrels. This is much higher than what would be expected. As discussed in Section 9.0, the BLM RMG's CBNG groundwater production report (BLM 2011d, 2010e) (see **Appendix E**) provided the basis for calculation of the annual groundwater production values for this study. The calculated annual rates then provided the basis for calculation of the cumulative CBNG groundwater production.

Phase II Assumptions and Methodology

1. Cumulative conventional oil and gas production was calculated from 2003 forward based on cumulative 2003 production data from Phase I, the IHS actual data through 2008 (BLM 2011b), and the projected yearly production as discussed in Section 9.0.
2. Cumulative CBNG production was calculated from 2003 forward based on cumulative 2003 production data from Phase I, the IHS actual data through 2008 (BLM 2011b), the projected annual production presented in Stilwell et al. (2009) and Crockett and Stilwell (2005), and the township by township well projections provided by the BLM RMG (2010).
3. Cumulative conventional water production was calculated from 2003 forward based on cumulative 2003 water production data from Phase I, the IHS actual data through 2008 (BLM 2011b), and the projected annual data (see Section 9.0).
4. Cumulative CBNG water production was calculated from 2003 forward based on cumulative 2003 water production data from Phase I, the IHS actual data through 2008 (BLM 2011b), and the projected annual data (see Section 9.0).
5. Cumulative oil, conventional natural gas, CBNG, and associated water production were allocated on a subwatershed basis.

11.0 Determination of Water Injection and Discharge

Assumptions in the Phase I Task 2 Report

The following assumptions were used during Phase I. Assumption 2 has been retained for Phase II; assumption 1 has been eliminated.

1. Water reported in the IHS database for wells identified as injection is assumed to be the volume of water injected.
2. Water produced within a subwatershed either would be injected or discharged within the same subwatershed.

Phase II Assumptions and Methodology

1. Water produced within a subwatershed either would be injected or discharged within the same subwatershed. (Note: Percent of water discharged by method is discussed in Section 13.0.)

12.0 Estimate of Disturbed and Reclaimed Acreage Related to Conventional Oil and Gas and CBNG Activities

Assumptions in the Phase I Task 2 Report

The following assumptions were used during Phase I. Assumptions 1, 3, and 4 have been modified for Phase II; Assumption 2 has been eliminated.

1. The estimated per-well disturbance acreages would not change during the study (initial disturbance of 2.75 acres for conventional oil and gas wells and 5.2 acres for CBNG wells). Each per-pad disturbance acreage also accounts for a portion of the associated ancillary facilities (i.e., roads, gathering lines, power lines, and water handling facilities, as applicable).
2. Overall disturbance would be distributed evenly among wells.
3. A portion of the short-term disturbance would be reclaimed within the year after the well is drilled (0.75 acre for each conventional oil and gas well and 2.8 acres for each CBNG well).
4. Long-term disturbance due to CBNG and conventional oil and gas wells would be reclaimed within the year wells are listed as abandoned (2.0 acres for each conventional oil and gas wells and 2.4 acres for each CBNG well). This accounts for reclamation of associated roads, pipelines, water handling facilities, etc., as proportionally included in the disturbance acreage for each pad."

Basis and Rationale for New Assumptions

Stillwell et al. (2009) provides the following lists of disturbance assumptions for CNBG wells:

- Reclamation would not be completed until 2 years after well abandonment.
- Ten percent of the CBNG wells that reach their economic limit would be converted to water wells. BLM-managed wells would be released via a signed agreement. Surface disturbance would no longer be credited to CBNG activity.
- Only 50 percent of the roads would be reclaimed after well abandonment, this applies to both federal and non-federal surface. Unreclaimed roads would not be used for CBNG operations.
- Constructed well pads are 0.9 acre, with initial reclamation to 0.5 acre in 2 years (constructed well pads are built using earth moving equipment).
- Non-constructed well pads are 0.9 acre, with initial reclamation to 0.3 acre in 2 years (non constructed well pads are established by driving on top of the natural surface).
- Federal wells include both public domain and split estate.
- Flow lines follow roads and would not add additional long-term (over 2 years) surface disturbance.
- The area in acres disturbed initially by roads and flow lines for an undrilled location would be 2.07 acres; after initial reclamation it would be 0.92 acre.
- Approximately 25 percent of the wells drilled before 2008 had constructed pads, and approximately 70 percent of the wells drilled after 2008 would have constructed pads.
- At the end of 2028, there would be an estimated 10,460 active CBNG wells in the Buffalo FO area, based on calculated abandonment rates.
- During 1990-2008, 24.13 percent of all the wells drilled were on federal surface (public domain.).

- During 2009-2028, 59.55 percent of the wells drilled would be on federal minerals, and 27.89 percent would be on federal surface.

The CBNG-related disturbance acreages used during Phase I have been updated for Phase II to reflect the more recent assumptions summarized above from Stilwell et al. (2009). For purposes of the PRB Coal Review, one short-term (initial 2-year) disturbance acreage and one long-term (operational well life) disturbance acreage has been applied on a per well basis throughout the Wyoming PRB study area and throughout the time frame of the study (through 2030). Based on the Stilwell et al. (2009) assumptions, the most conservative short-term and long-term disturbance acreages would be 3.0 and 1.4 acres per well, respectively. These acreages include the disturbance acreage for the pad and the associated proportional disturbance acreage for the road and flow line (i.e., pipelines). While not explicitly stated in Stilwell et al. (2009), a disturbance factor for CBNG-related water impoundments can be calculated based on information present therein and other information provided by the BLM RMG. Stilwell et al. (2009) states that at the beginning of 2008, "total estimated disturbance due to water impoundments was approximately 19,548 acres in the Buffalo FO area." Assuming 25,762 existing wells at the beginning of 2008, the long-term disturbance would have been 0.80 acres per well. For purposes of this study, this per well acreage also has been applied to future wells, and the disturbance factor for water handling facilities (impoundments) has been considered to apply for the lifetime of the well. Therefore, the short-term and long-term per well disturbance acreages are assumed to be 3.8 and 2.2 acres, respectively. It is assumed that long-term disturbance (less 50 percent of the related per well road disturbance as discussed below) would be reclaimed within the year a well is abandoned.

Per the Stilwell et al. (2009) assumptions identified above, 10 percent of the CBNG wells that reach their economic life would be converted to water wells, and only 50 percent of the roads would be reclaimed. With a long-term per well pad disturbance of 0.5 acre, it is probable that most if not all of the pad disturbance area would be reclaimed following well conversion. Therefore, for purposes of this study, it is assumed that the well pads associated with converted wells would be reclaimed in the year that the wells reach the end of their productive lives. Retention of 50 percent of the roads for non-CBNG purposes (per Stilwell et al. [2009]) would result in a permanent disturbance. Based on a long-term per well road disturbance of 0.9 acre, permanent disturbance would be allocated on a subwatershed basis based on a per well permanent disturbance of 0.45 acre.

For CBNG wells, it is anticipated that a greater portion of future wells would be drilled on federal minerals than occurred up to 2008. Since much of the available state and fee acreage has been drilled, most of the remainder would be drilled on federal minerals. However, the available space to drill wells dictates final distribution.

Conventional oil and gas disturbance assumptions in Stilwell et al. (2009) are the same as used for Phase I of the PRB Coal Review (new short-term disturbance of 2.75 acres and long-term disturbance of 2.0 acres), and have been carried forward for Phase II. Different disturbance assumptions were used for the Casper FO RFD projections (Crockett and Stilwell 2005), probably based on depth and size of well locations needed. However, it has been assumed for the PRB Coal Review that conventional wells in the Casper FO portion of the study area are comparable in depth range to those in the Buffalo FO area, and that the disturbance assumptions used by Stilwell et al. (2009) as listed above are reasonable estimates for disturbance in the Casper FO portion of the study area.

Phase II Assumptions and Methodology

1. The estimated per-well disturbance acreages for conventional oil and gas wells would not change during the study (short-term [initial 2-year] disturbance of 2.75 acres and long-term [operational well life] of 2.0 acres). The disturbance assumptions apply to the entire study area, including the Casper FO portion. Each per-pad disturbance acreage also accounts for a portion of the associated ancillary facilities (i.e., roads, gathering lines, power lines, and water handling facilities, as applicable).

2. The estimated per-well disturbance acreages for CBNG wells would not change during the study (short-term [initial 2-year] disturbance of 3.8 acres and long-term [operational well life] of 2.2 acres). The disturbance assumptions apply to the entire study area, including the Casper FO portion. Each per-pad disturbance acreage also accounts for a portion of the associated ancillary facilities (i.e., roads, gathering lines, power lines, and water handling facilities).
3. Long-term disturbance due to conventional oil and gas wells (2.0 acres per well) would be reclaimed within the year the wells are identified as abandoned.
4. Ten percent of the CBNG wells that reach their economic life would be converted to water wells, with the pads reclaimed following conversion.
5. Of the 2.2 total acres of long-term disturbance per CBNG well, 1.75 acres would be reclaimed within the year the wells are indentified as abandoned. Fifty percent of the associated roads would be retained for purposes other than CBNG activity: therefore, the remaining 0.45-acre per well would represent permanent disturbance. The permanent disturbance would be allocated on a subwatershed basis.
6. Cumulative disturbance and reclamation acreages reflect 2003 CBNG and conventional oil and gas activity forward. (See assumption 11 in Section 2.0 relative to wells drilled prior to 2003.)

13.0 Estimate of the Volume of Water Disposed by Various Disposal Methods

Assumptions in the Phase I Task 2 Report

The following assumptions were used in Phase I. They have been replaced with an updated assumption for Phase II.

1. It is assumed that the percent of total produced water discharged to impoundments, outfalls, or through injection in each subwatershed would be allocated per the PRB Oil and Gas Final EIS (BLM 2003) estimates.
2. It is assumed that water disposal in subwatersheds without an indicated allocation in the PRB Oil and Gas Final EIS (BLM 2003) would be the same as identified in that document for the Clear Creek subwatershed.

Basis and Rationale for New Assumptions

Water disposal by disposal method was not addressed in the BLMs updated RFD projections (Stilwell et al. 2009; Crockett and Stilwell 2005). Alternately, reported CBNG discharge water volumes by discharge method were obtained from the WDEQ – Water Quality Division (WQD) for the period of January 1, 2008, through August 1, 2010. Discharge locations were assigned to subwatersheds using GIS, and the percent of water discharge by discharge method for each subwatershed subsequently was calculated as discussed below.

Phase II Assumptions and Methodology

1. The percent of total produced water discharged to impoundments, outfalls, or through injection in each subwatershed were allocated per **Table D-1**.

Table D-1 Percent of Total CBNG Water Production per Discharge Method[1,2,3]

Subwatershed (Receiving Water)	Headwater Reservoir or Unlined Off-channel Containment[4]	Unlined On-channel Containment or Direct Discharge to Drainage[5]	Playa Lake Containment[6]	Injection
Antelope Creek	NA	100	NA	NA
Clear Creek	91	NA	NA	9.0
Crazy Woman Creek	57.6	14.3	NA	28.1
Dry Fork Cheyenne River	NA	100	NA	NA
Lightning Creek	NA	100	NA	NA
Little Powder River	3.2	94.7	0.3	1.8
Middle Powder River	0.0	100	0.0	0.0
Salt Creek	NA	0.8	NA	99.2
Upper Belle Fourche River	0.1	99.9	0.0	NA
Upper Cheyenne River	NA	42.2	57.8	NA
Upper Powder River	1.5	96.8	0.2	1.5
Upper Tongue River	80	16.4	1.6	2.0

[1] Based on WDEQ (2010a,c) CBNG discharge monitoring reports for the period of January 1, 2008, through August 1, 2010. Does not include discharge to off-channel impoundments permitted by WOGCC.

[2] The percentages shown are not upper thresholds that can or would be enforced. They are merely a disclosure of effects of one of many various ways water may be handled to meet Wyoming's water quality standards and agreements with bordering states.

[3] The percentages shown represent the distribution of water handling methods assumed for the analysis, not the amount of water that actually reaches the river.

[4] Discharge to a headwater reservoir has requirements mandating containment of all effluent in addition to storm water runoff from a 50-year/24-hour storm event. Headwater reservoirs typically are not lined (WDEQ 2010b) and have less than 40 acres of contributing area (BLM 2011a).

[5] Direct discharges to drainages in the Powder River and Tongue River drainages typically are treated for sodium adsorption ratio and/or electrical conductivity.

[6] Discharge to a topographically and hydrologically isolated playa lake.

Notes:

NA = not applicable; no produced water discharge by identified category.

Percentages of 0.0 indicate total water production of less than 0.1 percent.

Percentages apply to CBNG and conventional oil and gas wells for this study. Conventional well water disposal (in the Little Missouri River, Middle Fork Powder River, Middle North Platte River, and South Fork Powder River subwatersheds are assumed to be allocated per Crazy Woman Creek, for which allocation is distributed to the primary disposal methods.

14.0 Migration of CBNG Wells Over Time

During Phase I, BLM developed the projected migration pattern of CBNG wells over time for use in the air and groundwater models. The assumptions and methodology used for Phase II are presented below.

Basis and Rationale for New Assumptions

Although Plan of Development (POD) approval is not a definitive indicator of imminent CBNG development, it can indicate areas that may have a higher likelihood of development in the near-term (3 to 5 years). Therefore, recent PODs and data provided by the Buffalo FO were used to determine the near-term CBNG development patterns.

Well migration patterns over time were developed based on the BLM RMG's (2010) maps of projected well numbers by township in the Wyoming PRB, the projected number of wells drilled per year in the Buffalo FO as provided in Figure A1-8 in Stilwell et al. (2009) (see Section 7.0 above), and recent PODs. Using the BLM RMG's maps, groups of townships were selected for well migration for each future year, with the sum of the projected wells similar to each year's well development projection as provided in Figure A1-8 (Stilwell et al. 2009). Initial townships chosen for well migration were based on recently approved PODs. It is recognized that the number of locations in the PODs may not equal the number of wells projected by the BLM RMG in a given township.

Stilwell et al. (2009) assumed that well life begins on the date of first production, and the average well life is 9 years. Depleted wells could be shut-in for long periods before abandonment actually occurs. However, it is assumed that the abandonment rates presented by Stilwell et al. (2009) are consistent with the stated 9-year well life indicated above.

Phase II Assumptions and Methodology

1. The migration of new CBNG wells and abandonment of CBNG wells over time generally would be from east to west across the study area, with infilling, as appropriate, based on the known extent of the coals and other factors as described below.
2. Based on the BLM RMG map of projected CBNG well numbers by township in the Wyoming PRB, the number of wells drilled per year in the Buffalo FO portion of the study area would approximate the projection provided in Figure A1-8 in Stilwell et al. (2009).
3. For the Buffalo FO portion of the study area, townships identified for near-term (3 to 5 years) CBNG well development would be based on Buffalo FO data and PODs that were approved from 2008 to June 2010 (BLM 2010b). Beyond that timeframe, townships would be selected based on each year's new CBNG well development projection as provided in Figure A1-8 (Stilwell et al. 2009) and the BLM RMG's maps of future well distribution by township.
4. For the Casper FO portion of the study area, wells were migrated in accordance with the BLM RMG's maps of projected CBNG wells per township and a rate of approximately 32 wells per year.
5. Wells in the Buffalo FO portion of the study area would be abandoned at rates shown in Figure A1-8 in Stilwell et al. (2009). Wells in the Casper FO portion of the study area would be abandoned based on an average well life of 9 years.

15.0 Producing Zone Allocation of CBNG Wells

For Phase II, CBNG wells were allocated by production zone, based on stratigraphy, for use in the groundwater model as discussed below.

Basis and Rationale for New Assumptions

The percent allocation of CBNG wells by subwatershed and production zone was based on information provided by the BLM RMG as discussed below.

Much of the early CBNG development in the Wyoming PRB study area occurred in subwatersheds where the primary target was the Wyodak coals. Based on the remaining available well locations, some of these subwatersheds are approaching full development. Historical data from IHS through 2009 for CBNG wells in the Wyoming PRB study area indicate a basin-wide average completion ratio of 81 percent Wyodak coals and 19 percent deep coals; the shallow coals (above the Wyodak) comprise less than 1 percent of the development. No defined upward or downward trends in these ratios were observed in the historical data through 2009. Ratios of Wyodak coals to deep coals in individual subwatersheds vary greatly. The Clear Creek, Crazy Woman Creek, and Middle Powder River subwatersheds have a high level of remaining development potential (based on the number of undrilled well locations) and historically have had the deep coals as a primary target. These conditions indicate that an overall larger percentage of the future wells in the PRB study area would be to deeper coals. Historically, there has been no drilling in the Lightning Creek subwatershed; however, it was assumed that all projected future drilling would be to the deeper coals (based on coal stratigraphy) (BLM 2010a).

Considering the coal stratigraphy of each subwatershed and applying the historic drilling ratio of each subwatershed to the number of wells projected to be drilled resulted in an overall basin-wide average percentages as follows: 3 percent shallow coals, 68 percent Wyodak coals, and 29 percent deep coals (see **Table D-2**). This ratio also takes into account the projections made on the Antelope Creek subwatershed to consider the transition from drilling mostly to the Wyodak coals in the north to drilling to the deep coals in the south.

Phase II Assumption and Methodology

1. A coal nomenclature was used that divides the coals into the following zones: shallow coals, Wyodak Zone, and deep coals as shown in **Table D-3**.
2. Shallow coals (coals above the Wyodak Zone) currently comprise less than 1 percent, and are projected to comprise approximately 3 percent, of all completions and do not significantly contribute to water or gas production.
3. The vertical allocation of actual wells to production zone for each subwatershed was based on the percent distribution by coal zone for each subwatershed as provided by the BLM (2011c, 2010a) (see **Table D-2**).
4. The vertical allocation of RFD CBNG wells was based on the lateral migration (temporal and spatial) of CBNG wells described above in Section 14. 0 and the percent distribution by coal zone for each subwatershed as provided by the BLM (2011c) (see **Table D-2**).

Table D-2 Predicted Vertical CBNG Well Allocation per Subwatershed

Subwatershed[1]	Percent Allocated per Coal Zone		
	Shallow	Wyodak	Deep
Antelope Creek[2]	0	73	27
Clear Creek	23	26	51
Crazy Woman Creek	2	39	59
Dry Fork Cheyenne River	0	0	100
Lightning Creek	0	0	100
Little Powder River	0	67	33
Middle Powder River	0	31	69
Salt Creek	0	100	0
Upper Belle Fourche River	0	98	2
Upper Cheyenne River	0	100	0
Upper Powder River	1	82	17
Upper Tongue River	0	87	13
Total Wells	**3**	**68**	**29**

[1] Only subwatersheds in the study area for which CBNG activity currently exists or is projected to occur are included.

[2] Projected future allocation for Antelope Creek subwatershed reflects overall percentages based on different allocations to Wyodak coals and deep coals for three sections of the subwatershed: 1) 90 percent Wyodak coals and 10 percent deep coals north of T40N; 2) 50 percent Wyodak coals and 50 percent deep coals within T40N (transition zone); and 3) 100 percent deep coals south of T40N.

Source: BLM 2011c, 2010a.

16.0 Other Assumptions

The following additional assumptions apply to Phase II.

1. Methanogenesis is an unproven and not as yet approved technology. Therefore, it was not included in the RFD scenario. (The RFD projections by Stilwell et al. [2009] provide no guidance relative numbers of wells that might be engaged in such activity.)
2. Oil mining activity was not considered in this study since oil mining activities do not occur within the study area.

Table D-3 Historic Coal Bed Names as Related to the Coal Bed Categories for the PRB Coal Review

Coal Bed Categories/ Geologic Units	Original Coal Bed Names		Previous Coal Bed Names		USGS[1]		WSGS	Goolsby and Finley
	Taff 1909	Mapel 1973	Montana	Wyoming	Montana	Wyoming	Wyoming	Wyoming
Shallow Coals: Wasatch Formation and Alluvium						Ulm 1 Ulm 2 (Healy) Ucross Wyamo Felix	Buffalo Cameron Murray Ucross Felix Arvada	
Wyodak Coals: Fort Union Formation, Upper Tongue River Member Wyodak-Anderson Coal Zone	Dietz 1 Dietz 2 Dietz 3	Upper Wyodak Lower Wyodak	Roland Smith Anderson Dietz 1 Dietz 2	Roland Smith/Swartz Anderson (Wyodak) Canyon (Big George)	Roland/Smith Dietz 1 Dietz 2 Dietz 3	Roland, Smith, Swartz Upper Wyodak (lower/upper, middle/upper, and upper/upper) Lower Wyodak (lower/lower, middle/lower, and upper/lower)	Roland Smith Anderson Canyon Big George	Smith Swartz Anderson Canyon Cook Wall Wyodak
Deep Coals: Fort Union Formation Lower Tongue River Member Deep Coals			Canyon Cook Otter Wall Pawnee Cache Sawyer Knobloch Flowers/Goodale Terret	Carney Werner Gates Kennedy Carson Broadus Roberts Kendrick	Canyon Cook Otter Wall Pawnee Cache Sawyer Knobloch Flowers/Goodale Terret	Carney Werner Gates Kennedy Carson Broadus Roberts Kendrick	Cook Wall Pawnee Moyer	Pawnee Cache

[1] The USGS Wyodak coal zone includes the following coals: Roland, Smith, Swartz, Anderson, Canyon, Big George, Sussex Coal (Hardie and van Gosen 1986), Badger, School, and Wyodak.

Sources: Flores et al. 2010; Goolsby and Finley 2000; Jones and Rodgers 2007.

17.0 References

AECOM. 2009. Update of the Task 2 Report for the Powder River Basin Coal Review Past and Present and Reasonably Foreseeable Development Activities. Prepared for the Bureau of Land Management, High Plains District Office and Wyoming State Office. December 2009.

Bank, G. C. and V. A. Kuuskraa. 2006. The Economics of Powder River Basin Coalbed Methane Development. U.S. Department of Energy. Prepared by Advanced Resources International, Inc. 98 p. January 2006.

Bureau of Land Management (BLM). 2011a. Clarification Regarding Headwater Reservoirs Provided by M. Brogan, BLM, to M. Giere, AECOM. January 14, 2011.

_____. 2011b.Revised actual 2003-2010 CBNG and conventional oil and gas data, well location files, and associated assumptions provided by A. Meeks, BLM, to M. Giere, AECOM. October 13, 2011.

_____. 2011c. Percent allocation of CBNG wells per coal zone for the Salt Creek Subwatershed provided by M. Brogan, BLM, to M. Giere, AECOM. October 5, 2011.

_____. 2011d. Summary of 2011 Update to [CBNG Water] Pumpage Rate Estimates. December 22, 2011.

_____. 2010a. Information and table provided by M. Brogan, and F. Crockett, BLM, to M. Giere, AECOM, regarding CBNG drilling by production zone and subwatershed. September 23, 2010.

_____. 2010b. PODs Approved Under PRB EIS. Internet website: http://www.blm/gov/wy/st/en/field_offices/Buffalo/minerals.html. Accessed on July 2, 2010.

_____. 2010c. Information provided by F. Crockett, BLM, to W. Berg, AECOM, relative to project CBNG well numbers for Converse County. Meeting July 21, 2010.

_____. 2010d. Information provided by M. Brogan, BLM, to M. Giere, AECOM, relative to projected CBNG well numbers for the Buffalo Field Office area. September 22, 2010.

_____. 2010e. Estimation of CBNG Groundwater Pumpage Rates for Drainage Basins in the Powder River Basin, Wyoming – Final. Prepared by F. Crockett, BLM Wyoming State Office, Reservoir Management Group, Cheyenne, Wyoming. December 2010.

_____. 2003. Final Environmental Impact Statement and Proposed Plan Amendment for the Powder River Basin Oil and Gas Project. Wyoming State Office and Buffalo Field Office, Cheyenne and Casper, Wyoming. January 2003.

_____. 2001. Reasonably Foreseeable Development Scenario for Oil and Gas Development in the Buffalo Field Office Area, Wyoming. Internet website: http://www.blm.gov/wy/st/en/info/NEPA/bfodocs/prb_eis.html. Accessed on April 12, 2010.

Bureau of Land Management (BLM) Reservoir Management Group (RMG). 2010. Maps provided by F. Crockett, BLM RMG, to W. Berg, AECOM, providing RFD CBNG well numbers per township in the Wyoming PRB study area. April 28, 2010.

_____. 2005. Wyoming State Office. Personal communications with W. Berg and D. Dufresne, ENSR. March and April 2005.

Crockett, F. 2011. Projected CBNG water production data through 2030 provided by F. Crockett, Bureau of Land Management Reservoir Management Group, to M. Giere, AECOM. December 2011

Crockett, F. and D. Stilwell. 2005. Reasonable Foreseeable Development Scenario for Oil and Gas, Casper Field Office, Wyoming. Internet website: http://www.blm.gov/wy/st/en/programs/Planning/rmps/casper.html. Accessed on April 15, 2010.

Flores, R. M., B. D. Spear, S. A. Kinney, P. A. Purchase, and C. M. Gallagher. 2010. After a Century - Revised Paleogene Coal Stratigraphy, Correlation, and Deposition, Powder River Basin, Wyoming and Montana. U.S. Geological Professional Paper 1777. 97 p. September 2010.

Goolsby, J. E. and A. K. Finley. 2000. Correlation of Fort Union Coals in the Powder River Basin, Wyoming: A Proposed New Concept. In: Classical Wyoming Geology in the New Millennium; 51st Field Conference Guide Book, 2000. Wyoming Geological Association. Casper, Wyoming. pages 51-74.

Jones, N. R. and J. R. Rodgers. 2007. Coal Correlation and Coal Zones in the Powder River Basin Wyoming. Wyoming State Geological Survey Open File Report 07-3F.

Stilwell, D., S. W. Davis, A. M. Elser, and F. Crockett. 2009. Reasonable Foreseeable Development Scenario for Oil and Gas Buffalo Field Office Planning Area, Wyoming. Internet website: http://www.blm.gov/wy/st/en/programs/Planning/rmps/buffalo/docs.html. Accessed on April 12, 2010.

U.S. Geological Survey National Resource Assessment Team. 1995. 1995 Assessment of United States Oil and Gas Resources. U.S. Geological Survey Circular 1118, 30 p. Internet website: http://energy.cr.usgs.gov/oilgas/noga/1995.html. Accessed on April 12, 2010.

Wyoming Department of Environmental Quality - Water Quality Division (WDEQ-WQD). 2010a. CBNG discharge water volumes by discharge method for the period of January 1, 2008, through August 1, 2010, provided by K. Shreve, Environmental Program Principal, WDEQ-WQD, to D. Fetter, AECOM. August 3, 2010.

_____. 2010b. Information relative to headwater reservoirs provided by K. Shreve, Environmental Program Principal, WDEQ-WQD, to D. Fetter, AECOM. August 5, 2010.

_____. 2010c. CBNG discharge water injection volumes provided by A. Nunn, WDEQ-WQD, to D. Fetter, AECOM. September 13, 2010.