2.0 TECHNICAL APPROACH

Two separate technical approaches were used to estimate future groundwater and surface water impacts in the eastern PRB of Wyoming. Groundwater modeling was conducted for the eastern PRB of Wyoming using the CMGM that was developed for the PRB Coal Review study. The protocol for the CMGM, a summary of the calibration report (Environmental Simulations, Inc. [ESI] 2009), and a discussion of the modeling results for the base year (2002) conditions are presented in the Task 1B report (AECOM 2009a).

For surface water, the Surface Water Quality Analysis Technical Report (Greystone and ALL Consulting 2003) was reviewed and updated for the PRB Coal Review. The update included adjustment of the models to include more current data and the application of more current research and field studies to issues such as channel stability and the impacts of CBNG-related groundwater disposal to ephemeral or intermittent drainages. The results of the surface water cumulative effects analysis for the PRB Coal Review are presented in the Task 3B Water Resources Cumulative Impact Assessment Water Quality and Channel Stability (ACE 2009) report and summarized in this Task 3B report.

A separate channel stability evaluation was conducted by ACE, with the results included in the Task 3B Water Resources Cumulative Impact Assessment Water Quality and Channel Stability (ACE 2009). A summary of that evaluation, including a brief description of the technical approach, is presented in Chapter 4.0 of this Task 3B report.

2.1 Groundwater

For groundwater, the technical approach included the development of a groundwater model for the eastern PRB that used as a starting basis the original regional PRB groundwater model developed by Applied Hydrology Associates (AHA) and Greystone Environmental Consultants, Inc. (GEC) (2002) for the PRB Oil and Gas EIS (BLM 2003). The resulting CMGM focused on the coal mines in the eastern PRB of Wyoming and the zone within 25 miles to the west of the coal mines impacted by CBNG development. The CMGM is discussed in detail in the Task 1B report (AECOM 2009a) and in the Groundwater Model Calibration Report (ESI 2009). A brief summary of the CMGM development is presented below.

2.1.1 Groundwater Modeling Approach

To construct the CMGM, AECOM and ESI first enhanced the original regional PRB groundwater model (AHA and GEC 2002) in order to make the regional PRB groundwater model more reflective of hydrologic conditions in the PRB and to allow the model to run more efficiently. Prior to constructing the CMGM model, the original regional PRB groundwater model was revised by making changes to the model layers and the model boundary conditions. These changes, and other enhancements discussed below, resulted in a revised regional PRB groundwater model. The revised regional PRB model was recalibrated and then telescoped to produce the CMGM.

Enhancements made to the regional PRB groundwater model prior to recalibration included: 1) reducing the number of model layers from 17 geologic units to 6 hydrostratigraphic units (HSUs);

2) extending the eastern model domain to the east and adding a MODFLOW general head boundary along the southeastern side of the model domain east of the coal mines located south of Gillette, Wyoming, for the Upper Fort Union HSU (model Layer 5); 3) replacing the constant heads used for ephemeral streams in the PRB with MODFLOW drain cells; 4) replacing drain cells used for CBNG wells with the MODFLOW well package; 5) refining the position of the contact between the Wasatch and Upper Fort Union in the area of the coal mines; 6) adjusting the amount of recharge to model Layer 1 from CBNG discharge to reflect studies estimating recharge from CBNG discharge to ephemeral streams; 7) use of MODFLOW2000 instead of MODFLOW96 for the modeling code; and 8) adding additional monitoring well targets around the coal mines from the Gillette Area Groundwater Modeling Organization (GAGMO) databases for 1990 and 2002. These enhancements resulted in a revised regional PRB groundwater model that more accurately reflects hydrologic conditions and groundwater flow in the PRB, provides the modeler with more flexibility in model construction and operation, and allows the model to run more efficiently.

Once the revised regional PRB groundwater model was recalibrated, the telescoped submodel (the CMGM) was made for the area of the eastern PRB that contains the active coal mines and CBNG activity using the telescopic mesh refinement capabilities of ESI's Groundwater Vistas (version 4.1). Additional enhancements that were made to the CMGM included: 1) a tighter grid spacing of 0.25 mile throughout the model domain, replacing the 0.5-mile grid spacing in the revised regional PRB groundwater model, to better assess groundwater drawdown impacts near the coal mines; 2) merging the stratigraphy in the revised regional PRB groundwater model (Goolsby, Finley, and Associates 2001) with the more detailed coal stratigraphy around the coal mines (BLM 2005), and adjustment of layer thicknesses and transmissivity where the two stratigrpahic models merged to allow for a smooth transition between the stratigraphic models; 3) use of a minimum hydraulic conductivity value of 0.20 meter per day for the Upper Fort Union (model Layer 5); 4) addition of a set of MODFLOW specified head cells along the southern boundary of the model domain in the Upper Fort Union (model Layer 5); and 5) adjustment of the Belle Fourche River base elevation to reflect the actual river base level along its course in the CMGM. These enhancements enable the CMGM to more accurately represent the hydrologic interactions between aquifer units, groundwater flow between aquifers and streams, and groundwater pumpage in the zone of overlap between coal mining and CBNG activity in the eastern PRB. Other changes to the CMGM and the revised regional PRB groundwater model are discussed in the Task 1B report (AECOM 2009a).

Since the purpose of the CMGM was to predict cumulative impacts near the coal mines, it was important that the model be calibrated both regionally and in the vicinity of the coal mines. Therefore, additional water level data were used in calibration of both the revised regional PRB groundwater model and the CMGM, thereby making it possible to directly compare the calibration results between the two models. These data included the following:

- GAGMO water level data measured prior to 1980. These data are termed "base year" water levels in the GAGMO database and were measured at the time the well was drilled.
- GAGMO water level data for 1990.
- GAGMO water level data for years from 1990 to 2002.

- GAGMO water level hydrographs for 18 wells near the coal mines.
- Wasatch monitoring wells near the coal mines available from WDEQ/LQD files (70 additional monitoring wells).
- BLM monitoring wells in the eastern PRB and private wells east of the coal mines that were screened in the Upper Fort Union.

In total, an additional 70 monitoring wells in the Wasatch Formation were added to the CMGM for better calibration in the Wasatch near the coal mines. The CMGM subsequently was calibrated to year 2002 for the eastern PRB and verified with transient calibration to 18 well hydrographs near the coal mines for year 2003.

Predictive simulations using the CMGM were used to estimate the cumulative impacts on groundwater resources in the model domain due to CBNG development and coal mining activities from the calibration years of 1990 and 2002 to year 2020. Predictive simulations were modeled for years 2010, 2015, and 2020, as selected by the BLM and presented in the report.

Resaturation of coal mine backfill material for the predictive years was simulated based on the projected progression and reclamation of coal mines during the predictive periods (2010, 2015, and 2020) as provided by BLM (2007b). Separate predictive scenarios were simulated for year 2050, a time period representing the hypothetical end of coal mining in the eastern PRB, through steady state. For purposes of post-mining resaturation modeling, it also was assumed that CBNG development would end in 2030. The hypothetical predictive runs for 2050 through steady state were used to determine the final rebound of groundwater levels in the Wasatch and Fort Union aquifers and changes to the hydrology of these aquifers due to the presence of mine backfill in areas previously mined for coal.

2.1.2 Estimation of Future Coal Mine Groundwater Pumpage

The projected locations of coal mine pits from 2002 to 2020, as provided by the BLM (2007b), were used for placement of the MODFLOW drain cells that were used to represent pumpage of groundwater by the coal mines in the CMGM. The conductance of the drain cells used for the mine pits was set during model calibration. Thus, the amount of groundwater removed by the drain cells reflects calibration to GAGMO monitoring wells surrounding each mine, rather than estimated or recorded pumpage rates. Mines that have substantial discharge of groundwater to ephemeral drainages have recharge cells placed at the approximate location of discharge to represent the infiltration of the discharge into HSU-1.

2.1.3 Estimation of Future CBNG Groundwater Pumpage

One of the key issues for predicting impacts to the Wasatch and Fort Union aquifers from CBNG development through the year 2020 is the estimation of future CBNG groundwater pumpage rates. The estimated groundwater pumpage rates used in the PRB Coal Review were determined by the BLM (2007a) through analysis of past patterns in CBNG development and groundwater pumpage in the eastern PRB. This analysis is presented in Appendix A and is summarized below.

The BLM's (2007a) analysis considered six major drainage basins (referred to in this study as subwatersheds) in the eastern PRB: Antelope Creek, Dry Fork Cheyenne River, Little Powder River, Upper Belle Fourche River, Upper Cheyenne River, and Upper Powder River (**Figure 2-1**). **Table 2-1** summarizes the well statistics for CBNG wells in these subwatersheds. The average well life ranges from 6.2 to 8 years, with a mean of approximately 7.0 years. Well depths range from shallow wells in the relatively new Antelope Creek field (788 feet average total depth) and the Upper Cheyenne River drainage (566 feet average total depth) to deep wells in the Dry Fork Cheyenne River field (average total depth of 1,725 feet). The Dry Fork Cheyenne River and Antelope Creek fields are relatively new, with only 1 percent and 26 percent of the projected wells drilled as of October 2006. Current average pumpage rates for groundwater range from 10.57 gallons per minute (gpm) per well in the Dry Fork Cheyenne River field to 1.89 gpm per well in the relatively mature Upper Cheyenne River field. The estimated future pumpage rates for each subwatershed show a decline in water production to approximately 1 to 2 gpm per well in all fields by 2020.

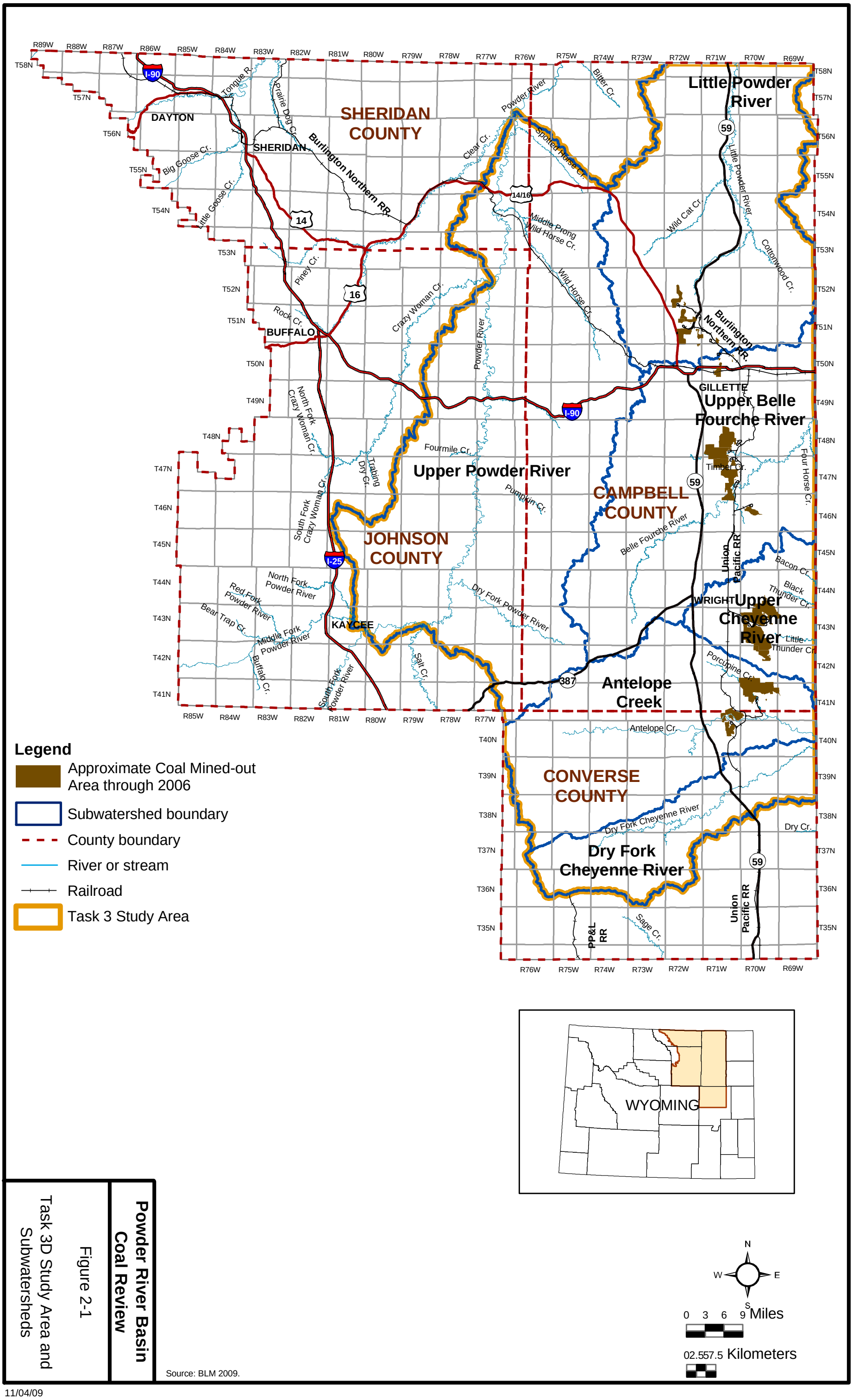
Table 2-1
Estimated Future Groundwater Consumption by CBNG Wells in the Eastern Powder River Basin

Subwatershed (Drainage Basin)	CBNG Well Average Total Depth (feet)	CBNG Average Well Life (years)	Estimated Number of Wells	Drilled Wells as Percent of Projected	June-August 2006 Pumpage (gpm/well)	Decline Rate 2005-2006	Estimated CBNG Pumpage Rates (gpm/well)		
							2010	2015	2020
Antelope Creek	788	8.0	5,020	26%	2.5	29%	2	2	2
Dry Fork Cheyenne River	1,725	no data	1,195	1%	10.57	87%	5	3	2
Little Powder River	655	7.1	7,191	46%	2.23	9%	2	1	1
Upper Belle Fourche River	930	6.8	10,848	63%	5.36	-6%	5	3	1
Upper Cheyenne River	566	6.2	1,212	50%	1.89	28%	2	2	1
Upper Powder River	1,291	8.0	24,930	30%	5.33	-6%	5	4	2

Source: BLM 2007a.

2.1.3.1 Antelope Creek Subwatershed

CBNG groundwater pumpage began in the Antelope Creek subwatershed in 2000. Nominal pumpage rates peaked around 40.5 gpm per well in 2002. Data from July 2006 show that the average rate per well had declined to 2.5 gpm per well. The gas production rate in 2006 was well above the economic limit of 10 thousand cubic feet of gas (MCFG) per day per well, suggesting that there should not be a large decrease in wells in the next few years. The average pumping rate was therefore expected to decline slowly from 2006 to 2020. Through August of 2006, 26 percent of the expected total wells in this subwatershed had been drilled, and total water production from 2000 to



Source: BLM 2009.

Powder River Basin Coal Review

Figure 2-1

Task 3D Study Area and Subwatersheds

11/04/09

August 2006 had been 21,764 acre-feet. The projected CBNG groundwater pumpage rate was estimated at 2 gpm per well from 2010 through 2020.

2.1.3.2 Dry Fork Cheyenne River Subwatershed

CBNG activity in the Dry Fork Cheyenne River subwatershed currently is in the early stages of development, thus making it difficult to project gas production and groundwater pumpage rates into the future. CBNG groundwater pumpage began in 2004 and had not stabilized by August of 2006. By August 2006, only 1 percent of the estimated total 1,195 wells expected in this area had been drilled. No gas production has been reported and groundwater pumage is not expected to stabilize for a few years. The average groundwater pumpage rate in 2005 was 21 gpm per well. By August 2006, this pumpage rate had declined to 10.6 gpm per well. It is estimated, based on preliminary data, that the average groundwater pumpage rate per well will decline to 5 gpm by 2010, declining steadily to 2 gpm per well by 2020.

2.1.3.3 Little Powder River Subwatershed

CBNG groundwater production in the Little Powder River subwatershed began in 1987 and has been continuous since that time. Groundwater pumpage rates generally were below 6 gpm per well until 1996 when pumpage rates began increasing, reaching 14 gpm per well in 1999. Groundwater pumpage rates then began to decrease to the current 2 gpm per well. CBNG groundwater production from the Little Powder River subwatershed is currently approximately 254 acre-feet per month, with the average gas rate per well of 34 MCFG per day declining at a rate of 9 percent per year. It is expected that the average groundwater pumpage rate per well will be 2 gpm in 2010, declining to 1 gpm per well by 2015 and remaining at that rate.

2.1.3.4 Upper Belle Fourche River Subwatershed

CBNG development in the Upper Belle Fourche River subwatershed produced groundwater and gas sporadically from 1989 to 1992, then continuously after 1992. This area is still being developed as suggested by the increasing number of CBNG wells and the increasing production rates for gas and water. The average pumpage rate for groundwater peaked in 1999 and then began declining. The rate has been stable at 5 gpm per well since 2002. The average gas production rate has been steady at 80 MCFG per day per well since 2002. As of August 2006, 63 percent of the estimated total 10,848 CBNG wells had been drilled. Projected groundwater production rates per well are 5 gpm in 2010, declining to 3 gpm in 2015 and 1 gpm in 2020.

2.1.3.5 Upper Cheyenne River Subwatershed

The first CBNG wells were drilled in the Upper Cheyenne River subwatershed in 1994, with groundwater production starting in 1997. Groundwater pumpage peaked at 40 gpm per well in 1998. Groundwater production has been declining since 2001 and reached a nominal rate of 1.9 gpm in August of 2006. It is expected that many wells will reach their economic limit in the next few years. As of August 2006, approximately 50 percent of the expected 1,212 total wells had been drilled, and 26,685 acre-feet of groundwater had been produced. The average rate of groundwater production per well is expected to be 2 gpm in 2010, declining slowly to 1 gpm per well by 2020.

2.1.3.6 Upper Powder River Subwatershed

CBNG groundwater and gas production in the Upper Power River subwatershed began in 1989; however, production rates were erratic and intermittent until 1999. As of August 2006, 124,000 acre-feet of groundwater had been produced. When continuous CBNG production began in 1999, the number of producing wells increased from 5 to 165, and the average groundwater production per well decreased from 55 gpm to 10 gpm by April of 2000. Average groundwater production by 2002 was down to 5.3 gpm per well. As of 2006, approximately 30 percent of the estimated total number of wells of 24,930 had been drilled. Groundwater production is expected to decline to 5 gpm per well by 2010, declining to 2 gpm per well by 2020.

The decline curves and estimated future CBNG groundwater production for each subwatershed provided by the BLM (2007a) were incorporated into the CMGM by assigning a total groundwater production value to each subwatershed and then partitioning that groundwater production among the CBNG wells. Each well was assigned an equal water production rate, so that the total number of wells in each subwatershed multiplied by the water production rate equaled the total production rate for that subwatershed for that modeled year. The CBNG wells were migrated with time westward across the CMGM model domain from 2002 to 2020 according to data and files provided by the BLM (2007b).

2.1.4 Estimation of Future CBNG Discharge to Drainages

CBNG outfalls in the original regional PRB groundwater model that occur within the CMGM domain were used for the CBNG discharge locations in the PRB Coal Review study. These outfalls are represented in the CMGM as recharge cells to allow for infiltration of the CBNG discharge water into HSU-1 (upper model layer) as recharge. The recharge assigned to a recharge cell was set at 60 percent of the total pumping rate for all CBNG wells in the model grid cell. The recharge rate of 60 percent is based on the approximate estimates of a conveyance loss of 70 to 80 percent for CBNG discharge and the approximate estimate that 80 percent of the conveyance loss is due to infiltration. The outfall discharge rates used in the CMGM for the predictive years (2010, 2015, and 2020) reflect the total pumping rate for all CBNG wells in that model grid cell. The per well pumping rates for the predictive years were based on actual permitted pumping rates available from the WOGCC for wells operating through 2004, and the scaling down of pumping rates over the 7-year life cycle of the wells as estimated by the BLM (2007a).

2.2 Surface Water

The Surface Water Quality Analysis Technical Report (Greystone and ALL Consulting 2003) prepared for the PRB Oil and Gas EIS (BLM 2003) was reviewed and updated for the Wyoming PRB study area for use in the PRB Coal Review study. The approach used in the revised surface water analysis is presented in the Task 3B Water Resources Cumulative Impact Assessment Water Quality and Channel Stability (ACE 2009) report and summarized below.

The surface water analysis focused on two main issues for the eastern PRB: 1) the cumulative effects to ephemeral drainages as a result of CBNG water discharge through outfalls that combine the discharge from a number of wells and 2) the cumulative effects to ephemeral and intermittent drainages due to coal mine development. Discharge from CBNG wells varies over time, with the

greatest discharge being during the first year of development. Typically, discharge from a CBNG well ranges from 10 to 25 gpm during the first year, decreasing to approximately 1 to 3 gpm by the third or fourth year in the 7-year life cycle of a well. For coal mines, the expansion of a mine pit through a drainage requires rerouting of the drainage during mining and then reclamation and restoration of the drainage when the mine pit is backfilled and the mine reclaimed. This disruption and subsequent restoration of an ephemeral drainage results in surface water runoff and sediment loading that differ from the original undisturbed drainage. The surface water quality analysis evaluated changes to SAR and EC in affected drainages and compared these changes to: 1) Wyoming, Montana, and South Dakota water quality restrictions for surface waters flowing across state boundaries and 2) the Ayers and Westcot Diagram for irrigation water quality (Ayers and Westcot 1985). The surface water quality analysis considered cumulative effects in both normal years and dry years. In this report, ACE's (2009) surface water analysis is summarized with respect to irrigation suitability of CBNG discharge water after mixing with both normal and dry year flows in the six subwatersheds in the Wyoming PRB study area (**Figure 2-1**).

The cumulative effects surface water analysis addresses current conditions (2003) and three future RFD scenarios for years 2010, 2015, and 2020. Based on the information developed in support of the analysis and documented in the Task 1B Report (AECOM 2009a) and Task 2 Report (AECOM 2009b), the cumulative effects have been addressed on a subwatershed basis. The six subwatersheds in the Wyoming PRB study area are shown in **Figure 2-1** and include: Antelope Creek, Dry Fork Cheyenne River, Little Powder River, Upper Belle Fourche River, Upper Cheyenne River, and Upper Powder River.

The cumulative effects analysis conducted by ACE (2009) focused on the cumulative impacts to surface water quality and channel stability with respect to the surface water resources within the study area. In general, the cumulative impacts directly relate to the water quantity and quality associated with the discharges from base year and RFD coal mining activities, CBNG wells, and conventional oil and gas wells compared to the water quantity and quality of the receiving drainages. Of particular importance is the amount of production water or discharge that is directly conveyed to the receiving drainages. Based on information and data presented in the Task 1B and Task 2 reports, it is assumed that the production water discharged directly to the receiving drainages would be limited to CBNG water discharge. In general, the existing data reflect that water production from coal mining activities would be largely consumed on site. Water production from conventional oil and gas wells typically requires treatment to meet water quality standards associated with the WYPDES permitting requirements, before it is discharged to the surface.

2.2.1 Surface Water Quality

Potential impacts to surface water quality as a result of projected CBNG development were evaluated during completion of the PRB Oil and Gas EIS (BLM 2003) and documented in a supporting technical report (Greystone and ALL Consulting 2003). Key water quality parameters for predicting the potential effects of CBNG development focused on the suitability of surface water for agricultural irrigation. Consequently, SAR and salinity, measured by EC, were utilized for the prediction. The cumulative effects analysis for the PRB Coal Review utilized the same water quality parameters and involved a similar evaluation.

2.2.2 Evaluation Criteria

Table 2-2 summarizes the most restrictive and least restrictive regulatory standards for EC and SAR applicable to the subwatersheds in the Wyoming PRB study area (ACE 2009). The limits presented in **Table 2-2** were utilized during the comparison of EC and SAR values for resulting mixtures of existing stream flows and discharges from CBNG wells under various flow conditions and RFD projections for the years 2010, 2015 and 2020.

Table 2-2
Summary of Proposed Limits for SAR and EC

Subwatershed	Most Restrictive Proposed Limit (MRPL)		Least Restrictive Proposed Limit (LRPL)	
	SAR	EC (μS/cm[1])	SAR	EC (μS/cm[1])
Little Powder River	5	2,000	9.75	2,500
Upper Powder River	2	2,000	9.75	2,500
Upper Belle Fourche River	6	2,000	10	2,500
Dry Fork Cheyenne River, Upper Cheyenne River, Antelope Creek	10	2,000	10	2,500

[1] μS/cm = microsiemens per centimeter.

Sources: WDEQ, MDEQ, and South Dakota Legislative Council.

With respect to the information presented in **Table 2-2**, the WDEQ applies numeric water quality standards for EC and SAR that were adopted for water bodies downstream in South Dakota. Specifically, these standards apply to the Upper Belle Fourche River, Antelope Creek, Upper Cheyenne River, and Dry Fork Cheyenne River. In March of 2003, the Montana Board of Environmental Review adopted numeric standards for EC and SAR for surface water sources. These standards apply to the Little Powder River and Upper Powder River (ACE 2009). Implementation of the guidelines in **Table 2-2** currently is under legal review.

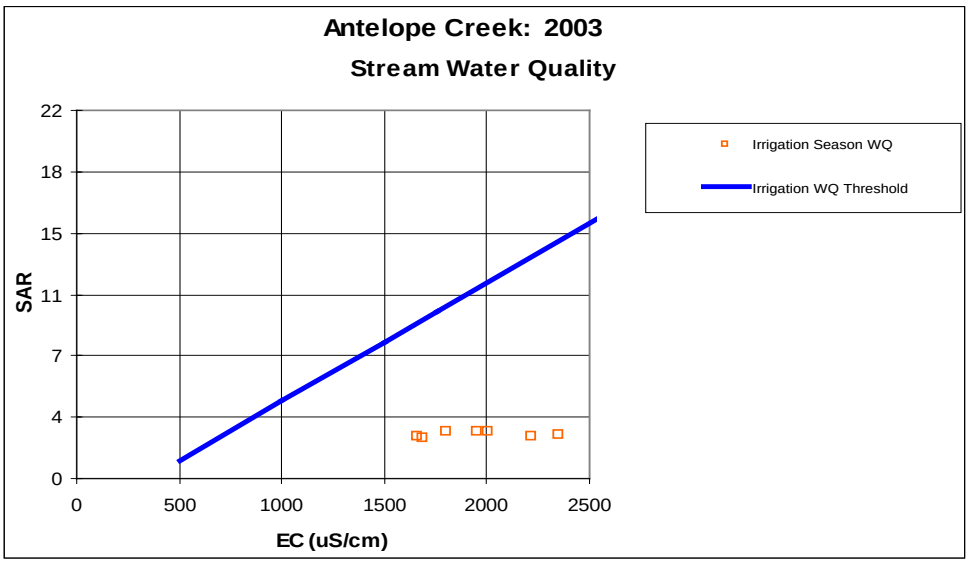
2.2.2.1 Irrigation Suitability Diagram

The Ayers and Westcot (1985) irrigation suitability diagram was used to compare water quality before and after mixing with discharges from CBNG wells (ACE 2009). The diagonal line on the diagram is used as the no-impact threshold for SAR and EC values of the water. Water quality would be expected to cause “no reduction in the rate of infiltration” as a result of dispersion of soils by SAR if the value fall below and to the right of the irrigation threshold line (Ayers and Westcot 1985). Alternatively, waters located to the left and above the threshold line for irrigation would be likely to cause a slight to moderate reduction in the rate of infiltration (Ayers and Westcot 1985).

This EC/SAR relationship in the Ayers Westcot irrigation suitability diagram is utilized to determine the effect of irrigation waters on the infiltration capacity of soils. Elevated SAR values may reduce the permeability in clayey soils, consequently reducing the infiltration rate. It should be noted that the significance of the effects associated with a reduction in infiltration rate varies with soil type, and increases on clay and clay-loam soils. In addition, the EC/SAR relationship typically indicates that

as salinity increases, the potential impacts of SAR decrease; however, this relationship should not be applied without limits (ACE 2009). The potential impact of rainfall on sodic soils can cause SAR problems by substantially lowering the EC, with little change in the SAR. An attempt to address this potential problem, along with the inherent variability in soils, is made through the application of an absolute maximum SAR value during the analysis.

Figure 2-2 provides an example of an Ayers and Westcot diagram and shows the irrigation suitability for the existing stream water quality (2003 current conditions) associated with Antelope Creek. Ayers and Westcot diagrams for the other subwatersheds in the study area are presented in ACE 2009. As indicated in **Figure 2-2**, the existing water quality in Antelope Creek appears to be suitable for irrigation (ACE 2009).



Note: WQ = water quality.

Source: ACE 2009.

Figure 2-2 Antelope Creek: 2003 Stream Water Quality

2.2.3 Surface Water Quality Modeling

The surface water model used for the technical report (Greystone and ALL Consulting 2003) prepared in support of the PRB Oil and Gas EIS (BLM 2003) was used by ACE for the PRB Coal Review surface water cumulative effects analysis. This spreadsheet model uses a steady-state, mass balance approach to estimate steady-state concentrations of EC and SAR.

Input parameters to the spreadsheet model included.

- Estimated CBNG well production water (million gallons per year [mmgpy])
- CBNG well production water SAR
- CBNG well production water EC (µS/cm)
- Channel loss (percent)

- Subwatershed stream flow (acre-feet)
- Subwatershed stream flow SAR
- Subwatershed stream flow EC (µS/cm)

The following assumptions were used by ACE (2009) for purposes of water quality modeling.

- Assuming SAR behaves as a single constituent of water, mixed SAR was estimated using a simple flow-weighted mass balance equation.

- Impacts to the receiving streams were evaluated for hydrologic conditions associated with relatively dry years as well as normal or average years. The dry year analysis evaluated the maximum likely impacts to surface water quality.

- The model assumed complete mixing.

- A channel loss value of 70 percent was used in the model.

2.2.3.1 Stream Flow

Average monthly and annual flows at pertinent gauging stations for the major drainages within each subwatershed were obtained by ACE (2009) from the Powder/Tongue River Basin Water Plan (HKM Engineering et al. 2002a) and the Northeast Wyoming River Basins Water Plan (HKM Engineering et al. 2002b). The development of the stream flow data relied on historic stream flow gaging data to the maximum extent possible. The subwatersheds in the study area, however, are characterized by a scarcity of historic stream flow records. As a result, ACE (2009) developed stream flow data at several locations within the study area. The methodology used to collect the historic records of stream flow, establish a study period, and to extend or fill-in the stream flow data where records were unavailable, was summarized in the basin plans (HKM Engineering et al. 2002a,b).

The impact analysis conducted by ACE (2009) assumed two hydrologic conditions: a dry year study period and a normal year study period. The dry year analysis was used to evaluate the maximum likely impacts to surface water quality, assuming limited flow in the receiving streams.

2.2.3.2 Stream Water Quality

EC and SAR values for the streams within the study area were identical to the values used in the technical report (Greystone and ALL Consulting 2003) in support of the PRB Oil and Gas EIS (BLM 2003). Limited data were available to characterize the water quality in the Dry Fork Cheyenne River; therefore, data available for the neighboring subwatershed (Antelope Creek) were used for the water quality impact analysis (ACE 2009).

2.2.3.3 CBNG Well Production Water

Production water from existing and projected CBNG wells was obtained from the Task 2 report (AECOM 2009b). Sources for these data included, but were not limited to, the IHS Energy Services database and data from the WOGCC.

2.2.3.4 CBNG Well Production Water Quality

EC and SAR values for the production water associated with the CBNG wells in the study area were documented in the technical report by Greystone and ALL Consulting (2003) in support of the PRB Oil and Gas EIS (BLM 2003). In addition, the WDEQ/Water Quality Division provided pertinent and more recent water quality data for effluent water quality from CBNG wells in all subwatersheds, with the exception of Antelope Creek and Dry Fork Cheyenne River (ACE 2009). The water quality data obtained from both of these sources were reviewed by ACE (2009) and used to describe the water quality associated with CBNG production water.

2.2.3.5 Managed Water Loss

The PRB Oil and Gas EIS (BLM 2003) assumed water produced from CBNG wells would be managed through containment, land application disposal, and injection, and would not have direct effects on quality and quantity of surface water because none of the discharged water would reach drainages in the subwatersheds under these water handling options. The percentage of CBNG production water managed through these options is referred to as managed water loss (MWL). The percentage of CBNG production water included in the MWL varies between subwatersheds and is presented in **Table 2-3**. It should be noted that all CBNG water discharged directly into the drainages ultimately may be consumptively used by downstream water users. Based on the profile of water users within the subwatersheds, it is likely that this water would be used for irrigation purposes (ACE 2009).

Table 2-3
Percent of Total Water Production from CBNG Wells per Discharge Method

Subwatershed	Untreated Discharge into Drainages	Passive Treatment	Active Treatment	Infiltration Impoundment	Containment Impoundment	Land Applied Disposal	Injection
Upper Powder River	35	0	10	40	5	5	5
Little Powder River	45	0	0	30	10	10	5
Antelope Creek	55	0	0	35	5	0	5
Upper Cheyenne River	55	0	0	35	5	0	5
Dry Fork Cheyenne River	55	0	0	35	5	0	5
Upper Belle Fourche River	45	0	0	40	5	0	10

Source: BLM 2003.

2.2.3.6 Conveyance Loss

Studies conducted by the BLM (2003) have shown that conveyance losses for direct discharge to drainages are approximately 70 to 90 percent, depending on the time of year. Evaporation losses, which are a large component of conveyance losses, can be 80 percent during the summer months in Wyoming. Thus, most CBNG discharge water either infiltrates or evaporates within a few miles of the discharge outfall and generally is not recorded at U.S. Geological Service (USGS) stream gauging stations. Impacts to surface water flow and quality are thus limited to within a few miles of the discharge outfall and, as of 2002, have not been recorded by the network of USGS gauging stations.

Conveyance losses would vary by subwatershed as a function of the total CBNG production water discharged and the channel, soils, slope of the channel, type of drainage (ephemeral versus perennial), cover/vegetation within the channel, and time of year (ACE 2009). A conveyance loss of 70 percent was selected by ACE (2009) for the water quality assessment and modeling and has been used in the predictive scenarios for surface water quality.