APPENDIX C

SUMMARY OF GROUNDWATER MODEL MODIFICATIONS

SUMMARY OF GROUNDWATER MODEL ENHANCEMENTS

The original regional PRB groundwater model prepared for the PRB Oil and Gas EIS (BLM 2003a), as developed for the BLM by AHA and GEC (2002), was modified for the PRB Coal Review to produce a groundwater model more suited to modeling the combined impacts of CBNG development and coal mine dewatering in the eastern PRB of Wyoming. Enhancements first were made to the regional PRB groundwater model. The resulting revised regional PRB groundwater model was recalibrated and then telescoped to produce a submodel focused on the overlap zone of coal mine dewatering and CBNG development using the TMR module of Groundwater Vistas. The enhancements to the regional PRB groundwater model and additional enhancements made to the telescoped Coal Mine Groundwater Model (CMGM) during its development are summarized below. This comprehensive summary includes enhancements that were made to facilitate modeling of base year (2002) conditions, as well as enhancements that were made to facilitate modeling for the predictive years (2010, 2015, and 2020).

Enhancements to the Original Regional PRB Groundwater Model

Some of the design features in the original regional PRB groundwater model were retained for the revised regional PRB groundwater model. Examples include the use of a uniform 0.5 by 0.5 mile grid spacing throughout the model domain and use of Goolsby, Finley, and Associates (2001) stratigraphy. The enhancements made to the original regional PRB groundwater model to create the revised regional PRB groundwater model are summarized below.

1. The 17 geologic layers in the original regional PRB groundwater model were combined to form 6 hydrostratigraphic units (HSUs) in the revised regional PRB groundwater model. This modification was made because of the lack of water level and hydraulic data for most of the layers in the original model. As a result of this modification, the revised regional PRB groundwater model is more reflective of hydrologic conditions in the PRB. The change also allows the model to run more efficiently. In summary, Layers 1 through 6 in the original regional PRB groundwater model represented the Wasatch Formation and were combined into HSUs 1 through 3 in the revised regional PRB groundwater model. Layer 7 in the original regional model represented the confining layer between the Wasatch and the Fort Union formations and is represented by HSU-4 in the revised regional model. Layers 8 through 15 in the original regional model represented four coal zones in the Upper Fort Union, and these were combined into HSU-5. Layers 16 and 17 represented the Lower Fort Union/Lebo and Tullock members of the Fort Union Formation; these layers were combined into HSU-6.

2. Cells not used in the original regional PRB groundwater model (i.e., “dead space”) were removed to reduce storage requirements for the model and to decrease run times.

3. The original regional PRB groundwater model was converted from Visual MODFLOW96 files to the Groundwater Vistas file format. The model then was run using MODFLOW2000.

4. Constant heads used for perennial rivers in the original regional PRB groundwater model were converted to the MODFLOW River Package. Conductances were set during calibration.

5. Streams that are perennial over only part of their reach, such as the Belle Fourche and Antelope Creek, were converted from the MODFLOW River Package to the MODFLOW Drain Package. All ephemeral streams were modeled using the MODFLOW Drain Package in the original regional PRB groundwater model; this was maintained in the revised regional PRB groundwater model. Initial conductance values were taken from the original regional PRB groundwater model. Final conductance values were based on calibration.

6. The starting recharge for precipitation was changed in the revised regional PRB groundwater model to 5 percent of precipitation for regional precipitation recharge and to 10 percent of precipitation for recharge along the clinker zones east of the coal mines. The calibrated values were 0.612 inch per year for regional recharge and 1.18 inches per year for clinker recharge.

7. The solver used in the original regional PRB groundwater model was changed to the PCG2 solver in the revised regional PRB groundwater model.

8. Calibration targets from GAGMO (1990, 2000, 2002) reports were incorporated into the revised regional PRB groundwater model (approximately 350 monitoring wells). BLM and USGS wells also were added.

9. The lower Wasatch Formation (HSU-3) in the revised regional PRB groundwater model was extended to the east in the area of the coal mines based on geologic data provided by the BLM (2007d). In addition, the location of the clinker outcrop areas was revised based on geologic mapping provided by the BLM (2007d). Also, the location of the contact between the Wasatch and Upper Fort Union formations in the area of the coal mines was refined based on mapping provided by the BLM (2009b).

10. A low-permeability layer was placed between the Wasatch and Fort Union formations (between HSU-3 and HSU-5) to represent the thick clay and claystone units that separate the Wasatch Formation and the upper coals of the Fort Union Formation. This layer incorporates geologic Layer 7 in the original PRB groundwater model, which includes the siltstone and claystone above the first major coal unit in the Upper Fort Union. This layer was assigned as HSU-4.

11. The eastern model domain of the original regional PRB groundwater model was extended to the east, and a MODFLOW general head (CHD) boundary was added

along the southeastern side of the model domain east of the coal mines located south of Gillette, Wyoming, for the Upper Fort Union Formation (HSU-5). This modification was made based on available water level data along the eastern edge of the model domain, thus allowing water flow into and out of the model domain to enhance calibration in Layer 5. Boundary conditions for the remainder of the revised regional PRB groundwater model were taken from the original regional PRB groundwater model of AHA and GEC (2002).

12. Mine pit locations and mine pit bottom elevations used in the revised regional PRB groundwater model were provided by the BLM (2005b, 2007b). Mine pumping rates were based on calibration in the revised regional PRB groundwater model. For mines with substantial discharge to ephemeral drainages, recharge cells were placed at the approximate location of discharge to facilitate infiltration of discharge water into HSU-1.

13. For the revised regional PRB groundwater model, the locations of CBNG wells through 2006 were based on data obtained from the WOGCC website and IHS database files (IHS 2007). The locations of new and plugged and abandoned CBNG wells from 2007 to 2020 were based on estimates provided by the BLM (2007c). The wells were screened at the appropriate depth in the model. CBNG wells were converted from the MODFLOW Drain Package used in the original regional PRB groundwater model to the MODFLOW Well Package.

14. CBNG well pumping rates through 2004 were set based on permitted pumping rate data obtained from the WOGCC database, BLM (2007a), and IHS (2007). Beyond 2004, pumping rates were based on estimates of future CBNG development in the eastern PRB provided by the BLM (2007a).

15. CBNG discharge outfall locations in the revised regional PRB groundwater model were taken from the original regional PRB groundwater model. Outfall discharge rates up to 2004 were based on permitted CBNG well pumping rates, and outfall pumping rates from 2004 through 2020 were based on estimated CBNG well pumping rates provided by the BLM (2007a). The amount of recharge to HSU-1 from CBNG discharge was adjusted in the revised regional PRB groundwater model to reflect more recent studies. As a result, recharge from outfalls was set at 60 percent of the total outfall rate. For water discharged by CBNG wells to ephemeral drainages, recharge cells were used over the estimated stretch of the drainage receiving the recharge (within 2 to 3 miles of the outfalls). All other recharge was applied to the same model cell as the CBNG well pumping cell.

Construction of the CMGM

The CMGM was developed by taking a subarea from the revised regional PRB groundwater model using the TMR capability of Groundwater Vistas. The CMGM focuses on the overlap zone of coal mine dewatering and CBNG development in the eastern PRB. The CMGM

preserved many of the boundary conditions and features of the revised regional PRB groundwater model. The initial enhancements made to the CMGM are summarized below.

1. A tighter grid spacing of 0.25 by 0.25 mile was used throughout the CMGM domain to better model the impacts of CBNG pumping and discharge and coal mine dewatering.

2. The model domain boundaries of the CMGM on the west, north, and south for the area of the model domain encompassed by the Wasatch Formation were set as MODFLOW constant head boundaries with time varying heads to match changes in water levels in the revised regional PRB groundwater model just beyond the domain boundaries **(Figure 4.1-4**). Due to the lack of available water level data, the southern model domain boundary for the Wasatch located southwest of the southern group of coal mines in Subregion 3 (**Figure 4.1-4**) was set as a no-flow boundary, as was done in the original regional PRB groundwater model.

3. The eastern model domain of the CMGM was moved a few miles eastward to include all the clinker zones associated with the coal mines south of Gillette, Wyoming. The boundary conditions for the Upper Fort Union (HSU-5) in the CMGM were set as no-flow boundaries, except along the eastern model domain between the Subregion 2 and Subregion 3 groups of coal mines. This eastern model boundary was changed to a MODFLOW general head boundary for HSU-5 from the Subregion 2 group of coal mines southward to, and including, all of the Subregion 3 group of coal mines southeast of Wright, Wyoming (**Figure 4.1-4**). This general head boundary allowed for groundwater in the Upper Fort Union (HSU-5) to flow eastward out of the model domain, as well as flow westward into the model domain from the Upper Fort Union located east of the model boundary. This general head boundary was added to the CMGM to better represent the perceived groundwater flow in the Upper Fort Union based on well data obtained by the BLM for the area east of the Subregion 2 and Subregion 3 coal mines. (For HSU-6 [Lower Fort Union/Tullock], the eastern model domain was left as a no-flow boundary condition.) Along the southern model domain, just south of the southernmost group of coal mines in Subregion 3, the no-flow boundary condition for the Upper Fort Union (HSU-5) was changed to a constant head boundary condition to better model the water flux in the Upper Fort Union in this area (**Figure 4.1-4**).

4. The coal mine pits were changed from the MODFLOW Well Package to the MODFLOW Drain Package, and the 3-dimentional configuration of the coal mine pits over time was provided by the BLM (2005b) for 1990 through 2002. Estimated coal mine pit migrations and pit bottom elevations from 2002 through 2020 also were provided by the BLM (2007b). Drain elevations were placed 5 meters above the pit floor bottoms, and the drain conductances were set during calibration.

5. Outside of the coal mine boundaries, the stratigraphy of the original regional PRB groundwater model obtained from Goolsby, Finley, and Associates (2001) was

preserved. Within the coal mine boundaries, the coal stratigraphy provided by the BLM (2005c) was used. These two stratigraphic packages were merged to the west of the coal mine boundaries. The merged data set then was contoured to form a new data set with consistent elevations for the coal layers. Layer thickness and transmissivity were changed, as needed, to facilitate the merging of the two stratigraphic packages in the CMGM.

6. A minimum hydraulic conductivity of 0. 2 meters per day was used in the CMGM for the Upper Fort Union (HSU-5).

7. Approximately 70 monitoring wells in the Wasatch Formation near the coal mines of the eastern PRB were obtained from WDEQ/LQD files and GAGMO reports and added to the CMGM to improve calibration in the Wasatch Formation (HSUs 1 through 3).

8. The elevation of the Belle Fourche River was changed to reflect the actual topographic elevation of the base of the river (based on USGS topographic maps) across the model domain. This facilitated a more accurate modeling of the interaction between the Belle Fourche River and the Wasatch Formation aquifer. Antelope Creek was modeled as a MODFLOW drain package across the model domain, and the elevation of the base of the river was adjusted across the model domain to reflect topographic base elevations from USGS topographic maps.

9. Vertical groundwater flow in the CMGM was based on calibration of the model because of: 1) the lack of aquifer data on vertical flow and 2) the rather incomplete understanding of groundwater flow in the PRB due to the lack of long-term aquifer studies. Initial starting values were based on the vertical conductivity for confining layers already in the original regional PRB groundwater model.

10. Rechage to the Upper Fort Union along the clinker outcrop zones is not well known. Therefore, final recharge values for the clinker outcrop zone was based on calibration.

11. The mine pit area for each of the operating coal mines was converted to a mine backfill aquifer in the time step during which the mine reclaims that portion of the mine pit. For mines with reclaimed areas in the base year (2002), the reclaimed areas have a backfill zone with approximate hydraulic properties and water levels from GAGMO reports. From 2002 to 2020, conversion of mine pits to backfill aquifers was done only for the predictive years (2010, 2015, and 2020) and was based on the projected progression and reclamation of coal mines as provided by BLM (2007b). Hydraulic properties assigned to cells with backfill were based on Martin et al. (1988).