EXECUTIVE SUMMARY

ES.1 INTRODUCTION

The Task 3B report for the Powder River Basin (PRB) Coal Review summarizes the modeled changes in surface water quality and groundwater level changes projected for 2010, 2015, and 2020 in the eastern PRB within approximately 25 miles of the coal mines. The base years used for comparison of groundwater impacts were 2002 (the year used for calibration of the groundwater model for the eastern PRB) and 1990 (a time period before coal bed natural gas [CBNG] pumpage). The base year used for comparison of surface water quality impacts was 2003.

Projected groundwater level changes primarily are due to CBNG groundwater withdrawal in the Upper Fort Union Formation and to both CBNG pumping and discharge along with coal mine dewatering in the Wasatch Formation. Near the coal mines, coal mine dewatering of the Upper Fort Union also has affected groundwater levels in that formation. These changes were modeled using the Coal Mine Groundwater Model (CMGM) that was developed for the PRB Coal Review study. The numerical modeling code used in the CMGM was MODFLOW2000, running within the Groundwater Vistas modeling platform. Groundwater level recovery in the eastern PRB after the cessation of both CBNG development and coal mining, and the effect on groundwater flow paths associated with coal mine pit backfill and reclamation after the cessation of coal mining in the eastern PRB, also were modeled. For purposes of modeling groundwater recovery, it was assumed that CBNG development in the eastern PRB would cease by 2030 and surface coal mining would cease by 2050. Details of the numerical CMGM design, calibration, and projection of 2002 groundwater levels and drawdown between 1990 and 2002 for the Upper Fort Union and the Wasatch are presented in the Task 1B report (AECOM 2009a).

For groundwater modeling purposes, the estimation of future CBNG groundwater production was based on actual permitted pumping rates available from the Wyoming Oil and Gas Conservation Commission (WOGCC) for wells operating through 2004, and the scaling down of pumping rates over the 7-year life cycle of a pod of CBNG wells as estimated by the Bureau of Land Management (BLM) (2007a). The location of CBNG wells through 2006 was based on data available from the WOGCC website and IHS Energy Services (IHS) database files (IHS 2007), with CBNG well locations from 2007 to 2020 based on projections provided by the BLM (2007c). Coal mine groundwater pumpage was developed from data provided by the coal mine operators and from data on projected locations of coal mine pits over time as provided by the BLM (2007b). It was assumed that all discharge of CBNG water would be to ephemeral drainages. A percentage of this discharge was assigned as potential recharge to groundwater.

Projected changes in surface water quality are due to mixing of CBNG production water discharge with natural flow in the modeled drainages. These changes were modeled by Anderson Consulting Engineers, Inc. (ACE) (2009) using a linear mixing model that combines surface water flow and water quality with CBNG discharge volume and water quality using linear equations. A stream channel stability analysis also was conducted by ACE (2009), which evaluated the potential effects to stream channels due to projected CBNG production water discharge. For CBNG discharge, the direct discharge to ephemeral drainages for each drainage basin was used as the guide for modeling water quality or estimating impacts to channel stability and channel properties.

ES.2 GROUNDWATER LEVEL CHANGES

Projected groundwater level changes in the Wasatch generally are due to coal mine dewatering and CBNG pumping and discharge, which generally result in local mounding of groundwater in the Wasatch near CBNG fields and drawdown near the coal mines. Antelope Creek and Wild Cat Creek remove groundwater from the Wasatch because their stream base elevations are below the groundwater levels in the Wasatch. The Belle Fourche River in the CMGM domain does not remove groundwater from the Wasatch because its base elevation is above groundwater elevations in the Wasatch. Along some reaches of the Belle Fourche outside of the model domain, the river is perennial due to groundwater baseflow from the Wasatch. Also, the Wasatch Formation is not a true aquifer in that it has water-bearing sand units, but no consistent and uniform groundwater level over the eastern PRB. In the CMGM, however, the Wasatch was modeled as an aquifer due to the large area covered by the model domain. Consequently, the Wasatch can contribute water to the Belle Fourche and other ephemeral streams in the eastern PRB, whereas the numerical model will show the water level in the Wasatch below the stream bottom and thus will not remove water. For the Upper Fort Union, groundwater level changes are due to CBNG pumpage and coal mine dewatering, with the most substantial groundwater level changes caused by CBNG pumpage located mainly southwest of Wright. Between 2002 and 2020, the projected reduction in coal mine dewatering and the expected reduction in CBNG pumpage from Wright northward toward Gillette are projected to result in groundwater rebound in the Upper Fort Union both within the coal mine boundaries and especially within the basin west of the coal mines.

Modeled Cumulative Groundwater Impacts for Year 2010

Wasatch Formation: Based on model results for 1990 to 2010, groundwater flow in the Wasatch for 2010 is to the northeast south of Wright, Wyoming. East of Wright, the groundwater flow changes to northward and then to northwestward with flow staying on the northwestward course to the north end of the model domain in the eastern PRB. Antelope Creek acts as a drain and removes water from the Wasatch over most of its course in the eastern PRB. There is a 20-foot groundwater mound west of the Subregion 2 coal mines related to water discharge from the CBNG wells. Southeast of Gillette, there is a 50-foot decline in groundwater levels due to municipal pumpage. At the northern end of the model domain, there is a groundwater decline of 20 to 30 feet near Wild Cat Creek due to CBNG pumpage. The main area of drawdown in the Wasatch since 1990 is in the northern pod of the Subregion 3 coal mines, where there is 30 to 70 feet of drawdown within the mine boundaries and 10 to 30 feet of drawdown in the Wasatch west of the mine boundaries due to mine dewatering. CBNG discharge results in a groundwater mound of 10 to 20 feet west of Wright and another mound west of the Subregion 2 coal mines of up to 20 feet. Overall, the primary effects projected for the Wasatch include the drawdown in the Subregion 3 coal mines, the removal of groundwater by Antelope Creek, and 10 to 20 feet of mounding in areas of CBNG discharge.

Based on modeling results for 2002 to 2010, coal mine-related drawdown in the Wasatch in the Subregion 3 coal mine area is up to 70 feet, with most of the drawdown being located in the northern pod of mines. For CBNG-related pumpage and discharge, a predicted decrease in pumpage by 2010 results in groundwater rebound west of Wright in the range of 10 to 20 feet and localized rebound west of the Subregion 2 coal mines.

Upper Fort Union Formation: The most evident feature for projected groundwater levels in the Upper Fort Union for 2010 is a substantial groundwater depression of 25 to 575 feet southwest of Wright caused by CBNG pumpage from 1990 to 2010. Groundwater flow south of Wright, except for the area of the groundwater depression, is to the northeast toward the Subregion 3 coal mines. Groundwater flow north of Wright is to the northwest. Groundwater flows into the Subregion 3 coal mines from both the west and the east. For the Subregion 2 coal mines, groundwater flow into the mines is mainly from the west. Modeled drawdown in the Upper Fort Union in the coal mine areas is in the range of 100 to 200 feet in the Subregion 3 mines, 25 to 100 feet in the Subregion 2 coal mines, and up to approximately 100 feet in the Subregion 1 coal mines north of Gillette. Municipal pumpage at Gillette results in a groundwater depression southeast of Gillette in the range of 50 feet.

Based on modeling results for 2002 to 2010, coal mine-related pumpage in the Fort Union in the Subregion 3 coal mine area results in 25 to 150 feet of drawdown in and near the southern pod of mines, and 25 to 100 feet of drawdown in the northern pod of mines. In the Subregion 2 coal mine area, drawdown from 25 to 125 feet occurs in the southern pod of mines, with 25 to 75 feet in the northern pod of mines. CBNG pumpage results in extensive drawdown southwest of Wright ranging up to 350 feet. West of the northern pod of mines in Subregion 3, groundwater levels rebound up to 150 feet due to the reduction in CBNG pumpage. North of Wright along State Route (SR) 59, groundwater levels rebound up to 125 feet. West of the Subregion 2 coal mines, groundwater levels rebound in the range of 50 to 275 feet, and near the Subregion 1 coal mines, groundwater levels rebound approximately 25 feet.

Modeled Cumulative Groundwater Impacts for Year 2015

Wasatch Formation: Based on model results for 1990 to 2015, groundwater flow in the Wasatch for 2015 is similar to 2010. South of Wright, groundwater flow is to the northeast toward the Subregion 3 coal mines. North of Wright, groundwater flow is to the northwest. Antelope Creek acts as a drain and removes groundwater from the Wasatch over most of its course. There is a projected groundwater mound of 10 to 20 feet west of the Subregion 2 mines due to CBNG discharge, and there is a projected groundwater depression of up to 50 feet southeast of Gillette due to municipal pumpage. Near Wildcat Creek, CBNG pumpage results in an additional drawdown of approximately 10 feet. The most substantial modeled drawdown in the Wasatch since 1990 is in the Subregion 3 coal mines, where there is 30 to 70 feet of drawdown within the mine boundaries and 10 to 30 feet of drawdown in the Wasatch west of the mines. There is groundwater mounding up to 10 feet around Wright due to CBNG discharge. Overall, modeled groundwater levels, groundwater flow patterns, and groundwater drawdown in the Wasatch for 2015 are similar to 2010.

Based on modeling results for 2002 to 2015, coal mine pumpage in the Wasatch results in drawdown in the area of the Subregion 3 coal mines in the range of 10 to 60 feet near the southern pod of mines and from 30 to 80 feet in the northern pod of mines. West of the Subregion 3 coal mines, drawdown in the Wasatch ranges from 10 to 20 feet. Drawdown near the Subregion 1 and Subregion 2 coal mines is less than 10 feet. CBNG pumpage and discharge in the Wasatch results in approximately 20 feet of drawdown west of Wright, approximately 10 feet of drawdown near the Subregion 2 coal mines, and approximately 10 feet of mounding along SR 59.

Upper Fort Union Formation: Based on model results for 1990 to 2015, the substantial groundwater depression southwest of Wright due to CBNG pumpage, as projected for 2010, shifts

to the south. Projected 2015 groundwater drawdown in the Upper Fort Union in this area of CBNG pumpage since 1990 ranges up to 450 feet. Groundwater flow patterns in the Upper Fort Union are similar to 2010, with groundwater flow south of Wright being to the northeast toward the Subregion 3 coal mines, and north of Wright, groundwater flow is to the northwest. Around the Subregion 3 coal mines, groundwater flows into the mine areas from both the west and east. For the Subregion 2 mines, groundwater flow is mainly from the west but also from the east. Drawdown in the Subregion 3 mines ranges from 25 to 150 feet. For the Subregion 2 mines, drawdown ranges from 25 to 50 feet in the northern pod of mines and from 50 to 150 feet at the southern end of the subregion. There is local rebound of groundwater levels in the northern pod of mines in Subregion 1. Southwest of the Subregion 2 mines, there is a CBNG-related groundwater depression of 50 to 125 feet, with drawdown southwest of Wright ranging from 25 to 450 feet.

Model results for 2002 to 2015 show groundwater rebounding in parts of the eastern PRB. In the Subregion 3 coal mines, there is up to 200 feet of rebound in the southern pod of mines. For the Subregion 2 coal mines, there is up to 25 feet of rebound in the northern pod of mines. For the Subregion 1 mines north of Gillette, rebound of water levels is up to 50 feet in the Upper Fort Union. Within the basin area of the eastern PRB, a reduction in CBNG pumpage from Wright northward to the Subregion 2 coal mines has generated substantial rebound in groundwater levels in the Upper Fort Union along SR 59. Southeast of Wright, rebound is up to 275 feet since 2002. From Wright northward along SR 59, the rebound ranges from approximately 25 feet on the margins to 100 feet along the highway area.

Modeled Cumulative Groundwater Impacts For Year 2020

Wasatch Formation: Based on model results for 1990 to 2020, groundwater flow in the Wasatch is similar to that modeled for 2015 and 2010. South of Wright, groundwater flow is to the northeast toward the Subregion 3 coal mines. North of Wright, groundwater flow is to the northwest. There is a groundwater mound of 10 to 20 feet west of the Subregion 2 coal mines, with mounding of approximately 10 feet extending northward, due to CBNG discharge. Southeast of Gillette, there is a groundwater depression of approximately 10 feet due to municipal pumpage. Antelope Creek acts as a drain and removes water from the Wasatch, and in the Wild Cat Creek area there is drawdown of 10 to 30 feet due to CBNG pumpage. Drawdown in the Subregion 3 coal mines ranges from 30 to 70 feet within the mine boundaries and from 10 to 30 feet west of the mines in the basin.

Based on modeling results for 2002 to 2020, drawdown in the Wasatch due to coal mine pumpage is evident only in the Subregion 3 coal mine area, ranging from 10 to 50 feet in the southern pod of mines and from 10 to 20 feet in the northern pod of mines. Drawdown west of the mines in the PRB ranges from 10 to 20 feet. Groundwater rebound of approximately 10 feet is evident in both the northern and southern pod of mines in Subregion 3 due to reclamation of the coal mine pits and resaturation of the backfill material. CBNG-related rebound of approximately 10 feet occurs over most of the model domain due to a decrease in CBNG pumpage.

Upper Fort Union Formation: Based on modeling for 1990 to 2020, the groundwater depression in the Upper Fort Union southwest of Wright shifts more to the southwest as compared to 2015, and the groundwater level decline in the depression ranges up to 400 feet. Groundwater flow is to the northeast toward the Subregion 3 coal mines south of Wright; north of Wright, groundwater flow is to the northwest. Groundwater flows into the Subregion 3 mines from the west and the east; groundwater flows into the Subregion 2 mines mainly from the west. There is a 50-foot groundwater

depression southeast of Gillette due to municipal pumpage. Groundwater drawdown in the coal mine areas ranges from 25 to 100 feet in the Subregion 3 mines, from 25 to 100 feet in the northern pod of mines in Subregion 2, and from 50 to 125 feet in southern pod of mines in Subregion 2. For the Subregion 1 mines, there is local drawdown in groundwater levels of approximately 25 feet.

Based on model results for 2002 to 2020, there is 50 to 100 feet of groundwater rebound in the Upper Fort Union in the Subregion 3 mines due to a reduction in coal mine pumpage and ongoing reclamation. For the Subregion 2 mines, the rebound is up to 50 feet, and for the Subregion 1 mines the rebound is up to 25 feet. Groundwater rebound in the Upper Fort Union within the basin has been substantial due to a reduction in CBNG pumpage. In the area southeast of Wright, rebound is up to 300 feet. West of the Subregion 2 mines, rebound is up to 225 feet. Between Wright and the Subregion 2 mines along SR 59, reduction in CBNG pumpage results in a broad area of rebound ranging from 25 to 100 feet. Overall, the reduction in coal mine dewatering and the substantial reduction in CBNG pumpage since 2002 results in groundwater rebound in the Upper Fort Union.

ES.3 SURFACE WATER QUALITY

The surface water quality analysis focused on reasonably foreseeable development (RFD) scenarios for normal and dry year conditions to show the difference in potential cumulative impacts to surface water quality based on stream flow and climate. Wet years were not analyzed because increased runoff and stream flow would result in potential water quality impacts considerably less than the normal and dry year RFD scenarios.

For this analysis, “mixing” refers to the mixing of CBNG production water discharge and natural stream flow. Electrical conductivity (EC) is a measure of total dissolved solids; sodium adsorption ratio (SAR) is a measure of the amount of sodium in the water than can react with clays and, thus, reduce infiltration into soil and the ultimate use of the soil for growing crops. The Most Restrictive Proposed Limit (MRPL) and Least Restrictive Proposed Limit (LRPL) for SAR and EC are set for each subwatershed by the Wyoming Department of Environmental Quality in conjunction with neighboring states that receive flow across state boundaries from the specified river in the subwatershed. These limits refer to desired concentrations for SAR and EC and are used as guidelines for evaluating potential impacts to water quality.

Normal year Conditions

Antelope Creek: From 2003 to 2020, EC is projected to decline due to mixing with CBNG production waters, and SAR values are projected to increase. The data indicate that the MRPL and LRPL would not be exceeded for either EC or SAR after mixing of CBNG production waters. Based on the data, surface water is projected to be suitable for irrigation use in all months.

Dry Fork of the Cheyenne River: For the Dry Fork of the Cheyenne, there is no projected discharge of CBNG production water to the drainage through 2020. Therefore, surface water quality conditions for 2010, 2015, and 2020 would be the same as for the base year (2003).

Little Powder River: From 2003 to 2020, EC is projected to decline, and SAR is projected to increase slightly due to mixing with CBNG production waters. The data indicate that EC values

would exceed the MRPL except for March and May during 2010, and March during 2015 and 2020; however, it would not exceed the LRPL except for January and August from 2010 to 2020, and also in September, November, and December from 2015 to 2020. SAR values are projected to exceed the MRPL and not exceed the LRPL. Based on the data, surface water is projected to remain suitable for irrigation to 2020.

Upper Belle Fourche: From 2003 to 2015, EC is projected to decline due to mixing with CBNG production water, and SAR is projected to increase slightly. There is no projected discharge of CBNG production water to the drainage in 2020; therefore, EC and SAR values for this time period would be the same as projected for the base year (2003). The data indicate that EC would not exceed the MRPL, except for October in 2010 and October through January in 2015, and would not exceed the LRPL. The projected SAR values would exceed the MRPL from August to January in 2010 and from September to January of 2015, and would not exceed the LRPL for all months. Based on the data, surface water is projected to be suitable for irrigation to 2020.

Upper Cheyenne River: From 2003 to 2010, EC is projected to decrease due to mixing with CBNG production water, and SAR values would not change. There is no projected discharge of CBNG production water to the drainage in 2015 or 2020. Based on the data, EC values would exceed the MRPL, except for August 2010, and exceed the LRPL, except for July through September 2010. SAR values would not exceed the MRPL and LRPL. Based on the data, surface water would remain suitable for irrigation from 2010 to 2020.

Upper Powder River: From 2003 to 2015, EC is projected to decrease slightly, and SAR values would increase slightly, due to mixing with CBNG production water. There is no projected discharge of CBNG production water to the drainage in 2020. The data indicate EC values would exceed the MRPL, except for May and June for 2010 to 2015, and would exceed the LRPL during July through December from 2010 to 2015. SAR values would exceed the MRPL, except for March in 2010 and 2015 and May in 2015, and would not exceed the LRPL. Based on the data, surface water is projected to remain suitable for irrigation from 2010 to 2020.

In summary, for normal year flows, discharge of CBNG production water to these six drainages generally would reduce the EC and increase the SAR slightly; however, the surface water would remain suitable for irrigation in most months. The MRPL and LRPL may be exceeded for EC and SAR in 1 or more years and in any given year for 1 or more months, but not for all months in the year. For most drainages, discharge of CBNG water increases flows substantially and, thus, is responsible for changes in EC and SAR. The Dry Fork Cheyenne River and Upper Powder River subwatersheds are the main exceptions, because they receive little or no contribution from CBNG discharge.

Dry year Conditions

Antelope Creek: From 2003 to 2020, EC values would be reduced due to mixing with CBNG waters, and SAR values would increase. The data indicate that the MRPL and LRPL would not be exceeded for either EC or SAR for all years after mixing of CBNG production water. Based on the data, surface water would remain suitable for irrigation except for June and August from 2010 to 2020.

Dry Fork of the Cheyenne River: For the Dry Fork of the Cheyenne, no CBNG production water discharge is expected to the drainage through 2020. Therefore, water quality conditions would be the same as the modeled base year (2003) for all years to 2020.

Little Powder River: For the Little Powder River, the EC would be reduced and the SAR increased due to mixing with CBNG waters from 2003 to 2020. The MRPL would be exceeded for all years for EC during the months of February, April, June, and August in 2010; during November through February and during April, June, and August in 2015; and all months except March in 2020. EC values would exceed the LRPL in September 2010; August 2015; and January, August, November, and December 2020. SAR values would exceed the MRPL in all months and years except March 2015 and March and May 2020. The LRPL for SAR only would be exceeded in September 2010. The water would remain suitable for irrigation from 2010 to 2020 except for September and October 2010.

Upper Belle Fourche: From 2003 to 2015, EC values would decline due to mixing with CBNG production waters, and SAR values would increase slightly. There is no projected discharge of CBNG production water to the drainage in 2020. EC values would not exceed the MRPL or LRPL from 2010 to 2015. SAR values would exceed the MRPL in 2010, except for March and July, and also would exceed the MRPL from August to January 2015. Based on the data, surface water would be unsuitable for irrigation from August to October during 2010 and in October 2015.

Upper Cheyenne River: From 2003 to 2010, EC values would decline due to mixing with CBNG production waters, and SAR values would increase slightly. There is no projected discharge of CBNG production waters to the drainage in 2015 or 2020. EC values would exceed the MRPL except for August 2010; the LRPL would be exceeded except for July to September 2010. For SAR, neither the MRPL nor the LRPL would be exceeded. Based on the data, surface water would remain suitable for irrigation to 2020.

Upper Powder River: From 2003 to 2015, EC values would decrease slightly due to mixing with CBNG waters, and SAR values would increase slightly. There is no projected discharge of CBNG production water to the drainage in 2020. EC values would exceed the MRPL except for the months of May and June for 2010 and 2015, and the LRPL would be exceeded July through December for 2010 and 2015. SAR values would exceed the MRPL, except for May and June 2015, and would not exceed the LRPL for all years. Based on the data, surface water would remain suitable for irrigation to 2020.

In summary, during dry year flows, the suitability of surface waters in the six modeled drainages for irrigation generally would be reduced due to the greater percentage of CBNG production water in the drainage after mixing. Both EC and SAR values would exceed the MRPL and LRPL more frequently compared to normal year flows. Even though the waters' suitability for irrigation would be reduced (except for the Upper Belle Fourche River) surface water generally would remain suitable for irrigation during the majority of months of the irrigation season.

ES.4 STREAM CHANNEL STABILITY

In general, cumulative impacts to channel stability largely relate to changes in water quantity associated with discharges from existing or projected development activities as compared to the

runoff characteristics of the receiving drainages. Of particular importance is the quantity of discharge water directly conveyed to the receiving drainages. For purposes of this evaluation, it was assumed that the water discharged directly to the receiving drainages would be limited to CBNG activities (ACE 2009), which are projected to be the primary source of discharge water in the study area through 2020. A site-specific assessment also was performed to evaluate the impact of increased stream flows associated with discharge of CBNG production water in Caballo Creek on existing and reclaimed channels, as well as diversion channels and structures constructed in accordance with coal mine permit criteria.

The perennial stream evaluation calculated the change in channel width for the Little Powder River as less than 0.3 percent. For the Belle Fourche River, it was calculated to be less than 0.2 percent (ACE 2009). These results suggest that for the larger perennial streams the effect of CBNG production water discharge would be minimal. Geomorphic relationships provided insight into the potential impacts of the CBNG production water discharge on the mean annual discharge events associated with the perennial drainages. Based on the projected relatively low increase in mean annual discharge in the perennial streams, the potential trends predicted by the geomorphic relationships (increases in channel width, depth, and meander wavelength) would be considered imperceptible.

To have an impact on channel stability that is manifested in active channel erosion, CBNG production water discharge likely would have to represent a substantial portion of the channel-forming discharge in watersheds where the channel slope is steep enough and the width, depth, and sinuosity low enough to impact channel morphology. Based on the magnitude of the projected CBNG production water discharges compared to the channel-forming discharge (1.5- to 2-year recurrence interval), the impact more likely would be evident in small ephemeral drainages that are characterized by steep channel gradients, lower sinuosity, and smaller widths and depths. Overall, as the drainage area increases, the channel slope typically decreases along with an increase in sinuosity, thereby reducing the impact of CBNG production water discharge on channel stability.

The 2-year peak discharge for Caballo Creek at the eastern (downstream) Subregion 2 coal mine boundary was estimated to be approximately 400 cfs. The estimated contribution of CBNG production water discharge of 1.1 cfs represents less than 1 percent of the 2-year peak discharge. Based on the relative magnitude of the flow contribution from CBNG production water discharge, geomorphic relationships confirm the conclusion that the minor contribution from CBNG production water discharge to the flow in Caballo Creek likely would not result in active erosion to the channel. These results were confirmed by observations of the existing channels during the field reconnaissance.

A threshold may exist where the contribution of CBNG production water discharge may create erosion within the receiving drainage channel. Based on the channel slope, channel sinuousity, and watershed area, drainages such as Caballo Creek may not realize an increase in channel erosion but would more likely realize an increase in vegetation diversity and density along the channel. Smaller drainages, such as Bone Pile Creek or Duck Nest Creek (tributaries to Caballo Creek), may be more likely to exhibit channel erosion depending on the magnitude of the flow contribution from CBNG water production compared to the channel-forming discharge. However, field observations in these watersheds found similar increases in vegetation along all of the channels.

ES.5 GROUNDWATER RECOVERY

Groundwater recovery for the Wasatch and Upper Fort Union formations was modeled relative to year 1975. This date was selected as a time before coal mines began substantial pumping of groundwater and before CBNG pumpage. Thus, 1975 represents near steady-state for the eastern PRB in the CMGM model for the Wasatch and Upper Fort Union formations.

Wasatch Formation

Based on the modeling results, the Wasatch Formation is projected to recover from CBNG pumpage and discharge and coal mine dewatering in approximately 300 to 500 years. This recovery is a modeled recovery, and the assumption in the CMGM is that the Wasatch is a continuous aquifer. In reality, the Wasatch is not a continuous aquifer, but a complex fluvial/deltaic depositional system with local areas of groundwater and sometimes fairly continuous zones of groundwater within sand lenses. These areas of groundwater may recover faster than has been estimated by the CMGM model, or in some cases, they may take longer than the model-estimated 300 to 500 years. Therefore, the estimated steady-state for the Wasatch of 300 to 500 years is approximate and based on assumptions that were required for construction of the CMGM that may not apply to all areas of the Wasatch. Also, the Wasatch would continue to be used for stock water and locally for domestic water supply following the end of coal mining and CBNG development. Recovery modeling assumed that no use of groundwater in the Wasatch would continue after year 2050. Thus, some areas of the Wasatch may recover very slowly to pre-mining or pre-CBNG groundwater levels.

Upper Fort Union Formation

Based on the modeling results, the Upper Fort Union is projected to recover to near, or approximately 80 percent of, steady-state conditions in approximately 300 to 500 years. The estimated final steady-state for the Upper Fort Union is approximately 500 years. Pumpage of groundwater from the Upper Fort Union has been from the coal-bearing zones, either for removal of CBNG or for removal of coal in the coal mines in the eastern PRB that follow the outcrop of the coal along the eastern structural boundary of the PRB. For groundwater recovery to occur in the Upper Fort Union, water has to flow back into the coal-bearing formations affected by groundwater removal. In the CMGM model, this flow of groundwater during recovery is controlled by the boundary conditions of the model, the distribution of recharge, and the overall distribution of hydraulic conductivity and storage in the Upper Fort Union (Layer 5 in the CMGM model). Recovery of the Upper Fort Union may take longer than the model-estimated 300 to 500 years. Recovery of a groundwater system that took millions of years to develop often can require considerably more time than that estimated by a numerical model. It has been assumed in the modeling of recovery by the CMGM that all pumpage in the eastern PRB ceases in year 2050. Assuming Gillette continues its municipal pumpage, and other areas of the eastern PRB utilize groundwater in the Upper Fort Union after year 2050, recovery of the groundwater levels in the Upper Fort Union may be a slow process and may take longer than the model-estimated 300 to 500 years.

Transport Modeling Results

Based on data in the Gillette Area Groundwater Monitoring Organization's (2003, 2000) reports, the average total dissolved solids (TDS) in coal mine pit backfill aquifers in the PRB is approximately 3,700 milligrams per liter (mg/L), with the highest average value for any coal mine subregion being approximately 4,800 mg/L for Subregion 1. Coal mine pit backfill aquifer water has an average TDS below Wyoming stock water standards (5,000 mg/L). Thus, movement of pit backfill water westward into the Wasatch and Fort Union aquifers would not degrade the water quality of these aquifers relative to use for stock watering. The westward extent of the 1,000 mg/L TDS isopleth was modeled to represent the location where the TDS of groundwater leaving the coal mine backfill aquifers would be reduced through groundwater flow and dispersion to a level approximately equal to the current average TDS in the Wasatch and Fort Union aquifers. After 500 years (the approximate time for flushing of the backfill aquifers by groundwater) the 1,000 mg/L isopleth is anticipated to extend up to 2,000 feet west of the reclaimed coal mine pits in all of the coal subregions of the eastern PRB. Thus, the maximum projected impact to groundwater quality in the Wasatch and Fort Union aquifers would be limited to a distance of up to 2,000 feet west of the reclaimed coal mine pits.

ES.6 OVERALL SUMMARY OF PROJECTED CUMULATIVE EFFECTS

Overall, changes in the eastern PRB from 2002 to 2020 involve an assumed gradual reduction in pumpage rates for CBNG wells as they mature and continue to migrate to the west and southwest, tapping deeper levels of the coal-bearing units in the Upper Fort Union. Based on modeling results, this leads to a shift in drawdown in the Upper Fort Union to the southwest of Wright, with a corresponding rebound in groundwater levels west of the coal mines along SR 59 as the CBNG wells in this area cease production and pumpage of groundwater. For the Wasatch, discharge of CBNG water from 2002 to 2020 results in mounding of up to 30 feet in the areas of substantial CBNG pumpage. It also is assumed that the coal mines would continue to operate and dewater up to 2050; however, reclamation of mined-out areas would allow groundwater to rebound in the backfill aquifers that develop in the reclaimed areas. Based on modeling results, drawdown within the active coal mine areas and to the west of the mines for approximately 2 to 3 miles the same from 2002 to 2020. Discharge of CBNG water to ephemeral drainages in the eastern PRB leads to a decrease in EC in most drainages and an increase in SAR; however, the final mixed water continues to be suitable for irrigation in most drainages during the normal precipitation years and for most months during the dry years. During the dry year, months with normally low flows often have a mixed water that would not be suitable for irrigation during those months if they receive substantial CBNG discharge.

Based on the groundwater modeling results for 2010, groundwater flow in the Wasatch and Upper Fort Union is to the northeast south of Wright and gradually shifts to the northwest east of Wright. Most drawdown in the Wasatch (up to 70 feet) is in the Subregion 3 coal mines located southeast of Wright. West of the Subregion 3 coal mines, drawdown in the Wasatch is 10 to 20 feet. Groundwater mounds due to CBNG discharge of up to 30 feet are present west of Wright and west of the Subregion 2 coal mines. For the Upper Fort Union, there is a substantial groundwater depression, with up to 575 feet of drawdown since 1990 (350 feet of drawdown since 2002),

southwest of Wright. Drawdown since 1990 in the coal mine areas is up to 250 feet in the Subregion 3 coal mines, up to 125 feet in the Subregion 2 coal mines, and up to75 feet in the Subregion 1 coal mine areas. Drawdown since 2002 is 150 feet or less in the coal mine areas. Rebound in the Upper Fort Union since 2002 is up to 100 feet along SR 59.

Based on groundwater modeling for 2015, groundwater flow patterns in the Upper Fort Union and the Wasatch are the same as projected for 2010. Drawdown in the Wasatch is mostly in the Subregion 3 coal mines and ranges up to 80 feet, with up to 30 feet of drawdown west of the mines since 1990. Drawdown in the Wasatch since 2002 is up to 60 feet in the Subregion 3 mines and up to 30 feet west of the mines. Groundwater mounding up to 20 feet within the Wasatch continues to be present in areas of CBNG water discharge. For the Upper Fort Union, the groundwater depression noted in 2010 southwest of Wright shifts further to the south, and the drawdown is up to 475 feet since 1990 (350 feet since 2002). Drawdown in the Subregion 3 coal mines is up to 150 feet in the Upper Fort Union, with comparable drawdown in the Subregion 2 coal mines and considerably less drawdown in the Subregion 1 coal mines. Rebound of groundwater levels since 2002 is projected in the Upper Fort Union, with up to 200 feet of rebound in some areas of the Subregion 3 coal mines and 25 to 50 feet of rebound in the Subregion 1 and Subregion 2 coal mine areas. There is a general rebound of up to 275 feet in the Upper Fort Union along SR 59 due to the reduction in CBNG pumpage since 2002.

Based on groundwater modeling results for 2020, groundwater flow patterns in the Wasatch and Fort Union are much the same as projected for 2010 and 2015. Drawdown in the Wasatch is up to 70 feet in the Subregion 3 coal mines, and up to 20 feet in both the Subregion 1 and Subregion 2 coal mines. Groundwater mounds up to 20 feet are present near Wright and west of the Subregion 2 coal mines. Since 2002, drawdown in the Wasatch is up to 60 feet in the Subregion 3 coal mines and up to 20 feet in both the Subregion 1 and Subregion 2 coal mines. Drawdown in the Upper Fort Union is 425 feet southwest of Wright since 1990 (350 feet since 2002). Drawdown in the Subregion 3 coal mines is up to 125 feet, with up to 75 feet in the Subregion 2 coal mines and up to 25 feet in the Subregion 1 coal mines. Rebound of groundwater levels up to 125 feet is found in the reclaimed areas of the coal mines. Groundwater rebound of up to 20 feet since 1990 is found in the basin west of the Subregion 2 coal mines and near Wright. Since 2002, rebound of groundwater levels west of the Subregion 2 coal mines is up to 175 feet, and up to 275 feet in the Upper Fort Union along SR 59.

After 2050, modeled groundwater levels in the eastern PRB begin to rebound due to the projected cessation of CBNG pumpage around 2030 and the projected cessation of coal mining around 2050. The Wasatch begins to show noticeable rebound after approximately 50 years (around year 2100) and substantial rebound after 200 years (year 2250). The Upper Fort Union shows recovery after 50 to 100 years (2100 to 2150) and substantial recovery after 200 years (2250). Both the Wasatch and the Upper Fort Union are projected to rebound and reach approximately 80 percent of steady-state in 300 to 500 years after the cessation of coal mining, or around 2350 to 2550.

Resaturation of the coal mine pit backfill to form backfill aquifers may take approximately 100 years after cessation of coal mining and will result in the westward migration of groundwater with elevated TDS levels. Modeling of this westward migration suggests that TDS levels should be down to approximately the current background value of 1,000 mg/L for the Wasatch and Upper Fort Union aquifers within approximately 2,000 feet of the final western extent of the coal mine boundaries in

2050. Thus, no impact to groundwater quality in either the Wasatch or the Upper Fort Union is expected beyond approximately 2,000 feet west of the final coal mine boundaries.