APPENDIX A

PLANT SITE GROUNDWATER CONCEPTUAL MODEL AND NUMERICAL MODEL UPDATE

Colstrip Steam Electric Station
Colstrip, Montana

updated july 2015

NewFields

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PLANT SITE GROUNDWATER CONCEPTUAL MODEL AND NUMERICAL MODEL UPDATE
Colstrip Steam Electric Station
Colstrip, Montana

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EXECUTIVE SUMMARY

NewFields Companies LLC (NewFields) prepared this report to describe revisions made to the conceptual model and design of a numerical groundwater flow model previously developed for the Plant Site area associated with the Colstrip Steam Electric Station (CSES) in Colstrip, Montana (**Figure ES-1**). PPL Montana (PPLM) initiated groundwater modeling of the Plant Site area in 2004 to develop a better understanding of the hydraulic interactions between process ponds, groundwater, and surface water at and near the facility.

The revised model was calibrated to Plant Site environmental data collected during time periods that reflect a range of groundwater conditions that have occurred over the past 20 years. The groundwater system at the Plant Site has been altered in the past through construction and operation of various impoundments (e.g., process ponds, sediment ponds, water storage facilities) and installation of various capture wells to intercept groundwater that is affected by seepage of process water.

MODEL BACKGROUND

This initial Plant Site conceptual and numerical models were developed in 2004 and 2005. The numerical model was designed using the U.S. Geological Survey (USGS) code MODFLOW-2000. USGS code MODPATH was used to simulate advective transport of constituents in groundwater. The groundwater model was revised in 2008 using MODLFOW SURFACT (code that extends the capabilities of MODLFOW) based on more recent hydrologic information (e.g., additional lithologic information, new aquifer test results, additional water level data, new water quality data, capture well extraction rate data, among others) obtained by PPLM since the initial model was developed.

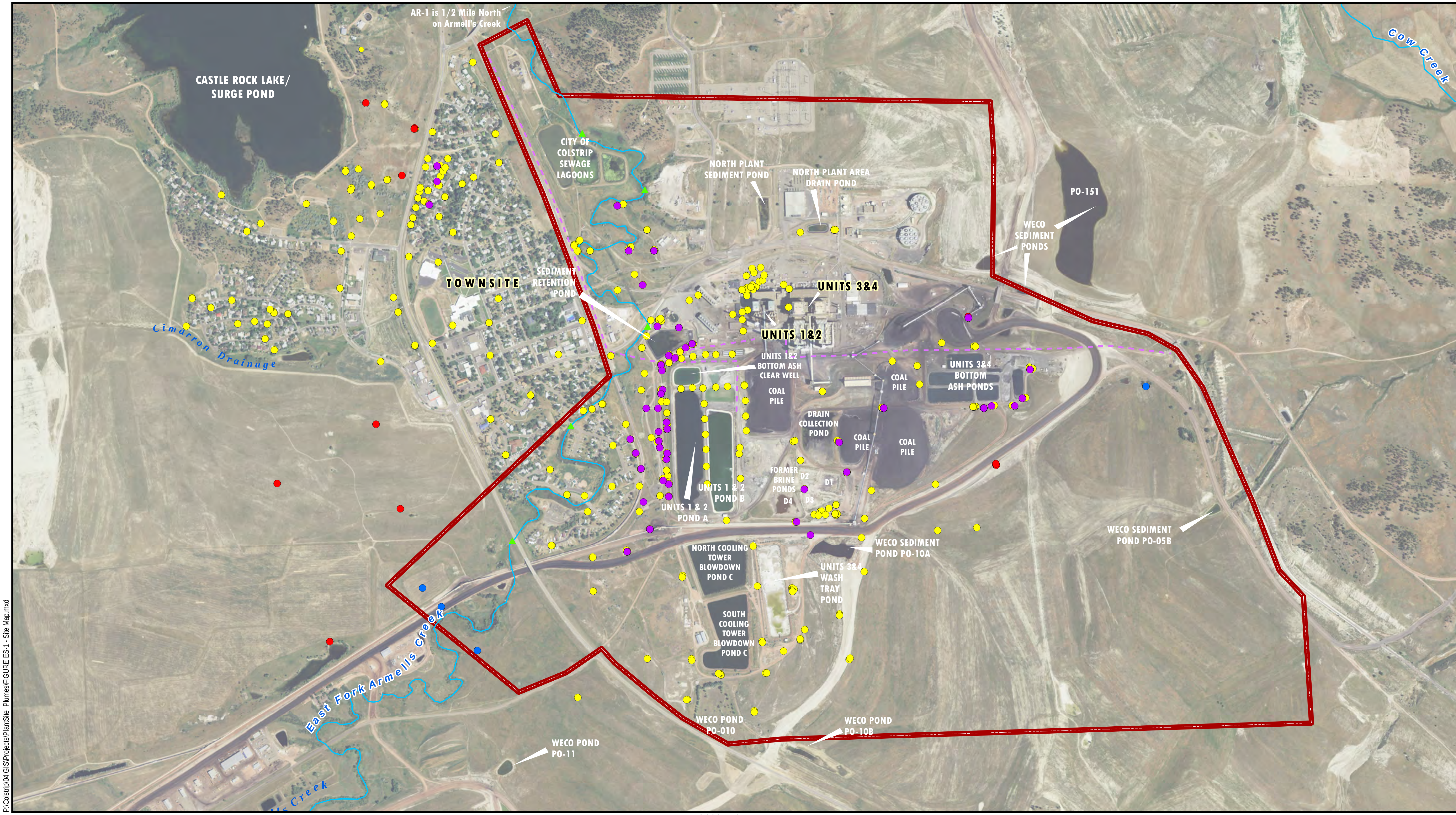
As the groundwater model evolved and groundwater flow became more complex due to construction of additional groundwater capture systems, it became apparent the 2008 model did not have sufficient vertical resolution to differentiate between spoils, overburden, and different layers of alluvium. This made it difficult for the model to simulate detailed groundwater flow and solute transport in particular areas of interest. As a result, PPLM elected to redesign the model (through the addition of model layers and other refinements) to create a better tool to allow for a more robust evaluation of the performance and effectiveness of groundwater capture systems.

GOALS AND OBJECTIVES

The overall goal of updating the conceptual and numerical models for the Plant Site was to improve the overall understanding of the groundwater flow system and provide information to improve water management strategies.

Specific objectives of completing the analyses described in this report were to:

- Refine the numerical groundwater flow model geometry, aquifer properties, and vertical discretization to more accurately simulate groundwater flow in distinct hydrostratigraphic intervals.
- Assess the adequacy of the groundwater monitoring well network and capture systems.
- Make the numerical groundwater model for the Plant Site more consistent with models developed for the Stage I and II Evaporation Pond and Units 3 and 4 EHP areas by including more layers based on lithology/stratigraphy and using similar values for background recharge.



Note: 2003 NAIP Imagery

- Gauging Station
- Monitoring Well
- Montana Bureau of Mines and Gelogy (MBMG) Well
- Western Energy Well
- Capture Well
- Fly Ash Slurry Pipelines
- Plant Site Area

0 Feet 1,200

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Plant Site Area Map
Plant Site Area Groundwater Model
CSES-Colstrip, Montana
FIGURE ES-1

The conceptual model of the site was expanded to include additional data obtained through installation of new wells, recent aquifer testing, results of more recent environmental monitoring, and reviews of recent operational practices. Brief summaries of our understanding of the Plant Site characteristics follow.

GEOLOGY AND HYDROSTRATIGRAPHY

The Plant Site area is underlain by the Fort Union Formation, a sequence of alternating and intercalated deposits of shale, claystone, mudstone, siltstone, sandstone, carbonaceous shale and coal. The main coal seams of interest near the CSES are the sub-bituminous Rosebud (~24 feet thick) and McKay seams (~8-10 feet thick) which can economically be strip-mined. In the Plant Site area, the Tongue River Member (nearest the surface) of the Fort Union Formation was subdivided into the following lithostratigraphic units; Rosebud Overburden, Rosebud Coal, Interburden, McKay Coal, and Sub-McKay.

Groundwater in the near-surface geologic units occurs in several strata. For purposes of the groundwater model, several hydrostratigraphic units were identified and incorporated into the model to increase the level of detail. These included:

- Alluvium/Colluvium – Alluvium consists of unconsolidated material (sand, gravel, silts), most prominently located along East Fork Armells Creek, the primary surface water feature in the area. Colluvium consists of unconsolidated materials present at ground surface in the Colstrip Townsite and the western portion of the Plant Site.

- Overburden – Rosebud overburden consists of siltstone and silty sandstone of variable thicknesses that is truncated in certain locations within and near the Plant Site through the down-cutting of surface water features, most prominently East Fork Armells Creek.

- Spoils/Fill – Strip-mining of coal involves removing the overburden (sediments overlying the coal), removing the coal, then backfilling the pit with the spoils. Spoils consists of a mixture of overburden materials, clinker, and waste coal that is present from ground surface to depths up to 110 feet beneath the eastern portion of the Plant Site. Fill is intermixed sandy silt with clay and fragments of scoria.

- Rosebud Coal/Clinker – Rosebud Coal is a 20- to 25-foot thick coal seam that is missing from much of the Plant Site area and the floodplain of the East Fork Armells Creek due to it either being mined or having been eroded away by stream action. Clinker, formed in areas where Rosebud Coal has burned, usually occurs near where coal seams outcrop.

- Interburden – Interburden consists of siltstone, shale, and sandstone lying stratigraphicly between the Rosebud and McKay Coal seams. This unit is missing from much of the floodplain of the East Fork Armells Creek due to erosion.

- McKay Coal – McKay Coal is an eight to 12-foot thick coal seam that has not been mined in the vicinity of the Plant Site. However, portions of this unit are missing from much of the floodplain of the East Fork Armells Creek due to natural stream erosion.

- Sub-McKay Bedrock – The Sub-McKay unit consists of interbedded siltstone, shale, and sandstone present beneath the McKay Coal. The Sub-McKay unit is at least at least 300 feet thick and is present across the entire study area. This unit is divided into shallow and deep zones for the purposes of describing differences in groundwater flow, but the zones have similar lithostratigraphy.

SURFACE WATER FEATURES

Several surface water features are present in the vicinity of the Plant Site that affect groundwater flow. These include water storage ponds, process ponds, surge pond, sediment storage facilities, sewage lagoons, and East Fork Armells Creek. Maintenance of the ponds has been conducted to varying degrees since inception of the CSES, transforming some from clay-lined features to those lined with synthetic materials. Some ponds have been redesigned to include engineered drains installed at the base of the features. Seepage of fluids from these ponds is variable and locally affects groundwater elevations and flow directions in shallower units. East Fork Armells Creek exhibits gaining and losing reaches within the Plant Site. Stream gains and loss are influenced by seepage from impoundments as well as operation of groundwater capture systems. Because of this, the stream serves as both a source and a sink to the near-surface groundwater systems.

WATER QUALITY

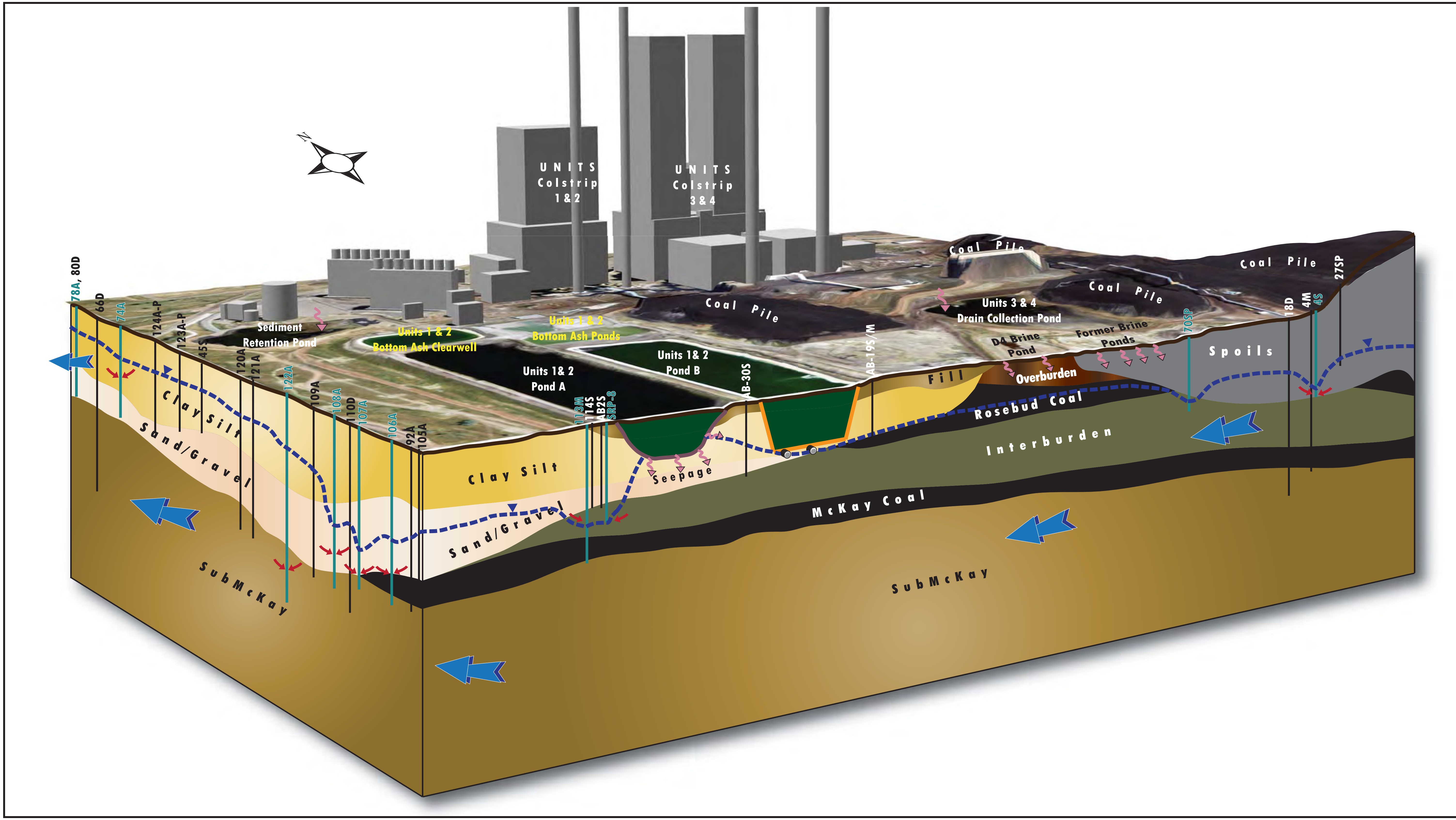
Water quality in the Plant Site area has been documented through an extensive surface water and groundwater monitoring program that has been active for decades and expanded over time. Dissolved constituents, including sulfate, magnesium, boron, and chloride, are present naturally in the regional groundwater system. These constituents are also present in process pond water, although at concentrations higher than those that naturally occur in groundwater.

Groundwater at and downgradient of the Plant Site contains levels of indicator parameters (including total dissolved solids (TDS), specific conductance (SC), sulfate, chloride, and boron) that are elevated with respect to baseline conditions. Some current and former process ponds at the Plant Site have likely served as sources of these parameters to groundwater. Baseline screening levels (BSLs) have been developed for these indicator parameters in an effort to help evaluate where groundwater has been affected by process water seepage. PPLM is currently reviewing and refining these BSLs.

CONCEPTUAL MODEL

Figure ES-2 is a block model illustrating our conceptual understanding of the hydrogeologic system in the Plant Site area. Seepage from process ponds is a major source of recharge within the Plant Site and, along with seepage from sediment ponds and stormwater collection areas, recharges the groundwater system, creating localized mounding. Groundwater capture via drains and wells is the largest component of outflow for the groundwater budget. The capture system depresses the water table adjacent to seeping process ponds and collects both impacted and non-impacted groundwater which is routed back to the various ponds on-site.

Most groundwater that is not captured by the pumping systems flows westward from under the process ponds and then turns northwest toward East Fork Armells Creek, which is a major point of outflow for the shallow system. As more capture wells have been added, less groundwater originating from under the process ponds has flowed into the creek. Groundwater at the eastern side of the Plant site area flows generally eastward toward the Cow Creek drainage. Groundwater flow in the deep Sub-McKay (deeper than 200 feet below ground surface) follows a more regional pattern that is generally from southwest to northeast beneath the Plant site. Vertical hydraulic gradients are upward along portions of East Fork Armells Creek where groundwater flows into surface water. Vertical gradients



Seepage/Infiltration From Process Pond/Source Area

Capture Well (106A)

Direction of Groundwater Flow

Potentiometric Surface

Capture of Impacted Water

Underdrain Pond B

Clay Liner Pond A

Geotextile Liner Pond B

Monitoring Well (92A)

Not To Scale

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Block Model
Plant Site Area Groundwater Model
CSES-Colstrip, Montana
FIGURE ES-2

beneath the remainder of the area are downward from Rosebud, alluvium and spoils intervals to the McKay Coal to the Shallow McKay and into the underlying deep McKay.

With the onset of mining and associated dewatering, flow directions in some areas surrounding the Plant Site (e.g. south of the South Cooling Tower Blowdown Pond C, **Figure ES-1**) have reversed toward mine cuts. With the construction of the Plant and associated operation of process ponds, localized recharge sources further altered groundwater gradients and flow directions. Currently, groundwater levels in most of the previously mined areas exhibit a long-term recovery trend, although renewed mining in Area B of the Rosebud Mine is beginning to draw down water levels in the south of the Plant Site. More robust liner and underdrain systems have been installed beneath several process ponds, reducing seepage from these sources, and expansion of the groundwater capture system is intercepting a large portion groundwater flow.

As suggested above, the hydrostratigraphy in the Plant Site area is complex. A once layer-cake stratigraphy has been eroded away along East Fork Armells Creek. Alluvium within the floodplain consists of fine-grained overbank deposits overlying coarser channel deposits consisting of sand and gravel. Mining operations have removed a significant portion of the overburden and Rosebud Coal in the Plant Site area, replacing it with mine spoils. Thicknesses and hydraulic properties of spoils are highly variable, adding to the complexity of the overall system.

Process pond water contains dissolved constituents that are also present in groundwater that is un-impacted by sources within the plant site, making it difficult to draw distinct lines between impacted and unimpacted groundwater. Groundwater quality that is influenced by current and former process ponds at the Plant Site is characterized by elevated levels of indicator parameters (dissolved boron, chloride, SC, and TDS) that are present at concentrations above that typically found in groundwater not affected by process ponds.

Most groundwater with concentrations of constituents above BSLs is currently being intercepted by the groundwater capture system and returned to lined ponds. Some of this groundwater is also being captured by the WECO dewatering wells located north of the Units 3 and 4 Bottom Ash Ponds. A portion of this groundwater is likely also discharging to East Fork Armells Creek. Historically, a major portion of groundwater originating from the Plant Site flowed into the creek. Increased pumping of the groundwater capture system over the last 10 years has reduced outflow of groundwater to the creek.

Currently, groundwater is not used for domestic or livestock purposes in the Plant Site area. Planned human health and ecological risk assessments will further evaluate contaminant fate and potential receptors.

MODEL DESIGN

As discussed above, the previous numerical groundwater flow models were revised to create a more robust representation of the hydrogeology at the Plant Site. This was generally completed by reviewing the changes in the conceptual model from previous versions and then revising the numerical model to account for these changes. New information considered included:

- Lithologic, water level, and water quality data from 54 wells.
- Aquifer test data from 33 wells in the Plant Site area.
- Water level and water quality information obtained from 2008 through 2014.

This new information was incorporated into the conceptual model and the numerical model was redesigned based on the current understanding of the physical flow system. New design features included the addition of model layers, refinement of the distribution of aquifer properties based on recent aquifer testing, adjusting the pumping rates of capture wells to better account for increasing pumping rates of these features in recent times, and taking into account the effect of renewed mining in Area B of the Rosebud Mine.

In revising the model, NewFields expanded the model domain spatially to address concerns expressed in previous versions of the model and added additional layers to the model to include two layers within the alluvium (fine-grained and coarse-grained layers, Layers 1 and 2), an Interburden and East Fork Armells Creek layer (Later 3), a McKay Coal and East Fork Armells Creek layer (Layer 4), and two layers in the Sub-McKay unit (Layers 5 and 6). The revised model layers (6 total) extended from a maximum elevation of 3467 feet above mean sea level (amsl) to 2950 feet amsl and covered an area of approximately 3,839 acres. The revised model domain was discretized into 255 rows and 253 columns with 333,825 total active cells with the grid telescoping from a uniform 100-foot spacing down to 25 feet in the area around the Plant Site process ponds.

Boundary conditions established in the updated numerical model include the following:

- General head boundaries (GHBs) refined to simulate hydrologic data collected during three distinct time periods. The data represented periods that included recent conditions (2014) as well as periods during which significant hydraulic events took place (e.g., an excursion from a pond). This range of data provides for a more robust calibration of both transient and steady-state model runs.
- No-flow boundaries were established along the perimeter of the active model domain where groundwater flow direction was assumed to be parallel to the model boundaries.
- The River package was used to simulate groundwater and surface water exchanges along East Fork Armells Creek and between the Surge Pond and the groundwater flow system. Stream elevations from synoptic measurements collected at gaging stations were used to assign river stage elevations within the model.
- MODFLOW's Hydraulic Flow Barrier (HFB) package was used to simulate two dams along the northeast and southeast boundary of the Surge Pond.
- Groundwater capture wells and water supply wells are represented using both the Well and the Fracture-Well (FWL5) packages.
- Underdrain systems installed below certain fly ash and bottom ash ponds were simulated in using the Drain package.
- The Recharge package was used throughout the model domain to simulate deep percolation (net recharge) in various zones based on groundwater and land use and also to represent seepage from impoundments.
- Aquifer parameters assigned in the model consisted of hydraulic conductivity, aquifer storage, and effective porosity. Parameterization of the model cells was based on the hydrostratigraphy of the subsurface delineated for the conceptual model.

MODEL CALIBRATION

Following revision of the model framework and boundaries and assignment of initial model parameters, the 2014 Plant Site groundwater model was calibrated to provide a measure of confidence in its ability to meet project objectives. The calibration process required establishing a set of calibration targets and then performing an iterative process comparing model results with the targets. Targets used to calibrate the 2014 Plant Site Model included: (1) measured water levels, (2) estimated flux into and out of the groundwater system as underflow, (3) net gains and losses in East Fork Armells Creek, (4) closeness of fit between simulated and observed potentiometric maps, and 5) closeness of fit between simulated and observed hydrographs and time-drawdown plots.

During calibration, input parameters values were varied iteratively within the range of values determined through field measurements and literature values. Input parameters varied during calibration included:

- Hydraulic Conductivity
- Pond Seepage
- Background Recharge
- Conductance of Head-Dependent Boundaries
- Storage
- Stage in the East Fork Armells Creek

The model was calibrated to several independent hydrologic data sets to evaluate how robust the model was under both steady-state and transient simulations. These included comparing model output to measured heads and estimated fluxes for two time periods (2003 and 2014) for steady-state conditions and against measured drawdown associated with two pumping tests, and transient head and flux data collected between December 2003 and January 2006.

The major parameters adjusted during model calibration were hydraulic conductivity and aquifer recharge. Recharge rates from ponds were typically adjusted more frequently than the background (undisturbed areas) recharge rates. To a lesser degree, the hydraulic conductivities of the head-dependent boundaries were adjusted, including those for drains, the river boundaries (East Fork Armells Creek and the Surge Pond), and general head boundaries. For the transient models, aquifer storage values were adjusted to assist in model calibration. An auto-sensitivity analysis was periodically used to identify specific zones within the model that were more sensitive. Particle-tracking was also periodically performed to check the match between simulated and observed transport of process pond-affected groundwater. Calibration results were evaluated against the modeling calibration goals, discussed previously.

The results of the calibration process indicate that the Plant Site groundwater model is well-calibrated. Calibration to several independent sets of steady-state and transient data provides confidence in the ability of the model to simulate flow and advective transport under a variety of hydrogeologic conditions within a reasonable range of error.

SENSITIVITY ANALYSES

A sensitivity analysis was performed to quantify uncertainty in the calibrated model related to uncertainty in model inputs. The sensitivity analysis was conducted by varying selected values of horizontal and vertical hydraulic conductivity, infiltrating zones of recharge, pond seepage zones, riverbed conductance, and model pumping rates through plausible ranges of values for these parameters. The sensitivity analysis also included modifying zones of key model inputs including: horizontal and vertical hydraulic conductivity; net recharge; pond seepage; streambed conductance; and pumping rates.

The results of the sensitivity analysis indicate the model is most sensitive to changes in recharge and hydraulic conductivity. Specific areas were identified within the model domain as being sensitive with respect to each of these input parameters.

Overall, the sensitivity analysis shows that the 2014 Plant Site model is relatively well-calibrated with increasing recharge having the greatest effect on the model calibration and both increasing and decreasing distinct hydraulic conductivity zones have measurable effects on model calibration. Model calibration appeared to be relatively insensitive to increases and decreases in river bed conductance and pumping rates. The range of uncertainty in model predictions could be reduced with greater certainty and refinement of these model parameters.

CAPTURE ANALYSIS

Particle tracking was used to evaluate the effectiveness of the current groundwater capture system. For this analysis, particles were placed in portions of Layers 1 through 5 in the model that currently exceed BSLs for indicator parameters. Particles were allowed to move forward in time and results were evaluated to determine if any portion of the groundwater system that currently exceeds BSLs is not being captured by the current groundwater capture system.

Capture analysis suggests that groundwater exceeding BSLs for indicator parameters originating from most known source areas in the Plant Site area will be intercepted by the capture system. The results from this analysis also suggest that the current capture system may not be completely capturing groundwater originating from the following areas:

- Areas of BSL exceedance in the alluvial groundwater around OT-7 and the Sewage Lagoons,
- A small area of BSL exceedance in the interburden and McKay around the North Plant Area Drain Pond,
- Areas of exceedance in spoils around the Units 3 & 4 Bottom Ash Ponds, and
- An area of BSL exceedance in spoils, Rosebud, interburden and McKay near the southern end of the Units 3 & 4 Cooling Tower Blowdown Pond.

Reverse particle tracking analyses were also completed for two monitoring wells to help evaluate the potential sources of elevated levels of indicator parameters detected in groundwater samples. Reverse particle tracking results for wells CA-19 and OT-7 indicate that groundwater intercepted by these wells does not originate at the Plant Site.

CONCLUSIONS

Calibration of the numerical groundwater flow model described in this report demonstrates the numerical groundwater flow model is capable of simulating groundwater flow and advective transport under a variety of hydrogeologic conditions. The numerical model is appropriate for use in evaluating elements of the conceptual model and the efficacy of groundwater capture systems, either currently operating or being considered in the future.

Development of the conceptual and numerical groundwater flow model along with model calibration, model sensitivity analysis, and capture analysis have led to the following conclusions:

- The Plant Site area has a complex and dynamic groundwater flow system. In addition to complex hydrostratigraphy and diverging groundwater flow, several impoundments provide sources of variable seepage to groundwater. These include the Plant Site process ponds, WECO sediment ponds, the Surge Pond, and the City of Colstrip Sewage Lagoons. Periodic dewatering of nearby strip-mines has also influenced groundwater flow.
- Groundwater quality that has been influenced by seepage from current and former process ponds at the Plant Site is characterized by elevated levels of certain parameters, including dissolved boron, chloride, SC, and TDS.
- A few areas peripheral to the Plant Site exceed the chloride BSL, but generally do not exceed BSLs for other constituents of concern. Sources other than process ponds may be responsible for chloride detected in these areas.
- Increased pumping of the groundwater capture system over the last 10 years has changed gaining reaches of East Fork Armells Creek into losing reaches.
- Groundwater capture via drains and wells is the largest component of outflow for the groundwater budget.
- Vertical gradients are mostly downward within the Site, except areas near gaining reaches of East Fork Armells Creek and in areas affected by pumping around some capture wells completed in shallower units (e.g. spoils, overburden and alluvium).
- The numerical groundwater flow model has been calibrated to multiple sets of hydrogeologic data that represent a range of conditions and is able to reproduce flow fields, heads, and fluxes within a reasonable range of error under a variety of hydrologic stresses. This provides confidence in the predictive capabilities of the model.
- The numerical groundwater flow model is most sensitive to recharge rates, particularly recharge through unvegetated portions of the Plant Site and seepage from the Units 3 and 4 Bottom Ash Ponds and WECO Sediment Pond PO-151.
- Capture analysis of the areas exceeding BSLs suggests that the vast majority of groundwater exceeding BSLs is captured (at least 98 percent of particles were captured) by the current capture system (exceptions noted below).
- Capture analysis indicates that groundwater in two areas that currently exceed BSLs would flow into East Fork Armells Creek without being captured by the current system:
    - Particles in alluvial groundwater near well OT-7 and the Sewage Lagoons is predicted to reach the creek in few years, and,
    - Particles in a small area of groundwater in the Interburden and McKay around the North Plant Area Drain Pond are predicted to reach the creek after more than 50 years.
- Capture analysis indicates some areas of groundwater exceeding BSLs would remain within the Plant Site Area but would not be captured using the current system within 50 years including:

- o An area in spoils and bedrock under the Wash Tray Pond,
- o Areas around the former Brine Ponds,
- o Groundwater in Rosebud, interburden and McKay hydrostratigraphic units from beneath the South Units 3 & 4 Cooling Tower Blowdown Pond.

The model predicts other areas would never be captured using the current system including:

- o Groundwater in spoils around the 3 & 4 Bottom Ash Ponds,
- o Groundwater in spoils, Rosebud, interburden and McKay hydrostratigraphic units south of the South Units 3 & 4 Cooling Tower Blowdown Pond.

Results of reverse particle tracking analyses completed for well CA-19 indicate that water sampled from the well originates at the water table a short distance southwest of the well, not from the Plant Site. Reverse particle tracking analyses completed for well OT-7 indicates some of the water sampled from OT-7 originates from East Fork Armells Creek and some originates from beneath the Townsite.

Predictive uncertainty analysis shows that the portion of captured vs. uncaptured particles does not vary substantially with reduction in groundwater capture rates. This analysis suggests that the current groundwater capture analysis is not very sensitive to decreases in capture well pumping rates.

Based on the fact that the modeled total pumping rate is the largest component of outflow in the groundwater budget and that simulating capture with reduced pumping rates achieved nearly full capture, the capture system could be optimized to achieve more efficient capture.

In developing the conceptual and numerical models, several potential data gaps have been identified and are discussed briefly below.

Even though, simulation of plume capture using particle tracking was not sensitive to adjustment of current capture rates, future capture analysis that might consider fewer active pumping wells and/or lower pumping rates might be sensitive to this parameter. Developing a more accurate method of measuring capture well pumping rates would increase model accuracy.

The water balance and flux targets for the steady-state models are currently based on synoptic stream flow measurements obtained during spring-time conditions. Completing a synoptic gaging run during dry /low water season (October- March) would help increase model accuracy and enhance the understanding of groundwater/surface water interactions.

- Particle tracking suggests that groundwater originating from the Units 3 and 4 Bottom Ash ponds is moving to the east. There are currently no monitoring wells in this area. Installation of monitoring wells would better define groundwater flow and quality in this area.
- The groundwater model extends over a relatively large region. Currently, water level data used in the model to establish boundaries and head targets were derived from various time periods. A groundwater level measurement event conducted during a single monitoring event (during low water season (October-March) would be best) including Plant Site wells, Colstrip Townsite wells, Western Energy wells, and Surge Pond wells would provide for a better calibration data set and better justification of model boundaries.

- Currently, the surface water elevations in several WECO sediment ponds (particularly PO-151, PO-10A, and PO-10B) are unknown. Surveying elevations of water surfaces at these locations would enhance the understanding of groundwater/surface water interaction and the importance of these ponds as potential sources of recharge to the groundwater system.
- Water quality analyses suggest some abandoned pond areas that periodically fill with water and ultimately recharge the local groundwater system may be source areas for constituents of interest. These include the Units 3 & 4 Wash Tray Pond and the former Brine Ponds. Currently, only limited data exist regarding the timing of filling of these ponds and the duration of ponded water in the impoundments. If PPLM elects to maintain the depressions of the former ponds, monitoring water conditions in these impoundments would allow more accurate estimation of groundwater recharge.

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1.0 Introduction

This report describes the redesign and calibration of a numerical groundwater flow model previously developed for the Plant Site area associated with the Colstrip Steam Electric Station (CSES) in Colstrip, Montana (**Figure 1**). The work described herein was completed by NewFields on behalf of PPL Montana, LLC (PPLM), the operator of the CSES. PPLM initiated groundwater modeling efforts of the Plant Site area in 2004 to develop a better understanding of the hydraulic interactions between process ponds, groundwater capture systems, and surface water at and near the facility in an effort to mitigate existing (see below) and potential future impacts to the environment.

1.1 Site Description

The CSES is a four-unit coal fired electrical generation facility (**Figure 2**). Colstrip Units (Units) 1 and 2 are 333-megawatt, coal-fired steam electric generating units that have been in use since 1975. Units 3 & 4 are 800-megawatt generating units that began producing power in October 1983 and April 1986, respectively.

The Yellowstone River is the source of process water used for Units 1 through 4. Water is piped from the river to Castle Rock Lake (Surge Pond), west of the Colstrip townsite, and then to various Units. Process water is used for various purposes, including cooling of the Units, within the scrubbers, and for creating slurries to transport fly ash and bottom ash to nearby settling and evaporation ponds.

There are three general areas of process ponds associated with the CSES (**Figure 1**). The Plant Site includes several process ponds located near Units 1 through 4. The Stage I and II Evaporation Pond area is located about two miles northwest of the Plant Site and includes the Stage I and II Evaporation Ponds that accept scrubber slurry and paste from Units 1 and 2. Units 3 & 4 Evaporation Holding Ponds (EHPs) are located approximately 2.5 miles southeast of the Plant Site. Process pond seepage, pipeline spills, and accidental tears in pond liners have resulted in impacts to groundwater quality in various portions of the facility.

1.2 Modeling Background

Maxim (2004) developed a preliminary conceptual model of the hydrogeologic system near the Plant Site and Stage I and II Evaporation Pond areas. Their Preliminary Conceptual Model Report (Maxim 2004) includes a characterization of process ponds used at the facility and a statistical analysis of baseline groundwater quality. The document also describes the hydrostratigraphy of the area, aquifer characteristics, groundwater flow, and interactions between surface water and groundwater. In addition, the report discusses contaminant transport pathways and receptors.

Geomatrix (2006) describes initial development of the numerical groundwater model for the Plant Site area. This initial Plant Site model was developed using the U.S. Geological Survey (USGS) code MODFLOW-2000 (Harbaugh and others, 2000). The USGS code MODPATH (Pollack 1994) was used to simulate advective transport of constituents in groundwater. Groundwater Vistas© was used as a graphical interface for model pre- and post-processing.

The numerical groundwater model was updated in 2008 using new hydrologic information obtained by PPLM since initial model development (Geomatrix 2008). New information considered in the 2008 model included the following:

- Lithologic descriptions for wells installed since 2005.
- Results from aquifer tests completed for wells located downstream of the Plant Site.
- Aquifer responses observed in monitoring wells surrounding the D-4 Brine Pond following a breach in the liner.
- Depth to groundwater data collected since 2005.
- Water quality data collected since 2005.
- Capture well extraction rates for the period 2001 to 2007.

The updated 2008 model was used to perform additional groundwater capture analyses in areas near the Units 3 & 4 Bottom Ash Pond and the generating Units based on data obtained from installation of wells 83A through 91S in late 2008 (**Figure 2**). Results of that capture analysis suggested that the existing model construct did not have sufficient vertical detail to differentiate between spoils, overburden, and different layers of alluvium, making it difficult for the model to simulate detailed groundwater flow and solute transport in these areas. As a result, PPLM decided that it would be advantageous to add additional detail to the model (through the addition of model layers) to aid in future groundwater capture analyses.

At PPLM's request, AMEC Geomatrix (2009) prepared a work plan to guide redesign and calibration of the Plant Site numerical groundwater model. This document reports the result of efforts to include more detail into the model, as guided by the AMEC Geomatrix work plan. **Table 1** compares several components of the original numerical groundwater model (2006) and the two updates and revisions (2008 and 2014).

Table 1. Comparison of the 2006, 2008n and 2014 Numerical Groundwater Model Features

Model	Model Layers	Layer 1 Represents	Deeper Layer(s) Represents	Domain Size (acre)	Calibration Data Sets	Bottom Elevation of Model (feet amsl)
2006 Plant Site Model	2	Shallow Fine Alluvium, Deep Coarse Alluvium, Colluvium, Overburden Rosebud Coal, Spoils and Interburden	Layer 2: McKay Coal and Upper Sub-McKay	2365	2001-2003 Steady-state	3,100
2008 Plant Site Model	2	Shallow Fine Alluvium, Deep Coarse Alluvium, Colluvium, Overburden Rosebud Coal, Spoils and Interburden	Layer 2: McKay Coal and Upper Sub-McKay	2365	2001-2003 Steady-state 2006 Steady-state 2004-2005 Transient 78 A and 82 A Pumping Tests	3,100
2014 Plant Site Model	6	Shallow Fine Alluvium, Colluvium, Overburden and Spoils	Layer 2: Deep Coarse Alluvium, Colluvium, Rosebud Coal, Spoils Layer 3: Interburden Layer 4: McKay Coal Layer 5: Upper Sub-McKay Layer 6: Deep Sub-McKay	3839	December 2003 Steady-state February 2014 Steady-state 2004-2005 Transient 78 A and 82 A Pumping Tests	2,950

1.3 Goals and Objectives

The overall goals of updating the numerical groundwater model were to improve the overall understanding of the groundwater flow system and provide information to improve water management practices.

Specific objectives of completing the analyses described in this report were to:

- Refine the numerical groundwater flow model geometry, aquifer properties, and vertical discretization to more accurately simulate groundwater flow in distinct hydrostratigraphic intervals.
- Assess the adequacy of the current (2014) groundwater monitoring well network and capture system.
- Make the numerical groundwater model more consistent with models developed for the Stage I and II Evaporation Pond and Units 3 & 4 EHP areas by including more layers based on lithology/stratigraphy and using similar values for background recharge.

2.0 Conceptual Model

This chapter describes the hydrogeologic conceptual model for the Plant Site area. Included are descriptions of geology, hydrostratigraphy, aquifer characteristics, groundwater flow, interactions between surface water and groundwater, water quality, and water balance. A summary of the conceptual model is included at the end of this section.

2.1 Geologic Lithologic and Hydrostratigraphic Units

The following subsections describe regional and site geology.

2.1.1 Regional Geology

The Plant Site Area is located in the northern portion of the Powder River Basin, an asymmetrical basin oriented northwest to southeast. This orientation of this structural basin is largely responsible for the general regional orientation of the bedding associated with the various geologic units in the area. The near-surface geology in the area is dominated by the Fort Union Formation which includes strata that generally dip gently (less than a few degrees) to the east in the western portion of the site and to the south in the eastern portion, across the coal field. In some localized areas of the CSES, high-angle faults are present that steepen dips (Roberts and others, 1999).

Stratigraphy in the Plant Site Area and more regionally consists of, in descending order, the Fort Union Formation, Hell Creek/Lance Formation, Fox Hills Sandstone, and Bearpaw Shale. The Fort Union Formation is divided into three members; the upper Tongue River Member, the middle Lebo Shale Member, and the lower Tullock Member. The Tongue River Member is exposed at the surface in the general vicinity of the Plant Site. The Lebo Shale and Tullock Member are exposed north of the Site. At Colstrip, the total thickness of the Fort Union Formation is about 650 feet.

The Fort Union Formation consists of alternating and intercalated deposits of shale, claystone, mudstone, siltstone, sandstone, carbonaceous shale and coal. The formation was deposited in a fluvial system of meandering, braided, and anastomosed streams near the basin center and by alluvial fans at the margins. The fluvial systems associated with the Fort Union Formation were typically oriented northeast-southwest (Flores and Ethridge, 1985).

Numerous coal seams are present within the Tongue River Member of the Fort Union Formation. A tropical to sub-tropical climate created an environment in which thick peat deposits accumulated in swamps and bogs (Nicols and others, 1989, Flores and others, 1999) which ultimately led to the formation of the coal seams. Because of the depositional setting in which bogs or channels terminate or have bounds, the coal beds may pinch out laterally or stop abruptly. The main coal seams of interest near the CSES are the sub-bituminous Rosebud (~ 24 feet thick) and McKay seams (~ 8-10 feet thick) which can economically be strip-mined. These two coal seams merge into a single seam on the west side of the Little Wolf Mountains near the Absaloka Mine. The Rosebud Coal, however, is the only seam mined in the area due to inferior quality of the McKay Seam which makes it undesirable for use in many coal-fired boilers. Both the Rosebud and McKay Coals are generally cleated, containing natural vertical fractures generally oriented perpendicular to the bedding plane.

The depositional setting described above results in numerous lateral facies changes within the sedimentary rock in the area. Channel sandstones often grade laterally into siltstones or shale. Cementation (the chemical binding of individual grains to one another) is highly variable within the units and mostly occurs as weak calcium carbonate cement although thin deposits with silica cementation also are present. Localized thin limestone beds also are infrequently present in the geologic package in the region.

2.1.2 Site Geology and Lithologic Units

The Tongue River Member of the Fort Union Formation underlies the Plant Site area. The formation dips 1 to 2 degrees to the southeast in the local area. The Tongue River Member consists of a 350–foot thick (maximum) sequence of interbedded siltstone and fine-grained silty sandstone as well as several coal seams. The principal coal seams in the Plant Site area are the Rosebud and McKay coal units. In the Plant Site area, the Tongue River Member is subdivided into the following lithostratigraphic units; Rosebud Overburden, Rosebud Coal, Interburden, McKay Coal, and Sub-McKay.

The depositional setting near the Plant Site area created numerous lateral facies changes within the sedimentary rock deposits. Channel sandstones often grade laterally into siltstones or shale resulting in preferential pathways for groundwater flow. Clinker, which consists of burned coal and baked and altered overburden, also is present near where coal seams outcrop, as result of natural burning of coal.

Unconsolidated materials overlie the Tongue River Member in several areas. These include colluvium located near the ridge tops, alluvium in drainage bottoms, and spoils in mined areas near the Plant Site (Hydrometrics 1995). The Rosebud Coal was strip-mined from the eastern portion of the Plant Site in the past, leaving a zone of spoils that was left behind after mining. Beneath the spoils in the eastern portion of the Plant Site are eight to 12 feet of unconsolidated material, shale, and mudstone, which in turn overlay the McKay Coal. The Rosebud Coal was missing from the western portion of the Plant Site in the vicinity of the East Fork Armells Creek and, therefore, was never mined in this area.

Each general lithostratigraphic unit is described below in terms of texture and extent in the Plant Site area. Lithology and hydrostratigraphy were examined in detail in support of the model redesign presented in this document. Well logs from 262 Plant Site, Townsite, Western Energy and Montana Bureau of Mines and Geology wells (**Figure 3**) were reviewed to delineate the areal extent and elevation of contacts between hydrostratigraphic units. The lateral extent of the various hydrostratigraphic units was determined using well logs, aerial photos, geologic maps, mine extent maps and 1971 era USGS topographic maps (**Figure 4,** [Western Energy 2013a, b, c, d, e, f]). Elevations of lithologic contacts were determined from depths noted in 262 wells logs along with well survey elevations. These data were used to create lithostratigraphic contacts surfaces for each of the major hydrostratigraphic units. The surfaces were created using a Natural Neighbor interpolation and refined based on conceptual interpretation and knowledge of stream erosion characteristics and the extent of mine disturbance. **Figure 5** presents contoured lithologic contact surfaces.

2.1.2.1 Alluvium/Colluvium

Alluvium is present along many of the drainage bottoms (both existing and historic) in the Plant Site area. The most prominent deposit is along East Fork Armells Creek. The ancestral East Fork Armells Creek eroded through the shallow bedrock, Rosebud and McKay Coals, and in some places into the sub-McKay deposits. At the western edge of the Plant Site, alluvial deposits of clay, silt, sand and gravel reach thicknesses of 35 feet or more. The basal gravel associated with the alluvium typically follows East Fork Armells Creek but is also present at the base of other tributary drainages that no longer flow in their channels due to mining alterations. Clinker fragments are typically also found throughout finer-grained alluvial deposits. The extent of alluvial deposits is presented in **Figure 4**; the base of the alluvium unit is shown on **Figure 5**.

Colluvium is generally fine-grained unconsolidated sediments. This unit is present at ground surface in the Colstrip Townsite and the western portion of the Plant Site. The extent of colluvium is presented in **Figure 4** with the base of the unit shown on **Figure 5**.

2.1.2.2 Overburden

Rosebud Coal overburden consists of siltstone and silty sandstone of variable thicknesses. This unit is absent over much of the site due to mining and or erosion from East Fork Armells Creek. The extent of Rosebud overburden is presented in **Figure 4,** and the base of the unit illustrated on **Figure 5**. This surface also reflects the top of the Rosebud Coal, where present in the subsurface.

2.1.2.3 Spoils/Fill

Strip-mining of coal involves removing the overburden (sediments overlying the coal), removing the coal, then backfilling the pit with the previously removed overburden. The replaced material is termed "spoils." Spoils consist of a mixture of overburden materials, clinker, and waste coal that is present from ground surface to depth of up to 110 feet beneath the eastern portion of the Plant Site. The material is present southwest of the Colstrip Townsite and over much of the southeastern part of the Plant Site (directly east of Units 1&2 Pond B and Units 1&2 Cooling Tower Blowdown Ponds, and Units 3&4 Bottom Ash Ponds). A minor amount of spoils is present directly southeast of the Units 1&2 Pond A (**Figure 4**). **Figure 5** presents the contoured elevation of the base of the spoils. This surface also reflects the base of the previous strip mines (generally near the top of the Interburden Unit).

A zone of up to 32 feet of "fill" exists around the Units 1 & 2 Fly Ash ponds A and B. Fill consists of a mixture of sandy silt with clay and fragments of scoria. The origin of fill material varies and is generally placed on top of original ground surface as a construction material. Data regarding hydraulic properties of fill material are not available (however, this unit is largely unsaturated within the model domain).

2.1.2.4 Rosebud Coal/Clinker

Rosebud Coal is a 20- to 25-foot thick coal seam that is absent from much of the Plant Site area and the floodplain of the East Fork Armells Creek due to either being mined or having been eroded away by the creek. The extent of Rosebud Coal is presented in **Figure 4** with the base of the unit shown on **Figure 5**. This surface also reflects the top of the interburden.

Clinker is a thermally altered rock also referred to as scoria. Clinker formed in areas where Rosebud Coal has burned, usually near where coal seams outcrop. This is most easily identified as red cap rock on hills around the region. Burning of the coal baked the overlying strata, reducing the coal volume, leaving a void for the overlying rock to collapse into or resulting in slow settling of the overlying rock into the space formerly held by the coal. Clinker knobs exist around the Surge Pond and north and east of the sewage lagoons and southeast of the Plant Site (**Figure 4**).

2.1.2.5 Interburden

Interburden consists of siltstone, shale, and sandstone lying stratigraphicly between the Rosebud and McKay Coal seams. This unit is missing from much of the floodplain of the East Fork Armells Creek due to erosion. The extent of interburden is presented in **Figure 4** with the base of the unit shown on **Figure 5**. This surface also reflects the top of the McKay Coal.

2.1.2.6 McKay Coal

McKay Coal is an 8- to 12-foot thick coal seam that has not been mined in the Plant Site area. However, portions of this unit are missing from much of the floodplain of the East Fork Armells Creek due to stream erosion. The extent of McKay Coal is presented in **Figure 4** and the base of the unit shown on **Figure 5.** The variation of the base contour of the McKay unit across the Plant Site area as shown on **Figure 5** is a result of a combination of a gentle southeasterly dip and subsequent faulting events. The base of the McKay unit also represents the top of the Sub-McKay unit.

2.1.2.7 Sub-McKay Bedrock

The Sub-McKay unit consists of interbedded siltstone, shale, and sandstone present beneath the McKay Coal. The Sub-McKay unit is at least at least 300 feet thick and is present across the entire study area. This unit is divided into shallow and deep zones for the purposes of describing differences in groundwater flow, but the general lithostratigraphy of the two zones is similar. Although lithology is similar within the shallow and deep zones (sandstone interfingered with mudstone and shale) the location and number of lateral facies changes varies, which leads to variations in hydrogeologic properties.

Diagram 1 shows the general hydrostratigraphy of the Plant Site area. Water bearing units include alluvium, overburden, clinker, spoils, Rosebud Coal, interburden, McKay Coal, and Sub-McKay sandstones and mudstones.

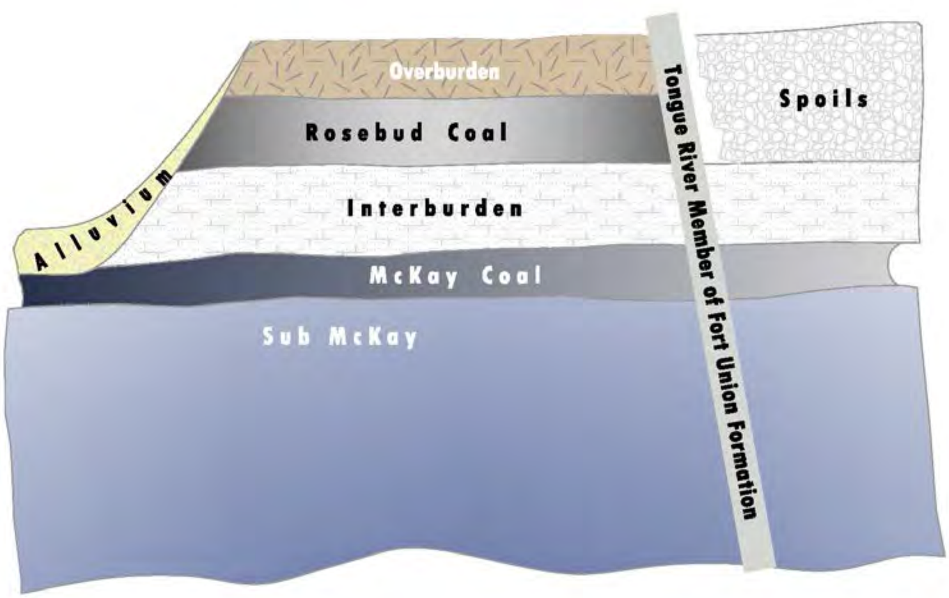

Diagram 1. General Hydrostratigraphy

Figure 6 is a hydrogeologic cross section along line A-A'. As is illustrated, the relatively flat layers of overburden, Rosebud Coal, interburden, and McKay Coal have been eroded in a significant portion of the floodplain of East Fork Armells Creek. In this region, the cut valley is filled by alluvial sediments that generally coarsen with depth. In the eastern portion of the Plant Site, the overburden and the Rosebud Coal have been mined out and the mine pits have been backfilled with a thick sequence of spoils.

2.1.3 Hydraulic Properties

Numerous hydraulic tests have been conducted in the Plant Site and surrounding areas, as documented in Hydrometrics (1995, 2007 and 2015). **Table 2** summarizes hydraulic property values and statistics for the hydrostratigraphic units tested. This table also includes ranges of aquifer properties documented in peer reviewed studies of the Fort Union Formation. These statistics are based on hydraulic tests conducted at over 90 wells located at the Plant Site, Colstrip Townsite, and Stage I and II areas. **Appendix A** presents a summary of the tabulated data for each well tested. Many wells tested had low yields (< 1 gpm); slug tests were typically performed on such wells. Slug test results estimate the hydraulic conductivity only of the area immediately surrounding the well, which may not be representative of the average hydraulic conductivity of larger area, and accuracy of slug tests can be affected by poor communication between the borehole wall and the surrounding formation. Transmissivity and hydraulic conductivity estimates derived from tests of the low yield wells were assumed to provide for only an estimate of the magnitude and range of these parameters.

Table 2. Summary of Aquifer Properties by Hydrostratigraphic Unit.

Aquifer Properties from Plant Site, Colstrip Townsite and Stage I and II areas						
Hydro Stratigraphic Unit	Geometric Mean [1] Transmissivity ($feet^2$/day)	Geometric Mean [1] Hydraulic Conductivity (feet/day)	Minimum Hydraulic Conductivity (feet/day)	Maximum Hydraulic Conductivity (feet/day)	Arithmetic Mean Saturated Thickness (feet)	Geometric Mean [1] Storativity
Alluvium	225	18.3	0.15	355	14	0.0003
Spoils/Fill	111	7.5	0.01	622	19	N/A
Rosebud	149	12.5	0.9	65	13	N/A
Interburden	13	1.1	0.02	39	15	N/A
McKay	26	2.3	0.06	9.3	10	N/A
Sub-McKay	41.5	2.5	0.03	242	18	0.0008

Aquifer Properties from Studies[2] of the Fort Union Formation			
Hydro Stratigraphic Unit	Transmissivity ($feet^2$/day)	Hydraulic Conductivity Range (feet/day)	Storage Coefficient
Alluvium	1,900	0.00007 – 492	--
Spoils	0.1 – 64	0.02 – 5.7	0.00001 to 0.00003
Rosebud	1.3 – 1,700	0.1 – 68	--
Interburden	28	0.9	--
McKay	0.7 – 31	0.01 – 3.1	--
Sub-McKay	--	0.0001 – 89.6	--
Coal	--	0.0009 – 896	0.0002 – 0.01

N/A – not applicable "--" – no data available.
1– The geometric mean indicates the central tendency or typical value of a set of numbers by using the product of their values. For aquifer property values that vary by more than two orders of magnitude the geometric mean is often thought to be more representative of average values than the arithmetic mean (Fetter, 1994).
2 – Rehm and others. (1980), Van Voast and Reiten (1988), and Van Voast and others. (1977)

2.1.3.1 Alluvium

Hydraulic properties of the alluvial deposits within and near the Plant Site area vary appreciably. Hydraulic conductivity estimates range from 0.15 up to 355 feet/day with a geometric mean of 18.3 feet/day. The lower values are associated with the fine-grained alluvial sediments while the higher values are associated with the deeper sand and gravel deposits. As described previously, the alluvial unit tends to coarsen with depth from fine-grained silt and clay deposits to underlying sand and gravel. Aquifer tests in the sand and gravel unit had semi-confined to confined responses with a geometric mean storativity of 0.0003.

2.1.3.2 Spoils/Fill

Spoils exhibit a wide range hydraulic conductivity values, ranging from 0.01 to 622 feet/day with a geometric mean of 7.5 feet/day. Spoils tend to exhibit higher horizontal and vertical hydraulic conductivity values compared to pre-mining overburden Lateral variations in groundwater flow conditions may exist near spoils. If the hydraulic conductivity of the spoil is higher than the adjacent deposits, the spoils will act as a drain. Conversely, if the hydraulic conductivity is lower, an impediment to flow would occur. In general, the permeability of the spoils is similar to the adjacent bedrock; however, spoils in the area north and west of the Units 3&4 Bottom Ash Ponds tend to have higher hydraulic conductivity as is evidenced by the relatively high yield (~50 gpm) in the WECO dewatering well installed in this area (**Figure 2**). Hydraulic properties of fill material are likely similar but no site-specific data are available.

2.1.3.3 Rosebud Coal/Clinker

Hydraulic conductivity in Rosebud Coal was found to range from 0.9 to 65 feet/day with a geometric mean of 12.5 feet/day (**Table 2**).

Clinker permeability values are not available for the Plant Site area but range from 55 to 10,177 feet/day in the Units 3 and 4 Area. Hydraulic conductivity values are dependent on the amount of fine-grained sediments that have moved vertically into the available pore spaces within the unit and the degree and nature of fracturing present. Typically, however, clinker is present above the water table in the Plant Site area. The enhanced permeability of this unit at the surface or near-surface generally serves to create areas of relatively high net recharge to groundwater.

2.1.3.4 Interburden

The measured hydraulic conductivity of interburden ranges from 0.02 to 39 feet/day with a geometric mean of 1.1 feet/day. The higher end values (6.8 to 39 feet/day) occurred in tests conducted in areas where the overlying bedrock has eroded, likely resulting in partial weathering of the interburden unit. Wells screened in interburden that was not exposed to weathering ranged from 0.02 to 0.04 feet/day.

There are likely fractures present in this unit that may create preferential flow paths. However, no information is available documenting the presence, orientation, or hydraulic properties of fractures. For this reason, flow in this unit is assumed to be horizontally isotropic.

2.1.3.5 McKay Coal

The McKay Coal unit exhibits slightly lower permeability than the Rosebud Coal. The hydraulic conductivity in the McKay Coal is ranged from 0.06 up to 9.3 feet/day, with a geometric mean of 2.3 feet/day.

2.1.3.6 Sub-McKay

The siltstone and sandstone of the Sub-McKay unit exhibited a hydraulic conductivity ranging from 0.03 up to 242 feet/day and a geometric mean of 2.5 feet/day. Due to the dip of the Fort Union Formation the Sub-McKay unit is present near ground surface near the Stage I and Stage II ponds. Most of the wells yielding higher permeability are in locations where the Sub-McKay is present at shallower depths. The relatively higher permeability values measured at these locations are likely due to increased fracturing. This unit generally behaves as a semi-confined aquifer and has a geometric mean storativity of 0.0008.

There are likely fractures present in this unit that may create preferential flow paths. However, no information is available documenting the presence, orientation or hydraulic properties of fractures. For this reason flow in this unit is assumed to be horizontally isotropic.

2.2 PRECIPITATION

The climate in Colstrip Montana is considered semi-arid with an average annual precipitation (based on 83 years of site data) of 15.20 inches (**Table 3** and **Appendix B**). **Figure 7** presents the average monthly precipitation for the period of record along with the 2003, 2004, 2005, and 2013 monthly precipitation totals (these years were selected because they correspond to periods for model calibration described below in **Section 4.0**). Most precipitation occurs between the months of April and October; on average, precipitation exceeds one-inch during each of these months. Precipitation typically peaks in the months of May and June; on average, precipitation exceeds 2.6 inches during both of these months.

Table 3. Average Monthly Precipitation

Month	Average Monthly Precipitation*
January	0.60
February	0.55
March	0.92
April	1.61
May	2.67
June	2.66
July	1.29
August	1.16
September	1.25
October	1.27
November	0.64
December	0.57
Total	15.20

*Data from Western Regional Climate Center. Averages include period of record through 1927-2014.

The average annual precipitation has varied over the last 40 years, a period that coincides with the approximate life of the Plant Site and the ponds. **Figure 8** presents the annual total precipitation as a variance from the average of 15.2 inches. In general, the 1980s, the 1990s, and the early 2000s all had average to below average precipitation. Conversely, since 2005, precipitation at Colstrip has generally been above average. In particular, measured annual precipitation during calendar years 2005, 2011 and 2013 exceeded the average by more than 8 inches.

2.3 SURFACE WATER HYDROLOGY

Several surface water features exist in the area near the Plant Site. These include:

- East Fork Armells Creek;
- Castle Rock Lake (aka, the Surge Pond);
- City of Colstrip Sewage Lagoons
- Small neighborhood drainage and impoundment (referred to in this report as the Cimarron Drainage);
- Several PPLM Process Ponds; and,
- Several Western Energy Company (WECO) sediment retention ponds.

These surface water features are shown on **Figures 2** and **Figure 3** and are discussed below.

2.3.1 East Fork Armells Creek

The primary drainage in the area is the East Fork of Armells Creek. Fifteen synoptic runs have been conducted on the East Fork Armells Creek since 1993 (Hydrometrics 2001, 2007, 2010, 2012a, and 2014a). **Table 4** and **Figure 9** present flow measurements for East Fork Armells Creek. Stations AR-12 through AR-3 are located in the vicinity of the Plant Site, Station AR-2 is located just downstream of the City of Colstrip Sewage Lagoons, and Stations AR-1 through AR-10 are located downstream of the Surge Pond (**Figure 2**).

All synoptic flows were measured in the spring time between March 17th and June 16th. Data indicate that East Fork Armells Creek usually has little flow at station AR-12 during this time of year. During all synoptic runs, the creek gained flow between station AR-12 and AR-5. In recent years (2008 to 2014), the stream has generally lost flow between stations AR-5 and AR-4, whereas prior to that the creek generally had a slight increase in flow between these two stations. This change in trend is likely due to increased pumping of capture wells at the Plant Site. Between stations AR-4 and AR-3, flow conditions fluctuate from year-to-year from slightly gaining to slightly losing. East Fork Armells Creek gains appreciable flow between stations AR-3 and AR-2. This is attributable to return flow of seepage form the City of Colstrip Sewage Lagoons. A greater increase in flow occurs between stations AR-2 and AR-1 that is attributable to water that seeps beneath the dam at Castle Rock Lake into groundwater and then flow into the creek.

2.3.2 Castle Rock Lake (Surge Pond)

Castle Rock Lake, formerly known as the Surge Pond, is an approximately 150-acre man-made impoundment that was built in 1974 to store water to be used for the coal-fired steam electric plant. The lake was constructed in a small drainage that was tributary to East Fork Armells Creek. The lake elevation is maintained by inflow from a pipeline that routes water from the Yellowstone River. The stage in the lake varies by up to 10 feet (between 3274 and 3284 feet amsl) (**Appendix C**). The lake likely acts as a flow-through lake with the stage generally slightly below the groundwater elevation on the western side of the lake and well above groundwater elevation on the east side of the lake.

2.3.3 Colstrip Sewage Lagoons

The City of Colstrip sewage lagoons receive sludge and water from the wastewater treatment facility that currently processes about 200,000 gallons per day (City of Colstrip 2014). Water that does not evaporate from the sewage lagoons seeps to the groundwater system.

Table 4. Flow Measurements for East Fork Armells Creek

	AR-12*	AR-5	AR-4	AR-3	AR-2	AR-1
Distance Downstream	0	1700	3434	5368	6419	10662
	Flow (gpm)					
4/8/2014	99	334	223	337	498	1176
3/20/2013	31	104	45	63	274	938
3/21/2012	35	152	66	78	190	1042
4/5/2011	25	125	108	90	296	768
3/30/2010	5	24		5.8	229	368
4/8/2009	15	108	69	108	296	525
4/3/2008	15	112	73	37.5	219	319
5/14/2007	8	116	121	200	417	835
5/27/2005	7.5	49	94	172	395	736
6/16/2004		10	11	31	134	346
5/21/2003		49	55.4	139	319	705
4/25/2000		76	112	108	230	368
4/15/1996		65	121	121	417	471
3/17/1994		107	136	281	368	471
6/15/1993		48	63	189	346	395
Ave Flow	27	99	93	131	309	631
GEOMEAN	18	75	77	93	292	577
Gain/loss (Ave)		72	-6	38	178	322
Max	99	334	223	337	498	1176
Min	5	10	11	6	134	319

*note the majority of flow values at AR-12 are estimated.

2.3.4 Cimarron Drainage

The Cimarron Drainage is a small ephemeral drainage which flows over reclaimed spoils west of the Cimarron neighborhood and then through the Townsite. This drainage is impounded approximately one-quarter mile upgradient of Highway 35. The drainage is poorly defined below the impoundment for approximately a third of a mile. The drainage then winds through the neighborhoods around Poplar and

Olive Drive before discharging just north of the Sewage Lagoons to East Fork Armells Creek. The drainage collects storm water runoff and likely recharges the groundwater system.

2.3.5 PPLM Process Ponds

A number of process ponds are located within the Plant Site. All of these ponds were constructed using some type of liner (natural clay or synthetic). The ponds are described as follows (Hydrometrics 2015):

- Units 1 and 2 Pond A- This pond is clay-lined and was historically used to store fly ash water. The pond was removed from scrubber service in May 2005 and is currently being used as a clean-water storage pond (storm water runoff, etc.).

- Units 1 and 2 Pond – Originally, this pond was lined with clay. In 2003/2004, the pond was double-lined with 45 mil RFP and a leachate collection system was installed between the liners and under both liners. The pond was placed back in-service in 2004. Normally, this pond receives scrubber return water from the Stage II Evaporation Pond but can receive scrubber slurry during emergency conditions.

- Units 1 and 2 Clearwell- Originally, this pond was lined with clay and was used as the fly ash clear well. The pond was removed from scrubber service in May 2005. In 2006, this pond was double-lined with 45 mil RFP liner and a leachate collection system installed between the liners and under both liners. This area is currently being used as the Unites 1&2 Bottom Ash Pond Clearwell.

- Units 1 and 2 Bottom Ash Pond- This pond is clay-lined and is used to collect bottom ash and drain collection pit effluent.

- Units 1 and 2 Brine Water Disposal Ponds (D-1 through D-4) - These ponds all were constructed using synthetic liners and were used to store brine water. None of these ponds is in use any longer. Ponds D-1, D-2 and D-3 were closed in 1994 and the liners were removed. Pond D-4 breached in 2005 and was subsequently drained and removed from service. In 2006, the D-4 pond liner was folded to the southwest corner to envelope pond bottom solids. Thus, the liner was effectively removed from the eastern portion of the pond. Although these ponds no longer receive any directed water, they remain as depressions in the local topography and thus collect runoff.

- Units 1 and 2 Cooling Tower Blowdown Pond (Pond C) - This pond is clay-lined, and originally received cooling tower blowdown and raw water. In 1987, the pond was split into two sections (North and South). In 2004, the North Pond began receiving water from groundwater collection systems, and in 2005, raw water and storm water runoff were sent to this pond for storage. Since 2000, the South pond has been receiving raw water and storm water runoff that is used for dust control through application of water.

- Units 3 & 4 Wash Tray Pond- This pond is clay-lined and originally served as a scrubber pond for the wash tray loop. This pond was abandoned in 1995 and now receives storm water runoff.

- Units 3 & 4 Drain Collection Pond- This pond is clay-lined and, historically, it received miscellaneous scrubber plant drains, wash-down and scrubber slurry at times. In 1999, this pond was abandoned and now remains to collect storm water.

- Units 3 & 4 Bottom Ash Ponds- These ponds are clay-lined and serve to collect bottom ash and main plant sumps.

- Units 3 & 4 North Plant Area Drain Pond- This pond is lined with high density polyethylene (HDP). It receives raw water pretreatment filter backwash, cooling tower overflow, and miscellaneous north plant drainage.

- Units 1-4 North Plant Area Sediment Pond - This pond is clay-lined and receives surface drainage from the north plant and warehouse areas.

- Units 1-4 Sediment Retention Pond – This pond is lined with HDP and receives plant storm water drainage and occasional scrubber overflow or cooling tower basin overflow. This water is pumped to the Units 1 and 2 Pond A or Pond B, depending on quality.

2.3.6 WECO Ponds

Western Energy Company (WECO) maintains many sediment ponds and stock water ponds throughout Rosebud Mine (Western Energy 2011, 2013). Several of the WECO ponds are located near the Plant Site. The WECO ponds are denoted on **Figures 2** and **3** as WECO PO-##. These ponds are assumed to be unlined.

2.4 Groundwater Flow

The ancestral East Fork Armells Creek eroded through shallow bedrock, (overburden, interburden and Rosebud and McKay Coal), and in some places, into the Sub-McKay deposits. As a result, groundwater exits these units into the adjacent alluvium and much of this water subsequently flows into East Fork Armells Creek.

2.4.1 Potentiometric Surfaces

Potentiometric surface maps were constructed using primarily water levels from PPLM's water level data base, augmented with data obtained by Montana Bureau of Mines and Geology (GWIC 2013) and Western Energy (2013f) to provide greater spatial coverage. Data used to create potentiometric surface maps is contained in **Appendix D.**

The modeling analysis discussed below addresses groundwater conditions spanning from 2003 to 2014. Two sets of potentiometric surface maps were created to represent conditions at the beginning and end of this period. These maps are used in evaluating steady-state model calibration (as explained below). The time periods selected represent winter conditions when seasonal aquifer stresses are at a minimum and are most representative of steady-state conditions.

The first set of potentiometric surface maps represents flow conditions in late 2003 for the shallow groundwater systems (includes alluvium, overburden, Rosebud Coal, and interburden), the McKay Coal, the upper Sub-McKay, and a deeper component of the SubMcKay (**Figures 10** through **13,** respectively). **Figures 10**, **11**, and **12** were prepared with groundwater elevations measured in December 2003. **Figure 13** was prepared using data from measured between 2003 and 2013 because minimal data are available for wells completed in the deep SubMcKay system (the figure therefore assumes that groundwater elevations in the deep system have not changed appreciably over this period, and the figure provides only a conceptual snapshot of flow directions and gradients).

The second set of potentiometric surface maps represents groundwater conditions in early 2014 for these same units (**Figures 14** through **17**). **Figures 14**, **15**, and **16** were created using groundwater elevation data measured PPLM monitoring wells primarily between January 3, 2014 and March 4, 2014. Groundwater data measured in several PPLM wells from outside this period were used to provide addition spatial coverage. In addition, data for several wells on the edge or outside of the Plant Site are from other sources including the Montana Bureau of Mines and Geology Groundwater Information Center (GWIC 2013), Rosebud Mine (Western Energy 2013 a through 2013f), and Big Sky Mine (Big Sky 2011). These data were included to provide a conceptual snapshot of flow direction and gradient near and outside of model boundaries (discussed in **Section 3.3** below). Groundwater elevation data illustrated in Figures **14** through **17** include symbols that indicate when the water levels were measured.

Shallow groundwater flow within and near the Plant Site area is primarily toward the East Fork Armells Creek. However, a southwest to northeast trending flow divide is identifiable along the eastern edge of the Plant Site in both 2003 and 2014. Groundwater east of this divide flows east toward the Cow Creek drainage while west of the divide, the groundwater moves toward East Fork Armells Creek. During both periods evaluated, local mounding is evident around the Units 3 & 4 Wash Tray Pond and around the Units 3 & 4 Bottom Ash Ponds. A combination of a Western Energy Report indicating the Rosebud Mine was active in 2014 and a 2014 aerial photo showing that the Area B mine cuts were dewatered in 2014 suggests shallow groundwater flow is toward the dewatered mine cuts in Area B of the Rosebud Mine due south of the Plant Site (Western Energy 2013 b).

Figures 11 and **15** are potentiometric surface maps for McKay Coal in 2003 and 2014, respectively. Groundwater flow directions in this unit are similar to those in shallow groundwater. Flow is generally toward East Fork Armells Creek with a southwest to northeast trending flow divide present along the eastern edge of the Plant Site. It is assumed that the dewatering of the Rosebud Coal in Area B of the Rosebud Mine will result in reduced heads in the underlying McKay unit; however no groundwater elevation data in the McKay unit exist to support this assumption. The assumption is that groundwater in the McKay Coal underlying these cuts likely flows upward with a minimal component of horizontal flow.

Potentiometric maps were created for the shallow (<100 feet below the contact with the McKay Coal) and deep (>100 feet below the contact with McKay Coal) SubMcKay intervals because flow in the shallow Sub-McKay unit more closely resembles local flow directions and gradient observed in shallower hydrostratigraphic units while flow in the deep SubMcKay exhibits a more regional pattern. **Figures 12** and **16** are potentiometric maps for the shallow Sub-McKay in 2003 and 2014, respectively. The shallow Sub-McKay represents water levels from wells completed in the upper 100 feet of the Sub-McKay. The groundwater flow in this unit again reflects some of the characteristics of the shallow flow system, with flow generally toward East Fork Armells Creek and a southwest to northeast trending flow divide along the eastern edge of the Plant Site.

Figures 13 and **17** are potentiometric maps for the Deep Sub-McKay in 2003 and 2014, respectively. These maps were created using groundwater elevation data measured in wells screened in the Sub-McKay unit at least 100 feet below the contact with the overlying unit (McKay Coal or alluvium). The number of wells and amount of groundwater elevation data available for this unit is limited. Groundwater flow at this depth is notably different than in shallower units. Flow is generally to the east-northeast toward the lower reach of Rosebud Creek and Yellowstone River, which are thought to be regional discharge points for the deep regional groundwater flow system. Groundwater elevations in deep wells are generally greater than 70 feet lower than overlying water table elevations, indicating downward hydraulic gradients exist between the shallow and deep flow systems across the study area.

2.4.2 Influence from Mining

Mine dewatering has caused local areas of drawdown in spoils, Rosebud, interburden, and McKay, groundwater. This is evident due south of the Plant Site in Area B of the Rosebud Mine (Western Energy 2013b). Conversely, Area E of the Rosebud mine has not been mined since the 1980s and groundwater elevations have steadily been increasing, particularly in wells completed in spoils in or adjacent to Area E. The locations of these mining areas are shown on **Figure 1**.

2.4.3 Horizontal Gradients

Horizontal hydraulic gradients in shallow groundwater are variable with the steepest (up to 0.10) gradients occurring in the shallow units existing below the main dam of the surge pond (**Figures 10** and **14**). The flattest gradients (0.002) exist south and southwest of the Plant Site where flow directions divide. The remaining areas have horizontal gradients that generally range between 0.006 and 0.017. Most gradients in the McKay and Shallow Sub-McKay intervals are within this range. Horizontal gradients in the deep Sub-McKay groundwater are less influenced by the creek, pond seepage, and dewatering and have more consistent horizontal gradients ranging from 0.004 to 0.008.

2.4.4 Vertical Gradients

Figure 18 illustrates vertical gradients calculated from February 2014 water levels measured in paired wells[1]. Vertical gradients at well pairs are almost exclusively downward across the site. Relatively strong downward gradients were measured at the 3 & 4 Bottom Ash Ponds between interburden and McKay at well pair 20S/20M (downward gradient of -0.858) and between McKay and Sub-McKay at well pair 21M/21D (downward gradient of -0.577). The single upward gradient is at the well pair 9M/9S. The vertical gradient at this well pair is virtually zero; it oscillates from positive to negative.

An upward gradient exists at well pair 104A/103D. This well pair is located near East Fork Armells Creek. Prior to the onset of pumping capture wells, it is assumed that there was a consistent upward gradient in the alluvium along East Fork Armells Creek.

Well pairs in which one well is a capture well were excluded from this figure as these pumping wells often reverse the natural gradients depending on the depth of the pumping well. For instance, pumping in spoils wells around the Units 3 & 4 Bottom Ash Ponds has created an upward gradient between

1 Well pairs include multiple wells, completed at different depths. Well pairs in which one well is a capture well were excluded from this analysis.

interburden and spoils isolated at the well pair 20SP/20S. Similarly, pumping in Sub-McKay wells near the Sediment Retention Pond has created a downward gradient between alluvium and SubMcKay at well pair 44S/77D.

2.4.5 Seasonality of Vertical Gradients

Figure 19 presents hydrographs of several pairs of wells. This figure shows that downward gradients have been measured through time. In the Southern Units 3 & 4 Wash Tray Pond Area, there is consistently a strong downward gradient between spoils and McKay and virtually no gradient between Rosebud and McKay. In the Units 3&4 Wash Tray Pond Area, there has consistently been a strong downward gradient between spoils and interburden, McKay and Sub-McKay units. The vertical gradient between interburden/McKay and Sub-McKay has been variable through time. The Units 3 & 4 Bottom Ash Pond area has consistently had a downward gradient from Spoils to McKay and from McKay to Sub-McKay. The magnitude of the downward gradient between the McKay and Sub-McKay has increased over time. In the former brine pond area, a small downward gradient has persisted between Interburden and McKay and a very strong downward gradient has persisted between these units and the underlying Sub-McKay. There is a small downward gradient between interburden and McKay in the Units 1 and 2 A/B Pond and Sediment Retention Pond area. Downward gradients have persisted and are particularly strong around the eastern edge of the Surge Pond.

2.4.6 Surface Water-Groundwater Interaction

As described in **Section 2.3**, multiple surface water features are present in the Plant Site, Colstrip Townsite, and surrounding areas. Plant Site process ponds and WECO ponds all have water elevations above the surrounding groundwater table, and these ponds likely are sources of recharge to the groundwater system to some degree. Seepage to groundwater from ponds with robust liner systems is assumed to be minimal.

The Surge Pond likely acts as a flow-through lake. The stage of the lake is generally slightly below groundwater elevations on the western side of the lake and well above groundwater elevations on the east side of the lake (**Figure 13**). It is therefore assumed that some groundwater flow into to the lake at its west side and seeps from the lake into groundwater on the east side.

East Fork Armells Creek acts as both a source and a sink to the groundwater system. As described above, this stream has both gaining and losing reaches adjacent to the Plant Site. The reach of the creek between stations AR-5 and AR-4 has been a losing reach in recent years. This is likely induced by pumping at capture wells because prior to the installation of many alluvial capture wells, this reach did not lose flow.

2.5 TEMPORAL VARIATION

In general, groundwater elevations in the Plant Site area increased between December 2003 and February 2014. **Figure 20** presents selected groundwater hydrographs from monitoring wells located within several areas around the Plant Site. **Appendix E** presents water level data for all the wells regularly monitored within the Plant Site and Townsite areas.

These hydrographs show that most of the eastern and southern extents of the Plant Site have had increasing water levels since the 1980s. This is evident in the Southern Cooling Tower Blowdown Pond, Wash Tray Pond, Units 3 & 4 Wash Tray Pond and Former Brine Pond areas. This trend is particularly evident in the western most spoils wells (e.g. 37SP, 21SP-2, 35SP). This increasing trend is likely related to recovering groundwater levels at Area E of the Rosebud mine for several years. In addition, Western Energy has added water to sediment ponds PO-010 and PO-10A for dust suppression. Seepage from the south side of the 3&4 Bottom Ash ponds may have also provided some recharge to the spoils.

Water levels in the area near the Units 1&2 A/B Pond and Sediment Retention Pond have been generally decreasing since the 1990s. The declining water levels in this area are likely due to the expansion of the capture system located primarily along the western edge of the Units 1 & 2 Pond A. The draining and subsequent installation of an underdrain in the Units 1 & 2 Fly Ash Pond B is also visible in the 2003-2004 timeframe on the hydrographs.

The Colstrip Townsite wells do not appear to be influenced by any of the mining or process pond water operations. Several hydrographs seem to be influenced by long term precipitation patterns (See **Section 2.2**). Wells CA-2A, CA-2, OT21S, OT21M, OT25M and OT20M all show a decreasing trend from approximately 1997 through 2004 followed by an increasing trend beginning in 2005. Several wells located close to the Surge Pond show yearly cycles that are either related to the yearly trends in the Surge Pond or season precipitation.

2.6 WATER QUALITY

Groundwater quality at the Plant Site has been described by Maxim (2004) and Geomatrix (2007). Recent trends in groundwater quality have been described by Hydrometrics (2007, 2011, 2012b, 2015). Dissolved constituents including sulfate, chloride, boron, magnesium, potassium, selenium, sodium, sulfate are present naturally in the Plant Site area groundwater system. These constituents have also been detected in process pond water from the Plant Site, often at concentrations higher than those that naturally occur in groundwater (Geomatrix 2006). Other sources of some dissolved constituents beyond process ponds occur in the Plant Site area. This includes many unpaved roads on which magnesium and chloride has been applied for dust suppression. Some groundwater at and downgradient of the Plant Site contains levels of these dissolved constituents that are elevated with respect to surrounding groundwater in the area that is not impacted by process water (Maxim 2004).

Because these constituents are all present in baseline groundwater, and in some cases there are other potential sources of major ions beside process ponds, the occurrence of a single constituent in groundwater above baseline levels does not necessarily indicate that groundwater has been impacted by process water. A suite of indicator parameters has been historically used to assess whether groundwater has been affected by process ponds (Maxim 2004, Hydrometrics 2012a). These indicator parameters include Total Dissolved Solids (TDS), specific conductance (SC), dissolved boron, chloride, sulfate, and calcium-to-magnesium ratio. The Administrative Order on Consent (AOC) Regarding Impacts Related to Wastewater Facilities Comprising the Closed-Loop System at the Colstrip Steam Electric Station (CSES) located in Colstrip, Montana (MDEQ 2012) identifies several constituents of interest (COIs), which it defines as those parameters found in soil, groundwater, or surface water that: (1) result from Site operations and the wastewater facilities, and (2) exceed background or unaffected reference area concentrations. COIs include, but are not limited to, sulfate, boron, selenium, potassium, sodium, magnesium, TDS, and salinity as measured by SC.

2.6.1 Baseline Groundwater Quality

Baseline water quality for the area near the Plant Site and Stage I and Stage II Evaporation Ponds has been characterized by Maxim (2004) and Arcadis (2007). Arcadis (2007) calculated baseline screening levels (BSLs) for alluvium, soils, and bedrock to help evaluate whether concentrations of chemical constituents in groundwater are elevated relative to water not impacted by process ponds in the area. For this analysis, all groundwater quality data from overburden, Rosebud Coal, interburden, McKay Coal and Sub-McKay Coal groundwater were grouped together. Statistically-derived baseline values for each constituent in unimpacted wells were calculated using an upper confidence limit for a percentile (i.e., a tolerance limit) in accordance with USEPA guidance for establishing BSLs for groundwater (USEPA 1989, 1992, 1998a, 1998b), based on the 95 percent confidence interval for the 95th percentile (95/95UTL). It should be noted that calculated BSLs are currently under review by the Montana Department of Environmental Quality (MDEQ).

Table 5. Summary of Background Screening Levels (BSLs)

Groundwater Unit	Constituent			
	Boron (mg/L)	Chloride (mg/L)	Laboratory Specific Conductance (μmhos/cm)	Sulfate (mg/L)
Alluvium	1.5	213	5300	3400
Spoils	1.2	73	7390	5000
Bedrock	1.3	48	3940	2310

Source: Arcadis (2007). Note: Calculated bedrock BSLs included data from bedrock units including McKay Coal and Rosebud Coal. ARCADIS did not calculate separate BSLs for wells screened in McKay Coal or Rosebud Coal.

2.6.2 Source Areas and Groundwater Quality Changes

Process wastewater constituents in current and former process ponds in the Plant Site area have seeped into groundwater and have served as sources of indicator parameters to groundwater (Hydrometrics 2012a). Hydrometrics (2012b) summarized the function, storage capacity, years in service, and type of liners for process ponds within the Plant Site. In addition, a fly ash slurry pipeline ruptured in 1997 near well OT-7 (**Figure 2**), that may serve as a continuing source of impacts to alluvial groundwater (Hydrometrics 2012b).

This section discusses changes in groundwater quality at different source areas within the Plant Site over the last few years. Water quality trends presented and discussed are based on information contained in recent annual reports by Hydrometrics (2011, 2012b, 2013a, 2014b).

2.6.2.1 Former Brine Pond Area

Historically, high salinity water (TDS >100,000 milligrams per liter [mg/L]) was stored in the Units 1-4 Brine Ponds (D1, D2, D3 and D4) in the central portion of the Plant Site (**Figure 2**). These ponds were lined. Beginning in 1980, liners in Ponds D-1, D2, and D3 began to seep and a groundwater collection system was installed (PPLM 2000). Ponds D1, D2, and D3 were subsequently closed and their liners removed in 1994. Saline solids have been removed from beneath the D1, D2, and D3 Ponds.

In October and November 2005, water levels and SC in wells adjacent to the D4 brine pond increased rapidly indicating a breach in the ponds liner (PPLM 2006, Hydrometrics 2007). Extension cracks, oriented approximately northeast-southwest, were observed in the ground adjacent to the D4 Pond. Ground displacement was observed across the cracks and ripples were observed in the pond's Hypalon liner. The surface features were parallel with former coal mine pits that were backfilled with spoils.

The D4 Pond was dewatered by the end of November 2005. A total of 1.4 million gallons of groundwater was collected from wells 4S, 19SP, 26SP, 29SP, and 70S in November and December 2005. The D4 pond was closed in late 2007 by installing a synthetic reinforced polypropylene (RPP) cap, adding topsoil, and establishing a vegetative cover (Hydrometrics 2011). Sediments beneath the former D4 Brine Pond were investigated in 2013 to evaluate their potential as a source of impacts to local groundwater quality (Hydrometrics 2013b). Removal of the sediments that may serve as a source of constituents to groundwater is planned.

Impacted groundwater in the Brine Pond area is being collected in wells B-1, B-4, B-5, 4S, 26SP, 29SP, 70SP, 111SP, and the D4 underdrain system resulting in improvements in groundwater quality in this area. Concentrations of indicator parameters in samples from collector wells 4S, 70SP and monitoring wells B-6, B-7, 18S, 18SP, 25SP, 4M, and 41SP have decreased between 2007 and April 2014. Concentrations of indicator parameters in well 12R-2 exhibit a general decreasing trend between 2010 and April 2014. Concentrations of indicator parameters in collection well 26SP exhibit an increasing trend between 2010 and 2014.

2.6.2.2 Units 3 & 4 Bottom Ash Pond Area

Water in the Units 3 & 4 Bottom Ash Ponds and Clear Well (**Figure 2**) contain concentrations of indicator parameters that are above BSLs but generally lower than in other process ponds. Water stored in the Bottom Ash Ponds in recent years has contained bromide, which is generally not detectable in un-impacted groundwater. Groundwater from the Units 3 & 4 Bottom Ash Pond Area is currently being captured from wells including 21S and 51SP through 54SP. The WECO dewatering well just north of the ponds also captures some groundwater north of the Bottom Ash Ponds.

Concentrations of indicator parameters (including boron and sulfate) in monitoring wells 84SP, 85SP, 86SP, and 89SP have declined since the wells were installed in 2008. Between October 2011 and October 2013, concentrations of indicator parameters from monitoring well 21SP-2 increased but then decreased in April 2014. Boron concentrations in wells 53SP and 54SP increased substantially between 2008 and 2009 but have decreased between 2010 and April 2014.

2.6.2.3 Units 1 & 2 A/B Ponds and Units 1-4 Sediment Retention Pond (SRP) Area

The Units 1 & 2 A/B Ponds are located in the northwest portion of the Plant Site (**Figure 2**). These ponds historically received fly ash slurry and water seeping from the ponds to groundwater contained elevated concentrations of indicator parameters. Since 2005, the Units 1 & 2 Pond A has received storm water runoff, and other water of relatively good quality. Fly ash remains in the bottom of the Pond A and likely serves as a continuing source of indicator parameters to groundwater. The Units 1 &

2 Pond B was drained in 2004 and synthetic liners and a leachate collection system between and under the liners were installed.

Seepage from the Bottom Ash Clearwell (located north of the Units 1 & 2 A/B ponds) historically served as a source of chemical constituents to groundwater. A double liner with an underdrain system was installed beneath this pond in 2006.

The Units 1-4 Sediment Retention Pond is located north of the A/B ponds (**Figure 2**). The Sediment Retention Pond receives storm water and occasional scrubber overflow or cooling tower basin overflow. The Sediment Retention Pond was originally lined with Hypalon® and then relined with High Density Polyethylene (HDPE) in 1989.

PPLM operates an extensive network of capture wells surrounding the A/B ponds and Sediment Retention Pond to capture groundwater. The Pond B underliner collection system intersects the groundwater table and serves to provide additional groundwater capture.

Water quality in wells downgradient of the Units 1&2 A/B Ponds and Sediment Retention Pond area has been improving in many wells in this area as a result of implementation of various mitigation measures. Concentrations of indicator parameters in the following wells have been steadily decreasing in recent years: 1S, 1D, 13S, 43S, 44S, 45S, 46S, 47S, 48S, 49S, 50S, 56D, 57M-P, 59-MP, 78A, 107A, 108A, 109A, 110D, SRP-3, SRP-4, SRP-5, SRP-6, SRP-8.

Groundwater quality in some wells in this area remains relatively stable over the last several years, including wells 5M, 5S, 31M, 58M, 58M-P, 59M, 72M, 812, and SRP-7. Concentrations of boron in well 77D immediately downgradient of the Sediment Retention Pond increased between 2009 and 2013, but other indicator parameters have not increase in this well. Water quality in a few wells in this area has declined in the last few years. Water quality in wells SRP-1 and SRP-2 located at the southeast corner of the Units 1-4 Sediment Retention Pond (**Figure 2**) had been stable or slightly improving since 2006. However, in the spring of 2014, concentrations of indicator parameters increased substantially in these wells. Boron concentrations in well 10D increased rapidly in April 2013 but decreased between then and April 2014.

SC and TDS levels in well CA-19A are relatively high and are not reflective of water quality in surrounding wells suggesting there may be a local source of impact in this wells. This well is completed in shallow fine-grained sediments above the sand and gravel system. PPLM initiated passive groundwater capture in this low-yield well in 2010 and TDS levels decreased rapidly in response and have remained stable since that time.

2.6.2.4 Northwest of Plant Site

As of 2007, the extent of groundwater containing concentrations of indicator parameters exceeding BSLs extended from the northwest corner of the Plant Site north to the Colstrip sewage lagoons. Since that time, mitigation measures incorporated at the Plant Site have resulted in generally improved water quality in this area. Since 2007, concentrations of indicator parameters have dropped substantially in wells 64A, 66D, 74A, 75A, 78A, 81A, 82A, and 83A.

Concentrations of indicator parameters in Well OT-7, located west of East Fork Armells Creek are relatively high and have not improved greatly since 2003. This well is completed in shallow fine-grained sediments above the sand and gravel system. It is likely that there is a local source of elevated constituents detected in this well. An area near this well was used to stage sludge removed from the creek during a fly ash slurry spill cleanup.

2.6.2.5 Units 3&4 Wash Tray Pond, Units 1&2 Cooling Water Blowdown Pond

The Wash Tray Pond was used as a scrubber pond for the wash tray loop until 1995. Piping is in place to route return water from the Units 1&2 B Pond to the Units 3 & 4. The pond has not been used to store process water since then but does periodically receive and store runoff. Recent increases in the concentrations of indicator parameters suggest that water infiltrating through base material in the pond likely serves as a source of indicator parameters to groundwater. The North and South Cooling Water Blowdown ponds store process water from various sources but generally contain water with lower SC and TDS than most other process ponds in the area.

Concentrations of indicator parameters dropped appreciably in wells completed in the Rosebud Coal and spoils, near the Wash Tray Pond (7R, 9M, 16SP, and 17S) when the pond was taken out of continuous service in 1995. More recently, there has been a slight trend of declining water quality in the area suggesting material remaining in the pond bottom may be a source of solutes. 2011 was a relatively wet year, and up to 5 feet of water was collected in the Wash Tray Pond. Concentrations of indicator parameters began to increase in wells 17SP and 7R in late 2011 and have continued to increase. Boron and chloride concentrations in McKay well 14M have generally increased since 2011.

2.6.3 Extent of Groundwater Exceeding BSLs

Figures 21 through **32** are plume maps showing the extent of groundwater exceeding BSLs for indicator parameters including boron, chloride, SC, and sulfate in alluvium, spoils and bedrock. **Appendix F** contains the data used to create these figures. The figures were created by contouring concentrations in samples obtained from wells that exceeded BSLs (**Table 5**). Most of the data used to create the maps was taken from groundwater samples obtained during April 2014. Nine of the wells shown on these figures were not sampled during April 2014, but were selected from recent dates to provide spatial coverage. Data on the plume maps for these wells were taken from the most recent sample dates within +/- 5 months of April 2014 (**Appendix F**).

Figures 21 through **24** are plume maps for boron, chloride, SC and sulfate in alluvial groundwater. These figures show that groundwater in alluvium containing indicator parameters above BSLs extends from southwest of the Units 1 & 2 A Pond to just north of the Sediment Retention Pond and the Units 1&2 Blowdown Towers and to just east of the Units 1 & 2 B Pond near wells AB-14S, AB-16S, and AB-17S, which is about the eastern extent of alluvium. Boron in alluvium extends farther north to the City of Colstrip sewage lagoons and south to well 68A. **Figure 27** shows that there is a small area east of East Fork Armells Creek near well 63S that exceeds the BSL for chloride. This appears to be from a localized source and could be related to use of magnesium chloride for dust suppression.

Figures 21 through **24** show there is an area surrounding well OT-7 on the western edge of alluvium north of the Plant site that exceed BSLs for boron, chloride, SC, and sulfate that is likely from a localized source as was described in Section 2.6.2.4 above. Wells 133A through 137A were installed in 2013 to help define the extent of impacts in this area.

Figures 25 through **28** are plume maps for boron, chloride, SC and sulfate in groundwater within spoils. **Figures 27** and **28** show that the extent of groundwater in spoils containing chloride, SC, and sulfate at concentrations above BSLs extends from well 26SP southeast of the former D4 brine pond, northeast to well 41SP just west of the Units 3 & 4 Bottom ash ponds. In addition, well U3-1 immediately north of Unit 3, contains sulfate at concentrations exceeding BSLs. **Figure 25** indicates that the extent of boron exceeding BSLs in spoils groundwater extends a little farther northeast to well 84SP and a farther southwest to well 126SP southeast of the Wash Tray Pond. In addition, wells near the southeast corner of the 3 & 4 Bottom Ash Ponds (51SP through 54SP) also contain boron at concentrations exceeding the BSL. **Figure 26** shows that the extent of chloride exceeding BSLs is similar to that of boron with the exception that it includes wells northwest of the Units 3 & 4 Bottom Ash Ponds (22SP, 84SP, 86SP, 89SP) and a small area near the North Pond (well 24S). In addition groundwater in well 28SP east of WECO Sediment Pond 10A exceeds the BSL for chloride.

Figures 29 through **32** show the lateral extent of groundwater exceeding BSLs for boron, chloride, SC and sulfate for wells completed in bedrock (overburden, Rosebud Coal, McKay, Sub-McKay). Because these figures show multiple stratigraphic units, they are integrated vertically. The area of bedrock with the highest concentration of indicator parameters is near overburden wells 5S and 91S west of the Units 1 & 2 B Pond. The extent of constituents exceeding SC and sulfate BSLs in bedrock extends from south of the South Cooling Tower Blowdown Pond north to well 23M near the North Plant Pond and Well 80D north of the Sediment Retention Pond, west to well 15D near East Fork Armells Creek and east to the Units 3&4 Bottom Ash Pond area. There are a few areas where chloride exceeds the BSL in bedrock wells that appear to be separate from Plant Site plume, including near wells 36M and WM-135 south of the former Brine Pond area and 3 & 4 Bottom Ash Ponds, respectively, and near wells 99D and 103D southwest of the Units 1 & 2 A/B Ponds.

2.6.4 Vertical Movement of Constituents

Examination of groundwater quality data and plume maps for alluvium, spoils, and bedrock (**Figures 21** through **32**) along with vertical gradient data indicate that areas with appreciable vertical movement of groundwater containing concentrations of indicator parameters above BSLs include the following areas:

- Water infiltrating from the Units 1 & 2 A pond and Sediment Retention Pond is driving water from alluvium underlying the ponds down into underlying interburden, McKay, and Sub-McKay bedrock units. This phenomenon is also occurring from shallow alluvium to deeper alluvium just west of the A Pond.
- Water infiltrating from the Units 3 & 4 Bottom Ash ponds is driving water from spoils into underlying overburden, interburden, and McKay bedrock.
- Downward gradients appear to be driving groundwater containing chloride from spoils down into underlying interburden and McKay bedrock WS-116, WM-135, south of 3 & 4 Bottom Ash Ponds.
- Chloride and sulfate are above BSLs in well 36M, indicating that downward gradients created by seepage from adjacent WECO Sediment Pond 10A is driving constituents from spoils down into underlying interburden and McKay bedrock.

Figures 76 through **80** show the extent of groundwater exceeding BSLs for indicator parameters for Layers 1 through 5.

2.7 WATER BUDGET

A groundwater budget was developed as part of the conceptual framework that bounds the design of the numerical model. The groundwater balance is represented generally by the following equation:

inflow = outflow + change in storage

Changes in groundwater storage are caused by seasonal changes in groundwater elevations due to rising and lowering of the water table. The water balance presented below assumes a general steady-state condition, where inflows equal outflows and there is no change in storage. In reality, transient stresses on the aquifer occur during wet periods, due to changes in pond management and pumping. Transient aquifer stresses are considered as part of the numerical modeling effort.

The steady-state groundwater balance can be expressed by the following equation, based on significant sources of groundwater recharge and groundwater discharge at the site:

$$GW_{in} + PS + SW + INF = GW_{out} + BF + GE$$

Where:

GW_{in}	=	*groundwater underflow from upgradient of the Study Area*
PS	=	*pond seepage*
SW	=	*discharge of surface water to groundwater from streams*
INF	=	*infiltrating recharge (precipitation and lawn irrigation minus evapotranspiration)*
GW_{out}	=	*groundwater underflow leaving the Study Area to the south*
BF	=	*groundwater discharge to surface water (baseflow)*
GE	=	*groundwater extraction*

In order to quantify the water balance, a domain must be established. **Figures 10** through **17** show the domains in which each component of the water balance is calculated. The domain was established in order meet requirements of the groundwater flow model (as described below). In general, the model domain margins are designed to run either perpendicular or parallel to groundwater flow. **Table 6** presents ranges of estimated flow rates for each component of the groundwater budget. The following subsections described how the estimates were developed using available data.

The water balance was defined for two time periods: December 2003 and February 2014. These periods were selected to support the two periods for steady-state model calibration discussed below (**Section 4.0**).

Table 6. Summary of Water Balance for 2014 and 2003

	2013/2014						2003					
	Min (ft^3/d)	Max (ft^3/d)	Estimate (ft^3/d)	Min (gpm)	Max (gpm)	Estimate (gpm)	Min (ft^3/d)	Max (ft^3/d)	Estimate (ft^3/d)	Min (gpm)	Max (gpm)	Estimate (gpm)
Inflows												
Underflow In	28,365	113,462	56,731	147	589	295	28,365	113,462	56,731	147	589	295
PPLM Pond Seepage	1,830	178,489	18,089	10	927	94	1,830	178,489	18,089	10	927	94
WECO Ponds Seepage	7,567	75,674	23,930	39	393	124	7,567	75,674	23,930	39	393	124
Sewage Lagoons Seepage	16,888	26,738	22,517	88	139	117	16,888	26,738	22,517	88	139	117
Surge Pond Seepage	4,113	41,132	13,007	21	214	68	4,113	41,132	13,007	21	214	68
Recharge (net infiltration)	16,907	28,179	22,543	88	146	117	12,648	21,080	16,864	66	109	88
Total IN	75,671	463,673	156,816	393	2,409	815	71,412	456,575	151,138	371	2,372	785
Outflows												
Underflow Out	27,186	81,559	54,372	141	424	282	27,186	81,559	54,372	141	424	282
Flow to E.F. Armells Creek	33,209	55,348	44,278	173	288	230	33,209	55,348	44,278	173	288	230
Groundwater Extraction	58,512	86,867	68,643	304	451	357	25,145	38,812	30,554	131	202	159
Total OUT	118,907	223,773	167,293	618	1,162	869	85,539	175,718	129,205	444	913	671

Notes: ft^3/d = cubic feet per day; gpm = gallons per minute

2.7.1 Underflow In

Underflow was calculated using Darcy's Law.

$$Q = KiA$$

Where:
- Q = *flux*
- K = *Hydraulic Conductivity*
- i = *Hydraulic Gradient*
- A = *Cross Sectional Area*

Each portion of the domain where groundwater is interpreted to cross the domain was assessed. There are five relatively distinct areas where this occurs:

- From the south in the alluvium of East Fork Armells Creek,
- From the southwest, just south of East Fork Armells Creek,
- From the highlands in the southeast,
- From the highlands in the northeast, and,
- From the west.

Table 7 summarizes the lithologic units that are present at each of the "Underflow In" boundaries. Each of these areas has variable lithology dependent upon the depth. Four depth intervals are presented below for the underflow calculations, including:

- Depth Interval 1- includes the shallow interval that extends from ground surface to the base of the interburden (in some cases the interburden may be missing due to erosion),
- Depth Interval 2- comprises the depth interval of the McKay Coal (in some cases the McKay Coal may be missing due to erosion),
- Depth Interval 3- comprises the depth interval of the Sub-McKay from its contact with the overlying hydrostratigraphic unit (McKay or alluvium) down to an elevation of 3100 feet amsl, and,
- Depth Interval 4 - comprises the deep Sub-McKay and extends from an elevation of 3100 feet amsl to 2950 feet amsl.

In general, the geometric mean value for hydraulic conductivity in each lithologic unit (**Table 2**) was used to calculate underflow. Two exceptions are for alluvium and Sub-McKay. Alluvium was divided between the shallow-most fine grain alluvium (which represents the upper approximately 14 feet of the alluvial package) which was assigned a hydraulic conductivity of 1 feet/day and the remaining approximately 25 feet of coarser alluvium, which was assigned a hydraulic conductivity of 60 feet/day. A value of 2 feet/day was used for the calculations of flux in through the Sub-McKay.

Table 7. Primary Lithology and Hydraulic Characteristics along Underflow-In Boundary

Location	**Depth Interval 1 Lithology and Hydraulic Conductivity** (feet/day)	**Depth Interval 2 Lithology and Hydraulic Conductivity** (feet/day)	**Depth Interval 3 Lithology and Hydraulic Conductivity** (feet/day)	**Depth Interval 4 Lithology and Hydraulic Conductivity** (feet/day)
Southern Armells Drainage	Alluvium 1/60	Alluvium 1/60	Sub-McKay 2	NA
Southwest	Spoils/Interburden 7.5/1.1	McKay 2.3	Sub-McKay 2	Sub-McKay 2
Southeast	Clinker 100	McKay 2.3	Sub-McKay 2	NA
Northeast	Spoils/Interburden 7.5/1.1	McKay 2.3	Sub-McKay 2	NA
West	Spoils/Interburden 7.5/1.1	McKay 2.3	Sub-McKay 2	NA

NA – not applicable no underflow

The saturated thicknesses, gradients, and lengths of these boundaries are also variable depending upon depth. **Table 8** summarizes the saturated thicknesses, gradients, and approximate lengths of these boundaries. Lengths of inflow boundaries are inferred from potentiometric surface maps and vary with depth.

Table 8. Approximate Saturated Thickness, Gradient, and Length along Underflow-In Boundary

	Depth Interval 1			Depth Interval 2			Depth Interval 3			Depth Interval 4		
Location	Saturated Thickness (feet)	Gradient	Length (feet)	Saturated Thickness (feet)	Gradient	Length (feet)	Saturated Thickness (feet)	Gradient	Length (feet)	Saturated Thickness (feet)	Gradient	Length (feet)
Southern Armells Drainage	29	0.005	2000	8	0.006	1300	NA	NA	NA	NA	NA	NA
South West	38	0.002	3600	13	0.005	4100	110	0.002	11300	150	0.004	12000
South East	54	0.002	1227	6	0.002	1480	NA	NA	NA	NA	NA	NA
North East	31	0.008	3609	9	0.003	3609	NA	NA	NA	NA	NA	NA
West	48	0.006	4725	10	0.006	4725	130	0.005	4725	NA	NA	NA

NA – not applicable no underflow

Based on these estimates, approximately 56,700 feet^3/day or 295 gallons per minute (gpm) are estimated to flow into the domain as "Underflow-In."

2.7.2 Pond Seepage

Potential seepage from key process and sediment ponds in near the Plant Site area was estimated using the Darcian flow equation presented by Bouwer (1982). Under seepage conditions, the base of the pond is saturated and the following equation applies:

$$Q = A \times K_c \frac{H_w + L_c - h_i}{L_c}$$

Where: Q= *flux*
A= *area of water body*
H_w = *water depth above liner*
K_c = *saturated hydraulic conductivity of earthen liner*
L_c = *thickness of earthen liner*
h_i = *pressure head of water at bottom of liner- assumed to be zero*

Where available, the estimated seepage was compared to values estimated by Hydrometrics (2014b).

Minimum and maximum hydraulic conductivity estimates were used to calculate the range of seepage from clay-lined and unlined ponds. The geometric mean of the resulting flux was used as our "estimate" of seepage. Minimum hydraulic conductivity for clay liners was based on the laboratory testing (1.4×10^{-4} feet/day, Hydrometrics 2015). The maximum hydraulic conductivity was based on the high end for silty clay reported by Driscoll (1991) of 1.32×10^{-2} feet/d. Unlined ponds, such as the WECO ponds, were evaluated using minimum and maximum hydraulic conductivity based on the low and high end values for silty clay reported by Driscoll (1991) of 1.32×10^{-3} feet/d and 1.32×10^{-2} feet/d, respectively.

Estimated seepage for ponds lined with geosynthetic liners was calculated using Bouwer (1982) equation above and the estimated hydraulic conductivity reported by Hydrometrics (2015). The minimum seepage for these geosynthetic-lined ponds was assumed to be 0 and the maximum seepage was calculated as ten times the "estimated value."

Table 9 presents the various ponds analyzed along with the resultant minimum, maximum, and estimated seepage rates from each pond along with prior estimates provided in Hydrometrics (2012a). All ponds except the Sewage Lagoons and the Surge Pond were assessed using the above equation.

As discussed previously, the City of Colstrip Sewage Lagoons are used to process wastewater, currently at a rate of 200,000 gallons/day (City of Colstrip 2014). The seepage for those lagoons was calculated by subtracting the estimated evaporation off the lagoons from 200,000 gallons per day. The average annual pan evaporation is 41.27 inches (Western Regional Climate Center 2014) and the area of the sewage lagoons is approximately 448,000 feet^2 (approximately 4221 feet^3/d of evaporation). This results in an estimated seepage of 22,500 feet^3/ day or 117 gpm.

Table 9. Pond Seepage Estimates

Pond	Area (feet^2)	Thickness (feet)	Head on pond bed (feet)	Kmin (feet/day)	Kmax (feet/day)	Q min (feet3/day)	Qmax (feet3/day)	Q Estimate (feet^3/day)	Hydrometrics (2014b) Estimate (feet^3/day)
Units 1 & 2 Pond A	610,000	3	13	1.4E-04	1.32E-02	446	42,838	4369	4620
Units 1 & 2 Bottom Ash Ponds	90,900	3	3	1.4E-04	1.32E-02	25	2,394	244	250
South Cooling Tower Blowdown Pond C	480,000	3	15	1.4E-04	1.32E-02	395	37,922	3868	3850
Units 3 & 4 Bottom Ash Pond Area	460,000	3	1	1.4E-04	1.32E-02	84	8,076	824	616
Units 3 & 4 Wash Tray Pond (wet area*)	335,000	3	1	1.30E-03	0.13	581	58,067	5807	655
North Cooling Tower Blowdown Pond	460,000	3	5	1.4E-04	1.32E-02	168	16,152	1647	1540
Units 1 & 2 Bottom Ash Clear Well- Lined	83,125	0.1476	30	4.90E-06	4.90E-06	0	64	6	6.35
Units 1 & 2 Pond B- Lined with underdrain	399,375	0.1476	36	4.90E-06	6.00E-05	0	270	27	27.0
Sediment Retention Pond-Lined	133,125	0.1476	3	5.40E-06	5.40E-06	0	8	1	0.85
Units 3 & 4 Auxiliary Scrubber Drain Pond (Duck Pond)	10,000	0.1476	3	5.40E-06	5.40E-06	0	1	0.05	0.05
Units 3 & 4 North Plant Area Drain Pond	19,200	0.1476	3	5.40E-06	5.40E-06	0	2	0.23	0.23
North Plant Sediment Pond	26,200	3	1	1.4E-04	1.32E-02	5	460	47	57.8
Units 3 & 4 Drain Collection Pond (wet area*)	234,375	0	0.5	1.4E-04	1.32E-02	96	9,258	944	2503 (c)
Brine Pond Area D4 Pond (wet area*)	68,125	3	0.5	1.4E-04	1.32E-02	11	1,047	107	
Brine Pond Area D1, 2, and 3 Pond	125,625	3	0.5	1.4E-04	1.32E-02	20	1,930	197	
PO-151 WECO Sediment Ponds-Northeast Side	700,000	2(a)	10(b)	1.32E-03	1.32E-02	5,530	55,304	17489	
PO-10A WECO Sediment Pond-South Side	102,000	1(a)	3(b)	1.32E-03	1.32E-02	537	5,372	1699	
PO-10B WECO Water Collection Pond - Southern	153,500	1(a)	3(b)	1.32E-03	1.32E-02	808	8,085	2557	
PO-010 WECO Water Collection Pond - Southern	175,000	1(a)	2(b)	1.32E-03	1.32E-02	691	6,913	2186	

* - wetted perimeter estimated from recent air photos
(a) - value estimated
(b) - value estimated based on topography
(c) Hydrometrics (2014b) estimated seepage assuming the entire area of the pond was wetted.

The seepage through the Surge Pond was estimated by a process similar to that for process ponds. However, since the Surge Pond is a flow-through pond, the gradient between the pond and the surrounding groundwater system is not a constant and is much smaller than the head on the pond. A unit gradient was assumed for these calculations. In reality, the gradient under the surge pond is highly variable. Again, a range of hydraulic conductivity values was used to calculate the range of seepage and then the geometric mean of the resulting flux was used as our estimate of seepage. In this case, the minimum and maximum hydraulic conductivity was based on the low and high-end values for silty clay reported by Driscoll (1991) of 1.32×10^{-3} feet/day and 1.32×10^{-2} feet/d, respectively. The area of the Surge Pond within the domain was 3,124,000 feet^2. Using this value with the geometric mean for hydraulic conductivity resulted in a flux of 13,007 feet^3/day (68 gpm) (**Table 6**). For comparison, Bechtel (1974) estimated seepage from the entire Surge Pond as 112 gpm. Bechtel's estimate, prorated for the area within the current model domain, results in an estimate of 52 gpm.

2.7.3 Surface Water Discharge

Across the length of the model domain there are a few areas where East Fork Armells Creek discharges to the groundwater system, however, East Fork Armells Creek is primarily a gaining stream where groundwater discharges to East Fork Armells Creek. Therefore, in the water balance the net gain to the stream is accounted for as a component of outflow in the groundwater budget (see **Section 2.7.6**).

2.7.4 Recharge

This component of the groundwater balance is referring to deep percolating recharge (i.e., infiltrating precipitation minus evapotranspiration). Measuring actual groundwater recharge is difficult but it can be estimated through soil moisture water balances, analysis of stable isotopes, and, in many cases it can be calculated by balancing the water budget. Through review of literature and previous studies of hydrology in the Plant Site area (including previous numerical groundwater modeling), it was determined that areas that would provide for direct infiltration recharge to the groundwater system are part of the conceptual model for this site. Five distinct areas were designated in this study, including:

- Background Areas,
- Irrigated Lawns,
- Clinker,
- Un-Vegetated Areas, and
- Impervious Areas.

2.7.4.1 Background

Background areas account for most surface area within the domain (126,300,000 feet^2) of the model. These areas are generally covered in grasses and low shrubs and recharge to the groundwater system within such areas was assumed to be a small percent of annual precipitation. A large portion of precipitation is anticipated to become runoff or evapotranspire before reaching groundwater. A net recharge rate of 1.5 percent of annual precipitation was assumed over this area based on values used in a groundwater model developed for Area C of the Rosebud Mine. Again, December 2003 and February 2014 data were assessed to support design and calibration of steady-state models described below

(**Sections 3.0** and 4.**0**) using the precipitation that fell during the 12 prior months. **Table 10** summarizes the precipitation and estimated background recharge for the two time periods evaluated.

Table 10. Precipitation and Estimated Background Recharge for Jan 2003-Dec 2003 and Feb 2013-Jan 2014

Area (feet^2)	**Estimated percent of Precipitation**	**Precipitation Feb 2013-Jan 2014** (inches)	**Estimated Recharge Feb 2013-Jan 2014** (feet^3/day)	**Precipitation Jan 2003-Dec 2003** (inches)	**Estimated Recharge Jan 2003-Dec 2003** (feet^3/day)
126,303,550	1.5%	23.58	10,199	16.49	7,133

2.7.4.2 Lawn Irrigation

A sizeable area within the Colstrip Townsite contains irrigated lawns. Net percolation in areas with irrigated lawns tends to be higher than for unirrigated native grassland. The area of lawn irrigation in the Townsite was estimated from aerial photographs to be 9,420,700 feet^2. This area was assumed to receive about 1.7 inches of annual net recharge based on a previous model calibration (Geomatrix 2006, 2008).

2.7.4.3 Clinker Recharge

As described above, clinker outcrops exist around the Surge Pond and north and east of the sewage lagoons and southeast of the Plant Site (**Figure 4**). Clinker typically has very high permeability due to settling or collapse of the rock, which results in secondary porosity. However, in most cases clinker is present above the water table in the Plant Site area. Thus, the enhanced permeability associated with these areas generally serves to create areas of heightened recharge. Again, lacking studies that estimate the recharge through this lithologic unit, the estimates for recharge through clinker were based on past studies of the system which required elevated local recharge to maintain groundwater elevations in these regions. These areas (estimated to be 2,840,000 feet^2) were assumed to receive roughly seven percent of annual precipitation as net recharge. This value was based on that presented in a previous model calibration (Geomatrix 2006, 2008). The estimated volume of net recharge in these areas for Jan 2003-Dec 2003 and Feb 2013-Jan 2014 is 1,070 feet^3/d and 748 feet^3/d, respectively.

2.7.4.4 Un-Vegetated

There are large areas around the Plant Site that have been cleared of vegetation but not paved (visible on **Figure 2**). In some cases, these areas are gravel-covered and in other cases the land is bare ground or coal waste. Because these areas are typically flat and have no vegetation, it is anticipated that both runoff and evapotranspiration are lessened. Lacking studies that estimate the recharge through these areas, the estimates for recharge were considered comparable to clinker recharge. These areas (approximately 20,212,000 feet^2) were assumed to receive roughly seven percent of annual precipitation as recharge. The estimated recharge in these areas for Jan 2003-Dec 2003 and Feb 2013-Jan 2014 is 7,617 feet^3/d and 5,327 feet^3/d, respectively.

2.7.4.5 Impervious

There are large areas in the Plant Site that have been covered with impervious material (paving and buildings [visible on **Figure 2**]). These areas (1,786,000 feet^2) are assumed to receive no recharge.

2.7.5 Underflow Out

Underflow-Out was calculated the same way as Underflow-In, using Darcy's Law. Each portion of the domain where water is interpreted to move out of the domain was assessed. There are three relatively distinct areas where groundwater is interpreted to cross out of the domain, including:

- To the north in the alluvium of East Fork Armells Creek,
- To the east toward Cow Creek in Intervals 1 through 3,
- To the northeast in Interval 4, and
- To the south toward Rosebud Area B Mine Cut.

Each of these areas has variable lithologies, dependent upon the depth (see **Section 2.7.1**). **Table 11** summarizes the lithologic units and associated hydraulic conductivity that are present at each of the "Underflow-Out" boundaries.

Table 11. Primary Lithologies and Hydraulic Characteristics along Underflow Out Boundaries

Location	**Depth Interval 1 Lithology and Hydraulic Conductivity** (feet/day)	**Depth Interval 2 Lithology and Hydraulic Conductivity** (feet/day)	**Depth Interval 3 Lithology and Hydraulic Conductivity** (feet/day)	**Depth Interval 4 Lithology and Hydraulic Conductivity** (feet/day)
North Armells Drainage	Fine/ Coarse Alluvium 1/60	Fine/Coarse Alluvium 1/60	Sub-McKay 2	NA
East /Northeast	Spoils/ Interburden 7.5/1.1	McKay 2.3	Sub-McKay 2	Sub-McKay 2
South	Spoils/Interburden 7.5/1.1	McKay 2.3	N/A	N/A

NA – not applicable no underflow

The saturated thicknesses, gradients, and lengths of these boundaries are also variable depending upon depth. **Table 12** summarizes the saturated thicknesses, gradients, and approximate lengths of these boundaries. Based on these estimates approximately 54,400 cubic feet per day (feet^3/day) or 282 gallons per minute (gpm) are estimated to flow out of the domain as "Underflow Out."

Table 12. Approximate Saturated Thicknesses, Gradients, and Lengths along Underflow Out Boundary

	Depth Interval 1			**Depth Interval 2**			**Depth Interval 3**			**Depth Interval 4**		
Location	**Saturated Thickness (feet)**	**Gradient**	**Length (feet)**	**Saturated Thickness**	**Gradient**	**Length (feet)**	**Saturated Thickness (feet)**	**Gradient**	**Length (feet)**	**Saturated Thickness**	**Gradient**	**Length (feet)**
North Armells Drainage	25	0.005	500	15	0.004	500	77	0.003	500	NA	NA	NA
East	37	0.006	6350	9	0.007	6350	93	0.007	6350	150	0.008	13000
South	26	0.006	4200	NA	NA	NA	NA	NA	NA	NA	NA	NA

NA – not applicable no underflow

2.7.6 Baseflow

As was discussed above, East Fork Armells Creek is primarily a gaining stream and is a component of outflow in the groundwater budget. Multiple synoptic gaging studies have been done on the stream. However, no synoptic gaging has been conducted during the seasons similar to the two time periods being assessed as part of this study (December 2003 and February 2014). Therefore, the lowest flow measurements (June 2004 [see **Figure 9**]) which are assumed to correlate best with the time periods for this study were used. The end of the model domain is about halfway between AR-2 and AR-1(**Figure 2**). The gain in flow along the stream up to this location in the June 2004 study is interpolated to be approximately 230 gpm or 33,200 feet^3/day (**Figure 9**).

2.7.7 Groundwater Extraction

PPLM has installed an extensive groundwater extraction system that consists of capture wells and underdrains within the Plant Site area (**Figure 33**). Between 2003 and 2014, several of the wells shown on **Figure 33** were either converted from monitoring wells into capture wells or were installed for the purpose of capture. The volume of water extracted from the capture system has been monitored and recorded for several years. Recently, it was determined that methods used to measure volumes and rates pumped from wells were inaccurate due to back-pressure head loss in the lines (Hydrometrics 2012a). Hydrometrics (2015) estimates that actual current pumping rates for capture wells are about 25 percent lower than measured rates.

Table 13 presents the estimated pumping rates for groundwater extraction wells during the fourth quarter 2003 and/or January-February 2014. These pumping rates are 75 percent of the measured rates. Total estimated groundwater extraction in the fourth quarter of 2003 was 159 gpm and the total estimated groundwater extraction in January of 2014 was 357 gpm.

2.8 Changes to Conceptual Model since 2008

Geomatrix (2007, 2008) provided a detailed description of the conceptual model of groundwater flow and solute transport near the Stage I and II Evaporation Ponds and Plant Site areas. Additional hydrogeologic data have been collected since the Plant Site conceptual model was last updated (Geomatrix 2007, 2008). The following new information was considered in the modeling refinement discussed in this report.

- Lithologic and well depth data from 54 wells presented in **Table 14**. This includes: wells installed west of Pond A and east of East Fork Armells Creek; wells installed east the Units 3 & 4 Bottom Ash Ponds; wells installed around the Cooling Tower Blowdown Pond and the Wash Tray Pond; and, wells installed near Well OT-7.
- Aquifer test data from 33 wells in the Plant Site area.
- Water level and water quality information obtained from 2008 through 2014.

Major changes to the conceptual model since the 2007 conceptual model report include:

- Based on water levels measured in Western Energy wells, it is now interpreted that, in the shallow system, there is a component of flow into the domain from the northeast (**Figure 14**).

- Based on renewed mining and dewatering in Area B of the Rosebud Mine, the conceptual model incorporates flow out due to the influence from mine dewatering at this location.
- The alluvium is now considered as two separate units; a shallow fine-grained unit and a deeper coarse grained unit.
- Although groundwater extraction has been a component of the water balance for years, as the capture system has expanded, groundwater extraction now accounts for the largest component of outflow from the groundwater system.

Table 13. Summary of Estimated Groundwater Extraction Rates

Well	January 2014 Estimated Pumping Rate (gpm)	Fourth Quarter 2003 Estimated Pumping Rate (gpm)	Well	January 2014 Estimated Pumping Rate (gpm)	Fourth Quarter 2003 Estimated Pumping Rate (gpm)
B-1	0	3.13	55D	0.32	0.87
B-4	0	3.13	56D	14.9	1.80
B-5	0	3.13	58M	2.41	0.17
106A	4.49	-	59M	0.01	0.18
107A	3.88	-	5M	0.17	4.88
108A	10.66	-	5S	0	0
10M	7.41	7.06	68A	4.55	-
10S	4.79	8.10	6M	0	0
111SP	4.26	-	70SP	3.98	-
114S	1.27	-	74A	11.25	-
115M	0.87	-	75A	10.6	-
116M	4.59	-	78A	0.42	-
117A	2.16	-	79A	49.96	-
118A	1.19	-	82A	8.51	-
119A	0	-	98M	10.55	-
122A	9.17	-	SRP-1	0.7	0.33
19SP	0.07	0	SRP-2	0.02	1.20
1D	6.68	5.74	SRP-3	8.13	3.33
21S	3.21	5.82	SRP-4	4.99	6.96
26SP	2.5	0	SRP-5	12.77	2.84
29SP	5.97	0	SRP-6	0.39	1.05
31M	0.99	0.43	SRP-7	0.49	1.05
43S	0	0	SRP-8	0.61	1.05
4S	0.12	0	Pond B-Underdrain	38.5	-
51SP	4.98	5.54	WECO Dewatering Well	54.5	50.00
52SP	0.11	7.75	704	10.97	10.90
53SP	6.88	7.90	725	9.7	7.40
54SP	0.93	0.21	729	9.98	6.79

Note: - = Well was installed after 2003.

Table 14. Wells Installed Since 2007

Well ID	Aquifer	Install Date	Total Depth	Well ID	Aquifer	Install Date	Total Depth
84SP	Spoils	6/23/2008	60	111SP	Spoils	10/26/2009	57
85SP	Spoils	6/23/2008	63	112R	Rosebud/Clinker	7/21/2011	40
86SP	Spoils	6/23/2008	42	113M	McKay	11/19/2012	38
87SP	Spoils	6/23/2008	70	114S	Alluvium	11/19/2012	25
88M	McKay	6/23/2008	60	115M	McKay	11/19/2012	39
89SP	Spoils	6/19/2008	69	116M	McKay	11/19/2012	37
90R	Rosebud/Clinker	8/27/2008	40	117A	Alluvium	11/19/2012	25
91S	Overburden	11/20/2008	37	118A	Alluvium	11/19/2012	25
92A	Alluvium	5/28/2009	38	119A	Alluvium	11/21/2012	35
93A	Alluvium	5/28/2009	45	120A	Alluvium	11/28/2012	40
94A	Alluvium	5/28/2009	43	121A	Alluvium	11/28/2012	40
95D	Sub-McKay	5/28/2009	75	122A	Alluvium	11/28/2012	39
96A	Alluvium	5/28/2009	25	123A-P	Alluvium	2/14/2013	27
97A	Alluvium	5/28/2009	39	124A-P	Alluvium	2/14/2013	26
98M	McKay	9/29/2009	43	125M	McKay	11/12/2013	84
99D	Sub-McKay	5/28/2009	40	126SP	Spoils	11/12/2013	57
100A	Alluvium	4/30/2009	31.5	127M	McKay	11/12/2013	75
101A	Alluvium	5/5/2009	40	128R	Rosebud/Clinker	11/12/2013	56
102A	Alluvium	5/5/2009	22	129D	Sub-McKay	11/13/2013	69
103D	Sub-McKay	5/5/2009	80	130M	McKay	11/13/2013	52
104A	Alluvium	5/5/2009	36	131M	McKay	11/14/2013	146
105A	Alluvium	6/16/2009	36	132SP	Spoils	11/14/2013	120
106A	Alluvium	6/15/2009	34	133A	Alluvium	11/18/2013	35
107A	Alluvium	6/15/2009	42	134A	Alluvium	11/18/2013	20
108A	Alluvium	6/15/2009	40	135A	Alluvium	11/18/2013	35
109A	Alluvium	6/16/2009	38	136A	Alluvium	11/18/2013	40
110D	Sub-McKay	6/17/2009	46	137A	Alluvium	11/18/2013	20

2.9 Conceptual Groundwater Model Summary

Figure 34 is a block model illustrating our conceptual understanding of the hydrogeologic system in the Plant Site area. Seepage from process ponds is a major source of recharge within the Plant Site. Seepage from process ponds, sediment ponds, and stormwater collection areas recharges the groundwater system, creating localized mounding. Groundwater capture via drains and wells is the largest component of outflow for the groundwater budget. The capture system depresses the water table adjacent to seeping process ponds and collects both impacted and non-impacted groundwater.

Most groundwater that is not captured flows westward from under the process ponds and then turns northwest toward East Fork Armells Creek, which is a major point of outflow for the shallow system. As more capture wells have been added, less groundwater originating from under the process ponds has flowed into the Creek. Groundwater at the eastern side of the Plant site area generally flows eastward toward the Cow Creek drainage. Groundwater flow in the deep Sub-McKay (deeper than 200 feet below ground surface) follows a more regional pattern that is generally from southwest to northeast beneath the Plant Site. Vertical hydraulic gradients are upward along portions of East Fork Armells Creek where groundwater flows into surface water. Vertical gradients beneath the remainder of the area are downward from Rosebud, alluvium, and spoils intervals to the McKay Coal to the Shallow McKay and into the underlying deep McKay.

With the onset of mining and associated dewatering, flow directions in some areas surrounding the Plant Site (e.g. south of WECO POND P-10, **Figure 2**) has reversed toward mine cuts. With the construction of the Plant Site and associated operation of process ponds, localized recharge sources further altered gradients and flow directions. Currently, groundwater levels in most of the previously mined areas exhibit a long-term recovery trend, although renewed mining in Area B of the Rosebud Mine is beginning to draw down water levels south of the Plant Site. More robust liner and underdrain systems have been installed beneath several process ponds, reducing seepage from these sources, and expansion of the groundwater capture system is intercepting a large portion groundwater flow.

The hydrostratigraphy in the Plant Site area is complex. A once layer-cake stratigraphy has been eroded away along East Fork Armells Creek. Alluvium within the floodplain consists of fine-grained overbank deposits overlying coarser channel deposits consisting of sand and gravel. Mining operations have removed a significant portion of the overburden and Rosebud Coal in the Plant Site area, replacing it with mine spoils. Thicknesses and hydraulic properties of spoils are highly variable, adding to the complexity of the overall system.

Process pond water contains dissolved constituents that are also present in groundwater that is un-impacted by sources within the plant site, making it difficult to draw distinct lines between impacted and unimpacted groundwater. Groundwater quality that is influenced by current and former process ponds at the Plant Site is characterized by elevated levels of parameters such as dissolved boron, chloride, SC, and TDS that are present at concentrations above that typically found in groundwater not affected by process ponds.

Most groundwater with concentrations of constituents above BSLs is currently being intercepted by the groundwater capture system and returned to lined ponds. Some of this groundwater is also being captured by the WECO dewatering wells located north of the Units 3 & 4 Bottom Ash Ponds. A portion of this groundwater is likely also discharging to East Fork Armells Creek. Historically, a major portion of groundwater originating from the Plant Site flowed into the creek. Increased pumping of the groundwater capture system over the last 10 years has reduced groundwater flow into the creek.

Currently, groundwater is not used for domestic or livestock purposes in the Plant Site area. Planned human health and ecological risk assessments will further evaluate contaminant fate and potential receptors.