UNITS 3 & 4 EHP AREA
GROUNDWATER CONCEPTUAL MODEL AND
UPDATED NUMERICAL MODEL
Colstrip Steam Electric Station
Colstrip, Montana

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EXECUTIVE SUMMARY

This report describes the update and calibration of a conceptual hydrogeologic model and numerical groundwater flow model previously developed for the Units 3 & 4 Effluent Holding Pond (EHP) area of Colstrip Steam Electric Station (CSES) in Colstrip, Montana (Figure ES-1). The work described herein was completed by NewFields Companies LLC (NewFields) on behalf of Talen Energy (Talen), the current operator of the CSES. PPL Montana, LLC (PPL Montana) initiated groundwater modeling efforts in this area in 2003 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 and potential future process pond seepage impacts to the environment.

On August 3, 2012, PPL Montana, LLC and the Montana Department of Environmental Quality (MDEQ) entered into an Administrative Order on Consent (AOC). As part of the AOC, Talen has committed to prepare Site Reports for the Plant Site, Stage I Evaporation Pond (SOEP), Stage II Evaporation Pond (STEP), and Units 3 & 4 Evaporation Holding Pond (“3 & 4 EHP” or “EHP”) areas. The AOC Site Reports are required to present information regarding groundwater models and results of modeling. This report presents methods and results of recent work to update and expand the previous conceptual and numerical groundwater model for the Units 3 &4 EHP area and is included as an appendix to the broader AOC site report for the Units 3 &4 EHP area.

MODEL BACKGROUND

Geomatrix (2005) developed a conceptual model of the hydrogeologic system in the Units 3 & 4 EHP area. The conceptual model was updated in 2013 using data available through 2012, and provided the basis for development of a numerical groundwater flow model (NewFields, 2013).

The NewFields (2013) numerical flow model covered an area about 5.7 miles by 2.5 miles. The model was bounded to the north by Cow Creek, to the south by South Fork Cow Creek, to the west by the Drain Pit 5 (DP5) drainage and extends east to the confluence of Cow Creek and South Fork Cow Creek. The model consisted of 8 layers and grid spacing varied from 25 to 100 feet. The model was used to simulate steady-state conditions for early 2003 and late 2012 and transient conditions for 2003 to 2006.

GOALS AND OBJECTIVES

The overall goals of updating the numerical groundwater model are to:

1. Improve the basic understanding of the site groundwater system in the vicinity of the Units 3 & 4 EHP;
2. Provide a tool that will help to assess the current monitoring well network;
3. Help identify data gaps;
4. Evaluate the effectiveness of the site capture systems; and
5. Improve water management practices.
Specific objectives of completing the numerical groundwater update described in this report were to:

1. Adjust model layer geometry (as needed) to better reflect the actual hydrostratigraphy based on information obtained from wells installed since 2012;
2. Revise recharge zones based on changes in pond configuration, pond management practices, and liner advancements;
3. Adjust pumping rates to reflect more recent estimates, and add pumping wells to reflect expansion of the capture system between 2013 and October 2015;
4. Calibrate the expanded model to a variety of head and flux data representative of January 2003 and October 2015 steady-state conditions; and
5. Use the calibrated model to assess the effectiveness of the groundwater capture system operating in the area near the Units 3 & 4 EHP.

GEOLOGY AND HYDROSTRATIGRAPHY

The Units 3 & 4 EHP area is underlain by the Tongue River Member of the Fort Union Formation. 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 (Nichols et al., 1989; Flores et al., 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 (approximately 24 feet thick) and McKay seams (approximately 7 to 12.5 feet thick), which can be economically 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 Colstrip area due to the quality of the McKay seam, which makes it undesirable for use in many coal-fired boilers. Both the Rosebud and McKay Coals are cleated, containing natural vertical fractures generally oriented perpendicular to the bedding plane. The Tongue River Member that is present beneath the McKay Coal is referred to as the Sub-McKay Bedrock. Diagram ES-I illustrates the general hydrostratigraphy, and Table ES-I provides descriptions of the hydrostratigraphic units beneath the Units 3 & 4 EHP area.
Table ES-1. Hydrostratigraphy at the Units 3 & 4 EHP

<table>
<thead>
<tr>
<th>Units</th>
<th>Description*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alluvium/ Colluvium</td>
<td>Unconsolidated surficial sediments, consisting of alluvium and colluvium, are present at the Units 3 &amp; 4 EHP area. Alluvium present at the site consists of interbedded sand, gravel, clay and silt, typically coarsening with depth. Clinker fragments are typically also found throughout finer-grained alluvial deposits. Alluvium occurs primarily along the drainage bottoms, and is present in the following drainages: Drain Pit 5, Cow Creek, Main Dam, Saddle Dam, and South Fork Cow Creek. Colluvium present in the Units 3 &amp; 4 EHP area is generally fine-grained unconsolidated sediments consisting of silt and clay and sometimes weathered Clinker. These deposits occur at and near the land surface on hilltops, slopes, and valleys.</td>
</tr>
<tr>
<td>Rosebud Coal/ Clinker</td>
<td>This unit consists of Rosebud Coal and clinker deposits overlying burned coal in many areas within the Units 3 &amp; 4 EHP area. Clinker is a thermally altered rock (also referred to as scoria) and is formed in areas where Rosebud Coal has burned, usually near where coal seams crop out. 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. Rosebud Coal is up to 25 feet thick in small unburned islands, and its base occurs at elevations of between 3,220 and 3,240 feet amsl in the area surrounding Units 3 &amp; 4 EHP. The clinker comprises up to 90 feet of pink to red claystone, siltstone, and fine-grained sandstone that is vesicular and fractured. In scattered areas, residual Rosebud Coal is present at the base of the clinker as ash or a combination of ash and unburned coal. It is important to note the most clinker in the Units 3 &amp; 4 EHP area is at an elevation above the water table and appears to be unsaturated.</td>
</tr>
<tr>
<td>Interburden</td>
<td>Interburden consists of siltstone, shale, and sandstone lying stratigraphically between the Rosebud and McKay Coal seams. This unit is missing from much of the Cow Creek and South Fork Cow Creek drainages. Where present, Interburden thicknesses are generally 10-20 feet, although the interburden is 2 feet thick on the flat to the northwest of the EHP and is more than 30 feet thick in some areas southeast of the EHP. This unit has been altered by burning in some areas northeast and northwest of the Units 3 &amp; 4 EHP.</td>
</tr>
<tr>
<td>McKay Coal</td>
<td>The McKay Coal unit ranges in thickness from 7 to 12.5 feet and contains carbonaceous shale in some places. The McKay Coal is not present within the lower elevations of the Cow Creek and South Fork Cow Creek drainages where it has been removed by erosion. The base of the McKay Coal occurs at elevations generally between 3,190 and 3,220 feet amsl.</td>
</tr>
<tr>
<td>Sub-McKay Bedrock</td>
<td>Beneath the McKay Coal, bedrock includes interbedded and inter-fingered claystone, siltstone, fine-grained sandstone, and minor carbonaceous shale and coal stringers of the Tongue River Member that are collectively referred to as Sub-McKay. The Robinson Coal bed is 0 to 8 feet thick (Matson and Blumer, 1973) and is present at an elevation of about 3,070 feet amsl in the area (Roberts et al., 1999). For the purposes of this report, the Sub-McKay includes the Robinson coal seam and underlying Tongue River bedrock. The Sub-McKay unit is more than 300 feet thick and is present beneath the entire Colstrip area. This unit is divided into shallow and deep zones for the purposes of describing differences in groundwater flow, but the zones have similar lithology.</td>
</tr>
</tbody>
</table>

*amsl = above mean sea level

SURFACE WATER FEATURES

Several natural and artificial surface water features are present in the Units 3 & 4 EHP area, including:

- EHP Ponds;
- Cow Creek;
- South Fork Cow Creek; and
- Stock Ponds.
The Units 3 & 4 EHP area consists of seven cells, some of which are active and some are inactive. Certain cells do not have synthetic liners while others are lined with either high density polyethylene (HDPE) or reinforced polypropylene. Historic water elevations in the cells as well as pond water elevations over time are provided in appendices to this report. The seven cells are shown on Figure 1-2 and consist of the following at the Units 3 & 4 area include the following:

- Cell A;
- Cell B/New Clearwell;
- Cell C;
- Cell D;
- Cell E;
- Cell F;
- Cell G;
- Cell H; and
- Cell J (Old Clearwell).

The Units 3 & 4 EHP was originally designed to host effluent without geo-synthetic liners. The first ponds were lined with native soils amended with bentonite below an elevation of 3,200 feet above mean sea level (amsl), which is the approximate elevation below which permeable Sub-McKay sandstone is exposed. An underdrain system, consisting of 6-inch slotted corrugated polyethylene pipe was installed above the bentonite (the underdrain is not operated currently). The laterals for the underdrain system were connected to a sump located between what is now the Old Clearwell and Cell C (Bechtel, 1985). If used in the future, the water will be pumped to a lined cell. A bentonite-amended concrete cutoff wall keyed into the bedrock was also constructed to limit lateral seepage through clinker present in the pond area.

The EHP is located in the headwaters of the Cow Creek basin, which includes two main intermittent streams: Cow Creek north of the EHP and South Fork Cow Creek south of the EHP. A few minor tributary drainages in the EHP area include the Drain Pit 5 drainage, which drains the west side of the EHP as wells as reclaimed mine lands to the west of the EHP. A small drainage north of the Main Dam drains the north side of the EHP and several small drainages drain the east side of the EHP below the Saddle Dam.

**WATER QUALITY**

A suite of indicator parameters has been historically used to assess whether groundwater has been affected by seepage from the process ponds (Hydrometrics, 2013). These indicator parameters include Total Dissolved Solids (TDS), specific conductance (SC), dissolved boron, chloride, sulfate, and calcium-to-magnesium ratio. Potassium, selenium, and sodium are also listed as constituents of interest in the AOC. These constituents have been detected in process pond water derived from the EHP, often at concentrations much higher than those that occur in background groundwater (Geomatrix, 2005). Because these constituents are all present in background and pre-EHP groundwater, the occurrence of
concentrations of a single constituent in groundwater above BSLs does not necessarily indicate that groundwater has been impacted by process water.

Neptune (2016) calculated background screening levels (BSLs), for these constituents to represent background or unaffected reference areas concentrations by calculating a single set of BSLs for all three areas (Plant Site, Stage I & II Evaporation Ponds, and Units 3 & 4 EHP). As a result, the geospatial variations in concentrations that are present near the EHP in the historical dataset were incorporated into the entire dataset used to calculate the BSLs. Several wells sampled prior to EHP operation exhibited concentrations of indicator parameters that exceeded BSLs. BSLs that were calculated by Exponent (2011) for the EHP area separate from the Plant Site and SOEP/STEP areas were generally higher than current BSLs. This information suggests that the BSLs calculated by Neptune (2016) may not fully represent pre-EHP groundwater conditions. The Units 3 & 4 EHP area has much more exposed ash and Clinker where the Rosebud Coal has burned. Constituents in the ash and clinker can leach at higher concentrations than in other bedrock intervals, which could account for higher background levels in the EHP area. As a result, the exceedance of a BSL of a single constituent in groundwater is not necessarily an indication of impacts related to process ponds. Therefore, the evaluation of local conditions is conducted on a case by case basis using a multiple lines of evidence approach, with one variable being the BSLs.

Process water from the EHP is the primary source of elevated concentrations of constituents of interest in groundwater. Other sources of COIs have also affected groundwater quality west of the EHP including various releases from a fly ash slurry pipeline near Drain Pit 5 and from a return water pipeline near Drain Pit 3. In addition, water seeping from mine spoils west of the EHP appears to affect alluvial groundwater quality in the Drain Pit 5 drainage. Water from all of these sources has affected groundwater quality surrounding the EHP in the Rosebud/Clinker, Alluvium/Colluvium, McKay, and Sub-McKay units surrounding the EHP.

CONCEPTUAL MODEL

Figure ES-2 is an animated block model (paper copies of this report contain a static image) illustrating the conceptual understanding of the hydrogeologic system in the Units 3 & 4 EHP area based on data collected through 2015.

The block model, in combination with estimated water balance, describes our current understanding of recharge, discharge, groundwater flow, and how these relate to the spatial distribution of constituents. Major elements of the conceptual model are summarized below.

The shallowest hydrostratigraphic units are the Rosebud/Clinker and alluvium. A few islands of Rosebud Coal exist. In other places, the Rosebud Coal has burned in place creating Clinker, which consists of baked shale, siltstone and sandstone and often a layer of ash. Alluvium consists of sand, gravel, silt, and clay. The Rosebud is underlain by the Interburden unit, which consists of interbedded claystone, siltstone, and sandstone. Interburden is underlain by the McKay Coal, which is underlain by the Sub-McKay. The Sub-McKay consists of layers of sandstone interbedded with coal (including the Robinson Coal) and shale stringers and layers of siltstone and claystone.
Seepage from the EHP is the greatest source of recharge to groundwater in the area. The other major source is areal recharge from infiltrating precipitation and runoff. In addition, some groundwater enters the area via underflow from the northwest, west, and southwest. Shallow groundwater naturally flows radially south, west, north, and east away from the EHP. Vertical gradients carry groundwater downward from the Rosebud/Clinker units to the underlying McKay and Sub-McKay units, where the regional flow direction is east-northeast. Groundwater capture systems (including wells and trenches) intercept much of the groundwater originating from EHP cells. Groundwater leaves the area via underflow to the east and north in alluvium and bedrock. Rosebud Creek is the likely area of regional discharge. Minor amounts of groundwater likely discharge to surface water in the lower reaches of Cow Creek and South Fork Cow Creek east of the EHP during periods with higher water table elevations.

Hydrographs for monitoring wells suggest that Cell C and the Old Clearwell have had the greatest influence on groundwater elevations and are potentially large contributors of seepage from the ponds. Pasting of the fly ash prior to placement in the cells is reducing the permeability of the ponds, and reducing seepage to underlying groundwater. Seepage from EHP cells is greatest in areas where Clinker has been in contact with the edge of ponds. Groundwater elevations in Cell C are higher than in Cell G, and groundwater has been observed discharging from Clinker at the south end of Cell C and flowing into Cell G.

From 1988 through 1998, releases from Drain Pit 5 (Figure 1-2) and the adjacent scrubber slurry pipeline impacted groundwater quality within the drainage below this area that flows northeast toward Cow Creek. In addition, water samples from a mine cut (NP Cut) upstream of Drain Pit 5 contains concentrations of indicator parameters including chloride, SC, and sulfate (Figures 2-27, 2-28, and 2-29) that exceed alluvial BSLs. These elevated concentrations suggest that water draining from reclaimed mine pits to the west of the area may be affecting alluvial groundwater quality downgradient of Drain Pit 5. Operation of the DP5 trench capture system collects most of the impacted groundwater in this drainage. However, concentrations of boron, chloride and SC in alluvial well capture system (wells 1126A, 1047A, and 1048A) suggests that some water may be bypassing the system.

The cutoff wall surrounding the EHP cells limits the horizontal flow of groundwater containing concentrations of constituents above the BSLs from entering into surrounding groundwater. Some impacted groundwater seeps through the cutoff wall and migrates into the Rosebud/Clinker interval south and west of the ponds.

**Summary of Sources**

The following is a summary of known sources of dissolved constituents to groundwater in the Units 3 & 4 EHP area, including the operational and natural source areas:

- Vertical seepage of process water from the EHP cells;
- Horizontal seepage of process water below and/or through the cutoff wall or dams;
- Release of process water from the fly ash slurry pipeline and Drain Pit 5;
- Natural sources associated with *in situ* burned coal and ash; and
• Mine spoils west of the EHP.

The principal source of dissolved constituents in groundwater in the Units 3 & 4 areas is seepage from process ponds and the flooding of Cells F and H in 2003 and 2004, and the subsequent release of impacted water through and/or beneath the cutoff wall and dams. Based on facility records, 54 acres of the original Units 3 & 4 EHP surface footprint (which was approximately 370 acres, personal communication, Mike Holzwarth, Talen) were lined with a bentonite/soil mixture at elevations below approximately 3,200 feet amsl (Hydrometrics, 2016a) prior to pond filling. At the time of filling in the mid-1980s, process water that was discharged to Cell F was in direct contact with highly permeable Clinker. Other cells came on-line during the last 20 years, which also were not lined with geosynthetic material. The flooding of Cells F and H in 2003 and 2004 resulted in an increase in groundwater elevations south of the EHP and subsequent migration of impacted groundwater toward the South Fork Cow Creek Seep (SFCC Seep), the West Seep, and alluvium in the South Fork Cow Creek drainage.

Other sources of impacts have or may have led to groundwater containing constituent concentrations above BSLs. Release of water from Drain Pit 5, Clinker, mine spoils west of Drain Pit 5, and several fly ash slurry pipeline spills in that area led to impacts in alluvial groundwater downgradient of Drain Pit 5. Seepage from the Saddle Dam in 1999 led to impacts in groundwater east of the Saddle Dam. Clinker and ash resulting from the natural burning of the Rosebud Coal and McKay Coal appears to be a natural source of elevated concentrations of some constituents in groundwater in some locations.

Migration Pathways

Release of process water to the subsurface has led to zones of impacted groundwater around the EHP that ultimately follows several fairly distinct pathways. These pathways have resulted in the migration of groundwater described below.

1. **South Cutoff Wall to SFFC Seep to South Fork Cow Creek.** Water that seeped into the Rosebud/Clinker unit in 2003 and 2004 appears to have built up sufficient head to drive the water beneath and/or through portions of the cutoff wall. A geophysical survey completed in 2005 detected two zones of high conductivity groundwater along the south cutoff wall (Hydrometrics, 2005a). A high conductivity zone appeared at a depth just below the base of the cutoff wall near wells 1006M and 1007R suggesting that impacted water may have seeped through and/or beneath the cutoff wall at this location. Another zone of high conductivity water was detected from the water table down to a depth below the base of the cutoff wall near wells 1000M and 1004M suggesting that impacted groundwater possibly seeped through and beneath the cutoff wall in that area. Once south of the cutoff wall, impacted groundwater appears to follow distinct pathways.

One pathway extends in the Rosebud/Clinker hydrostratigraphic unit from south of the cutoff wall to where it subcrops in colluvium at the location of the SFCC Seep. Impacted groundwater in the Rosebud/Clinker unit issued as a contact spring at the SFCC Seep in 2004 and 2005, discharged into the alluvial system in that drainage, and then flowed down to the alluvial system in South Fork Cow Creek. Subsequent response measures enacted caused flows at this seep to cease in 2006 (Hydrometrics, 2016a). This pathway may extend vertically into the underlying McKay unit south of the cutoff wall via fractures where another pathway or pathways exist.
2. **South Cutoff Wall to PSW-4A & 1019A/M area.** A second pathway that impacted groundwater south of the cutoff wall is west of, and generally parallel to, the one described above. Impacted groundwater in the Rosebud/Clinker system appears to flow south from the cutoff wall in the Rosebud/Clinker unit then discharges into McKay and alluvium, eventually impacting the alluvium and McKay systems in South Fork Cow Creek near wells 1019AM and PSW-4A (Figures 2-26 through 2-33). This pathway, similar to the one described above, is probably fracture-controlled and may extend into the underlying McKay system south of the slurry wall. Permeability in the McKay unit is much lower than in the overlying Rosebud/Clinker (Table 2-1), and therefore transport of impacted water in the McKay unit is much slower.

3. **South Cutoff Wall to West Seep.** A third pathway that impacted groundwater in the Rosebud/Clinker unit is one that directs groundwater south of the cutoff wall, then west and then northwest (Figures 2-26 through 2-29). The Rosebud/Clinker unit subcrops at the location of the West Seep where groundwater discharged to the alluvial system between 2004 and 2006 (Hydrometrics, 2016a).

4. **Northwest Corner of Cutoff Wall to SP-15 North and SP-15 South.** In 2000, water quality at seep SP-15 began to deteriorate. Subsequent investigations (Hydrometrics, 2002, 2003) identified a pathway from the cutoff wall in the Rosebud/Clinker unit past wells 640P and 643P, and into the collapsed/burned McKay unit near well 642P. This groundwater is intercepted by the SP-15 North and SP-15 South trenches and capture well 1068A, and the Well 656R Capture System.

5. **Main Dam to Cow Creek.** EHP seepage flows beneath the cutoff wall and Main Dam in the Sub-McKay unit. This groundwater discharges into the alluvial system downgradient of the Main Dam and then continues to flow north toward Cow Creek. Various interception and capture systems, including the Chimney and Toe drains, are located in this drainage north of the Main Dam and prevent a substantial amount of impacted water from reaching Cow Creek. Just east of the Main Dam, impacted groundwater appears to flow beneath the cutoff wall to the north toward Cow Creek. Several capture wells are located in this area and are designed to capture this seepage.

6. **Northeast Corner of Cutoff Wall to Well 627D.** EHP seepage flows beneath and/or through the cutoff wall in the Sub-McKay toward well 627D. The northeastern extent of the Sub-McKay plume in this area appears to be between wells 627D and 1124D.

7. **Saddle Dam Drainage.** EHP seepage appears to have migrated through the Saddle Dam in Clinker then into underlying McKay a short distance east of the cutoff wall (Figures 2-30 through 2-33). Impacted groundwater has migrated further in the underlying Sub-McKay unit (Figures 2-34 through 2-37). Sub-McKay groundwater discharges two alluvial drainages downstream of the dam.

8. **Drain Pit 5 Drainage.** Groundwater is impacted by Drain Pit 5 releases and by several scrubber slurry and return water pipeline releases in the alluvial drainage northeast of Drain Pit 5. This groundwater migrates in alluvium down the drainage toward the DP-5 groundwater capture system and Cow Creek. There is also potential input into the alluvial system from spoil located upgradient of Drain Pit 5.
Some of the impacted groundwater appears ultimately to reach one of many groundwater interception/capture systems surrounding the EHP. In the past, impacted groundwater seeped to the surface locations including the SFCC Seep, West Seep, Seep SP-15, 552D Seep, and North EHP Seep (Hydrometrics, 2016a). Subsequent groundwater capture efforts have eliminated surface flows at all of these locations.

**Capture Systems**

Talen has installed an extensive groundwater capture system that consists of capture wells, drains, trenches, and chimney drains within the Units 3 & 4 EHP area to recover groundwater affected by process water and transport it back to the Units 3 & 4 EHP (Figure 2-46). Groundwater capture wells and trenches surround the EHP. The groundwater recovery systems and associated wells and trenches are summarized in Table ES-2, below. Captured water is either pumped to F Cell and evaporated through the forced evaporation system, or treated via the Vibratory Shear Enhancement Process (VSEP) and returned to the plant for re-use.

<table>
<thead>
<tr>
<th>Recovery System</th>
<th>Description</th>
<th>Pumped to</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main Dam Sump</td>
<td>North of Main Dam2 trenches and 6 wells; alluvium and Sub-McKay;</td>
<td>Cell F</td>
</tr>
<tr>
<td>Well 552D System</td>
<td>North of Main Dam, 5 wells, Sub-McKay</td>
<td>Cell F</td>
</tr>
<tr>
<td>Drain Pit 5 Trench/SP-15 South Trench/1068A</td>
<td>Northwest of EHP; 2 trenches and 2 wells; alluvium and McKay</td>
<td>3&amp;4 EHP VSEP</td>
</tr>
<tr>
<td>SP-15 North Trench</td>
<td>Northwest of EHP; 1 trench and 1 sump; alluvium McKay</td>
<td>Cell F</td>
</tr>
<tr>
<td>Saddle Dam Interception Trench</td>
<td>East of Saddle Dam; 1 trench and 2 wells; Rosebud/Clinker</td>
<td>3&amp;4 EHP VSEP</td>
</tr>
<tr>
<td>646D System</td>
<td>East of Saddle Dam, 4 wells, Sub-McKay</td>
<td>3&amp;4 EHP VSEP</td>
</tr>
<tr>
<td>Well 556D System</td>
<td>Northeast of EHP; 11 wells; Sub-McKay</td>
<td>Cell F</td>
</tr>
<tr>
<td>644D/645D System</td>
<td>Main Dam; 2 wells; Sub-McKay</td>
<td>Cell F</td>
</tr>
<tr>
<td>656R System</td>
<td>West of EHP; 4 wells; Rosebud/Clinker</td>
<td>Cell F</td>
</tr>
<tr>
<td>560A Trench System</td>
<td>East of Saddle Dam; 4 trenches and 14 wells; alluvium, Sub-McKay</td>
<td>3&amp;4 EHP VSEP</td>
</tr>
<tr>
<td>South Fork Cow Creek</td>
<td>South of EHP; 22 wells; alluvium, McKay</td>
<td>3&amp;4 EHP VSEP</td>
</tr>
<tr>
<td>South Rosebud/Clinker System</td>
<td>South and west of EHP; 8 wells; Rosebud/Clinker</td>
<td>Cell F, and 3&amp;4 EHP VSEP</td>
</tr>
</tbody>
</table>
MODEL DESIGN

The conceptual model described in the report provides the foundation for the development and parameterization of the current Units 3 & 4 EHP numerical model. The numerical model was developed based on the previous Units 3 & 4 EHP model documented in NewFields (2013) and adjusted with refinements from the updated conceptual model. The primary changes incorporated in the current Units 3 & 4 EHP model include the following:

- **Layer Elevations**: Model layer elevations were adjusted in several portions of the model based on lithologic contacts from well logs for new wells installed since 2012 and to better represent hydrostratigraphy and hydraulic communication;

- **Recharge**: Recharge zones within the ponds were revised based on changes in pond configuration, pond management practices, and liner enhancements. Additional recharge zones were added to represent Cells F and H in the 2003 simulation, and Cells B, F, and H, and an area of higher recharge to Clinker in the 2015 simulation;

- **Pumping Rates**: Pumping rates were adjusted to reflect more recent estimates;

- **Pumping Wells**: Additional pumping wells were added to the model to reflect expansion of the capture system between 2013 and October 2015; and

- **Calibration Data**: The model was calibrated to new data sets and the data sets were revised to represent January 2003 and October 2015 steady-state conditions.

MODEL CALIBRATION

Following revision of the model framework and boundaries and assignment of initial model parameters, the numerical 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 current model included: (1) measured water levels, (2) estimated flux into and out of the groundwater system as underflow, (3) closeness of fit between simulated and observed potentiometric maps, and (4) closeness of fit between simulated and observed hydrographs.

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

- Hydraulic conductivity;
- Conductance of head dependent (River Package) boundary cells representing EHP seepage;
- Capture well pumping rates;
- Recharge;
- Storage, and
- Cutoff wall permeability.

The model was calibrated to three independent hydrologic data sets. Calibration included comparing model output to measured heads and estimated fluxes for two time periods (2003 and 2015) for steady-state conditions.
state conditions and transient head and flux data collected between February 2003 through December 2006.

The most frequently adjusted parameter during steady-state calibration was hydraulic conductivity. The hydraulic conductivity component of the conductance of head dependent boundaries (River Package) representing EHP seepage was also adjusted within reasonable ranges. During transient calibration, pumping rates for some capture wells and storage parameters were adjusted more than others. Particle-tracking was periodically performed to check the match between simulated and observed movement of process pond-affected groundwater.

The Units 3 & 4 EHP groundwater model has been calibrated to several independent steady-state and transient data sets. Calibration statistics and good visual qualitative matches for the calibration data sets suggest this model is robust and adaptable to changing hydraulic conditions at the Units 3 & 4 EHP and surrounding areas. Based on the results presented in this section, the numerical model is an appropriate tool for conducting predictive exercises including groundwater flow and advective transport.

SENSITIVITY ANALYSES

A sensitivity analysis was performed to quantify uncertainty in the calibrated model relative to uncertainty in model inputs. The sensitivity analysis was conducted using the 2015 steady-state simulation by varying selected model input values within plausible ranges to document the effect on model calibration statistics. Parameters that appeared to have the greatest effect on residual statistics during manual and automated calibration were selected for analysis, including:

- Horizontal and vertical hydraulic conductivity in selected zones and horizontal hydraulic conductivity by layer;
- Net recharge rate for clinker and alluvium and all recharge zones collectively;
- Seepage rates for Cells B, F, and H;
- Conductance of River Package cells simulating Cells C, G, and the Old Clearwell (Cell J);
- Capture well pumping rates; and
- Hydraulic conductivity of the cutoff wall.

Results of the sensitivity analysis show that the model is most sensitive to the following:

- Increases and decreases in clinker/alluvium recharge;
- Increases in pond seepage at Cell B;
- Decreases in River Package conductance at Cell C; and
- Increases and decreases in horizontal hydraulic conductivity in Zone 11 (represents sandstone);
- Increases in vertical hydraulic conductivity in Zone 11; and
- Increases and decreases in horizontal hydraulic conductivity in model Layer 5.
Overall, the sensitivity analysis shows the numerical model is relatively well-calibrated with increases and decreases in Alluvium/Clinker recharge having the greatest effect on the model calibration. Model calibration was not sensitive to decreases and increases in capture well pumping rates, bed conductance for Cell G and the Old Clearwell, and seepage from Cell H. The sensitivity analysis also shows that the parameter specifications for the calibrated model are the most appropriate for evaluating site conditions and for particle tracking.

**PARTICLE TRACKING AND CAPTURE ANALYSIS**

Particle tracking was used to evaluate the effectiveness of the current groundwater capture systems. Five separate particle tracking simulations were completed, which included particles released from the presumed source area (EHP) and in saturated areas of the model exceeding BSLs in each of model Layers 2 through 5 (a small area of particles was added to Layer 6 in the Layer 5 simulation). 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 systems.

A summary of the uncaptured particles by specific model layer is as follows:

- **Layer 2**: Layer 2 particles placed in a large portion of the Rosebud/Clinker are not captured, but most particles placed in alluvium are captured.
- **Layer 3**: Particles released in most areas of Interburden exceeding BSLs are not captured, while particles released in most alluvium in South Fork Cow Creek drainage, the 560A drainage, and the Drain Pit 5 drainage upgradient of capture systems in those drainages are captured. Particles released in Layer 3 alluvium along Cow Creek and the downgradient end of the Drain Pit 5 and Main Dam drainages are not captured.
- **Layer 4**: Particles released in most areas of McKay coal exceeding BSLs are not captured, while particles released in most alluvium in South Fork Cow Creek drainage, the 560A drainage, and in the Drain Pit 5 and Main Dam drainages above capture systems in those drainages are captured. Particles released in Layer 4 alluvium in some of the Drain Pit 5, Cow Creek, and 560A drainages are not captured.
- **Layers 5 and 6**: Particles released in Sub-McKay north of the Main Dam and in most of the area east of the Saddle Dam are captured. Most particles released in Layer 5 northeast and northwest of the EHP are not captured.

The following is a summary of capture system effectiveness by system based on particle tracking results and other information:

- **South Fork Cow Creek System**: The South Fork Cow Creek capture system is achieving complete capture within alluvium.
- **South and West Rosebud System**: Particle tracking and groundwater elevation data for wells in this area suggests that this system is capturing most of the groundwater in the Clinker south and west of the cutoff wall. Pumping rates have decreased substantially in many of these wells as the Rosebud/Clinker unit has been dewatered. In Clinker wells such as 697R, 1013R, 1016R, 1162R,
groundwater levels have been drawn down below the contact between the Clinker and underlying Interburden by the capture system for at least part of the year. Particle tracking suggests that impacted groundwater in the Clinker may continue to migrate south beyond capture system wells, which is then captured by the South Fork Cow Creek System. However, several particles that originate in Rosebud/Clinker south of the cutoff wall migrate vertically into deeper layers without being captured. In addition, as groundwater levels in the Clinker have dropped, pumping has become much more intermittent in several wells or has stopped due to insufficient water in the capture wells to support continuous pumping.

- **Well 656R System:** This system captures most of the groundwater that seeps through the northern portion of the west slurry wall. However, some groundwater in Clinker in this area is not captured and is migrating downward into McKay and Sub-McKay intervals. A portion of water in the McKay generally issues to the SP-15 North and South trenches.

- **SP-15 North and South Trench System:** Groundwater in Clinker west of the Well 656R system is largely captured by the SP-15 North and South trench systems and well 657M.

- **Drain Pit 5 Trench:** Particle tracking suggests this trench captures all of the groundwater exceeding BSLs in alluvium upgradient on the Drain Pit 5 Trench. A few particles migrate beneath the trench in Sub-McKay, and concentrations of indicator parameters in wells downgradient of the trench exceed BSLs.

- **Well 552D System:** Particle tracking suggests that this system is capturing impacted groundwater migrating north of the cutoff wall just west of the Main Dam. However, particle tracking also suggests that impacted groundwater could be migrating beneath these capture wells. In addition, particles slowly migrate north in McKay and Sub-McKay intervals between this system and the northwest corner of the cutoff wall. Sub-McKay wells 614D and 551D within this pathway have exhibited concentrations of indicator parameters exceeding BSLs.

- **Well 644D/645D System:** These capture wells are capturing impacted groundwater on either side of the Main Dam. However, impacted groundwater may be seeping through and beneath the Main Dam between these two capture wells. Shallow groundwater in this pathway is largely captured by the Main Dam Valley Drain and Main Dam Interception Trench.

- **Main Dam Valley Drain and Sump Systems:** These systems are capturing a large portion of impacted groundwater migrating north from the Main Dam in alluvium and Sub-McKay bedrock. Particle tracking suggests that some groundwater originating in Cell C may be migrating in deeper Sub-McKay layers and may not be captured.

- **Well 556D System:** This system is capturing some groundwater migrating north and northeast from the northeast corner of the EHP. However, particle tracking and plume maps suggest that these systems are not capturing all impacted groundwater along these pathways in the Sub-McKay unit.

- **Valley Drain Interception Trench and Well 646D System:** This trench captures a small amount of shallow water seeping from the Saddle Dam area. Wells in this system capture much of the impacted groundwater in the Sub-McKay unit originating from the southern half of the Saddle Dam. Much of the impacted groundwater in the area is not captured by this system.
CONCLUSIONS AND RECOMMENDATIONS

Calibration of the numerical groundwater flow model described in this report demonstrates the 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 groundwater flow system in the Units 3 & 4 EHP area is complex and dynamic.
- Seepage from the EHP is a major source of groundwater recharge within the upper Cow Creek drainage, and groundwater capture systems are major points of discharge. Therefore, changes in water management at the EHP affects groundwater flow directions and gradients.
- Groundwater levels in several monitoring wells have increased by up to 40 feet since the filling of the EHP began in 1983.
- As groundwater elevations inside the cutoff wall increased, groundwater has seeped through and/or beneath the cutoff wall, the Main Dam, and the Saddle Dam.
- Groundwater flow is radially away from the EHP within the shallower hydrogeologic units (Rosebud/Clinker, McKay, and Interburden). Regional flow in the deep Sub-McKay is generally west to east.
- Vertical hydraulic gradients at paired wells are generally downward across the site with the exception of paired wells in alluvium along South Fork Cow Creek and Cow Creek where bedrock groundwater appears to discharge to alluvium in some areas.
- Most Sub-McKay wells and several McKay wells that have exhibited increasing water levels since 1983 do not contain concentrations of indicator parameters exceeding BSLs; this observation suggests that hydrostatic loading of the aquifer (i.e., an increase in hydraulic pressure due to aquifer compression) has occurred since the EHP cells have been filled.
- Joints, cleating, and fractures in coal and bedrock, and strata with varying permeability, can create preferential flow and transport pathways such as in areas north of the Main Dam (near...
Seep 552) and south of the EHP (near the SFCC Seep and South Fork Cow Creek). Other preferential pathways have not been identified but may exist.

- Several wells in the EHP area that were installed prior to EHP operation exhibited concentrations of indicator parameters that exceeded BSLs. The presence of groundwater exceeding BSLs before the EHP ponds were in operation is an indication that the BSLs calculated by Neptune (2016) may not adequately represent pre-EHP groundwater conditions. For this reason the exceedance of a BSL of a single constituent in groundwater is not necessarily an indication of impacts related to process ponds. Therefore, the evaluation of local conditions needs to be conducted on a case by case basis using a multiple lines of evidence approach, with one variable being the BSLs.

- It appears that groundwater quality has been influenced by seepage from the EHP as well as flooding of Cells F and H with process water in 2003 and 2004 resulting in pond water seeping through or under the cutoff wall. It appears that other releases of process water have also affected groundwater quality west of the EHP including releases from a fly ash slurry pipeline and from a return water pipeline near Drain Pit 3. In addition, water seeping from mine spoils near the NP Cut west of the EHP appears to affect alluvial groundwater quality in the Drain Pit 5 drainage.

- The extent of saturation (and therefore impacted groundwater) in Rosebud/Clinker outside of the cutoff wall is smaller in 2015 than it was in 2005 following the flooding of Cells F and H. In addition, concentrations of indicator parameters in most Clinker wells south and west of the EHP decreased substantially between 2005 and 2015. This is attributable to changes in water management within the EHP as well as the installation and operation of groundwater capture wells south and west of the cutoff wall that have reduced the extent of saturation and cutoff the flow of water to the SFCC and West seeps.

- Installation of additional monitoring wells between 2006 and 2015 has further delineated the extent of impacted groundwater and identified some impacted zones unknown before 2006, including downgradient of the Drain Pit 5 Interception Trench, east of the Saddle Dam, and northwest of the EHP.

- Concentrations of indicator parameters in Sub-McKay wells 620D, 644D, 645D, 1115D, 1128D, and 1129D north of the EHP increased between 2003 and 2015. Most of these wells are immediately adjacent to capture wells. Observed increases in these wells may be attributable to growing zones of influence that capture more impacted groundwater; similar increases are not generally observed in downgradient Sub-McKay wells.

- Concentrations of indicator parameters in wells 556D, 610D, and 621D northeast of the EHP generally increased between 2010 and 2015. These wells are all capture wells. Concentrations of indicator parameters in 2015 samples from well 611D downgradient of the capture wells exceed BSLs for indicator parameters. Although concentrations measured in these wells were lower in 2015 than they were in 2010, the concentrations remain above BSLs, suggesting that groundwater capture may not be complete. Particle Tracking suggests that this is the case. Transmissivity in this area is minimal, particularly at wells 611D and 612D, which limits the effectiveness of groundwater capture.
• Concentrations of indicator parameters in wells 1047A, 1048A, 1126A, which are downgradient of the Drain Pit 5 interception trench continue to exhibit indicator parameter concentrations above BSLs, suggesting that the interception trench may not be achieving complete capture of impacted groundwater.

• Concentrations of indicator parameters above BSLs persist in wells 1121D and 1148D. Particle tracking suggests that pumping wells 1127D and 1148D are not achieving complete capture in this area. However, well 1146D shows no impacts.

Capture analysis suggests that the current capture system array intercepts much of the impacted groundwater east of the Saddle Dam and in the 560A, Main Dam, Drain Pit 5, and South Fork Cow Creek drainages. Particle tracking results suggest that some un-captured groundwater originating from beneath the ponds may be migrating north and northeast of the EHP. To the west and south of the EHP are areas that exceed BSLs for indicator parameters in McKay and Sub-McKay.

Based on the modeling work described above, NewFields developed the following recommendations and identified data gaps:

• Impacted groundwater appears to be migrating north from the Main Dam area in alluvium and Sub-McKay bedrock. In the capture analysis, some particles migrate near the north model boundary in these units. Based on model simulations, capture of groundwater in the Sub-McKay near wells 1115D, 1087D, and 581D-2 is limited. Groundwater in a sandstone zone between approximately 3,140 to 3,190 feet amsl at wells 1115D and 1116D appears to be a conduit for impacted groundwater moving north from the EHP in the Sub-McKay unit. We recommend exploring options for increased capture from this interval, by possibly installing additional and/or deeper capture wells in the area.

• Particle tracking results and plume maps suggest that capture wells 609D-2, 556D, 610D, and 621D are currently capturing insufficient amounts of groundwater to capture particles migrating from the northeast corner of the EHP toward wells 611D and 585D. We recommend exploring options for increasing groundwater capture near these wells.

• Concentrations in wells downgradient of the Drain Pit 5 Trench that exceed BSLs. We recommend investigations to determine how groundwater downgradient of the trench might be captured more effectively.

• Particle tracking and plume maps suggest that groundwater in the McKay west and southwest of the slurry wall is not captured. We recommend further investigation in this area to evaluate capture of groundwater within the McKay unit.

• Particle tracking suggests that impacted groundwater may be migrating north from the northwest corner of the EHP. We recommend continued monitoring of water quality in Sub-McKay wells 614D and 1154D. If concentrations in these wells increase, wells should be used to capture groundwater.

• Particle tracking suggest that south of the EHP impacted groundwater may eventually migrate to McKay and Sub-McKay bedrock and move to the southeast. We recommend continued tracking of water quality trends in wells southeast of the EHP including well 1139M in the McKay and wells 589D and 1134D in the Sub-McKay. If concentrations of indicator parameters increase, consider converting to capture wells.
Particle tracking suggest a major portion of impacted groundwater outside the cutoff wall flows from Clinker inside the cutoff wall. Capture of groundwater in Clinker inside the cutoff wall would greatly restrict seepage outside of the cutoff wall.

Pumping of well 1085R suggests dewatering of the Clinker inside the cutoff wall may be effective at reducing seepage beneath and through the cutoff wall. We recommend converting wells 1003R, 1085R, and 1164R to capture wells after cells are lined or after paste reduces flow out of the cells so there is not constant recirculation of pumped water.

Having accurate flow rate measurements is important for evaluating capture system effectiveness. We recommend evaluating and developing methods to provide more accurate measurements of instantaneous pumping rates from capture wells and trenches.
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### ACRONYMS AND ABBREVIATIONS

<table>
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<tr>
<td>µmhos/cm</td>
<td>micromhos per centimeter</td>
</tr>
<tr>
<td>amsl</td>
<td>above mean sea level</td>
</tr>
<tr>
<td>AOC</td>
<td>Administrative Order on Consent</td>
</tr>
<tr>
<td>ATO</td>
<td>Automatic Time Stepping</td>
</tr>
<tr>
<td>Bechtel</td>
<td>Bechtel Power Corporation</td>
</tr>
<tr>
<td>BSL</td>
<td>Background/Baseline Screening Level</td>
</tr>
<tr>
<td>cm/sec</td>
<td>centimeters per second</td>
</tr>
<tr>
<td>COI</td>
<td>Constituent of Interest</td>
</tr>
<tr>
<td>CSES</td>
<td>Colstrip Steam Electric Station</td>
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<tr>
<td>DEM</td>
<td>digital elevation model</td>
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<tr>
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<td>Effluent Holding Pond</td>
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<tr>
<td>Exponent</td>
<td>Exponent, Incorporated</td>
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<td>FWL5</td>
<td>Fracture Well 5</td>
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<tr>
<td>GHB</td>
<td>General Head Boundary</td>
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<tr>
<td>gpm</td>
<td>gallons per minute</td>
</tr>
<tr>
<td>GWIC</td>
<td>Groundwater Information Center</td>
</tr>
<tr>
<td>HDPE</td>
<td>high density polyethylene</td>
</tr>
<tr>
<td>HFB</td>
<td>Horizontal Flow Barrier</td>
</tr>
<tr>
<td>Hydrometrics</td>
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<td>MBMG</td>
<td>Montana Bureau of Mines and Geology</td>
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<td>Montana Department of Environmental Quality</td>
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<tr>
<td>mg/L</td>
<td>milligrams per liter</td>
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<td>NewFields Companies, LLC</td>
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<td>Neptune</td>
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<tr>
<td>pH</td>
<td>log concentration (moles per liter) of hydrogen ions [H+] dissolved in water</td>
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<tr>
<td>RPP</td>
<td>Reinforced polypropylene</td>
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<tr>
<td>SC</td>
<td>specific conductance</td>
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<td>SFCC Seep</td>
<td>South Fork Cow Creek Seep</td>
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<td>SOEP</td>
<td>Stage I Evaporation Pond</td>
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<td>TDS</td>
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<td>USGS</td>
<td>United States Geological Survey</td>
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<td>UTL</td>
<td>Upper Tolerance Limit</td>
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1.0 INTRODUCTION

This report describes the update and calibration of a conceptual hydrogeologic model and numerical groundwater flow model previously developed for the Units 3 & 4 Effluent Holding Pond (EHP) area of Colstrip Steam Electric Station (CSES) in Colstrip, Montana (Figure 1-1). The work described herein was completed by NewFields Companies LLC (NewFields) on behalf of Talen Energy (Talen), the current operator of the CSES. PPL Montana, LLC (PPL Montana) initiated groundwater modeling efforts in this area in 2003 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 Section 2.5) and potential future process pond seepage impacts to the environment.

On August 3, 2012, PPL Montana and the Montana Department of Environmental Quality (MDEQ) entered into an Administrative Order on Consent (AOC) entitled “Administrative Order on Consent Regarding Impacts Related to Wastewater Facilities Comprising the Closed-Loop System at the Colstrip Steam Electric Station” (MDEQ/Talen Montana, 2012). As part of the AOC, Talen committed to prepare Site Reports for the Plant Site, Stage I Evaporation Pond (SOEP), Stage II Evaporation Pond (STEP), and Units 3 & 4 EHP areas (Figure 1-1). The AOC Site Reports are required to present information regarding groundwater models and results of modeling.

The report herein presents descriptions of methods used to update the previous conceptual and numerical groundwater models for the Units 3 & 4 EHP area and the resulting outputs from the revised models. This report is included as an appendix to the broader AOC Site Report for the Units 3 & 4 EHP area.

1.1 SITE DESCRIPTION AND HISTORY

The CSES is a four-unit coal-fired electrical generation facility located near the Town of Colstrip (Figure 1-1). 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 water used to supply Units 1 through 4. Water is piped from the river to Castle Rock Lake (Surge Pond), west of the Colstrip Townsite, and then to the various Units. 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: the Plant Site, Units 3 & 4 EHP, and the SOEP and STEP areas (Figure 1-1). The Units 3 & 4 EHP area, the focus of this report, is about 2.5 miles southeast of the Plant Site and accepts scrubber slurry from Units 3 & 4 (Figure 1-2). The Block Model outlined on Figure 1-2 is discussed in Section 2.8. The Plant Site includes several process ponds near Units 1 through 4. The SOEP and STEP areas are located approximately 2 miles northwest of the Plant Site. Process pond seepage, pipeline spills, and incidental tears in pond liners (in the Plant Site and STEP areas) have resulted in impacts to groundwater and surface water quality in various portions of the facility.
Prior to construction of the Units 3 & 4 EHP, the area was used chiefly for grazing. BNSF Railroad operated a rail spur for a period of time just south of the EHP. Area E of Western Energy Company’s Rosebud mine had been developed beginning in 1958 (MDSL, 1983).

Initial construction of the Units 3 & 4 EHP began in the early 1980s. Two dams were constructed in 1983 to impound scrubber slurry. The Main Dam and Saddle Dam were constructed across drainages north and east of the Units 3 & 4 EHP, respectively (Figure 1-2). A bentonite-amended concrete cutoff wall (cutoff wall) was constructed around the Units 3 & 4 EHP to limit lateral migration of groundwater. The wall was installed through unconsolidated materials (mainly clinker) and at least 5 feet into “tight” bedrock. The wall was designed with a minimum wall thickness of 2 feet and maximum permeability of 1 x 10^-7 centimeters per second (cm/sec). The cutoff wall beneath the Main Dam extends to approximately 3,010 feet above mean sea level (amsl; Hydrometrics, 2016a) at the base of a Sub-McKay sandstone layer. The cutoff wall west of the Main Dam extends to approximately 5 feet below the McKay Coal unit at an elevation of about 3,210 feet amsl. East of the Main Dam, the base of the cutoff wall was placed at an elevation of 3,200 feet (below McKay Coal). The cutoff wall beneath the Saddle Dam extends to 5 feet below the McKay Coal (average elevation of 3,200 feet amsl, Hydrometrics, 1988). The remaining portions of the perimeter cutoff wall extended to 5 feet into low-permeability interburden below the Rosebud Coal/Clinker to prevent lateral migration through clinker.

A 3-foot-thick layer of native soil amended with a minimum of 10 percent Wyo-Ben bentonite was placed over 54 acres of sandstone below an elevation of 3,200 feet to reduce seepage into the Sub-McKay sandstone, which was exposed at the surface of the Clearwell, Cell C, and Cell G (Figure 1-2). Other stratigraphic units including clinker were exposed at the ground surface at the base of the Units 3 & 4 EHP; the units were not lined. Since 2005, about 40 percent of the Units 3 & 4 EHP cells, including Cells B, F, and H, have been lined with a synthetic liner constructed over previously-deposited ash.

Effluent produced by generating Units 3 & 4 EHP is handled in a closed-loop system (Hydrometrics, 1998). Prior to 2003, scrubber slurry was piped into active cells of the Units 3 & 4 EHP and suspended solids were allowed to settle. The slurry contained high concentrations of dissolved solids including magnesium, calcium, sodium, sulfate, and boron (Hydrometrics, 1998). Decant from the active ponds flowed to the Clearwell where it was re-circulated into the plant scrubber system.

In December 1999, seepage was observed in two locations downslope of the Units 3 & 4 EHP Saddle Dam following raising of the water level in Cell G (Hydrometrics, 2000). Seepage was directed to a sump and then pumped to the EHP. Much of the dam foundation consists of permeable Rosebud/Clinker. In addition, cracks along the dam embankment surface that parallel the inboard edge of the cutoff wall were observed. Apparently water from the impoundment moved through defects in the cutoff wall and/or clay core and followed the base of the Rosebud/Clinker out to the outcrop, where it emerged in seeps (Hydrometrics, 2000). Clinker adjacent to the Saddle was grouted to prevent seepage and the 1,380-foot-long Saddle Dam Interception Trench was installed in 2000 to divert impacted groundwater to the Valley Drain sump (PPL Montana, 2000). In addition, several capture wells were constructed downgradient of the Saddle Dam.

Talen constructed a paste plant to improve water and fly ash management at the Units 3 & 4 EHP that began operation in December 2003 (Hydrometrics, 2005b). Since December 2003, scrubber slurry transported to the Units 3 & 4 EHP is concentrated at the paste plant and decant water is routed to the
Clearwell and then returned to the CSES. Paste is pumped to one of the cells and placed on the perimeter of the pond between the water line and pond berm. Hydrometrics (2005b) reports that the permeability of the paste is lower than the majority of materials that make up the walls (banks) of the ponds, and covering these materials with paste reduces the potential for seepage from the ponds. Talen has applied the low permeability paste to unlined surfaces within the Units 3 & 4 EHP in an effort to reduce seepage to the groundwater system. Forced evaporators are also used beginning in April 2006 to reduce the volume of water in the Units 3 & 4 EHP, thereby reducing the driving head for seepage.

Filling of the Units 3 & 4 EHP began with Cells C, F, G, and H and the Old Clearwell in November 1983. By December 1987, 35 feet of water and sludge were present in the Units 3 & 4 EHP. The Units 3 & 4 EHP were originally designed to have a maximum pond full elevation of 3,280 feet. By February 1988, the elevation of water in the Old Clearwell reached 3,194 feet, the combined Cell C and G was at 3,200 feet, and Cell F was at 3,257 feet (Hydrometrics, 1988).

Cell F was the first cell to reach the closure elevation of 3,280 feet (Hydrometrics, 2005b). Bedrock beneath Cell F is Clinker above an elevation of approximately 3,230 feet. By May 1986, the water level in Cell F was 14 feet above the base of the Clinker, and by February 1988, the water level was 29 feet above the base of the Clinker. Approximately 1.5 years after initiating filling of Cell F, seeps were noted inside the cutoff wall at the base of the Clinker outcrop south of Cells C and G.

In 2003 and 2004, PPL Montana flooded the surfaces of Cells F and H (Figure 1-2) to increase evaporation (Hydrometrics, 2005a). In September 2004, PPL Montana personnel discovered a seep outside the cutoff wall above South Fork Cow Creek (SFCC Seep) one-half mile south of the Units 3 & 4 EHP (Figure 1-2). In November 2004, PPL Montana personnel discovered another seep outside the cutoff wall approximately 3,200 feet west of the EHP (West Seep, Figure 1-2). Water from these seeps exhibited evidence of process water impacts. In addition, concentrations of process water indicator constituents in groundwater sampled from private stock well PSW-4 near South Fork Cow Creek (Figure 1-2) began to increase at that time.

Talen and Hydrometrics initiated an investigation in 2004 to define the extent of impacts from the 2003 and 2004 flooding events and installed additional groundwater capture systems. A substantial portion of the Clinker/Rosebud hydrostratigraphic unit south of the cutoff wall was found to be impacted by process water that ultimately discharged at the SFCC and West Seeps. In response to discovery of impacts related to the 2003/2004 flooding of Cells F and H, Talen installed surface water and groundwater capture systems below the SFCC Seep in 2004 and as surface water capture system at the West Seep in 2005.

Between 2007 and 2009, Talen constructed a new lined Clearwell in Cell B with a leachate collection system, which overlies a minimum of 10 feet of dried paste to provide a double containment cell within the existing concrete cutoff wall that surrounds the Units 3 & 4 EHP. Cell B became the New Clearwell in 2009 and the Old Clearwell was taken out of service.

In 2005, Cell F was lined and converted to a groundwater collection storage area with an underdrain system. In April 2006, a system of 15 forced evaporators began evaporating water from the groundwater collection storage area to help with water management. In 2013, a double-lined pond with two synthetic liners and both a between-liner and under-liner collection system was constructed at Cell H.
Between 2006 and 2015, PPL Montana drilled and constructed several additional monitoring wells and several new groundwater capture trenches and wells, and converted a few monitoring wells into capture wells. All captured groundwater is currently pumped to lined ponds or tanks.

Groundwater impacted by process water has been identified downgradient from the Units 3 & 4 EHP Main Dam, east of the Saddle Dam, directly south of the EHP, in South Fork Cow Creek alluvium, and northwest of the EHP. Mitigation activities, including groundwater capture via groundwater interception trenches and pumping wells, are currently on-going in these areas. Captured water is either pumped to F Cell and evaporated through the forced evaporation system, or treated via the Vibratory Shear Enhancement Process (VSEP) and returned to the plant for re-use. Operation of groundwater capture systems have resulted in improvements to groundwater quality (Hydrometrics, 2016a). Other mitigation activities that have been implemented include the installation of composite/synthetic liners in several cells of the EHP and disposal of scrubber slurry as a paste.

1.2 Modeling Background

Geomatrix (2005) developed a conceptual model of the hydrogeologic system in the Units 3 & 4 EHP area. The conceptual model was updated in 2013 using data available through 2012, and provided the basis for development of a numerical groundwater flow model (NewFields, 2013).

The NewFields (2013) numerical flow model covered an approximate area of 5.7 by 2.5 miles. The model was bounded to the north by Cow Creek, to the south by South Fork Cow Creek, to the west by the Drain Pit 5 drainage and extends east to the confluence of Cow Creek and South Fork Cow Creek. The model consists of 8 layers and grid spacing varies from 25 to 100 feet. The model was used to simulate steady-state conditions for early 2003 and late 2012 and transient conditions for 2003 to 2006.

This report presents an updated conceptual hydrogeologic model based on available data and information collected through the end of 2015. This report also describes a revised numerical groundwater flow model, which has been updated and calibrated based on the updated conceptual model. Revisions to the numerical model include adjusted layer elevations, revised pond seepage and groundwater capture representations, and inclusion of the most recent aquifer testing results. The model has been calibrated to several independent sets of groundwater elevation (head) data, including steady-state and transient data sets, using 2015 head and flux information. Calibration to several independent data sets demonstrates the model is capable of simulating groundwater flow under a variety of conditions, including current conditions measured at the end of 2015.

1.3 Goals and Objectives

The overall goals of updating the numerical groundwater model are to:

1. Improve the basic understanding of the site groundwater system in the vicinity of the Units 3 & 4 EHP;
2. Provide a tool that will help to assess the current monitoring and capture well network;
3. Help identify data gaps;
4. Evaluate the effectiveness of the site capture systems; and
5. Improve water management practices.

Specific objectives of completing the numerical groundwater update described in this report were to:

1. Adjust model layer geometry (as needed) to better reflect the actual hydrostratigraphy based on information obtained from wells installed since 2012;
2. Revise recharge zones based on changes in pond configuration, pond management practices, and liner advancements;
3. Adjust pumping rates to reflect more recent estimates, and add pumping wells to reflect expansion of the capture system between 2013 and October 2015;
4. Calibrate the expanded model to a variety of head and flux data representative of January 2003 and October 2015 steady-state conditions; and
5. Use the calibrated model to assess the effectiveness of the groundwater capture system operating in the area near the Units 3 & 4 EHP.
2.0 CONCEPTUAL MODEL

This section summarizes the hydrogeologic conceptual model for the Units 3 & 4 EHP area and includes updates to the original conceptual model (Geomatrix, 2005) and subsequent refinements (NewFields, 2013). The following new information was incorporated into the conceptual and numerical models discussed in this report:

- Lithologic information, water level data, and water quality data for wells installed between 2012 and November 2015 (Figure 1-2);
- Water level data obtained from all wells between 2012 and December 2015;
- Water quality data obtained from all wells between 2012 and December 2015; and
- Aquifer test data (6 pumping tests and 8 slug tests) obtained between 2012 and 2015 during testing of 10 wells (1153A through 1169R).

Included in this section are descriptions of geology, hydrostratigraphy, aquifer characteristics, groundwater flow, interactions between surface water and groundwater, water quality and presentation of a groundwater budget. A summary of the conceptual model is included at the end of this section.

Note that the elevation datum used for this study is in North American Vertical Datum (NAVD) 1988 unless otherwise noted. The only data that uses the older National Geodetic Vertical Datum (NGVD 1929) is the surface elevation data obtained from the USGS, which requires an upward adjustment of 2.303 feet to bring it into the newer datum. Similarly, the spatial location datum used is the North American Datum (NAD) 1983, which replaced the older NAD 1927 datum.

2.1 GEOLOGY AND HYDROSTRATIGRAPHY

The following subsections provide descriptions of our current understanding of the regional and site geology and hydrostratigraphy of the Units 3 & 4 EHP area, as updated using recently collected data and information.

2.1.1 Regional Geology

The Units 3 & 4 EHP complex is located in a broad upland area of sparsely timbered hills bisected by roughly north-south trending valleys near the town of Colstrip, Montana (Figure 1-1). Topographic elevations range from 2,930 feet above mean sea level (amsl) at the confluence of Cow Creek and South Fork Cow Creek to 3,320 feet amsl near the Units 3 & 4 EHP. An east-west surface water drainage divide is located just south of the southern portion of the EHP cutoff wall. Water drains to Cow Creek north of this divide and to South Fork Cow Creek to the south. Flow in both intermittent drainages is eastward.

Stratigraphy in the Units 3 & 4 EHP 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 near the EHP area.
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).

The Units 3 & 4 EHP area is underlain by the Tongue River Member of the Fort Union Formation. 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 (Nichols et al., 1989; Flores et al., 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 (approximately 24 feet thick) and McKay seams (approximately 7 to 12.5 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 the 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.

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.

In the Colstrip area, the Fort Union Formation is relatively flat with a regional dip of 1 to 2 degrees to the southeast (Hydrometrics, 1998). The Tongue River Member consists of an up to 350–foot thick sequence of interbedded siltstone and fine-grained silty sandstone and includes several coal seams. The principal coal seams in the study area are the Rosebud, McKay, and Robinson. Clinker, which consists of burned coal and baked and altered adjacent rocks, is also present, usually near where coal seams outcrop, as result of natural burning of coal. Unconsolidated materials overlie the Tongue River Member in several areas including colluvium below ridge tops and on slopes, alluvium in drainage bottoms, and mine spoils in mined areas southwest of the Units 3 & 4 EHP (Hydrometrics, 1998).

### 2.1.2 Site Geology and Lithologic Units

The Tongue River Member of the Fort Union Formation underlying the Units 3 & 4 EHP area 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 area are the Rosebud, McKay, and Robinson coal units. The Rosebud and McKay may be at or near the land surface while the Robinson is found at depth. The Tongue River Member is subdivided into the following lithostratigraphic units in the Colstrip area: Rosebud Overburden, Rosebud Coal, Interburden, McKay Coal, and Sub-McKay bedrock.

The depositional setting near the Units 3 & 4 EHP 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 (and in some cases interburden), also is present near where coal seams outcrop, as a result of natural burning of coal. Unconsolidated materials also overlie the Tongue River
Member in several areas. These include colluvium located near the ridge tops and alluvium in drainage bottoms.

In addition to these natural lithostratigraphic units, mine spoils are present west of the EHP within the model area. Rosebud Coal was strip-mined from Area E of the Rosebud Mine west of the EHP, leaving a zone of spoils from zero to several tens of feet thick.

Each general lithostratigraphic unit is described below in terms of texture and extent in the Units 3 & 4 EHP area. Lithology and hydrostratigraphy were examined in detail in support of the model refinement described in this document. Logs from wells located in the Units 3 & 4 EHP area (Figure 1-2) were reviewed to delineate the areal extent and elevation of contacts between alluvium and bedrock and between major coal, sandstone, and siltstone strata. In addition to using well logs, the lateral extent of the various lithologic units (shown on Figure 2-1 and Figure 2-2) was determined using aerial photos, geologic maps, mine extent maps, and 1971-era USGS topographic maps.

Eight cross-sections were also developed based on descriptions from well logs to illustrate the site geology and hydrostratigraphy. These cross-sections are presented on Figure 2-3 through Figure 2-7; locations of the cross-sections are shown on Figure 1-2. The cross-sections include the following:

- **Figure 2-3**: Cross-section A-A’ trends south to north through the EHP and shows the change in topography and geology from the pond area towards Cow Creek. Cross-Section B-B’ extends west to east along the southern boundary of the EHP.

- **Figure 2-4**: Cross-section C-C’ is a west-east cross section through the center of the EHP showing the drop in topography and replacement of Clinker/Coal with Alluvium/Colluvium. Cross-section D-D’ runs west to northeast (north of the EHP) and coincides with the northern extent of the A-A’ cross-section, showing how topography drops moving away from the ponds and Clinker/Coal is replaced by Alluvium/Colluvium in the vicinity of Cow Creek.

- **Figure 2-5**: Cross-section E-E’ runs south-north in the area to the west (upgradient) of the EHP and illustrates the consistent geology in that area. Cross-section F-F’ is a west to east section in the same area as E-E’ showing how Clinker/Coal is eroded to the west and replaced by Alluvium/Colluvium at lower elevation.

- **Figure 2-6**: Cross-section G-G’ goes from the southeast edge of the EHP and heads southeast to South Fork Cow Creek and follows the creek, again illustrating how alluvium replaces the upper units in the lower elevation drainages.

- **Figure 2-7**: Cross-section H-H’ runs from the northeast edge of the EHP and extends to the northeast to Cow Creek. Similar to other cross-sections, this one also shows how at lower elevations Alluvium/Colluvium replaces the upper units.

**Alluvium/Colluvium**

Unconsolidated surficial sediments, consisting of alluvium and colluvium, are present at the Units 3 & 4 EHP area at locations shown on Figure 2-1. Alluvium present at the site consists of interbedded sand, gravel, clay, and silt, typically coarsening with depth. Clinker fragments are typically also found throughout finer-grained alluvial deposits. Alluvium occurs primarily along the drainage bottoms, and is present in the following drainages:
• **Drain Pit 5**: This drainage begins west of the EHP and flows north where it is joined by the NP-cut, which drains mine spoils west of the EHP. The drainage then flows north where it joins the Cow Creek drainage.

• **Cow Creek**: This drainage begins northwest of the EHP and drains areas along the northern boundary of the EHP area to its confluence with South Fork Cow Creek about 4 miles east of the EHP.

• **Main Dam**: This drainage empties the area beneath the EHP from the Main Dam north to Cow Creek.

• **Saddle Dam**: This includes several small drainages that drain from the Saddle Dam northeast to Cow Creek. The 560A drainage begins below the south end of the Saddle Dam and runs northeast past the 560A and 1051A interception trenches until it meets Cow Creek (Figure 2-1). The 1079A interception trench drainage is parallel to and about 400 feet north of the 560A drainage and includes the 1073A and 1079A interception trenches. It eventually runs into the 560A drainage downstream of the 1051A and 1079A trenches. There is another small alluvial deposit further north near well 1028A that lies within an area that drains northeast to Cow Creek.

• **South Fork Cow Creek**: This drainage begins south of the EHP and drains eastward about 4 miles before turning northeast another mile to the confluence with Cow Creek. This area includes several small alluvial deposits in minor tributaries from the north and south.

Colluvium present in the Units 3 & 4 EHP area is generally fine-grained unconsolidated sediments consisting of silt and clay and sometimes weathered Clinker. These deposits occur at and near the land surface on hilltops, slopes, and valleys.

**Rosebud Coal/Clinker**

This unit consists of Rosebud Coal and clinker deposits overlying burned coal in many areas within the Units 3 & 4 EHP area. The extent of this unit is presented on Figure 2-1 and Figure 2-2.

Clinker is a thermally altered rock (also referred to as scoria) and is formed in areas where Rosebud Coal has burned, usually near where coal seams crop out. 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.

Rosebud Coal is up to 25 feet thick in small unburned islands, and its base occurs at elevations of between 3,220 and 3,240 feet in the area surrounding Units 3 & 4 EHP. The clinker comprises up to 90 feet of pink to red claystone, siltstone, and fine-grained sandstone that is vesicular and fractured. In scattered areas, residual Rosebud Coal is present at the base of the clinker as ash or a combination of ash and unburned coal. It is important to note the most clinker in the Units 3 & 4 EHP area is at an elevation above the water table and appears to be unsaturated (see cross-sections).

**Interburden**

Interburden consists of siltstone, shale, and sandstone lying stratigraphically between the Rosebud and McKay Coal seams. This unit is missing from much of the Cow Creek and South Fork Cow Creek
drainages. Where present, Interburden thicknesses are generally 10 to 20 feet although the interburden is 2 feet thick on the flat to the northwest of the EHP and is more than 30 feet thick in some areas southeast of the EHP. This unit has been altered by burning in some areas northeast and northwest of the Units 3 & 4 EHP.

**McKay Coal**

The McKay Coal unit ranges in thickness from 7 to 12 feet and contains carbonaceous shale in some places. The McKay Coal is not present within the lower elevations of the Cow Creek and South Fork Cow Creek drainages where it has been removed by erosion. The base of the McKay Coal occurs at elevations generally between 3,190 and 3,220 feet amsl. The approximate extent of the McKay Coal is shown on **Figure 2-1** and **Figure 2-2**.

**Sub-McKay Bedrock**

Beneath the McKay Coal, bedrock includes interbedded and inter-fingered claystone, siltstone, fine-grained sandstone, and minor carbonaceous shale and coal stringers referred to as Sub-McKay. The Robinson Coal bed is 0 to 8 feet thick (Matson and Blumer, 1973) and is present at an elevation of about 3,070 feet in the area (Roberts et al., 1999). For the purposes of this report, the Sub-McKay includes the Robinson coal seam and underlying bedrock. The Sub-McKay unit consists of interbedded siltstone, shale, and sandstone present beneath the McKay Coal. The Sub-McKay unit is more than 300 feet thick and is present beneath the entire Colstrip area. This unit is divided into shallow and deep zones for the purposes of describing differences in groundwater flow, but the zones have similar lithology.

**2.1.3 Hydrostratigraphic Units**

**Diagram 1** is a schematic showing the general hydrostratigraphy of the Units 3 & 4 EHP area. Water-bearing units in the area include alluvium, McKay Coal, and Sub-McKay sandstones and siltstones.
As is illustrated by the cross-sections shown on Figure 2-3 through Figure 2-7, the relatively flat layers of overburden, Rosebud Coal, Interburden, and McKay Coal have been eroded in a significant portion of the floodplain of both Cow Creek and South Fork Cow Creek, as well as to the east of the EHP. In these areas, the cut valley is filled by alluvial sediments that generally coarsen with depth.

Hydrostratigraphic units for the Units 3 & 4 EHP area include alluvium, Rosebud/Clinker (mostly unsaturated), Interburden, McKay, and Sub-McKay. Small areas of spoil associated with area coal mining are also present upstream of the EHP area in upper Cow Creek and South Fork Cow Creek. Hydraulic properties of these hydrostratigraphic units are discussed below.

### 2.1.4 Hydraulic Properties

Numerous hydraulic tests have been conducted within the Units 3 & 4 EHP, SOEP and STEP, Plant Site, and Townsite areas, as documented by Hydrometrics (1995), Geomatrix (2005 and 2007), and NewFields (2013). Appendix A includes a summary of aquifer test data provided by Hydrometrics that included the wells tested and results of test analyses, along with more recent testing data.

A summary of a statistical analysis of the data is presented in Table 2-1, which includes the range and central tendencies of transmissivity and hydraulic conductivity estimates of the various hydrostratigraphic units, based on hydraulic tests conducted in over 130 wells in the Units 3 & 4 EHP area. Table 2-1 also includes ranges of aquifer properties documented in referenced peer-reviewed studies of the Fort Union Formation. The following subsections discuss hydraulic characteristics of the major hydrostratigraphic units.

#### Table 2.1. Summary of Aquifer Properties by Hydrostratigraphic Unit.

<table>
<thead>
<tr>
<th>Hydrostratigraphic Unit</th>
<th>Aquifer Properties from Units 3 and 4 EHP Area</th>
<th>Aquifer Properties from Studies1 of the Fort Union Formation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Geometric Mean Transmissivity (feet²/day)</td>
<td>Geometric Mean Hydraulic Conductivity (feet/day)</td>
</tr>
<tr>
<td>Alluvium</td>
<td>226</td>
<td>33</td>
</tr>
<tr>
<td>Rosebud/Clinker</td>
<td>8,379</td>
<td>1,207</td>
</tr>
<tr>
<td>McKay</td>
<td>7.1</td>
<td>0.9</td>
</tr>
<tr>
<td>Sub-McKay</td>
<td>26</td>
<td>2.1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Hydrostratigraphic Unit</th>
<th>Transmissivity (feet²/day)</th>
<th>Hydraulic Conductivity Range (feet/day)</th>
<th>Storage Coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alluvium</td>
<td>1,900</td>
<td>0.00007 – 492</td>
<td>--</td>
</tr>
<tr>
<td>Rosebud</td>
<td>1.3 – 1,700</td>
<td>0.1 – 68</td>
<td>--</td>
</tr>
<tr>
<td>McKay</td>
<td>0.7 – 3.1</td>
<td>0.01 – 31</td>
<td>--</td>
</tr>
<tr>
<td>Sub-McKay2</td>
<td>0.7 – 3.1</td>
<td>0.01 – 3.1</td>
<td>--</td>
</tr>
</tbody>
</table>

N/A – not applicable
"--" – no data available.
2 - Assumes same values as McKay Hydrostratigraphic Unit.
Slug tests have been typically performed on low-yield wells. Slug test results estimate the hydraulic conductivity of only the area immediately surrounding the well, which may not be representative of the hydraulic characteristics of the aquifer beyond the immediate vicinity of the well. In addition, the accuracy of slug tests can be affected by poor communication between the borehole wall and the surrounding formation.

Slug test data can be useful as a guide for estimating hydraulic conductivity in an area where pumping test data are unavailable. Transmissivity and hydraulic conductivity estimates derived from tests of the low-yield wells were assumed to represent the magnitude and range of these parameters. A total of 91 slug tests have been performed to date at wells in the Units 3 & 4 EHP area (Appendix A).

Pumping tests typically provide for a better understanding of hydraulic conductivity than slug tests because these tests are longer in duration and stress a larger portion of the aquifer and in many cases water levels are monitored both in the pumping well and associated observation wells. Drawdown in observation wells provide more accurate information on the transmissivity of the water bearing units between the pumping and observation wells. A total of 85 pumping tests have been performed to date in the Units 3 & 4 EHP area (Appendix A).

Alluvium

Hydraulic conductivity estimates for alluvium ranged from 0.1 up to 1,529 feet/day with a geometric mean of 33 feet/day from a total of 52 analyses, with a standard deviation of 337. The lower values are associated with the fine-grained alluvial sediments, while higher values are associated with the sand and gravel deposits.

The lowest hydraulic conductivity values (between 1 and 10 feet/day) were determined from tests in wells WA-133, 1022A, 1039A, 1047A, 1068A, and 1084A (Figure 1-2). The highest hydraulic conductivity values (greater than 500 feet/day) were from tests conducted at wells 626A, 669A, and 1019A.

Aquifer tests from which storativity values could be calculated indicated a geometric mean storativity for alluvium of 0.018, with most values ranging from 0.001 to 0.29. Data from aquifer tests at WA-135 indicated an elastic storage coefficient at that location of about $3 \times 10^{-6}$ and a specific yield of 0.029 for WA-135.

Rosebud/Clinker

Transmissivity estimates for wells completed in Clinker within the Units 3 & 4 EHP area ranged from 259 to 84,670 feet$^2$/day. Hydraulic conductivity estimates for Clinker ranged from 55 to 10,720 feet/day with a geometric mean of 1,207 feet/day, as based on results from 10 analyses (Table 2-1), with a standard deviation of 3,046. Clinker permeability varies but is typically relatively high, with the actual value 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. The enhanced permeability of this unit at the surface or near-surface generally serves to create areas of relatively higher net recharge to groundwater. The geometric mean storativity of the unit is 0.047.

Site-specific estimates of transmissivity and hydraulic conductivity are not available for Rosebud Coal. Estimates of transmissivity and hydraulic conductivity from regional studies range from 1.3 to 1,700 feet$^2$/day and 0.1 to 68 feet/day, respectively (Table 2-1).
Spoil

Spoil consists of silt, clay, sandstone, coal fragments, and formerly overburden units that were removed and have been used to backfill areas where the Rosebud Coal was mined. Spoil is not present in the 3 & 4 EHP except in small isolated areas where test mining was conducted. Spoil is present in the headwaters of Cow Creek and South Fork Cow Creek, upstream of the 3 & 4 EHP area. Hydraulic conductivity of spoil units is highly variable. Areas with large rock or grain fragments situated near the base of backfilled pits may exhibit high permeability. More commonly, fine grained materials fill these pore spaces, resulting in lower hydraulic conductivity.

McKay

Transmissivity estimates from site-specific aquifer tests performed on wells completed in the McKay Coal range from 1 to 1,384 feet²/day with a geometric mean of 7.1 feet²/day (Table 2-1). Transmissivity estimates from regional studies ranged from 0.7 to 31 feet²/day. Hydraulic conductivity estimates from 19 site-specific aquifer tests in the McKay ranged from 0.0002 to 301 feet/day, with a geometric mean of 0.9 feet/day and a standard deviation of 76. For comparison, estimates from regional studies ranged from 0.01 to 3.1 feet/day. The geometric mean storativity was calculated at 0.051.

Sub-McKay

Site-specific estimates of transmissivity in the Sub-McKay ranged from 0.02 to 6,540 feet²/day with a geometric mean of 26.4 feet²/day. Hydraulic conductivity estimates for siltstone and sandstone beds within the Sub-McKay unit ranged from 0.03 to 340 feet/day for 135 analyses, with a geometric mean of 2.1 feet/day (Table 2-1), and a standard deviation of 43.

Storativity data for Sub-McKay wells range from 7 x10⁻⁵ to 1.3 x 10⁻¹. The geometric mean storativity for the Sub-McKay was calculated at 0.013.

Due to contrasting permeability, groundwater flow in the Sub-McKay is greater in sandstone layers relative to finer-grained bedrock (siltstone/sandstone/shale) layers. Potential preferential groundwater flow paths are discussed below in Section 2.4.2. Where no information is available indicating the presence of fractures, flow in this unit is assumed to be horizontally isotropic within sandstone and siltstone layers.

2.2 Precipitation

The climate in Colstrip, Montana is semi-arid with an average annual precipitation, based on 78 years of site data (from 1927 to 2015, excluding years with missing monthly data) from the Western Regional Climate Center (2015), of 15.18 inches (Table 2-2 and Appendix B).

Figure 2-8 presents the average monthly precipitation for the period of record along with the 2003, 2004, 2005, 2006, and 2015 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 during which, on average, exceeds 1-inch for each of these months. Precipitation typically peaks in the months of May and June with average precipitation exceeding 2.6 inches for each of these months.
The average annual precipitation has varied over the last 40 years, a period that coincides with the approximate life of the Units 3 & 4 EHP. Figure 2-9 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, while precipitation in 2014 exceeded the average by about 4 inches. Precipitation in 2015, however, was almost 4 inches below average.

### Table 2-2. Average Monthly Precipitation

<table>
<thead>
<tr>
<th>Month</th>
<th>Average Monthly Precipitation*</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>0.60</td>
</tr>
<tr>
<td>February</td>
<td>0.55</td>
</tr>
<tr>
<td>March</td>
<td>0.93</td>
</tr>
<tr>
<td>April</td>
<td>1.64</td>
</tr>
<tr>
<td>May</td>
<td>2.60</td>
</tr>
<tr>
<td>June</td>
<td>2.69</td>
</tr>
<tr>
<td>July</td>
<td>1.27</td>
</tr>
<tr>
<td>August</td>
<td>1.16</td>
</tr>
<tr>
<td>September</td>
<td>1.25</td>
</tr>
<tr>
<td>October</td>
<td>1.26</td>
</tr>
<tr>
<td>November</td>
<td>0.64</td>
</tr>
<tr>
<td>December</td>
<td>0.58</td>
</tr>
<tr>
<td>Total</td>
<td>15.18</td>
</tr>
</tbody>
</table>

*Data from Western Regional Climate Center (Appendix B). Averages include period of record from 1927 to 2015.

### 2.3 Surface Water Hydrology

Several surface water features are present in the Units 3 & 4 EHP area, including:

- EHP Cells;
- Cow Creek;
- South Fork Cow Creek; and
- Stock Ponds.

These surface water features are shown on Figure 1-2 and are discussed below.

#### 2.3.1 EHP Cells

The Units 3 & 4 EHP area consists of nine cells, some of which are active and some are inactive. Certain cells do not have synthetic liners while others are lined with either high density polyethylene (HDPE) or reinforced polypropylene (RFP). Historic water elevations in the cells are included as Appendix C. Pond water elevations over time are also shown in Figure C-1 (Appendix C). The seven cells are shown on Figure 1-2 and consist of the following:
• Cell A;
• Cell B/New Clearwell;
• Cell C;
• Cell D;
• Cell E;
• Cell F;
• Cell G;
• Cell H; and
• Cell J (Old Clearwell).

The Units 3 & 4 EHP was originally designed to host effluent without geo-synthetic liners. Instead, the first ponds were lined with native soils amended with bentonite below an elevation of 3,200 feet, which is the approximate elevation below which permeable Sub-McKay sandstone is exposed. An underdrain system, consisting of 6-inch slotted corrugated polyethylene was installed above the bentonite (the underdrain is not operated currently). The laterals for the underdrain system were connected to a sump located between what is now the Old Clearwell and Cell C (Bechtel, 1985). If used in the future, the water will be pumped to a lined cell. A bentonite-amended concrete cutoff wall into bedrock was also constructed to limit lateral seepage through clinker present in the pond area.

The EHP area was also originally constructed with a series of cells to serve as settling ponds. During original operations, fly ash slurry was piped to an “active” cell. Solids would settle and water would decant to an adjacent cell and ultimately to the Old Clearwell, located adjacent to the Main Dam. Clearwater (water with solids settled out) was pumped to the Plant and reused in the Units 3 & 4 Scrubbers.

Currently, fly ash contained in scrubber slurry from Units 3 & 4 EHP is pumped in a pipeline to the Units 3 & 4 EHP Paste Plant, which was constructed in 2003. The Paste Plant removes excess water from the scrubber slurry. This process increases the solids of the scrubber slurry from about 15 percent to about 65 percent. Clearwater (scrubber water with fly ash removed) is routed into the Clearwell and is returned to the Plant for re-use in the scrubbers.

Cells B, F, and H have synthetic liners and are currently active. Dewatering and paste application phases are underway at Cells C, G, and the Old Clearwell as a precursor to lining those ponds. The history and current status of these cells are as follows:

• **Cell A.** Cell A is constructed with a compacted bentonite/soil base. It received scrubber slurry from 1983 through 2005. It has received bottom ash since then.

• **Cell B.** Was originally constructed in 2003 and received fly ash slurry until 2008. In 2008, a 45 mil RFP liner with underdrain system was installed in Cell B, which overlies a minimum of 10 feet of dried paste to provide a double containment cell within the existing concrete cutoff wall that surrounds the Units 3 & 4 EHP. Cell B became the New Clearwell in 2009 and the Old Clearwell was taken out of service. The New Clearwell receives clear water from the paste plant for return to the scrubbers for reuse.

• **Cell C and Cell G.** These cells began receiving fly ash slurry in 1983. Exposed sandstone at the base of these cells was lined with a bentonite/soil mixture. Portions of Cell G have received fly...
In 2015, these cells were still receiving some water, although the lined Cells F and H (described below) are in the process of becoming the primary cells for water management. Standing water in Cell C and Cell G in 2015 is visible from aerial photos, but the area is far smaller than the extent of the ponds and what was visible in 2003. Pond water levels in Cell C have declined since 2010 (see Figure C-1, Appendix C). Seepage from these ponds is expected to diminish over time.

- **Cells D and Cell E.** These cells were constructed in 2003. They were filled with fly ash and are no longer used to store process water.

- **Cell F.** Cell F received fly ash slurry from 1983 until it reached the closure elevation of 3,280 feet (Hydrometrics, 2005). Approximately 1.5 years after initiating filling of Cell F, seeps were noted at the base of a clinker outcrop south of Cells C and G inside the cutoff wall (Geomatrix, 2005). By May 1986, the water level in Cell F was 14 feet above the base of the clinker and by February 1988 the water level was 29 feet above the base of the clinker. After closure, the reclaimed surface of Cell F received water via sprinklers to allow for evapotranspiration of water. In 2003 and 2004, F cell was flooded to enhance evaporation. A 45 mil reinforced polypropylene (RFP) liner with underdrain system was installed in Cell F in 2005. Cell F is currently used to store excess process water and captured groundwater. Water from this cell is also the source for forced evaporation systems.

- **Cell H.** Cell H began receiving fly ash in 1983 until it was filled and reclaimed in the 1990s. After closure, the reclaimed surface of Cell H received water via sprinklers to allow for evapotranspiration of water. In 2003 and 2004, Cell H was flooded to enhance evaporation. In 2013 a double-lined containment system that includes an upper 45 mil RFP liner, a between-liner collection system, a 37 mil RFP underliner, and an underliner collection system was constructed over the closed Cell H. Cell H is currently being used for water management so the Old Clearwell (Cell J), Cell G, and Cell C can be lined (Hydrometrics, 2016a).

- **Cell J (Old Clearwell).** The Old Clearwell was constructed in 1983 and lined with a bentonite/soil mixture where sandstone was exposed at the base. Before 2009 the old clear well collected decanted water from other cells prior to being pumped to the Plant for reuse. In 2015, the Old Clear well and the north end of Cell G combined to form Cell J, which was regraded. A double lined cell will be constructed over Cell J in 2016/2017.

### 2.3.2 Cow Creek and South Fork Cow Creek

The EHP is located in the headwaters of the Cow Creek basin, which included two main intermittent streams: Cow Creek and South Fork Cow Creek. A few minor tributary drainages drain the EHP including the Drain Pit 5 drainage, which drains the west side of the EHP as wells as reclaimed mine lands to the west of the EHP. A small drainage north of the Main Dam drains the north side of the EHP and several small drainages drain the east side of the EHP below the Saddle Dam. A small drainage runs from the south end of the Saddle Dam past the 560A capture system to Cow Creek.

Cow Creek is located to the north of the EHP and runs west to east (Figure 1-2). The creek represents the northern boundary of the numerical groundwater model for the Units 3 & 4 EHP area. South Fork Cow Creek is located to the south of the ponds and runs west to east, joining with Cow Creek to the east of the EHP. The creek represents the southern boundary of the numerical groundwater model for the Units 3 & 4 EHP area.
Both creeks are intermittent, with water present in the channels only during portions of the year. Based on observations from crest gages at the two creeks, the channels typically exhibit water during the months of April-June and October-November (Hydrometrics, 2014). There are no known flow measurement data for either creek.

2.3.3 Stock Ponds

Two stock ponds are present in the Units 3 & 4 EHP area (Figure 1-2). One pond is located near Cow Creek and the other near South Fork Cow Creek. Seepage rates for stock ponds are unknown, and the overall contribution to the water budget (see Section 2.6) is believed to be small. However, because seepage from these two ponds affects groundwater elevations locally, they are included in the groundwater budget.

2.4 Groundwater Flow

Groundwater beneath the Units 3 & 4 EHP area generally flows radially away from the EHP then eastward (see Figure 2-10 through Figure 2-15). Locally, flow directions and gradients are influenced by surface water in the EHP, the cutoff wall surrounding the EHP, Cow Creek and South Fork Cow Creek, and pumping of capture wells.

Shallow and intermediate groundwater flow beneath the EHP is strongly influenced by seepage from the ponds, forcing groundwater to leave the area in all directions. Away from the EHP, shallow and intermediate groundwater flow is influenced by Cow Creek and South Fork Cow Creek and associated alluvium. Along the creeks, shallow bedrock (overburden, interburden, and Rosebud and McKay Coal, and in some places the Sub-McKay) has been eroded. In the Units 3 & 4 EHP area, overburden is not present and the Rosebud Coal (as Clinker deposits) is only saturated in the vicinity of the EHP. Groundwater in the Interburden (where saturated), McKay Coal and Sub-McKay mostly flows away from the EHP and towards Cow Creek and South Fork Cow Creek. Groundwater in deep Sub-McKay exhibits a regional west to east flow. Much of the groundwater originating from beneath the EHP is being captured by wells prior to reaching the alluvium associated with the creeks. The direction of groundwater flow in alluvium along the creeks is generally eastward, parallel to the creeks.

2.4.1 Flow Directions

According to Hydrometrics (1982), prior to filling of the EHP cells, groundwater flow in the McKay and Sub-McKay units was generally from west to east. Reported groundwater elevations in McKay and Sub-McKay wells were considerably lower than in 2015. The reported hydraulic gradient (0.006) in the McKay unit was flatter. There was a minor hydrologic divide between south end of the EHP and South Fork Cow Creek with flow north toward the Cow Creek and south towards South Fork Cow Creek.

Figure 2-10 through Figure 2-15 are a series of potentiometric surface maps created for the shallow groundwater flow system hosting the water table, and the McKay, shallow Sub-McKay, and deep Sub-McKay units based on 2003 and 2015 data. The shallow flow system includes near-surface units in which saturated conditions are first encountered in the area. In different portions of the Units 3 & 4 EHP area, the water table is hosted in either alluvium, Rosebud/Clinker, Interburden, McKay, or Sub-McKay. In addition, the water table west of the EHP occurs within spoils associated with Area E of the Rosebud...
Mine. The McKay Coal occurs at depths ranging from 2 to 150 feet and hosts groundwater in many portions of the EHP area. The shallow Sub-McKay includes the uppermost 100 feet of saturated Sub-McKay bedrock. The deep Sub-McKay maps represent groundwater in bedrock about 250 feet below the McKay Coal or at elevations below about 3,100 feet amsl. Potentiometric surface maps were constructed using groundwater elevations primarily from Talen’s water level data base, augmented with data obtained by the Montana Bureau of Mines and Geology (GWIC, 2016), Thompson et al. (2016) and Western Energy (2013f). Data used to create potentiometric surface maps are contained in Appendix D.

The modeling analysis discussed below focuses on groundwater conditions which occurred between 2003 and 2015. This time span represents a period during which capture system were expanded and process pond water management underwent significant changes with lined ponds becoming active. 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 (described below).

Groundwater data used to construct the maps were selected to represent fall conditions when seasonal aquifer stresses are at a minimum and are most representative of steady-state conditions. Data from other time periods were used for some wells to provide additional spatial coverage. While these data might introduce some uncertainty in the areas they represent due to seasonal and annual fluctuations, the variation is typically small and these data points provide spatial coverage important in understanding the overall pattern of groundwater flow.

Figure 2-10 is a potentiometric surface map showing water table elevation contours in early 2003. Contours and well symbols on Figure 2-10 are color-coded to show the data from wells completed in the various hydrostratigraphic units that were used to construct the maps. Figures 2-11 and Figure 2-12 are potentiometric surface maps for the McKay, and the shallow and deep Sub-McKay, in early 2003, respectively. The 2003 potentiometric maps were prepared with groundwater elevations obtained primarily in wells measured during January 2003. For wells that were not monitored during January 2003, the water levels measured in wells during 2002 were used to provide greater spatial coverage.

Figure 2-13 is a potentiometric surface map showing water table elevation contours during the fall of 2015. Contours and wells symbols on Figure 2-13 are color-coded to show the wells associated with each hydrostratigraphic unit that were used to construct the map. Figures 2-14 and Figure 2-15 are potentiometric surface maps for the McKay and shallow and deep Sub-McKay units based on water levels measured during the fall of 2015, respectively. The 2015 potentiometric maps were created using groundwater elevation data measured in Talen monitoring wells in October 2015, where available. Groundwater elevations measured prior to October 2015 (May 2011 through May 2014 for alluvium, May 2006 through May 2014 for Mid Sub-McKay, and May 2014 for Deep Sub-McKay) were used in a few areas to provide spatial coverage where October 2015 data were not available (see Appendix D). In addition, data for several wells on the edge or outside of the Units 3 & 4 EHP area were obtained from other sources, including by Montana Bureau of Mines and Geology (GWIC, 2016), Thompson et al. (2016), and Rosebud Mine (Western Energy, 2013f).

The shallow flow system is generally defined as the hydrostratigraphic package that the alluvial system cuts through and is comprised of Alluvium, Rosebud/Clinker, Interburden, and Fill. Although the McKay
Coal is also absent away from the EHP (where it has been eroded away), it can be considered part of an intermediate flow system along with the shallow Sub-McKay below ground surface. The deep Sub-McKay Unit generally extends 250 feet below the McKay Coal or at elevations below 3,100 feet amsl. Flow in the shallow Sub-McKay unit more closely resembles local flow directions and gradients observed in shallow system while flow in the deep Sub-McKay exhibits a more regional pattern.

Shallow groundwater flow within and near the Units 3 & 4 EHP area (Figure 2-10 and Figure 2-13) is generally radially away from the Units 3 & 4 EHP. As is shown in Figure 2-2, pond seepage enters Clinker within the cutoff wall and then seeps through the cutoff wall. Groundwater flow in this area is restricted by the cutoff wall surrounding the EHP, but has likely seeped under the cutoff wall in some areas. The cutoff wall is keyed into competent bedrock beneath the Rosebud/Clinker, and groundwater in cinder wells west, south, and east the cutoff wall exhibit the highest concentrations of indicator parameters indicating that groundwater has seeped through some portions of the cutoff wall.

The Rosebud/Clinker unit is saturated within the cutoff wall and to the south and west of the Units 3 & 4 EHP. The highest groundwater elevation in the Rosebud/Clinker outside of the cutoff wall occurs immediately south of the ponds near wells 586R, 686R, and 1005R (Figure 2-10 and Figure 2-13). Groundwater in the Rosebud/Clinker flows south and west from the cutoff wall. A portion of water originating in the EHP appears to have flowed south through Clinker zones and into South Fork Cow Creek alluvium. Some groundwater in Rosebud/Clinker south of the cutoff wall apparently flows north along the west cutoff wall where it joins flow that appears to be coming through the northern portion of the west cutoff wall.

During 2005, some water from the EHP discharged at the South Fork Cow Creek and the West Seep (discussed in Section 2.4.5 below) and into alluvium. The SFCC Seep occurred where the Rosebud/Clinker subcrops in alluvium/colluvium. Groundwater capture wells completed in the Rosebud/Clinker (1001R, 1002R, and 1007R) are capturing groundwater and have lowered water levels in Rosebud/Clinker wells south of the cutoff wall by several feet since 2005. Since initiation of capture in these wells, water no longer discharges at the surface at West or SFCC seeps.

Groundwater flows northwest from the northwest corner of cutoff wall in the Rosebud/Clinker unit. Some of this groundwater is being captured by four wells (656R, 1031R, 1034R, 1037R). West of this area near well 642P, both the McKay and Rosebud/Clinker unit are burned and there is direct vertical communication between these units and impacted groundwater seeps in to downgradient alluvium. The SP-15 North and SP-15 South trenches and well 1060A capture water near the alluvial-McKay interface in these locations. Shallow groundwater from this area and from the area downgradient of the West Seep and mine cuts draining reclaimed mine lands west of the EHP flows in alluvium in the drainage near the location of Drain Pit 5, then north toward Cow Creek. Water within the Drain Pit 5 drainage is captured by the DP-5 trench and capture wells.

East of the Saddle Dam, groundwater flows to the east in Interburden and McKay Coal (Figure 2-11 and Figure 2-14) for a few hundred feet and in the Sub-McKay unit (Figure 2-12 and Figure 2-15) to the east-northeast roughly parallel to alluvial drainages in that area. Some groundwater in the Sub-McKay east of the Saddle Dam discharges into the alluvium in the 560A drainage and near well 1073A.

In the drainage bottoms south, east, north, and northeast of the Units 3 & 4 EHP, groundwater flow in the alluvium is parallel to the drainages. Groundwater in alluvium associated with the Cow Creek and
South Fork Cow Creek drainages continues to flow eastward along these drainages toward the confluence of the two forks.

North of the Main Dam, groundwater flows in shallow Sub-McKay strata toward the drainage bottom where it discharges to the alluvial system. The Main Dam Drain and Interception trenches and several capture wells intercept groundwater in both alluvium and Sub-McKay material below the Main Dam. Groundwater continues to flow north until it reaches the Cow Creek drainage where it changes to a more easterly direction. There is a relatively steep groundwater gradient from the Main Dam and cutoff wall toward the Main Dam Sump. From here, the gradient in the alluvial system flattens between the Main Dam Sump and Cow Creek.

East of the Saddle Dam, groundwater flows eastward from the cutoff wall in the Rosebud/Clinker into the McKay Coal and eventually into the Sub-McKay where it flows eastward toward Cow Creek. Groundwater in the Sub-McKay flows into alluvium near wells 635A and 1073A, where it is collected by trenches and several capture wells.

Two shallow wells east of the Saddle Dam were not used to construct the 2015 water table elevation map (Figure 2-13). Well 1123A is completed in shallow (< 20 feet) alluvium/colluvium and well 1165D is completed in shallow weathered Sub-McKay bedrock about 100 feet northeast of there. Both of these wells terminate in a fine-grained bedrock, which appears to act as an aquitard. Water levels in wells 1123A and 1165D are 30 to 40 feet higher than in surrounding wells, suggesting these wells are completed in a small perched zone that is not in direct hydraulic communication with the underlying shallow groundwater system. Therefore, groundwater elevations measured in these wells are not representative of shallow groundwater flow in the underlying saturated zone.

Flow in the deeper portion of the Sub-McKay (Figure 2-12 and Figure 2-15) interval is likely less influenced by seepage from the EHP cells and follows a more regional pattern to the east and northeast. The ultimate discharge points for deeper groundwater are likely the lower reaches of Cow Creek and Rosebud Creek.

2.4.2 Preferential Flow

Groundwater flow may be influenced by the presence of joints and fractures as well as stratigraphy. Stratigraphy has the greatest influence on preferential flow of groundwater. Groundwater preferentially moves through more permeable sand and gravel in alluvium and sandstone layers and lenses in bedrock relative to less permeable alluvial silt and siltstone, claystone and shale. As sandstone lenses pinch out, groundwater flow can be diverted laterally. Data from several investigation have helped evaluate the presence of potential preferential flow paths. Laterally extensive fractures sets have not been identified.

Geomatrix (2005) indicates that groundwater flow in some bedrock areas is controlled in part by geologic structure and fractures. Joints and fractures in rock are more permeable than the surrounding un-fractured rock. A series of generally south-southeasterly trending drainages are visible between the EHP and South Fork Cow Creek. These drainages probably formed along fracture trends that encouraged erosion. These fractures likely created preferential pathways for impacted water to form the SFCC Seep and to migrate to the alluvium in South Fork Cow Creek. This is discussed further in Section 2.8.2 below.
Hydrometrics also identified water bearing joints in Sub-McKay sandstone near Seep 552 north of the Main Dam (Hydrometrics 2001). These joints likely form preferential flow paths for transport of impacted groundwater.

Hydrometrics (2009) completed an investigation of groundwater flow and quality east of the Saddle Dam near the wells 560A and 1051A. The work included aquifer tests on several wells in the area and revealed a zone of shallow unconfined Sub-McKay sandstone south of an unnamed tributary to Cow Creek that exhibited relatively high hydraulic conductivity (25 feet/day to 125 feet/day). This zone includes wells 1062D, 1097D, 1098D, and 1099D. The greater permeability of this zone suggested that this may be a preferential pathway for transport of COIs. Just north of this zone, aquifer tests (Hydrometrics 2011a and 2010b) identified another zone of relatively high hydraulic conductivity (>100 feet/day) shallow sandstone.

### 2.4.3 Horizontal Gradients

Horizontal hydraulic gradients in shallow groundwater are variable with the steepest gradients (up to 0.4) occurring along the northeast portion of the cutoff wall in the shallow Rosebud/Clinker existing beneath the EHP and below the associated dams (Figure 2-10 and Figure 2-13). The flattest gradients in the shallow system occur away from the EHP in the alluvium along Cow Creek and South Fork Cow Creek where gradients range from 0.006 to 0.01 and also in clinker west of the cutoff wall.

In the McKay, flow directions are also radially away from the cells in the EHP (Figure 2-11 and Figure 2-14). East of the Saddle Dam gradients in the McKay are steepest at roughly 0.06, while to the south and west of the EHP gradients are flatter at about 0.02.

Most gradients in the mid Sub-McKay intervals are within the range noted for the shallow units. Horizontal gradients in the deep Sub-McKay groundwater are less influenced by the creek, pond seepage, and capture system pumping. Horizontal gradients in the deep Sub-McKay unit are relatively low at roughly 0.007.

### 2.4.4 Vertical Gradients

Figure 2-16 illustrates vertical gradients calculated from water levels measured in paired wells. The vertical gradients are also summarized in Table 2-3. Data used to calculate vertical gradients (screen and groundwater elevations) are included in Table E-1 in Appendix E along with diagrams illustrating the relative depths of screens and units for the well pairs (Figure E-1-1 through Figure E-1-7). Vertical gradients measured at well pairs are primarily downward in the Units 3 & 4 EHP area with few exceptions.

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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.
Table 2-3. Vertical Gradient Summary

<table>
<thead>
<tr>
<th>Well Pair</th>
<th>Upper Hydrostratigraphic Unit</th>
<th>Lower Hydrostratigraphic Unit</th>
<th>Gradient</th>
<th>Direction</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cow Creek North of EHP</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>607A/608D</td>
<td>Alluvium</td>
<td>Sub-McKay</td>
<td>-0.42</td>
<td>Down</td>
<td>10/6/2015</td>
</tr>
<tr>
<td>Cow Creek Northeast of EHP</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>591A/596D</td>
<td>Alluvium</td>
<td>Sub-McKay</td>
<td>-0.02</td>
<td>Down</td>
<td>10/6/2015</td>
</tr>
<tr>
<td>596D/595D</td>
<td>Sub-McKay</td>
<td>Deep Sub-McKay</td>
<td>-1.03</td>
<td>Down</td>
<td>10/6/2015</td>
</tr>
<tr>
<td>South Fork Cow Creek South of EHP</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PSW-4/1046D</td>
<td>Alluvium</td>
<td>Sub-McKay</td>
<td>0.05</td>
<td>UP</td>
<td>5/5/2015</td>
</tr>
<tr>
<td>South Fork Cow Creek Near Seep</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>568/598D-2</td>
<td>Alluvium</td>
<td>Sub-McKay</td>
<td>0.33</td>
<td>Up</td>
<td>10/6/2015</td>
</tr>
<tr>
<td>598D-2/599D</td>
<td>Sub-McKay</td>
<td>Deep Sub-McKay</td>
<td>-0.65</td>
<td>Down</td>
<td>10/6/2015</td>
</tr>
<tr>
<td>West of EHP Cell A</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>WR-128/WI-109</td>
<td>Rosebud/Clinker</td>
<td>Interburden</td>
<td>0.01</td>
<td>Up</td>
<td>8/7/2014</td>
</tr>
<tr>
<td>WI-109/WM-126</td>
<td>Interburden</td>
<td>McKay</td>
<td>-0.38</td>
<td>Down</td>
<td>8/7/2014</td>
</tr>
<tr>
<td>WM-126/659D</td>
<td>McKay</td>
<td>Sub-McKay</td>
<td>-0.84</td>
<td>Down</td>
<td>8/7/2014</td>
</tr>
<tr>
<td>Immediately South of Cell F/Cutoff Wall</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1000M/1009D</td>
<td>McKay</td>
<td>Sub-McKay</td>
<td>-0.83</td>
<td>Down</td>
<td>10/6/2015</td>
</tr>
<tr>
<td>South of EHP Cell F</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1012M/573D</td>
<td>McKay</td>
<td>Sub-McKay</td>
<td>-0.09</td>
<td>Down</td>
<td>10/6/2015</td>
</tr>
<tr>
<td>South of EHP Cell H</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>676R/675M</td>
<td>Rosebud/Clinker</td>
<td>McKay</td>
<td>-0.19</td>
<td>Down</td>
<td>10/6/2015</td>
</tr>
<tr>
<td>675M/589D</td>
<td>McKay</td>
<td>Sub-McKay</td>
<td>-0.61</td>
<td>Down</td>
<td>10/6/2015</td>
</tr>
<tr>
<td>East of Saddle Dam</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>590/590M</td>
<td>Interburden</td>
<td>McKay</td>
<td>-0.26</td>
<td>Down</td>
<td>8/4/20117/8/2015; 10/6/2015</td>
</tr>
<tr>
<td>590M/576D</td>
<td>McKay</td>
<td>Sub-McKay</td>
<td>-0.31</td>
<td>Down</td>
<td>8/4/2011</td>
</tr>
<tr>
<td>Northeast of Saddle Dam</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>633M/629D</td>
<td>McKay</td>
<td>Sub-McKay</td>
<td>-0.45</td>
<td>Down</td>
<td>10/6/2015</td>
</tr>
<tr>
<td>629D/584D</td>
<td>Sub-McKay</td>
<td>Deep Sub-McKay</td>
<td>-0.56</td>
<td>Down</td>
<td>10/6/2015</td>
</tr>
</tbody>
</table>

Relatively strong downward gradients were measured to the south of the EHP from the McKay to Sub-McKay in well pair 1000M and 1009D and in well pair 675M and 589D. Downward gradients were also measured at this location from the Rosebud/Clinker to McKay in well pair 676R and 675M, and from the McKay to Sub-McKay in well pair 1012M and 573D.

To the west of the EHP, downward gradients are apparent from the Interburden to McKay (WI-109 and WM-126) and from the McKay to Sub-McKay (WM-126 and 659D). The gradient between Rosebud/Clinker and Interburden at well pair WR-128 and WI-109 is inconclusive. The gradient for WR-128/WI-109 in the table indicates a very slight upward gradient but the time series plot of wells WR-128/WI-109 (Figure 2-17) indicates the water levels in these two wells are consistently similar suggesting a neutral gradient between these wells.

To the east of the Saddle Dam, most well pairs show a strong downward gradient from McKay to Sub-McKay to Deep Sub-McKay (590M and 576D; 633M and 629D; 629D and 584D). Well pair 590I and...
590M also shows a strong downward gradient from Interburden to McKay, and a time series plot of water levels for wells 590I and 590M (Figure 2-18) shows a consistent downward gradient between these wells over time.

To the north along Cow Creek, all gradients are also downward from Alluvium to Sub-McKay to Deep Sub-McKay (wells 607A/608D and 591A/596D/595D). At the South Fork Cow Creek, gradients are also downward from the Sub-McKay to Deep Sub-McKay at 598D and 599D near the SFCC Seep. Well pairs PSW-4/1046D and 568A/598D-2 exhibit an upward gradient from Sub-McKay to Alluvium, which may be a function of capture well pumping.

2.4.5 Variability of Vertical Gradients

Figure 2-17 and Figure 2-18 are hydrographs for the paired wells organized by location in the Units 3 & 4 EHP area that were discussed in Section 2.4.3. These figures show that downward gradients have been consistently measured through time at nearly all well pairs.

West and South of the EHP (Figure 2-17 and Figure 2-18), all well pairs exhibit a consistent downward gradient over time, as do well pairs east and northeast of the Saddle Dam (Figure 2-18). Wells near Cow Creek (Figure 2-17) show predominantly downward gradients over time, with the exception of a slight upward gradient from Sub-McKay to Alluvium (596D to 591A) during a stretch from 2004 to about 2010, though that has been downward since that time. At the South Fork Cow Creek (Figure 2-17), gradients appear to have been upward from Sub-McKay to Alluvium at both well pairs 598D-2 and 568A and at 1046D and PSW-4.

2.4.6 Surface Water-Groundwater Interaction

As described in Section 2.3, several surface water features are present in the model area. Water surface elevations in EHP cells are all above the water table and it could be inferred that all the cells have seeped water to groundwater to some degree, though that has lessened over time as ponds have been lined and pasted. Seepage to groundwater from ponds equipped with synthetic double liner systems is assumed to be relatively minor. Pond seepage estimates are discussed in Section 2.7.3.

Cow Creek and South Fork Cow Creek are both intermittent streams that are tributaries to Rosebud Creek, which drains north to the Yellowstone River near Rosebud, Montana. The drainages are divided by well-dissected uplands, and are characterized by little or no flow during most of the year. Elevation differentials between the creeks and adjacent uplands range from 20 to 30 feet near the headwaters to more than 200 feet east of the EHP. The Units 3 & 4 EHP is near the headwaters of Cow Creek with most of it occurring within a small tributary drainage to Cow Creek. Most surface-water flow occurs during snowmelt or precipitation events (Thompson et al., 2016). Both creek channels are sources of recharge when seasonal flow is present. The interaction between groundwater and the creeks at downstream locations is unknown but it is reasonable to assume they are a point of groundwater discharge from the alluvium at those downstream locations.

A number of seeps have been present in the Units 3 & 4 EHP area over time. However, with the installation of capture systems and trenches, along with the use of synthetically lined ponds within the EHP, these seeps have ceased to flow or are no longer of any consequence. Most notable of the seeps
are the West Seep to the west of the EHP, the North EHP Seep and 552 Seep to the north of the EHP, and the SFCC Seep to the south of the EHP.

The West Seep and SFCC Seep were first observed to be flowing in 2004 coincident with initial flooding of Cell F and Cell H. Discharge at the West Seep began in late 2004. A dam was built across the drainage a short distance downstream of the seep (West Diversion). Water collected behind the diversion was pumped to the EHP. Flow was initially 30 gallons per minute (gpm) in the seep and diminished after groundwater collection began; flow at the seep stopped by May 2006.

The North EHP Seep near well 604A and the 552 Seep near well 552D were investigated in 2001 (Hydrometrics, 2001). Both seeps are located in a drainage to the north of the EHP that trends northeast and then north towards Cow Creek. The Main Dam Drain Trench and Main Dam Sump Interception Trench (Figure 1-2) are located further down the same drainage and capture flow from the two seeps. As of 2013, water is reportedly no longer issuing from the North EHP Seep (Hydrometrics, 2013).

The SFCC Seep discharge was discovered in September 2004. A dam was built across the drainage a short distance downstream of the seep (South Fork Diversion) and capture wells were installed. Water collected behind the diversion was pumped to the EHP. The initial flow in the seep of 60 gpm was reduced by 2005 and the seep was dry by the fall of that year.

Several springs in the region provide sufficient quantities for livestock watering (Thompson et al., 2016). SP-14, located to the northeast of the Saddle Dam (Figure 1-2) has historically issued at the confluence of two drainages and has been used for stock watering. In 2004 and 2005, flow at SP-14 was described as being greater than usual (Hydrometrics, 2005a and 2006) with ponding below the spring observed but no flow rates were reported. In 2009, it was noted that the SP-14 flow was issuing primarily from the south drainage (Hydrometrics, 2010b) and, due to dwindling flows, a well (PSW-9) was installed to supplement the spring flow for stock watering.

SP-15, also known as the Scoria Seep, lies to the northwest of the EHP and was investigated in 2001 (Hydrometrics, 2001). Two trenches (SP-15 South Trench and SP-15 North Trench) were installed and began intercepting water in this area in 2002. Over time, the amount of water removed by the trenches has declined due to other upgradient pumping wells and reduced pond seepage in the EHP area.

There are also two stock ponds that are described in Section 2.3.3. The stock ponds appear to provide seepage to groundwater and affect water levels in wells nearby. Although seepage from the ponds appears to be small and localized, they are included in the numerical model to adequately simulate water levels in wells near the pond.

2.4.7 Temporal Variation

Hydrographs were generated for wells selected to represent changes in groundwater elevations at various locations in the Units 3 & 4 EHP area and were developed for each. The locations of these wells are shown on Figure 2-19, and the hydrographs, organized by location in the Units 3 & 4 EHP area, are shown on Figure 2-20 through Figure 2-25. Appendix E presents water level data for all the wells regularly monitored within the Units 3 & 4 EHP area.
Several factors have affected groundwater elevations in the Units 3 & 4 EHP area since their initial construction. These include initial filling of the EHP cells; changes in water management practices and lining and pasting of EHP cells; and, seasonal and annual changes in precipitation and snowmelt patterns. Groundwater elevations in many Sub-McKay wells increased by 20 to 40 feet and in many McKay wells increased by 5 to 15 feet between initial filling of the EHP and 2003, due to pond seepage and hydrostatic loading of bedrock (Geomatrix, 2005). Most Sub-McKay wells and several McKay wells that have exhibited increasing water levels since 1983 do not contain concentrations of indicator parameters exceeding BSLs. This is evidence of hydrostatic loading of the aquifer that has occurred since the EHP cells have been filled.

Groundwater levels in wells immediately south and west of the EHP are shown on Figure 2-20 and Figure 2-21 for Rosebud/Clinker and McKay wells, respectively. These hydrographs illustrate the benefit of reduced seepage from ponds in the EHP area as lined ponds began to be used for water storage. Wells in the Rosebud/Clinker (Figure 2-20) show a decline of 4 to 7 feet from 2005 to about 2009 and then remain fairly stable. Groundwater levels in wells in the McKay (Figure 2-21) have all been declining from about 2005 to 2015 with the steepest declines of 7 to 10 feet occurring in wells immediately south of the EHP (1000M, 1004M, and 1006M). The other wells shown on Figure 2-21 exhibit a steady decline in water levels of 3 to 7 feet from 2005 to 2015. Water levels in the wells shown on Figure 2-21 appear to be leveling off in 2015, although some appear to continue to be declining.

Figure 2-22 includes hydrographs for Sub-McKay wells near the Saddle Dam. Wells immediately below the dam (579D and 631D) show relatively little change in water levels from 2000 to 2014, but from 2014 to 2015 they both show a decline of roughly 5 feet. Further below the dam and just below the valley drain, well 630D exhibits little change in water levels except perhaps a slight decline beginning mid-2014. Just to the south of 630D well 563D shows a decline in water levels of about 2 feet starting in 2008. Water levels in 578D, located near the southeast end of the Valley Drain Trench and capture wells (646D, 647D, and 648D) also declined starting in 2008 but then rose between 2011 and early 2014 before declining again. Even further below the Saddle Dam and near the 1073A Trench, wells 580D and 1074D both exhibit declines in groundwater levels of about 2 feet beginning in 2008. Collectively these hydrographs can be interpreted as indicating a regional decline in groundwater levels below the Saddle Dam beginning around 2008 due to reduced pond seepage and increase groundwater capture in the EHP area.

Figure 2-23 presents hydrographs for Sub-McKay wells near the 556D capture system (immediately northeast of the EHP). Two of the pumping wells for the system (556D and 621D) are included on the figure. Monitoring wells immediately nearby the capture wells include 612D, which exhibits a decline of roughly 8 feet beginning in 2010, and 664D showing a decline in groundwater levels of about 4 feet starting in 2013. Farther downgradient from the capture wells, water levels in well 611D have declined a smaller amount, dropping about 1 foot between 2010 and 2016. Similar to the wells below the Saddle Dam, the wells in the 556D capture system area indicate a general decline in groundwater levels that can be interpreted to be due to reduced pond seepage and increased groundwater capture in the EHP area.

Groundwater elevations in Sub-McKay wells north of the main dam are presented on Figure 2-24. Three pumping wells from this area (1080D, 1081D, 1083D) that came online in late 2010 are included.
on the figure. Monitoring wells included on the figure include two that show little change in groundwater levels (602S and 1119D) and two that exhibit a groundwater decline of about 5 feet coincident with the pumping that began in 2010. Well EAP-514 shows a decline in groundwater levels of about 12 feet that began in early 2006. Data for other nearby wells (1117D and 116D) does not begin until late 2010, but that early data appears to show the tail end of a water decline similar to what is seen at EAP-514. The cause of the decline in water levels at EAP-514 in 2006 and thereafter is unclear but is thought to be related to placement of paste in the Old Clearwell and G Cell North. The continued decline likely reflects further dewatering of the Old Clearwell. Dropping water levels during the later period are likely a function of both dewatering the Old Clearwell and continued paste placement.

**Figure 2-25** includes hydrographs for alluvium wells near the SFCC Seep area. The graph includes hydrographs from two pumping wells (592A and 688A) at this location. Hydrographs for three monitoring wells in the area (568A, 569A, and 598D-2) are also included on **Figure 2-25**. Groundwater levels during the early portion of the time period showed a decline of roughly 5 feet, then during 2004 they rose 5 feet. During 2005, groundwater levels declined 5 feet and have remained relatively stable since that time.

### 2.4.8 Influence of Fracturing and Burned and Unburned Coal on Groundwater Flow

Much of the Rosebud Coal in the Units 3 & 4 EHP area is burned and the alteration of the overlying rock resulted in the formation of clinker. The clinker is highly permeable and allows relatively rapid flow of groundwater both horizontally and vertically. Where the Rosebud Coal and overlying rock are unburned or partially burned, this unit is much less permeable. Where unburned, coal and other rock adjacent to clinker can behave as a hydraulic barrier to horizontal flow thereby diverting water around the unburned coal. An example of this phenomenon occurs where a section of unburned Rosebud Coal is present just south of the southern cutoff wall (Cross Sections A-A' and B'-B', **Figure 2-3**). Groundwater flowing in the Rosebud/Clinker unit is diverted around this unburned section toward the West Seep and toward the SFCC Seep. Other areas of unburned Rosebud are present near the southeast corner of the cutoff wall near well 1001R. The unburned coal in the southeast corner likely prevented impacted water in the Rosebud/Clinker from migrating to the east and southeast.

Vertical groundwater flow is also influenced by the presence or absence of burned coal. An example of this occurrence is observed near and west of well 642P. Cross Section F-F' (**Figure 2-5**) and Exhibit 4 in Hydrometrics (2005) shows that, in addition to the Rosebud Coal, the McKay Coal is burned in this area resulting in altered Interburden that essentially creates a continuous clinker layer. Normally, vertical flow between the Rosebud/Clinker and the McKay and Sub-McKay units is inhibited by the presence of less permeable layers (e.g., shales and siltstones) between the units. The burning of the Interburden and McKay units allows much greater vertical hydraulic communication between the clinker and the base of the McKay.

Groundwater flow in bedrock is controlled by geologic structure and fractures. Joints and fractures in rock are more permeable than the surrounding un-fractured rock. A series of generally south-southeasterly trending drainages are visible between the southern cutoff wall and the South Fork Cow Creek (**Figure 1-2**). These drainages probably formed along fracture/joint trends that encouraged erosion. Joint orientation studies conducted on site determined the average joint plane has an azimuth of 328° and a dip near vertical of 86° and the two primary azimuth orientations observed on site are approximately 340° and 315° (Hydrometrics 2010c). These joints likely created preferential pathways for
impacted water to form the SFCC Seep and to migrate to the area near well PSW-4. Hydrometrics (2001) also identified water-bearing joints in Sub-McKay sandstone near Seep 552 north of the Main Dam with as many as four preferred orientations. Two of the primary joint-sets were oriented closely with the two orientations of the drainage valley (azimuth 6°, dip 75° and azimuth 21°, dip 71°). These joints may form preferential flow paths for transport of impacted groundwater.

2.5 WATER QUALITY

Groundwater quality in the Units 3 & 4 EHP area has been described in a number of documents, most recently by Hydrometrics (2013) and NewFields (2013). Dissolved constituents, including sulfate, chloride, boron, magnesium, potassium, selenium, and sodium are present in natural groundwater surrounding the EHP. These constituents have also been detected in process pond water derived from the EHP, often at concentrations higher than those that occur in background groundwater (Geomatrix, 2005). Groundwater in many wells downgradient of the EHP contains several of these constituents at concentrations above background levels (Geomatrix, 2005; NewFields, 2013; Hydrometrics, 2016a).

A suite of indicator parameters has been historically used to assess whether groundwater has been affected by seepage from the process ponds (Hydrometrics, 2013). 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. Because these constituents are all present in background and pre-EHP groundwater, the occurrence of concentrations of a single constituent in groundwater above BSLs does not necessarily indicate that groundwater has been impacted by process water (see Section 2.5.2).

Process water from the EHP is the primary source of elevated concentrations of constituents of interest in groundwater. Other sources of COIs have also affected groundwater quality west of the EHP including various releases from a fly ash slurry pipeline near Drain Pit 5 and from a return water pipeline near Drain Pit 3. In addition, water seeping from mine spoils west of the EHP appears to affect alluvial groundwater quality in the Drain Pit 5 drainage. Water from all of these sources has affected groundwater quality surrounding the EHP in the Rosebud/Clinker, Alluvium/Colluvium, McKay, and Sub-McKay units surrounding the EHP.

2.5.1 Background Groundwater Quality

BSLs for the Units 3 & 4 EHP area were calculated by Exponent (2011). More recently, Neptune (2016) calculated updated BSLs for the entire Colstrip area on behalf of Talen in consultation with the MDEQ. Neptune (2016) defined the currently used BSLs as the 95th upper confidence bound on the 90th percentile of the baseline data. This statistic is often termed an upper tolerance limit (UTL), which in this case, can be written as a 95/90 UTL. For the large groundwater dataset, a Random Forests clustering approach was utilized to determine a baseline dataset from which BSLs could be estimated. BSLs were calculated for five different stratigraphic intervals (alluvium, Spoils, Clinker, Coal-Related [Rosebud, Interburden, McKay], and Sub-McKay).
The BSLs for the indicator parameters are summarized in Table 2-4. It is noted that, in some cases, BSLs calculated by Neptune are considerably lower than those calculated by Exponent (2011). Neptune (2016) calculated background screening levels (BSLs), for these constituents to represent background or unaffected reference areas concentrations by calculating a single set of BSLs for all three areas (Plant Site, Stage I & II Evaporation Ponds, and Units 3 & 4 EHP). As a result, the geospatial variations in concentrations that are present near the EHP in the historical dataset were incorporated into the entire dataset used to calculate the BSLs. Several wells sampled prior to EHP operation exhibited concentrations of indicator parameters that exceeded BSLs. BSLs that were calculated by Exponent (2011) for the EHP area separate from the Plant Site and SOEP/STEP areas were generally higher than current BSLs. This information suggests that the BSLs calculated by Neptune (2016) may not fully represent pre-EHP groundwater conditions. The Units 3 & 4 EHP area has much more exposed ash and Clinker where the Rosebud Coal has burned. Constituents in the ash and clinker can leach at higher concentrations than in other bedrock intervals, which could account for higher background levels in the EHP area. As a result, the exceedance of a BSL of a single constituent in groundwater is not necessarily an indication of impacts related to process ponds. Therefore, the evaluation of local conditions is conducted on a case by case basis using a multiple lines of evidence approach, with one variable being the BSLs.

<table>
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<tr>
<th>Groundwater Unit</th>
<th>Constituent</th>
<th>Boron (mg/L)</th>
<th>Chloride (mg/L)</th>
<th>Laboratory Specific Conductance (µmhos/cm)</th>
<th>Sulfate (mg/L)</th>
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<td>1.6</td>
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<td></td>
<td>Laboratory Specific Conductance</td>
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<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>Sulfate</td>
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<tr>
<td>Spoils</td>
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<td>Laboratory Specific Conductance</td>
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<tr>
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<tr>
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<td>Laboratory Specific Conductance</td>
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<td></td>
<td>Sulfate</td>
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<tr>
<td>Sub-McKay</td>
<td>Boron</td>
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<td>4,470</td>
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<td></td>
<td>Laboratory Specific Conductance</td>
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<td></td>
<td>Sulfate</td>
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</tbody>
</table>

Source: Neptune (2016)

### 2.5.2 Extent of Groundwater Exceeding BSLs

Groundwater flows radially in all directions away from the EHP. As a result, groundwater impacted by process water has migrated along several pathways in different directions away from the EHP. Sources and pathways are discussed in Section 2.6 below.

Figure 2-26 through Figure 2-29 are maps showing the extent of groundwater exceeding BSLs for indicator parameters including dissolved boron, chloride, SC, and sulfate in alluvium and Rosebud/Clinker for 2015. The extent of groundwater that exceeds the BSLs for these same parameters for the McKay Coal are shown on Figure 2-30 through Figure 2-33, and for the Sub-McKay on Figure 2-34 through Figure 2-37. Appendix F contains the data used to create these figures. The following describes the extent of groundwater impacts in various portions of the Units 3 & 4 EHP area.
**Pre-EHP Groundwater Quality**

Hydrometrics (1982) and Geomatrix (2005) documented groundwater quality prior to EHP operation. Prior to filling of the EHP, alluvium, interburden, and McKay groundwater was magnesium-sulfate type. Sub-McKay groundwater was sodium-sulfate type, and groundwater in spoils west of the EHP was magnesium-bicarbonate type.

Geomatrix (2005) presented Piper diagrams showing major ion signatures for EHP water and a number of wells based on circa-2005 data. These Piper diagrams indicated that most wells with calcium to magnesium ratios less than one have magnesium-sulfate type water quality, similar to EHP water quality. These data suggested that calcium to magnesium ratio is a reasonable indicator of process water impacts. However, groundwater samples from some wells exhibited calcium to magnesium ratios of less than one prior to filling of the ponds indicating that a calcium to magnesium ratio less than one alone is not proof of process water impacts.

Table F-4 summarizes groundwater quality data from 1980 through 1983 prior to filling of the EHP. Hydrometrics (1982) provides additional groundwater quality data dating back to 1977. Table F-4 includes 61 samples from 20 wells in the alluvium and Rosebud/Clinker, 38 samples from 18 wells in the McKay/Interburden, and 55 samples from 23 wells in the sub-McKay. Many of these samples had concentrations of boron, chloride, specific conductance, and sulfate exceeding the BSLs listed in Table 2-4. Of these samples, 17 percent from alluvium and Clinker wells, 52 percent from McKay/Interburden wells, and 53 percent from Sub-McKay wells exceeded at least one BSLs for indicator parameters.

The pre-EHP exceedances of BSLs occur at wells located across the Units 3 & 4 EHP area including:

- **West of the EHP**: BSL exceedances occur in the Rosebud/Clinker, McKay, and Sub-McKay in wells WM-126, WR-128, EAP-515, and EAP-529;
- **North of the EHP, Cow Creek**: BSL exceedances occur in the Alluvium, McKay, and Sub-McKay in wells 552D, 554D, 555M, WA-133, WA-135, and WA-142;
- **South of the EHP**: BSL exceedances occur in the McKay and Sub-McKay in wells 571M, 572D 573D, 574D, WM-127, and WM-127;
- **South Fork Cow Creek**: BSL exceedances occur in the Alluvium in wells 568A, WA-136, WM-128, and WA-138;
- **Saddle Dam and East of the EHP**: BSL exceedances occur in the Alluvium and Sub-McKay in wells 560A, 563D, 564D, 565D, 566D, WI-108, and 580D; and
- **Inside Current EHP**: BSL exceedances occur in the Sub-McKay in well 572D.

The source of some of the elevated constituent concentrations in wells may be mining activities to the west and north upgradient of the EHP area and/or due to naturally-occurring ash associated with burned coal in clinker. The historical data discussed above showing groundwater exceeding BSLs before the EHP cells were in operation is an indication that the BSLs calculated by Neptune (2016) may not represent pre-EHP groundwater conditions.
South and Southwest of EHP

Previous investigations and groundwater modeling suggest that the groundwater impacted by process water seeped through portions of the cutoff wall flowing south in Clinker toward South Fork Cow Creek. This led to areas of groundwater impacted by process water expressing to the surface at the SFCC and West Seeps between 2004 and 2006 and ultimately into alluvial and McKay groundwater along South Fork Cow Creek.

Figure 2-26 through Figure 2-29 indicate that most areas with saturated Rosebud/Clinker beneath, south and southwest of the EHP contain concentrations of indicator parameters exceeding BSLs. The area southeast of the EHP near well 1015R appears to be recharged locally and is not impacted by process water. Figure 2-30 through Figure 2-33 indicate that, between the EHP and South Fork Cow Creek, the extent of groundwater with indicator parameters exceeding BSLs in McKay is limited to a zone including wells 675M, 1000M, 1004M, 1012M, 1149M, and WM-127. Figure 2-34 through Figure 2-37 indicate that Sub-McKay groundwater south and southwest of the EHP is generally not impacted. However, well 1008D just south of the cutoff wall exceeds the SC and sulfate BSLs, and well 573 to the southwest exceeds the sulfate standard.

South Fork Cow Creek

Figure 2-26 through Figure 2-29 indicate that groundwater in alluvium of South Fork Cow Creek between wells 1136A and 569A are impacted by process water. Wells 665A, 666A, 669A, and 670A are dry (Figure 2-10), indicating groundwater capture wells in this area have dewatered the alluvium, preventing downgradient migration of impacted groundwater in alluvium. Figure 2-30 through Figure 2-33 indicate a small area of McKay in South Fork Cow Creek contains groundwater that is impacted by process water. Figure 2-34 through Figure 2-37 indicate that most groundwater in Sub-McKay bedrock in South Fork Cow Creek is not impacted by process water. However, samples from 1152D and PSW-4 exceed sulfate and chloride BSLs and samples from 1152D and 10456D exceed boron BSLs.

West of the EHP

Figure 2-26 through Figure 2-29 indicate that most areas with saturated Rosebud/Clinker beneath and west of the EHP exceed BSLs for indicator parameters. Figure 2-30 through Figure 2-33 indicate that most of the groundwater in underlying McKay in this area also exceeds BSLs for most indicator parameters, but often with concentrations that are less than in overlying Clinker. The zone of McKay groundwater exceeding BSLs extends further north than the zone of impacted Rosebud/Clinker, as far as wells 1066M. Figure 2-34 through Figure 2-37 indicate that in the northwest portion of the EHP, Sub-McKay groundwater exceeding BSLs extends beneath the EHP to near the Drain Pit 5 drainage and immediately east of the cutoff wall as far south as EAP-515, but is not impacted to the southwest.

East of Saddle Dam

Comparison of Figure 2-13 to Figure 2-26 through Figure 2-29 indicates that saturated Rosebud/Clinker east of the Saddle Dam exceeds BSLs. Portions of three drainages northeast of the Saddle Dam exhibit constituents exceeding BSLs. Well 1123A is in a small area of saturated alluvium and exceeds all four BSLs. Groundwater in this area appears to be perched and may be recharged from a localized source. Wells 1073A and 1079A are in a small alluvial drainage to the east of 1123A. Well 1073A exceeds BSLs for SC, sulfate, boron, and/or chloride and well 1079A has been dry since
construction of the 1073A and 1079A interception trenches. The sample from well 560A, located in the next drainage southeast of those wells, exceeded BSLs for indicator parameters. Wells 1039A and 635A in alluvium upgradient of 560A exceed the BSL for sulfate, SC and boron. The water sample collected from 635A also exceeds the Chloride BSL. Alluvium downgradient of well 560A is mostly dry due to operation of the 560A and 1051A interception trenches. Figure 2-30 through Figure 2-33 indicate that groundwater in McKay interval east of the northern portion of the Saddle Dam at wells 632M and 633M exceeds BSLs. The McKay Coal in this area has burned and the remnant is highly weathered at these two wells. East of the southern portion of the Saddle Dam near well 590M where the McKay is unburned, groundwater does not exceed BSLs. Figure 2-34 through Figure 2-37 indicate that shallow Sub-McKay groundwater exceeds BSLs in a zone extending from the south end of the Saddle Dam northeast to well 1109A. Sub-McKay bedrock north of there in a zone extending from about wells 631D and 1043D to 1121D to 1093 also exceeds some BSLs.

**Northeast of EHP**

There is no saturated Rosebud/Clinker northeast of the EHP. Figure 2-30 through Figure 2-33 indicate that McKay in well 555M contains groundwater exceeding BSLs. Figure 2-34 through Figure 2-37 indicate that the zone of impacted groundwater in Sub-McKay bedrock extends from the northeast corner of the cutoff wall to well 628D.

**North of Main Dam**

There is no saturated Rosebud/Clinker or McKay north of the Main Dam. Figure 2-26 through Figure 2-29 indicate that alluvial wells from north of the Main Dam to well 607A or 654A exceed BSLs for SC and boron. The area of exceedance for chloride and sulfate extends even farther to well 625A. Figure 2-34 through Figure 2-37 indicates that the zone of Sub-McKay groundwater exceeding most BSLs extends from beneath the EHP to the northwest (near well 551D), across to the northeast (near well 628D or 627D) and has a finger extending farther north to wells 1091D. Well 1125D also exceeds the BSL for both chloride and sulfate and well 624D exceeds the chloride BSL.

**Drain Pit 5 Drainage**

Groundwater samples from alluvial wells in the Drain Pit 5 drainage between WA-142 and 1047A and 1048A all contain boron, sulfate, SC, and chloride concentrations exceeding BSLs. In addition, groundwater in well 1126A southwest of 1047A contains chloride exceeding the BSL.

**Comparison to Previous Plume Extent Maps**

Comparison of maps showing the extent of groundwater exceeding BSLs for indicators based on 2015 data to similar maps based on 2005 data (shown in Geomatrix, 2005) indicates the extent of groundwater exceeding BSLs in some units is larger or smaller. These are summarized below.

- **Rosebud/Clinker:** The extent of groundwater exceeding the dissolved boron BSL in Rosebud/Clinker shown on Figure 2-26 is similar to but slightly smaller than those shown on Figure 17a in Geomatrix (2005). This is attributable to the installation and operation of groundwater capture wells south and west of the cutoff wall that have shrunk the extent of saturation. This capture has prevented the seepage of water at the SFCC and West Seeps.
• **Alluvium:** Comparison of **Figure 2-26** to Figure 17d in Geomatrix (2005) indicates that the current extent of groundwater exceeding the boron BSL downgradient of the former West Seep is smaller due to groundwater capture preventing the seepage of impacted groundwater from the Rosebud/Clinker unit into alluvium. The current extent of groundwater exceeding the boron BSL extends further downgradient of the Drain Pit 5 interception trench in alluvium. This is due to the installation of additional monitoring wells, which shows that the extent of groundwater exceeding the boron BSLs extends downgradient to wells 1047A and 1126A. Figure 17d in Geomatrix (2005) indicated that there were two distinct zones of groundwater exceeding the boron BSL in South Fork Cow Creek alluvium: one near well 1019A and another extending from the SFCC Seep to well 568A. **Figure 2-26** shows that there is no alluvial groundwater extending from SFCC Seep to South Fork Cow Creek but the zone of groundwater exceeding the boron BSL in 2015 extends from well 1136A (just upgradient from 1019A) down to well 568A. **Figure 2-26** also shows that there are small areas of alluvium east of the Saddle Dam that were not shown in Geomatrix (2005). This is due to the installation of wells 1073A and 1079A, and 1123A that identified these areas of impacted groundwater.

• **McKay:** Comparison of **Figure 2-30** to Figure 17b in Geomatrix (2005) indicates that the extent of groundwater exceeding the boron BSL based on 2015 data is similar in many areas to 2005. The extent of boron exceeding the BSL in the McKay extends over a larger area northwest of the EHP in 2015 than it did in 2005. This is partly due to the installation of wells 1032M, 1128M, 1129M, and 1130M. This is also due to the fact that the newer BSL for boron calculated by Neptune (2016) is 1.1 milligram per liter (mg/L) as compared to the BSL of 1.8 mg/L used by Geomatrix (2005). The current extent of boron exceeding the boron BSL in the McKay unit is also larger southwest of the EHP. This is due in part to a slightly higher boron concentration in well WM-127, but is also attributable to the lower new BSL. **Figure 2-30** shows an area of McKay below South Fork Cow Creek that exceeds the boron BSL that was not shown in Figure 17c in Geomatrix (2005). This is due mostly to the installation of new wells in that area that helped identify groundwater impacts, as well as the fact that boron concentrations in well 1023AM were much higher in 2015 than in 2005.

• **Sub-McKay:** Comparison of **Figure 2-34** to Figure 17c in Geomatrix (2005) indicates that the extent of groundwater exceeding the boron BSL based on 2015 data is similar in many areas to 2005. However, the extent of groundwater exceeding the boron BSL in groundwater northwest of the EHP and east of the Saddle Dam is considerably larger in 2015 than in 2005 due to the installation of several wells that have better defined the plume in those areas.

### 2.5.3 Changes in Groundwater Quality

Process water in the Units 3 & 4 EHP that has seeped into underlying groundwater is a source of indicator parameters to groundwater (Hydrometrics, 2013). Accidental pipeline breaks and occasional problems with capture systems and trenches likely contributed to elevated indicator parameter concentrations downgradient of the EHP (Hydrometrics, 2013). However, water quality data from a number of well samples prior to use of the EHP units also exceeded BSLs (see Section 2.5.1), so elevated indicator parameter concentrations in some places may not be related to EHP operations.

This section discusses changes in groundwater quality at different subareas within the Units 3 & 4 EHP area over the period 2003 to 2015, with reference where appropriate to earlier conditions.
North of Main Dam

Figure 2-38 shows trends in groundwater quality for selected alluvial and Sub-McKay wells north of the EHP. This figure indicates that concentrations of boron, chloride, SC, and sulfate in alluvial wells 582A, 604A, and 605A-2 in the Main Dam drainage generally increased between 2003 and around 2009-2010. Concentrations in these three wells have generally leveled off except for boron and chloride in 604A which have continued to increase.

Well 605A-2 exhibits large fluctuations in concentrations, with appreciable declines in early 2009, early 2011, and early 2013 to 2015, all of which were followed by increases back to previous levels. Well 605A-2 is an alluvial capture well immediately downgradient (70 feet) the Main Dam Sump. Fluctuations in water quality in 605A-2 are likely a function of operation of the Main Dam Sump. If there is an interruption in power to the sump or maintenance work is conducted, water levels in the sump may increase and some water may bypass the sump into the alluvium and migrate downgradient to 605A-2.

Concentrations of boron and chloride in well 1084A exhibit a generally increasing trend between 2009 and 2015, though SC and sulfate concentrations in this well have been more consistent. Concentrations of indicator parameters in alluvial wells 607A and 654A, located downgradient of the Interception Trench generally decreased between 2004 and 2011, but have increased slightly since then.

Water quality trends for boron and TDS prior to 2003 were presented by Geomatrix (2005) for two wells in this area. WA-133 and 552D both had stable concentrations of boron right at the BSL level from 1981 to about 1995, then concentrations rose. In WA-133, boron rose to 7 mg/L in 1997 before declining to 3.5 mg/L in 2003. Boron concentrations rose in well 552D after 1995 to about 80 mg/L in 2003 and have declined slightly since then.

North of Eastern Half of the EHP

Figure 2-39 includes charts showing changes in water quality over time for selected Sub-McKay wells north of the eastern portion of the EHP. This figure indicates that concentrations of indicator parameters in several of the wells exhibit an increasing trend since 2013 including wells 620D, 644D, 645D, 1115D, 1128D, and 1129D. However, boron concentrations in well 1115D have decreased since 2011.

Northeast of the EHP

Figure 2-40 includes charts showing changes in water quality over time for selected wells northeast of the EHP. Concentrations of constituents in wells northeast of the EHP have been fairly stable since 2003. However, concentrations of indicator parameters in wells 556D, 610D, and 621D have generally increased since 2010.

Water quality trends for boron and TDS prior to 2003 were presented by Geomatrix (2005) for well 556D in this area. Boron concentrations in well 556D were stable at the BSL from 1981 to about 1994, then concentrations rose to about 45 mg/L in 2003. Boron concentrations in this well (Figure 2-40) have continued to rise since 2003 and are now at about 63 mg/L.
South and Southwest of the EHP

Figure 2-41 includes charts showing changes in indicator parameter concentrations over time for selected monitoring wells south and southwest of the EHP. This figure indicates that groundwater in Rosebud/Clinker south of the EHP have steadily decreased since 2006 as a result of reductions in seepage from the EHP and implementation of groundwater capture in Rosebud/Clinker wells in this area. This figure indicates that water quality in McKay wells 1000M and 1004M in this area have remained relatively stable, although chloride concentrations in well 1000M have increased.

Water quality trends for boron and TDS prior to 2003 were presented by Geomatrix (2005) for three wells in this area including 571M, 589M, and 573D. Both 571M and 589M exhibited boron concentrations exceeding the BSL prior to filling of the EHP. Boron and TDS concentrations in former McKay well 571M, located just inside the cutoff wall, increased at a steady rate between 1982 and 1990 and then concentrations increased substantially. In November 2004, well 571M was abandoned because evidence suggested the borehole annular seal leaked (Hydrometrics 2005). Concentrations in well 589M increased substantially in September 2003, apparently in response to the flooding of Cells F and H. Hydrometrics (2005) indicated that the annular seal in 589M was poor, so the observed trends were not representative of the McKay groundwater system south of the EHP at that time. Well 573D had stable boron concentrations of less than 1 mg/L from 1982 to 2004.

West of Northern EHP

Figure 2-42 includes charts showing changes in indicator parameter concentrations over time for selected monitoring wells west of the north half of EHP. Similar to Rosebud/Clinker wells south and southwest of the EHP, concentrations of indicator parameters in Rosebud/Clinker wells in this area have decreased steadily since 2006 as a result of reductions in seepage from the EHP and implementation of groundwater capture in Rosebud/Clinker wells. One exception is well 1035R, where concentrations of indicator parameters have not decreased over this same period.

East of Saddle Dam

Figure 2-43 includes charts showing changes in indicator parameter concentrations over time for selected monitoring wells near the 1079A and 560A Trench systems. This figure indicates that concentrations of indicator parameters between 2003 and 2015 in Sub-McKay well 648D, located about 500 feet east of the Saddle Dam in the 560A drainage, exhibit a long-term increasing trend. Concentrations in Sub-McKay capture well 646D, located about 30 feet away decreased between 2009 and early 2014 but have rebounded since then. Concentrations of boron, chloride, and sulfate in alluvial well 635A, located 60 feet downgradient of 648D, were relatively stable between 2003 and 2013, but all increased between mid-2013 and early 2014. Concentrations of chloride, SC, and sulfate subsequently decreased from mid-2014 through 2015, but boron concentrations have continued to increase. About 700 feet downgradient (northeast) of this area, concentrations of indicator parameters in alluvial well 560A and in the 560A capture trench were stable between 2003 and 2015. The 560A Trench has completely dewatered the alluvium downgradient of this point.

Water quality trends for boron and TDS prior to 2003 were presented by Geomatrix (2005) for wells 560A and 579D in this area. Both of these wells had boron concentrations exceeding the BSL prior to use of the EHP ponds. Boron concentrations in 560A were stable at about 2 mg/L between 1982 and
2001, then increased to about 2.5 mg/L. Boron concentrations in 579D were stable at 3 mg/L from 1984 through 2004.

South Fork Cow Creek

Figure 2-44 includes charts showing changes in indicator parameter concentrations over time for selected monitoring wells near South Fork Cow Creek. This figure shows declining trend over the last several years in concentrations of indicator parameters in wells with the highest concentrations, including 1019A/M, 1024A/M, 687A, 683A, 685A, and 1136A. This is likely a result of groundwater capture in Rosebud/Clinker south of the EHP that had been migrating towards South Fork Cow Creek and also due to alluvial groundwater capture wells along South Fork Cow Creek.

Drain Pit 5 Drainage

Figure 2-45 includes charts showing changes in indicator parameter concentrations over time for selected monitoring wells and the DP-5 interception trench (DP-5 IT) in the Drain Pit 5 Drainage. This figure indicates that concentrations of indicator parameters in the DP-5 IT and nearby alluvial wells (including 1027A, 1028A, and 617A) exhibited a generally declining trend between 2006 and 2011 as well. Concentrations in alluvial wells in this drainage were fairly stable between 2011 and 2015.

2.5.4 Vertical Movement of Constituents

Groundwater quality data and plume maps for alluvium/Rosebud/Clinker, McKay, and Sub-McKay (Figure 2-26 through Figure 2-37) along with cross sections showing boron concentrations (Figure 2-3 through Figure 2-7) and vertical gradient data (Figure 2-16) help identify areas where vertical movement of groundwater containing concentrations of indicator parameters above BSLs has occurred.

South of the cutoff wall, impacted groundwater has moved vertically through the underlying Interburden to McKay in a limited area near wells 675M, 1000M, and 1004M and 1012M. Well 675M contains concentrations of boron, chloride, SC and sulfate that exceed BSLs for Clinker. At this well, the Interburden unit between the Rosebud/Clinker and McKay is relatively permeable sandstone, which has allowed for some vertical migration. Most of the Rosebud/Clinker in other areas south of the cutoff wall is underlain by predominantly siltstone and shale, which has limited migration into underlying McKay and Sub-McKay units.

West of the cutoff wall, process pond impacted groundwater has seeped from Rosebud/Clinker, through interburden into the underlying McKay, but has not migrated into underlying Sub-McKay. In the area near wells 642P and 643P, this vertical movement has been enhanced by the burning of the McKay Coal as well as the Rosebud Coal, which increased vertical hydraulic communication between these units.

East of the southern portion of the Saddle Dam where Rosebud/Clinker is saturated, impacted water has not migrated into underlying McKay wells WM-124 and 590M. However, impacted water appears to have migrated horizontally through the Rosebud/Clinker interval then seeped downward through colluvium and interburden into underlying burned McKay at wells 632M and 633M northeast of the Saddle Dam.
Northeast of the EHP near McKay well 555M, some impacted water appears to have migrated vertically from the McKay into the underlying Sub-McKay unit. However, it appears that most of the impacted groundwater in the Sub-McKay unit in this area has migrated laterally from inside the cutoff wall.

North of the Main Dam, impacted groundwater migrates laterally in a Sub-McKay sandstone layer from the base of the cutoff wall and then migrates laterally in a Sub-McKay sandstone layer near wells 644D and 552D before seeping into alluvium near well 604A. As this water flows north within alluvium, some migrates vertically into the underlying Sub-McKay unit.

Northwest of the EHP, impacted groundwater in the McKay unit near wells 1032M, 1049M, 1158M, 1159M, and 1160M is migrating vertically into underlying shallow Sub-McKay bedrock.

### 2.6 WATER BUDGET

A groundwater budget was developed as part of the conceptual framework that bounds the design of the numerical model. This water budget includes estimated inflows and outflows for various components, along with a range (minimum and maximum) of inflows and outflow for 12 months leading up to January 2003 and October 2015 (the periods simulated by steady-state numerical modeling). The exception to this is for capture systems which were calculated using the three months prior to January 2003 and October 2015 because a shorter preceding time period would better represent conditions in January 2003 and October 2015. A summary of the inflows and outflows is provided in Table 2-5. Each component of the water budget was developed as an independent estimate with associated errors; thus, the water budget does not balance perfectly.

The groundwater budget is represented generally by the following equation:

\[ \text{inflow} = \text{outflow} + \text{change in storage} \]

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 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 in the Units 3 & 4 EHP area:

\[ GW_{in} + PS + INF = GW_{out} + BF + GE \]

Where:

- \( GW_{in} \) = groundwater underflow from upgradient of the Study Area
- \( PS \) = pond seepage
- \( INF \) = infiltrating recharge from precipitation
- \( GW_{out} \) = groundwater underflow leaving the Study Area
- \( BF \) = groundwater discharge to surface water (baseflow)
- \( GE \) = groundwater extraction
Table 2-5. Summary of Water Balance for 2002 and 2014-2015

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Min (feet³/d)</td>
<td>Max (feet³/d)</td>
</tr>
<tr>
<td><strong>Inflows</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Underflow In</td>
<td>7,446</td>
<td>217,156</td>
</tr>
<tr>
<td>Infiltrating Background Recharge</td>
<td>3,087</td>
<td>9,262</td>
</tr>
<tr>
<td>Infiltrating Clinker Recharge</td>
<td>15,285</td>
<td>45,855</td>
</tr>
<tr>
<td>Infiltrating Regraded Area Recharge</td>
<td>54</td>
<td>161</td>
</tr>
<tr>
<td>EHP Cells</td>
<td>26,525</td>
<td>106,099</td>
</tr>
<tr>
<td>Stock Ponds</td>
<td>26</td>
<td>103</td>
</tr>
<tr>
<td><strong>Total IN</strong></td>
<td>52,423</td>
<td>378,636</td>
</tr>
<tr>
<td><strong>Outflows</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Underflow Out</td>
<td>28,794</td>
<td>115,175</td>
</tr>
<tr>
<td>Capture Systems</td>
<td>7,839</td>
<td>24,075</td>
</tr>
<tr>
<td><strong>Total OUT</strong></td>
<td>36,633</td>
<td>139,250</td>
</tr>
</tbody>
</table>

Notes: feet³/d = cubic feet per day; gpm = gallons per minute

In order to quantify the water balance, a domain must be established. Figure 1-2 shows the model domain for which each component of the water balance is calculated. The domain was established in order to meet the 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. However, because the flow system is variable with depth, there are areas where flow enters the domain obliquely. Table 2-5 presents ranges of estimated flow rates for each component of the groundwater budget. The following subsections described how the estimates were developed.

The water balance was defined for two time periods: January 2003 (using data from January to December 2002) and October 2015 (using data from October 2014 to September 2015). These periods were selected to support the two periods for steady-state model calibration discussed below (Section 4.0).

### 2.6.1 Underflow In

Groundwater entering or leaving an aquifer from or to adjoining areas is referred to as underflow. Underflow into the model domain was calculated using Darcy’s Law:

\[ Q = KA \]

Where:
- \( Q \) = flux
- \( K \) = Hydraulic Conductivity
- \( i \) = Hydraulic Gradient
- \( A \) = Cross Sectional Area
Each portion of the domain where groundwater is interpreted to enter the domain was assessed. There are four general areas where groundwater inflow occurs:

- From the west edge of the domain in the Sub-McKay;
- From the west in unconsolidated material in the NP cut (Figure 1-2) which drains mine spoils west of the EHP;
- From the northwest to southeast in alluvium entering the domain along the Cow Creek Drainage; and
- From the north in alluvium along four other drainages.

At most of these boundary locations, data regarding hydraulic properties and gradients are sparse. The interpreted saturated thicknesses, gradients, and lengths of these boundaries are presumed to be variable depending upon depth and spatial location. Because of this, in most cases average or weighted average values were calculated. Table 2-6 summarizes the saturated thicknesses, gradients, approximate lengths, and calculated fluxes of these inflow boundaries. Lengths of inflow boundaries are measured perpendicular to the direction of groundwater flow inferred from the potentiometric surface maps; these lengths vary with depth.

Based on these estimates, approximately 19,103 feet$^3$/day (or 99 gpm) is estimated to flow into the domain as “Underflow In.” Minimum and maximum flows were calculated by varying hydraulic conductivity by 50 percent and 200 percent of the estimated value due to the estimated range in uncertainty and variability in these parameters as illustrated by the range of hydraulic conductivity values shown in Table 2-1.

### Table 2-6. Saturated Thickness, Gradient, Length, and Flux along Underflow-In Boundaries

<table>
<thead>
<tr>
<th>Location</th>
<th>Length Perpendicular to Flow (feet)</th>
<th>Saturated Thickness (feet)</th>
<th>Gradient</th>
<th>K Minimum (feet/day)</th>
<th>K Maximum (feet/day)</th>
<th>K Estimate (feet/day)</th>
<th>Q Minimum (cubic feet/day)</th>
<th>Q Maximum (cubic feet/day)</th>
<th>Q Estimate (cubic feet/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>From West in Sub-McKay</td>
<td>7,000</td>
<td>250</td>
<td>0.0054</td>
<td>0.5</td>
<td>2</td>
<td>1</td>
<td>4,703</td>
<td>18,812</td>
<td>9,406</td>
</tr>
<tr>
<td>From West in Alluvium at NP Cut</td>
<td>300</td>
<td>10</td>
<td>0.0044</td>
<td>100</td>
<td>400</td>
<td>200</td>
<td>1,320</td>
<td>5,280</td>
<td>2,640</td>
</tr>
<tr>
<td>From Northwest in Alluvium in Cow Creek Drainage</td>
<td>900</td>
<td>10</td>
<td>0.0044</td>
<td>0.5</td>
<td>2</td>
<td>1</td>
<td>19.8</td>
<td>79</td>
<td>40</td>
</tr>
<tr>
<td>From North in Alluvium along other drainages</td>
<td>380</td>
<td>20</td>
<td>0.0057</td>
<td>4</td>
<td>550</td>
<td>400</td>
<td>172.6</td>
<td>23,730</td>
<td>863</td>
</tr>
<tr>
<td>From North in Alluvium along other drainages</td>
<td>160</td>
<td>10</td>
<td>0.0131</td>
<td>4</td>
<td>550</td>
<td>20</td>
<td>83.7</td>
<td>11,503</td>
<td>418</td>
</tr>
<tr>
<td></td>
<td>120</td>
<td>10</td>
<td>0.0108</td>
<td>4</td>
<td>550</td>
<td>20</td>
<td>51.6</td>
<td>7,097</td>
<td>258</td>
</tr>
<tr>
<td>Total Inflow:</td>
<td>7,446</td>
<td>217,156</td>
<td>19,103</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
2.6.2 Recharge

This component of the groundwater balance is referring to deep percolation (i.e., infiltrating precipitation minus evapotranspiration), which is somewhat variable in the model area. Measuring actual groundwater recharge is difficult, but can be estimated by determining soil moisture water balances, analyzing stable isotopes, and in many cases, by balancing the water budget. Rates of recharge were estimated for the following distinct areas:

- Background areas;
- Clinker; and
- Regraded Areas in the EHP.

Estimates of recharge for these zones are described below. Maximum and minimum values were calculated as 50 and 150 percent of the estimated value.

**Background Recharge**

Background areas account for the second most surface area (Clinker covers more) within the domain of the model. The background area ranges from 118,776,025 feet² for 2003 and 117,921,925 feet² in 2015, with the difference being due to changes in pond management. 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 run off to streams or evaporate/transpire before reaching groundwater. Estimates of background area recharge rates in model versions for neighboring areas (Plant Site and SOEP/STEP) were based on estimates used in a groundwater model developed for Area D of the Rosebud Mine, located west of the CSES (Nicklin Earth and Water, 1999). That model used estimates of background recharge of about 1.5 percent of average annual precipitation. Average annual precipitation is 15.18 inches per year (Section 2.2). Table 2-7 summarizes the estimated background recharge for the two time periods evaluated.

<table>
<thead>
<tr>
<th>Area (feet²)</th>
<th>Estimated percent of Precipitation</th>
<th>Precipitation (inches)</th>
<th>Estimated Recharge (feet³/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>January 2003</td>
<td>118,776,025</td>
<td>1.5 percent</td>
<td>15.18</td>
</tr>
<tr>
<td>October 2015</td>
<td>117,921,925</td>
<td>1.5 percent</td>
<td>15.18</td>
</tr>
</tbody>
</table>

**Clinker Recharge**

As described above, Clinker outcrops exist around the EHP and elsewhere in the Units 3 & 4 EHP area (Figure 2-1). Clinker typically has relatively high permeability due to settling or collapse of the rock, which results in secondary porosity. The greater permeability of Clinker subsoil relative to other types of subsoil can result in higher rates of recharge. The area of Clinker ranges from 117,374,437 feet² for 2003 and 117,811,937 feet² in 2015, with the difference being due to changes in pond management.
Literature estimates of recharge through Clinker outcrops are not available. Estimates of recharge rates through Clinker outcrops were based on previous modeling for the Plant Site area (Geomatrix, 2008), where recharge through the unit was estimated to be approximately 7 percent of annual precipitation. Based on this value, the average annual precipitation rate of 15.18 inches per year, and the respective surface area of clinker, the estimated volume of net recharge in areas where Clinker is present for 2003 and 2015 are 30,570 feet$^3$/day and 30,676 feet$^3$/day, respectively.

**Regraded Area Recharge**

The regraded area covers a much smaller area than background and Clinker (roughly 1,238,125 feet$^2$) and, as such, only contributes a minor amount of recharge in the overall water budget. Recharge through the regraded areas is assumed to be less than through clinker but greater than background and was estimated to be 2.5 percent of average annual precipitation. Based on this value, the estimated volume of net recharge in regraded areas for both 2003 and 2015 is 107 feet$^3$/day.

### 2.6.3 EHP Cell Seepage

Operation of EHP cells changed between 2003 and 2015, with new ponds coming online, others being taken out of use, and in the case of Cell B, having a liner added. The status of each pond for these two time periods is noted in Table 2-8. In 2015, although Cell C, Cell G, and the Old Clearwell were not actively used for water storage, some water was still present in places and the ponds were therefore providing a source for seepage. Cell B was lined and became the New Clearwell between 2003 and 2015 and therefore is not assumed to be a source for seepage in 2015.

Estimated seepage values and parameters used to estimate the seepage are shown in Table 2-8. Seepage through the ponds without synthetic liners was estimated by using vertical gradient (i) based on a unit hydraulic gradient, estimated hydraulic conductivity of the paste/flyash at the bottom of the cells, and pond area. Hydraulic conductivity of the paste was based on laboratory tests, which indicated values ranging from 0.04 to 0.11 feet/day (Hydrometrics, 2007). Pond areas were calculated from air photos for the ponds. Estimates of pond seepage for ponds with synthetic liners, are based estimates from Hydrometrics (2016).

<table>
<thead>
<tr>
<th>Cell</th>
<th>Area (feet$^2$)</th>
<th>2003</th>
<th>2015</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Status</td>
<td>Flux (cfd)</td>
<td>Status</td>
</tr>
<tr>
<td>A</td>
<td>Active</td>
<td>5,319</td>
<td>Unused</td>
</tr>
<tr>
<td>B</td>
<td>Active</td>
<td>14,505</td>
<td>Lined</td>
</tr>
<tr>
<td>C</td>
<td>Active</td>
<td>22,400</td>
<td>Draining</td>
</tr>
<tr>
<td>F</td>
<td>No Water</td>
<td>------</td>
<td>Lined</td>
</tr>
<tr>
<td>G</td>
<td>Active</td>
<td>7,275</td>
<td>Draining</td>
</tr>
<tr>
<td>H</td>
<td>------</td>
<td>------</td>
<td>Lined</td>
</tr>
<tr>
<td>Old Clearwell</td>
<td>Active</td>
<td>3,550</td>
<td>Draining</td>
</tr>
<tr>
<td><strong>Total:</strong></td>
<td><strong>53,049</strong></td>
<td></td>
<td><strong>35,845</strong></td>
</tr>
</tbody>
</table>

cfd - cubic feet per day
The calculations indicate an estimated seepage from the ponds in 2003 and 2015 of 63,659 feet³/day and 34,886 feet³/day, respectively. Ranges of the seepage were calculated as 50 percent and 200 percent of the estimated value.

2.6.4 Stock Ponds

There are two stock ponds in the Units 3 & 4 EHP area. One lies near Cow Creek and has an area of approximately 40,000 feet² and the other lies near South Fork Cow Creek, covering an estimated area of 1,000 feet². Little information is available regarding the pond bottoms so hydraulic conductivity was estimated based on literature values for silty-clay. The uncertainty for seepage estimates from the stock ponds is not consequential because the estimated seepage for 2003 and 2015 of 52 feet³/day is a small portion of the overall water budget.

2.6.5 Underflow Out

Underflow out of the model domain into adjoining areas was calculated using Darcy’s Law, the same as for underflow in. Each portion of the domain where groundwater is interpreted to leave the domain was assessed. There are three general areas where groundwater outflow occurs:

- To the east in the Sub-McKay;
- To the north in the Sub-McKay; and
- From east in alluvium.

At most of these boundary locations, hydraulic data are sparse. The interpreted saturated thicknesses, gradients, and lengths of these boundaries are presumed to be variable depending upon depth and spatial location, so in most cases, average or weighted average values were calculated. Table 2-9 summarizes the saturated thicknesses, gradients, approximate lengths, and calculated fluxes of these outflow boundaries. Lengths of outflow boundaries are measured perpendicular to the direction of groundwater flow inferred from the potentiometric surface maps; these lengths vary with depth.

Based on these estimates, approximately 57,587 feet³/day (or 299 gpm) is estimated to flow out of the domain as “Underflow-Out.” Minimum and maximum flows were calculated by varying hydraulic conductivity by 50 percent and 200 percent of the estimated value.

<table>
<thead>
<tr>
<th>Location</th>
<th>Length Perpendicular to Flow (feet)</th>
<th>Saturated Thickness (feet)</th>
<th>Gradient</th>
<th>K Minimum (feet/day)</th>
<th>K Maximum (feet/day)</th>
<th>K Estimate (feet/day)</th>
<th>Q Minimum (cubic feet/day)</th>
<th>Q Maximum (cubic feet/day)</th>
<th>Q Estimate (cubic feet/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>To West in Sub-McKay</td>
<td>4,000</td>
<td>250</td>
<td>0.0077</td>
<td>0.45</td>
<td>1.8</td>
<td>0.9</td>
<td>3,482</td>
<td>13,929</td>
<td>6,964</td>
</tr>
<tr>
<td>To North in Sub-McKay</td>
<td>30,000</td>
<td>250</td>
<td>0.006</td>
<td>0.45</td>
<td>1.8</td>
<td>0.9</td>
<td>20,250</td>
<td>81,000</td>
<td>40,500</td>
</tr>
<tr>
<td>To East in Alluvium</td>
<td>1,000</td>
<td>40</td>
<td>0.0126</td>
<td>10</td>
<td>40</td>
<td>20</td>
<td>5,062</td>
<td>20,246</td>
<td>10,123</td>
</tr>
<tr>
<td>Total Outflow:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>28,794</td>
<td>115,175</td>
<td>57,587</td>
</tr>
</tbody>
</table>
2.6.6 Groundwater Capture Systems

Talen has installed an extensive groundwater capture system that consists of capture wells, drains, and trenches within the Units 3 & 4 EHP area to recover groundwater affected by process water and transport it back to the Units 3 & 4 EHP (Figure 2-46). Between late 2003 and 2015, several of the wells shown on Figure 2-46 were either converted from monitoring wells into capture wells or were installed for the purpose of groundwater capture. The groundwater capture wells and trenches are located to the east, west, north, and south of the EHP. The groundwater recovery systems and associated wells and trenches are summarized in Appendix G.

In late 2013 and early 2014, Hydrometrics (2016a) pumped well 1085R in an attempt to reduce water storage in clinker within and head against the cutoff wall. During this effort, groundwater levels were reduced by at least 19 feet. Results of this effort suggest dewatering of the Clinker in the cutoff wall may be affective at reducing seepage through and beneath the cutoff wall.

In 2015, Hydrometrics (2015b) installed four wells east of the Saddle Dam near well 1120C. Results of aquifer tests performed on these wells suggests groundwater capture is feasible in this area. Wells 1120C and 1169R will be converted to capture wells later in 2016. Toe drains were constructed as part of both the Main Dam and Saddle Dam (Hydrometrics, 1998). When groundwater elevations downstream of the Main Dam reach a certain height, groundwater is captured by toe drains positioned on each side of the dam (Hydrometrics, 1999). Water collected from the toe drains is directed to sumps where it is collected and pumped back to the Units 3 & 4 EHP for reuse.

Groundwater capture wells are routinely monitored for flow, hours operated, water level, and specific conductance. However, the extraction systems construction prohibit the installation of individual flow meters and the pumping rates are measured at the well head through a sampling port. As a result, the flow is measured without the back pressure that is present on the system under normal operating conditions. Less water is pumped when the system is back pressured, resulting in an overestimate of measured flow and calculated capture volumes. In some cases, the overestimate can be 100 percent or more (Hydrometrics, 2013), though recent evaluations (Hydrometrics, 2015a) suggest that actual current pumping rates for capture wells are about 25 percent lower than measured rates. In addition, scale buildup in piping and flow meters is problematic in the Colstrip area, resulting in the necessity for continual maintenance and also contributes to inaccurate flow measurements.

Appendix G presents the estimated pumping rates for each well that was actively pumped during the three months prior to January 2003 and/or October 2015. A three-month time period was used because pumping rates can vary more from month to month than the other water budget components so a quarterly time period provides a more accurate depiction of conditions in January 2003 and October 2015. These estimated pumping rates are less than the measured rates, ranging from 35 percent to 85 percent depending on the well and based on estimated measurement error provided by Hydrometrics (see Appendix G for the multiplier for each well). Ranges were assumed to be at 40 percent for the minimum and the measured rate for the maximum.

Total estimated average groundwater extraction from 16 wells, trenches, and sumps for the three months prior to January 2003 was 102 gpm, and the total estimated groundwater extraction from 70 wells, trenches, and sumps for the three months prior to October 2015 was 186 gpm. The maximum rates for the two periods was estimated to be 125 gpm for 2003 and 292 gpm for 2015, which is the
The water budget indicates that in 2003 about 31 percent of the pond seepage was captured by the groundwater extraction system. For 2015 that percentage increased such that all or almost all of the seepage is captured (80 percent for the maximum rate and 100 percent for the minimum and estimated rates). Model particle tracking (Section 6) evaluates the potential and movement of uncaptured pond water.

2.7 Refinements to Conceptual Model Since 2005

Geomatrix (2005) provided a detailed description of the conceptual model of groundwater flow and solute transport near the Units 3 & 4 EHP area. NewFields (2013) provided an update to the numerical model incorporating data through 2012, but a detailed update of the conceptual model was not provided at that time.

Additional hydrogeologic data have been collected since the Units 3 & 4 EHP conceptual model was last updated. These data include information from wells installed in the Units 3 & 4 EHP area up to 2012 (NewFields, 2013) and from wells installed from 2012 through 2015 (listed in Table 2-10). The following new information was considered in refining the conceptual model, as discussed in this report:

- Pumping rate of capture wells calculated as 35 to 85 percent of the measured extraction rates;
- Lithologic, water level, and water quality data, for wells 1153A through 1171R and 609D-2 and PSW-11;
- Water level data obtained from all wells between 2012 and December 2015;
- Water quality data obtained between 2012 and December 2015;
- Aquifer test data (15 pumping and slug tests) from numerous wells between September 2013 and April 2015 at wells 1153A through 1169R and PSW-11;
- Regional Montana Bureau of Mines and Geology Groundwater Information Center (GWIC, 2016) groundwater level data for establishing elevations at model edge boundaries; and,
- Water level data from the Rosebud Mine observation well network (Western Energy Company, 2013 a, b, c, d, and e).

The following is a summary of refinements to the conceptual model since 2007:

- Changes in water management in the EHP area have occurred since 2012. Changes include reduced pond seepage due to increased use of synthetically lined Cell H with associated pond level increases, and decreased use of Cell C (no synthetic liner) with associated pond level decreases;
- Additional capture wells have been added and the benefits from overall increased pumping have served to improve groundwater quality in areas impacted by process pond water;
- Estimates of recharge through Clinker outcrops have increased; and
- Capture well pumping rates are assumed to vary between 35 percent and 85 percent of the measured rates depending on the capture system.
Table 2-10. Wells Installed 2013-2015

<table>
<thead>
<tr>
<th>Well ID</th>
<th>Aquifer</th>
<th>Install Date</th>
<th>Total Depth*</th>
<th>Well ID</th>
<th>Aquifer</th>
<th>Install Date</th>
<th>Total Depth*</th>
</tr>
</thead>
<tbody>
<tr>
<td>1153A</td>
<td>Alluvium</td>
<td>6/18/13</td>
<td>15</td>
<td>1164R</td>
<td>Rosebud/Clinker</td>
<td>5/19/14</td>
<td>66</td>
</tr>
<tr>
<td>1154D</td>
<td>Sub-McKay</td>
<td>10/8/13</td>
<td>120</td>
<td>1165D</td>
<td>First Bedrock</td>
<td>7/8/14</td>
<td>28</td>
</tr>
<tr>
<td>1155D</td>
<td>Sub-McKay</td>
<td>10/8/13</td>
<td>83</td>
<td>1166D</td>
<td>First Bedrock</td>
<td>7/8/14</td>
<td>114</td>
</tr>
<tr>
<td>1156D</td>
<td>Sub-McKay</td>
<td>10/8/13</td>
<td>66</td>
<td>1167D</td>
<td>First Bedrock</td>
<td>7/9/14</td>
<td>67</td>
</tr>
<tr>
<td>1157D</td>
<td>Sub-McKay</td>
<td>10/9/13</td>
<td>190</td>
<td>1168R</td>
<td>Rosebud/Clinker</td>
<td>3/30/15</td>
<td>40</td>
</tr>
<tr>
<td>1158M</td>
<td>McKay</td>
<td>10/11/13</td>
<td>70</td>
<td>1169R</td>
<td>Rosebud/Clinker</td>
<td>3/30/15</td>
<td>33</td>
</tr>
<tr>
<td>1159M</td>
<td>McKay</td>
<td>10/15/13</td>
<td>64</td>
<td>1170R</td>
<td>Rosebud/Clinker</td>
<td>11/15/15</td>
<td>41</td>
</tr>
<tr>
<td>1160M</td>
<td>McKay</td>
<td>10/16/13</td>
<td>66</td>
<td>1171R</td>
<td>Rosebud/Clinker</td>
<td>11/5/15</td>
<td>35</td>
</tr>
<tr>
<td>1161D</td>
<td>Sub-McKay</td>
<td>10/16/13</td>
<td>85</td>
<td>609D-2</td>
<td>Interburden</td>
<td>7/10/14</td>
<td>130</td>
</tr>
<tr>
<td>1162R</td>
<td>Rosebud/Clinker</td>
<td>10/16/13</td>
<td>35</td>
<td>PSW-11</td>
<td>Sub-McKay</td>
<td>9/4/14</td>
<td>264</td>
</tr>
<tr>
<td>1163D</td>
<td>Sub-McKay</td>
<td>10/17/13</td>
<td>97</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Total Depth: Depth to bottom of screen, in feet

2.8 Conceptual Groundwater Model Summary

The hydrostratigraphy in the Units 3 & 4 EHP area is complex. Part of the stratigraphic sequence has been eroded away along Cow Creek, South Fork Cow Creek, and other tributary drainages in the area. Alluvium within the floodplain consists of fine-grained overbank deposits overlying coarser channel deposits consisting of sand and gravel.

Figure 2-47 is an animated block model illustrating our conceptual understanding of the hydrogeologic system in the Units 3 & 4 EHP area (click upper left corner of figure to activate animation; paper copies of this report contain a static image). The block model, in combination with the estimated water balance shown in Table 2-5, describe our current understanding of recharge, discharge, groundwater flow, and how these relates to the spatial distribution of contaminants. Major elements of the conceptual model are summarized below.

The shallowest hydrostratigraphic units are the Rosebud/Clinker and alluvium. A few islands of Rosebud Coal exist; in many places the Rosebud coal has burned in place creating Clinker, which consists of baked shale, siltstone and sandstone and often a layer of ash where the Rosebud has burned. Alluvium consists of sand, gravel, silt, and clay. The Rosebud is underlain by the Interburden unit which consists of interbedded claystone, siltstone, and sandstone. This is underlain by the McKay Coal, which is underlain by the Sub-McKay (including the Robinson Coal and underlying bedrock), consisting of layers of sandstone interbedded with coal and shale stringers and layers of siltstone and claystone.

Seepage from the EHP is the greatest source of recharge to groundwater in the area. The other major source is areal recharge from infiltrating precipitation and runoff. In addition some groundwater enters the area via underflow from the northwest, west, and southwest. Shallow groundwater flows radially south, west, north, and east away from the EHP. Vertical gradients carry groundwater downward from the Rosebud/Clinker units to the underlying McKay and Sub-McKay units, where the regional flow direction is east-northeast. Groundwater capture systems (including wells and trenches) intercept the vast majority of the groundwater originating from EHP cells. Groundwater leaves the area via
underflow to the east and north in alluvium and bedrock. Rosebud Creek is the likely area of regional discharge. Minor amounts of groundwater likely discharge to surface water in the lower reaches of Cow Creek and South Fork Cow Creek east of the EHP during high water periods.

Hydrographs for monitoring wells suggest that Cell C and the Old Clearwell have had the greatest influence on groundwater elevations and are potentially a large contributor of seepage from the ponds. Pasting of the cells is reducing the permeability of the ponds, reducing infiltration to underlying groundwater. Groundwater seepage from EHP cells is greatest in areas where Clinker has been in contact with the edge of ponds. Groundwater elevations in Cell C are higher than in Cell G, and groundwater has been observed discharging from Clinker at the south end of Cell C and flowing into Cell G.

From 1988 through 1998, releases from Drain Pit 5 (Figure 1-2) and the adjacent scrubber slurry pipeline impacted groundwater quality within the drainage below this area that flows northeast toward Cow Creek. In addition, water samples from a mine cut (NP Cut) upstream of Drain Pit 5 contains concentrations of indicator parameters including chloride, SC, and sulfate (Figures 2-27, 2-28, and 2-29) that exceed alluvial BSLs. These elevated concentrations indicate that water draining from reclaimed mine pits to the west of the area may be affecting alluvial groundwater quality downgradient of Drain Pit 5. Operation of the DP5 trench capture system collects most of the impacted groundwater in this drainage. However, concentrations of boron and chloride in alluvial wells downgradient of the capture system (wells 1126A, 1147A, and 1148A) indicate that some water may be bypassing the system.

The cutoff wall surrounding the EHP cells limits the flow of groundwater containing concentrations of constituents above BSLs from entering into surrounding groundwater. Some impacted groundwater seeps through and possibly under the cutoff wall and migrates into the Rosebud/Clinker interval south and west of the ponds.

2.8.1 Summary of Sources

The following is a summary of apparent sources of dissolved constituents to groundwater in the Units 3 & 4 EHP area, including the operational and natural source areas:

- Release of process water from the EHP cells;
- Seepage of process water below and/or through the cutoff wall or dams;
- Release of process water from the fly ash slurry pipeline and Drain Pit 5;
- Natural sources associated with ash and burned coal; and
- Mine spoils west of the EHP.

The principal source of dissolved constituents in groundwater in the Units 3 & 4 areas is seepage from process ponds and the flooding of Cells F and H in 2003 and 2004, and the subsequent release of impacted water through and/or beneath the cutoff wall and dams. Based on facility records, 54 acres of the original Units 3 & 4 EHP surface footprint (which was approximately 370 acres, personal communication, Mike Holzwarth, Talen) were sealed with a bentonite/soil mixture at elevations below approximately 3,200 feet amsl (Hydrometrics, 2016a) prior to pond filling. At the time of filling in the
mid-1980s, process water that was discharged to Cell F was in direct contact to highly permeable Clinker. Other cells came on-line during the last 20 years, which also were not lined to limit infiltration. The flooding of Cells F and H in 2003 and 2004 resulted in an increase in groundwater elevations south of the EHP and subsequent migration of process water impacted groundwater toward the SFCC Seep, the West Seep, and alluvium in the South Fork Cow Creek drainage.

Other sources of impacts have or may have led to groundwater containing constituent concentrations above BSLs. Release of water from Drain Pit 5, mine spoils west of Drain Pit 5, several fly ash slurry pipeline spills in that area led to impacts in alluvial groundwater downgradient of Drain Pit 5. Seepage from the Saddle Dam in 1999 led to impacts in groundwater east of the Saddle Dam. Clinker and ash resulting from the natural burning of the Rosebud Coal and McKay Coal appears to be a natural source of elevated concentrations of some constituents in groundwater in some locations.

2.8.2 Summary of Pathways

Release of process water to the subsurface has led to zones of impacted groundwater around the EHP that ultimately follows several fairly distinct pathways. These pathways have resulted in several plumes that are apparent in Figure 2-26 through Figure 2-37 and are described below.

1. **South Cutoff Wall to SFCC Seep to South Fork Cow Creek.** Water that seeped into the Rosebud/Clinker unit in 2003 and 2004 appears to have built up sufficient head to drive the water beneath and/or through portions of the cutoff wall. A geophysical survey completed in 2005 detected two zones of high conductivity groundwater along the south cutoff wall (Hydrometrics 2005a). A high conductivity zone appeared at a depth just below the base of the cutoff wall near wells 1006M and 1007R suggesting that impacted water may have seeped through and/or under the cutoff wall at this location. Another zone of high conductivity water was detected from the water table down to a depth below the base of the cutoff wall near wells 1000M and 1004M suggesting that impacted groundwater possibly seeped through and beneath the cutoff wall in that area. Once south of the cutoff wall, impacted groundwater appears to follow distinct pathways.

One pathway extends in the Rosebud/Clinker hydrostratigraphic unit from south of the cutoff wall to where it subcrops in colluvium at the location of the SFCC Seep. Impacted groundwater in the Rosebud/Clinker unit issued as a contact spring at the SFCC Seep in 2004 and 2005, discharged into the alluvial system in that drainage, and then flowed down to the alluvial system in South Fork Cow Creek. Subsequent response measures enacted caused flows at this seep to cease in 2006 (Hydrometrics, 2016a). This pathway may extend vertically into the underlying McKay unit south of the cutoff wall via fractures where another pathway or pathways exist.

2. **South Cutoff Wall to PSW-4A & 1019A/M area.** A second pathway that impacted groundwater south of the cutoff wall is west of, and generally parallel to, the one described above. Impacted groundwater in the Rosebud/Clinker system appears to flow south from the cutoff wall in the Rosebud/Clinker unit then discharges into McKay and alluvium, eventually impacting the alluvium and McKay systems in South Fork Cow Creek near wells 1019AM and PSW-4A (Figures 2-26 through 2-33). This pathway, similar to the one described above, is probably fracture-controlled and may extend into the underlying McKay
system south of the slurry wall. Permeability in the McKay unit is much lower than in the overlying Rosebud/Clinker (Table 2-1), and therefore transport of impacted water in the McKay unit is much slower.

3. **South Cutoff Wall to West Seep.** A third pathway that impacted groundwater in the Rosebud/Clinker unit is one that directs groundwater south of the cutoff wall, then west and then northwest (Figures 2-26 through 2-29). The Rosebud/Clinker unit subcrops at the location of the West Seep where groundwater discharged to the alluvial system between 2004 and 2006 (Hydrometrics, 2016a).

4. **Northwest Corner of Cutoff Wall to SP-15 North and SP-15 South.** In 2000, water quality at seep SP-15 began to deteriorate. Subsequent investigations (Hydrometrics, 2002, 2003) identified a pathway from the cutoff wall in the Rosebud/Clinker unit past wells 640P and 643P, and into the collapsed/burned McKay unit near well 642P. This groundwater is intercepted by the SP-15 North and SP-15 South trenches and capture well 1068A, and the Well 656R Capture System.

5. **Main Dam to Cow Creek.** EHP seepage flows below the cutoff wall and Main Dam in the Sub-McKay unit. This groundwater discharges into the alluvial system downgradient of the Main Dam and then continues to flow north toward Cow Creek. Various interception and capture systems, including the Chimney and Toe drains, are located in this drainage north of the Main Dam and prevent a substantial amount of impacted water from reaching Cow Creek. Just east of the Main Dam, impacted groundwater appears to flow beneath the cutoff wall to north toward Cow Creek. Several capture wells are located in this area and are designed to capture this seepage.

6. **Northeast Corner of Cutoff Wall to Well 627D.** EHP seepage flows beneath and/or through the cutoff wall in the Sub-McKay unit toward well 627D. The northeastern extent of the Sub-McKay plume in this area appears to be between wells 627D and 1124D.

7. **Saddle Dam Drainage.** EHP seepage appears to have migrated through the Saddle Dam in Clinker then into underlying McKay a short distance east of the cutoff wall (Figures 2-30 through 2-33). Impacted groundwater has migrated further in the underlying Sub-McKay unit (Figures 2-34 through 2-37). Sub-McKay groundwater discharges two alluvial drainages downstream of the dam.

8. **Drain Pit 5 Drainage.** Groundwater is impacted by Drain Pit 5 releases and by several scrubber slurry and return water pipeline releases in the alluvial drainage northeast of Drain Pit 5. This groundwater migrates in alluvium down the drainage toward the DP-5 groundwater capture system and Cow Creek. There is also potential input into the alluvial system from spoil located upgradient of Drain Pit 5.

Impacted groundwater appears ultimately to reach one of many groundwater interception/capture systems surrounding the EHP. In the past, impacted groundwater seeped to the surface locations including the SFCC Seep, West Seep, Seep SP-15, 552D Seep, and North EHP Seep (Hydrometrics, 2016a). Subsequent groundwater capture efforts have eliminated surface flows at all of these locations.
### 3.0 NUMERICAL GROUNDWATER MODEL

The Units 3 & 4 EHP numerical model described in this report (referred to as the “current” Units 3 & 4 EHP model) is designed to serve as a tool to assess the effectiveness of the groundwater capture well and trench systems installed at the Units 3 & 4 EHP area as well as provide a better understanding of the influence of the Units 3 & 4 EHP cells ponds on groundwater flow and water quality. The current Units 3 & 4 EHP model includes refinements to the previous model developed by NewFields (2013). The primary refinements include adjustments to model boundaries, layer elevations, and assignment of model properties based on data collected through October 2015. The model layer elevations were refined to more accurately reflect observed lithology in new wells installed in the area. The conceptual model described in Section 2.0 provides the foundation for the refinements made in the development and parameterization of the current Units 3 & 4 EHP model.

NewFields used hydrologic data sets to specify boundary conditions for several time periods for the Units 3 & 4 area. The simulated time periods for the current model are:

- **2003 Steady-State (January)** – represents conditions prior to flooding of Cells F and H in 2003 and 2004;
- **February 2003 through December 2006 Transient** – incorporates a period when large changes in transient aquifer stresses occurred, including flooding of Cells F and H; and
- **2015 Steady-State (October)** – includes the most recent comprehensive data set available.

The three time periods are simulated with three separate models of identical construction but with different pumping, recharge, and pond specifications that represent the time period simulated. Following calibration, the model was used to assess the effectiveness of capture systems. The model code, design, and calibration of the Units 3 & 4 EHP model are discussed below.

#### 3.1 Code Selection

The current Units 3 & 4 EHP model was developed using the U.S. Geological Survey (USGS) code MODFLOW-SURFACT Version 3 (HydroGeoLogic, 1998 and 2006). MODFLOW-SURFACT was used because it allows for variable saturation (described below). The USGS code MODPATH Version 3 (Pollock, 1994) was used to assess capture by simulation of advective transport of constituents in groundwater. The graphical-user-interface software Groundwater Vistas© (Version 6.82, Build 3) was used for model pre- and post-processing.

#### 3.2 Model Domain

The model domain is 30,300 feet (5.74 miles) by 12,400 feet (2.35 miles) and the margins are based on hydraulic boundaries. The shape of the model domain was developed in an attempt to have model boundaries generally parallel or perpendicular to groundwater flow. The model is bounded to the north by Cow Creek, to the south by South Fork Cow Creek, to the west by the Drain Pit 5 drainage and extends east to the confluence of Cow Creek and South Fork Cow Creek (Figure 3-1). The current model domain is identical to the model domain used in NewFields (2013).
The model contains 182 rows, 355 columns, 8 layers, and 516,880 cells (Figure 3-2). The majority of the model has a 100-foot column and row spacing. In one area of the model (560A drainage), the grid spacing is refined to 25-foot column and row spacing. The finer grid-spacing was implemented for a previous modeling effort that was evaluating the area northeast of the ponds and was not revised for this version of the model. Future model spacing revisions will be considered and discussed with DEQ when the current model is updated.

### 3.3 Model Layers

The current model domain was subdivided into eight layers, the same as the previous version (NewFields, 2013). However, layer elevations were updated from the previous model version using data from wells installed since 2012. Model layers are summarized (top to bottom) as follows:

- **Layer 1** is inactive with the exception of four small areas that are used to simulate overland flow in the transient simulation in areas of the SFCC Seep, West Seep, and two areas along the southern cutoff wall.

- **Layer 2** represents alluvium and colluvium in alluvial channels and Rosebud/Clinker and Coal in and around the EHP and east of the EHP. Layer 2 is between about 25 and 90 feet thick and has a bottom elevation between 3,230 and 3,240 feet amsl around the EHP.

- **Layer 3** represents alluvium, colluvium, and Interburden between the Rosebud and McKay coal. The majority of Layer 3 is between 10 and 20 feet thick with a bottom elevation between 3,210 and 3,220 feet amsl around the EHP.

- **Layer 4** represents alluvium, colluvium, and McKay Coal. This layer has a bottom elevation between 3,200 and 3,220 feet amsl and is between 5 and 15 feet thick around the EHP.

- **Layer 5** represents shallow Sub-McKay and is between 40 and 100 feet thick with a bottom elevation of approximately 3,100 feet amsl.

- **Layers 6 and 7** represent deep Sub-McKay and are both approximately 50 feet thick.

- **Layer 8** represents deep Sub-McKay bedrock and is 150 feet thick with a bottom elevation between approximately 2,870 and 2,710 feet amsl.

Ground surface was interpolated using a USGS digital elevation model (DEM) and is represented in Layers 1 through 5 of the model. Layer bottom elevations were established primarily as the contact between different strata including fine and coarse grained alluvium, major coal, sandstone, and siltstone strata as described in Section 2.1.2 and presented on Figure 2-1 and Figure 2-2. Major continuous coal, sandstone, and siltstone strata are typically represented within a single layer. However, these major strata are not typically laterally or vertically continuous and entire layers do not represent distinct aquifer (high permeable) or confining (low permeable) units. The Sub-McKay unit was further divided to provide greater resolution for heads and flow, and to better match the screened intervals of monitoring and capture wells.

The layer elevations extend from ground surface, at a maximum of 3,342 feet amsl, to the bottom of Layer 8 at an elevation of 2,709 feet amsl. A list of wells referenced in Section 2.0 and used in the numerical model are provided in Appendix H along with the associated model layer or layers.
Two of the cross-sections presented in Section 2.0 are repeated on Figure 3-3 and Figure 3-4 showing the model layers and associated units. Alluvium was split between three model layers (Layers 2, 3, and 4) to accommodate bedrock layers pinching out due to erosion. Layer 2 of the model simulates flow in the Rosebud/Clinker and shallow colluvium/alluvium near the land surface. Model Layer 3 represents Interburden and middle colluvium/alluvium. Model Layer 4 represents the McKay coal and deep colluvium/alluvium. Layers 5 through 8 represent the Sub-McKay bedrock through the Sub-Robinson bedrock.

Model layer elevations were adjusted in several portions of the model based on lithologic contacts from well logs for new wells installed since 2012 (wells 1153A through 1171R, see Table 2-10). Adjustments were made such that layer transitions corresponded with lithologic contacts. The lithologic contact elevations at all new wells, with the exception of 1165D through 1167D, required local adjustment of the bottom of Layer 2 (top of Layer 3). Similarly, lithologic contact elevations at all wells drilled below the Rosebud required local adjustment of the bottom of Layers 3 (top of Layer 4) and 4 (top of Layer 5).

For the variably saturated option in MODFLOW-SURFACT, layer types must be defined as either Type 3 or Type 0. Model Layers 1 through 5 are simulated as Type 3 layers (convertible layers), which allow transmissivity to vary depending on saturated thickness and simulate groundwater flow under either confined or unconfined conditions. Layers 6 through 8 are simulated as type 0 (confined) layers.

3.4 Boundary Conditions

The groundwater flow system was established by assigning model boundaries to the model domain. Model boundaries coincide with natural and artificial hydrologic boundaries that include groundwater flow into and out of the active model domain, areas where groundwater flow is restricted, and areas of parallel groundwater flow. The boundaries established for the current model represent the many stresses affecting the aquifer that create a complex flow field. Assigned boundary conditions are presented on a series of figures in Appendix I and are described below.

3.4.1 General Head Boundaries

The General Head Boundary (GHB) Package was used to represent groundwater underflow into and out of the active model domain, a stock pond located on South Fork Cow Creek, and water entering the model domain from mine spoils west of the EHP near two mine cuts near the Drain Pit 5 drainage. A GHB is a head-dependent boundary where the flow into or out of the model is equal to the difference between the head in the model cell and the head at a distance from the model boundary times the estimated conductance of the GHB. The conductance is estimated by the following equation:

\[
\text{Conductance} = \frac{WTK}{L}
\]

Where: \(W\) = Width of cell
\(T\) = Saturated thickness of cell
\(K\) = Hydraulic conductivity
\(L\) = Distance to the assigned head value
GHB cells were assigned to match observed and inferred underflow into and out of the model domain as depicted on the potentiometric surface maps (Figure 2-10 through Figure 2-15). The boundaries were established far enough from the EHP area to minimize potential boundary influences on the model results. GHB cells representing underflow into and out of the model domain were placed along the edge of the model domain in Layers 6 through 8 and portions of Layers 2, 3, 4, and 5 (Appendix I). Interpolated potentiometric lines along the southwest margin of Layer 5 (Figure 2-12 and Figure 2-15) are perpendicular to the model domain indicating there is no groundwater flow into or out of the model in this area. The outer edge of the domain in this area was assigned as a no-flow boundary (Figures I-5 and I-11 in Appendix I). GHB cells representing groundwater flow into the model domain from the two mine cuts located along the western edge of the model domain were placed in Layers 2 and 3. One GHB cell in Layer 2 was used to represent a stock pond on South Fork Cow Creek.

The assigned GHB parameters are provided in Appendix J. The hydraulic conductivity value assigned to GHB cells is 1 foot/day and the area and thickness of the GHB cells are equal to the cell size. A distance of 100 feet is used for the GHB cells to create a gradient across the model boundary. Head for GHB cells is assigned based on interpolated potentiometric lines for the Sub-McKay. Groundwater elevations measured in wells screened in deep Sub-McKay layers (Layers 6, 7, and 8) are similar between 2003 and 2015. Heads values for GHB cells in Layers 6, 7, and 8 were assigned based on observed groundwater elevations for wells screened in these layers, and the same values were used for 2003 and 2015.

GHBs are used also to simulate groundwater flow into the model domain in Layers 2 and 3 from two mine cuts on the western boundary of the model and a stock pond near well PSW-4A near South Fork Cow Creek (Appendix I). Head in these features is set to land surface and the area is equal to the cell size. The hydraulic conductivity is 1 foot/day for stock ponds and 10 feet/day for mine cuts. A distance of 100 feet is used for the GHB cells to create a gradient across the model boundary.

3.4.2 Constant Flux Boundaries

Constant flux boundary (Well Package) cells are used to simulate tributary underflow to the Cow Creek drainage Layer 4 (Figures I-4 and I-10 in Appendix I). Flux rates were estimated using Darcy's Flux Equation which uses hydraulic conductivity, area, and hydraulic gradient to calculate flow. Hydraulic conductivity was estimated from aquifer tests in alluvial wells and ranges between 4 and 550 feet/day (Appendix K). Hydraulic gradient and area were estimated using aerial images, and depth was assumed to be between 10 and 20 feet. Estimated flux ranges between 53 and 68,095 feet³/day. Minimum values were initially used for the simulations and then adjusted during the calibration process to reduce target residuals.

3.4.3 No-Flow Boundaries

No-flow boundaries are assigned along the perimeter of the active model domain where the groundwater flow direction is assumed to be parallel to the model boundaries, and in cells that are above ground surface. The no-flow boundaries were established using the potentiometric surface maps discussed in Section 2.4.1, above.
3.4.4 River Package Boundaries

The River Package was used to simulate seepage from evaporation ponds (Appendix I). The River Package is a head-dependent boundary condition that allows water to move into and out of the model cell based on the difference between the groundwater elevation and surface water stage. A conductance assigned to the river cell restricts the flow rate exchange. The conductance is estimated by the following equation:

\[
\text{Conductance} = \frac{KLW}{D}
\]

Where:

- \( K \) = Hydraulic conductivity
- \( L \) = Length of cell
- \( W \) = Width of cell
- \( D \) = Riverbed Thickness

Horizontal distribution of River Package cells is based on the apparent wetted perimeter from aerial photographs of the Units 3 & 4 EHP from 2003, and the apparent footprint of the ponds in 2015 (Appendix I). River Package cells in the 2003 simulation represent Cells A, B, C, G, and the old Clearwell (Cell F did not contain water in 2003). In the 2015 simulation, River Package cells were used to represent Cells C, G, and the old Clearwell (Cells H, B, and F were lined in 2013, 2009, and 2005, respectively and seepage is simulated using the Recharge Package in the 2015 simulation). For the 2015 simulation, it was assumed that, although water was not present at the surface, water was stored in the fly ash in the ponds and was contributing to groundwater (see Section 2.6.3). River Package cells are distributed vertically in Layers 2 through 5 based on the layer in which the original ground surface (prior to EHP construction) occurs within the model.

Parameter specifications for the ponds are included in Appendix L. Stage (head) for River Package cells in the 2003 simulation was assigned based on average January 2003 pond level measurements, and stage in the 2015 simulation was assigned based on average October 2015 pond level measurements (Appendix C). Bed thickness of the River Package cells was assigned based on the thickness of fly ash and paste as measured during bathymetric surveys conducted in 2005 (Hydrometrics, 2011) and 2013 (Hydrometrics, 2014). Hydraulic conductivity of the bed material (fly ash) was set to 0.0283 feet/day (Geomatrix, 2005) and the wetted cross-sectional area is set to the cell size. Stage, hydraulic conductivity, and thickness were adjusted during calibration (see Section 4.0).

3.4.5 Barriers

The cutoff wall around the Units 3 & 4 EHP area was simulated with MODFLOW’s Horizontal Flow Barrier (HFB) Package (Hsieh and Freckleton, 1993, Appendix I). This package implicitly represents a narrow (relative to the width of a model cell) feature between model cells with a lower hydraulic conductivity than adjacent cells. The model code calculates total conductance between adjacent model cells with user-specified width and hydraulic conductivity of the barrier, and widths and hydraulic conductivities of adjacent model cells. The HFB features representing the cutoff well around the EHP are in Layers 2 and 3 south and west of the EHP, and Layers 2 through 4 north and east of the EHP. The HFB features were assigned a width of 2.5 feet and an initial hydraulic conductivity of 0.00283 feet/day. Hydraulic conductivity was adjusted during calibration based on observed groundwater levels around the cutoff wall (see Section 4.0).
3.4.6 Wells

The Units 3 & 4 EHP area capture wells are simulated with MODFLOW’s Well Package and MODFLOW-SURFACT’s Fracture Well 5 (FWL5) Package (HydroGeoLogic Inc., 2006). The Well Package is a constant flux boundary used to simulate constant recharge or discharge from the groundwater system. Each Well Package cell is assigned a specified flux at which it will add or remove water from the groundwater system. The FWL5 Package, an alternative to the Well Package, was used for certain wells in the model because it is capable of representing wells that are screened across multiple model layers. Use of the FWL5 package can cause numerical instability but it has several characteristics that the standard Well Package does not have, including:

1. The well pumping rates are automatically allocated between layers penetrated by the well screen. Assigned rates are based on the simulated water level in the FWL5 well, the simulated water level in each screened model cell layer, and the thicknesses and hydraulic conductivities of each screened model cell layer;
2. When the groundwater level in the well drops below the bottom of the layer, the pumping rates are automatically reallocated to lower layers; and
3. If the water level drops below the pumping level, the flow rate is decreased until the pumping level is maintained.

Locations of active pumping wells are shown on Figure 3-5 (2003 steady-state model), Figure 3-6 (2003-2006 transient model), and Figure 3-7 (2015 steady-state model). Appendix G lists capture wells and initial pumping rates for the 2003 and 2015 steady-state models.

As discussed in Section 2.6.6, initial steady-state pumping rates for wells are set between 35 and 85 percent of reported pumping rates based on recommendations from Hydrometrics. The average pumping rates from October, November, and December 2002 were used for the 2003 steady-state simulation and the average pumping rate from July, August, and September 2015 were used for the 2015 steady state simulation (Appendix G). Pumping rates were adjusted during calibration (see Section 4.0).

3.4.7 Drains

Trench systems and seeps in the Units 3 & 4 EHP area are represented in Layers 2 through 5 using the MODFLOW Drain Package, the same as in the previous model (NewFields, 2013). The Drain Package is a head-dependent boundary that removes water from the model based on head in the aquifer and a user-defined drain elevation. The locations of the Drain Package cells in the model are shown on figures in Appendix I and parameter specifications for the drains are included in Appendix M.

Hydraulic conductivity for Drain Package cells ranged between 10 and 100 feet/day and elevation and spatial distribution of the cells were set using survey and as-built data, respectively. Simulated trenches include: 560A Trench, 1079A Trench, 1073A Trench, Drain Pit 5 Trench, SP-15 North and South Trenches, Secondary Sump, Saddle Dam Interception Trench, and the Main Dam Sump Capture System (Figure 1-2). In addition, the 1172D Trench, which began operating in April 2016, was included in the capture analysis (see Section 6.0).
3.4.8 Recharge

Multiple recharge zones were established throughout the model domain to simulate areal recharge from precipitation. Recharge zones specified in the model are shown on Figure 3-8 (2003 steady-state model) and Figure 3-9 (2015 steady-state model).

Recharge was assigned to the model using the MODFLOW Recharge Package. In the model, Recharge Package cells were assigned values representing net recharge (infiltration – evapotranspiration). Recharge areas were assigned initial rates based on the conceptual model (Section 2.6.2), and are summarized below.

Areal recharge to the model represents net infiltration or deep percolation (precipitation minus evapotranspiration and runoff) for areas not occupied by River Package Cells representing ponds (see Section 3.4.4). Areal recharge zones were assigned rates based on the conceptual model (Section 2.6.2). Recharge was assigned to zones with different geologic materials at the surface:

- Clinker;
- Alluvium;
- Overburden, Interburden, coal, Sub-McKay;
- Regraded surface; and
- Seepage from lined ponds (Cells B, F, and H).

In addition, the Recharge Package was also used to simulate seepage from a small Stock Pond near Cow Creek and well 1125D.

Initial recharge rates for the 2003 and 2015 steady state simulations are based on estimates discussed in Section 2.6.2. Recharge rates were adjusted during calibration (see Section 4.0).

3.5 Aquifer Parameters

Aquifer parameters assigned in the model consist of hydraulic conductivity, aquifer storage, and effective porosity. Parameter values were assigned to model cells based on the hydrostratigraphy of the subsurface delineated for the conceptual model described in Section 2.1.3.

3.5.1 Hydraulic Conductivity

Horizontal hydraulic conductivity (K_h) zones were developed using information obtained from lithologic logs, literature values, aquifer tests, and observed groundwater flow patterns. Geometric mean hydraulic conductivity values from field tests collected for the various hydrostratigraphic units (see Section 2.1.4) were assigned to the various units in the model as initial estimates. Zones of relatively higher hydraulic conductivity were assigned to alluvium and sandstone bedrock; zones of relatively lower hydraulic conductivity were assigned to finer-grained bedrock (e.g., siltstone and claystone).

The vertical hydraulic conductivities (K_v) of sedimentary rocks and unconsolidated deposits are generally less than the horizontal hydraulic conductivity. This phenomenon is caused by the original sediments
being deposited in horizontal layers and vertical compaction of sediments by the weight of overlying deposits.

Vertical hydraulic conductivity is commonly expressed as the ratio of horizontal to vertical hydraulic conductivity ($K_h:K_v$). Initial model values for the $K_h:K_v$ ratio were set at ranges between 10:1 and 100:1 based on the hydrostratigraphic unit.

Hydraulic conductivity zones representing lithologic units were further subdivided during calibration and the values assigned to these zones were adjusted within the measured ranges in order to meet calibration goals. The final calibrated hydraulic conductivity is described in Section 4.0. Hydraulic conductivity values from pumping test analyses for specific wells were honored in the model. In specific areas, low hydraulic conductivity zones were placed between capture wells to simulate the lack of hydraulic communication between some wells as part of the transient calibration process.

### 3.5.2 Aquifer Storage

Steady-state simulations do not involve aquifer storage parameters because groundwater is not released or stored from aquifers under steady-state conditions. For transient groundwater flow simulations, the movement of groundwater to and from storage in aquifer materials must be considered. Storativity of and unconfined aquifer is equivalent to specific yield. Storativity of a confined aquifers is a product of specific storage multiplied by aquifer thickness.

In an unconfined aquifer the storage or release of water is due to the specific yield, which represents the drainable portion of porosity below the water table. Specific yield values assigned to the model were based on material properties described in the available well logs and on reported literature values. Specific yield from the literature for various geologic material include the following:

- **Gravelly Sand**: 0.2-0.35 (Fetter, 1994);
- **Silt**: 0.03-0.19 (Fetter, 1994);
- **Clay**: 0-0.05 (Fetter, 1994); and
- **Siltstone**: 0.009-0.327 (Morris and Johnson, 1967).

Specific storage, which is what is input into the model, represents the volume of water stored or released from a confined aquifer per unit change in hydraulic head due to the compressibility of the aquifer matrix. Domenico and Mifflin (1965) list the following ranges of specific storage:

<table>
<thead>
<tr>
<th>Material</th>
<th>Specific Storage (ft$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plastic clay</td>
<td>$7.8 \times 10^4$ to $6.2 \times 10^3$</td>
</tr>
<tr>
<td>Stiff clay</td>
<td>$3.9 \times 10^4$ to $7.8 \times 10^4$</td>
</tr>
<tr>
<td>Medium hard clay</td>
<td>$2.8 \times 10^4$ to $3.9 \times 10^4$</td>
</tr>
<tr>
<td>Loose sand</td>
<td>$1.5 \times 10^4$ to $3.1 \times 10^4$</td>
</tr>
<tr>
<td>Dense sand</td>
<td>$3.9 \times 10^5$ to $6.2 \times 10^5$</td>
</tr>
<tr>
<td>Dense sandy gravel</td>
<td>$1.5 \times 10^5$ to $3.1 \times 10^5$</td>
</tr>
<tr>
<td>Rock, fissured</td>
<td>$1 \times 10^5$ to $2.1 \times 10^5$</td>
</tr>
<tr>
<td>Rock, sound</td>
<td>$&lt; 1 \times 10^6$</td>
</tr>
</tbody>
</table>
Initial values of specific yield and storativity were assigned to each hydraulic conductivity zone and adjusted during calibration. The calibrated storage parameters are described in Section 4.0.

3.5.3 Effective Porosity

Particle tracking (presented in Section 6.0) requires assignment of effective porosity values. The range of values for effective porosity based on literature for the various lithologic units are presented in Table 3-1. Final porosity values and uncertainty related porosity estimates is discussed in Section 6.0).

<table>
<thead>
<tr>
<th>Lithology</th>
<th>Effective Porosity Range</th>
<th>Effective Porosity Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gravelly Sand</td>
<td>0.2-0.35</td>
<td>Domenico &amp; Schwartz (1990)</td>
</tr>
<tr>
<td>Fine Sand</td>
<td>0.1-0.3</td>
<td>Domenico &amp; Schwartz (1990)</td>
</tr>
<tr>
<td>Silt</td>
<td>0.01-0.3</td>
<td>Domenico &amp; Schwartz (1990)</td>
</tr>
<tr>
<td>Clay</td>
<td>0.01-0.2</td>
<td>Domenico &amp; Schwartz (1990)</td>
</tr>
<tr>
<td>Siltstone</td>
<td>0.01-0.35</td>
<td>Domenico &amp; Schwartz (1990)</td>
</tr>
<tr>
<td>Coal</td>
<td>0.008-0.09</td>
<td>Brown and Parizek (1971),</td>
</tr>
<tr>
<td>Sandstone and siltstone</td>
<td>0.01-0.4</td>
<td>Domenico &amp; Schwartz (1990)</td>
</tr>
</tbody>
</table>

### Table 3-1. Summary of Effective Porosity Values from Literature

3.6 SUMMARY OF MODEL CHANGES

The conceptual model described in Section 2.0 provides the foundation for the development and parameterization of the current Units 3 & 4 EHP numerical model. The development of the current Units 3 & 4 EHP model was performed using the previous Units 3 & 4 EHP model documented in NewFields (2013) and applying refinements based on the updated conceptual model as discussed in Section 2.0. The primary changes incorporated in the current Units 3 & 4 EHP model include the following:

- **Layer Elevations**: As described in Section 3.3, model layer elevations were adjusted in several portions of the model based on lithologic contacts from well logs for new wells installed since 2012 and to better represent hydrostratigraphy and hydraulic communication;
- **Recharge**: Recharge zones within the ponds were revised based on changes in pond configuration, pond management practices, and liner advancements. Additional recharge zones were added to represent Cells F and H in the 2003 simulation, and Cells, B, F, and H, and an area of higher recharge to Clinker in the 2015 simulation;
- **Pumping Rates**: Pumping rates were adjusted to reflect more recent estimates;
- **Pumping Wells**: Additional pumping wells were added to the model to reflect expansion of the capture system between 2013 and October 2015; and
- **Calibration Data**: The model was calibrated to new data sets and the data sets were revised to represent January 2003 and October 2015 steady-state conditions.
4.0 MODEL CALIBRATION

Model calibration involves finding a combination of boundary conditions, input parameters, and stresses that generate head and flux values throughout the model that match field-measured head and flux values and achieve the calibration goals, as outlined below. Groundwater model development and calibration were conducted in general accordance with standard industry practices, such as described in Anderson et al. (2015).

Following refinement of the model framework and boundary conditions, and assignment of initial input parameters (Section 3.0), the model was calibrated to provide confidence in its ability to simulate groundwater flow under different conditions and to meet project objectives. The calibration process required first establishing a set of calibration targets and goals. Model inputs were then adjusted iteratively within appropriate ranges based on measured data to achieve a reasonable match between observed and simulated target values. The quality of the match was judged using both quantitative and qualitative methods.

The model calibration process involved adjusting uncertain input parameters within reasonable ranges to reduce the difference between measured and simulated target values. It is noted that achieving calibration does not guarantee the set of input parameters selected is unique and that other plausible inputs would not achieve similar calibration results. However, calibration and verification of the model to several independent and different sets of both steady-state and transient target data increase confidence in the model’s capability to simulate groundwater flow under a variety of aquifer conditions.

4.1 DEVELOPMENT OF CALIBRATION TARGETS AND DATA SETS

Both qualitative and quantitative targets were developed as part of the calibration process. Qualitative targets include potentiometric surface maps that were developed based on measured groundwater elevations, hydrographs of groundwater elevations over time, and time-drawdown plots from aquifer tests.

Quantitative targets used to calibrate the model include measured water levels and estimated groundwater flux into and out of the model domain. The following independent steady-state and transient hydrologic data sets were used to establish calibration targets:

- Heads and fluxes for the period of January 2003. Head targets were supplemented with additional groundwater level data measured at other times to provide greater spatial coverage (Steady-State);
- Time variant heads and fluxes measured between February 2003 and December 2006 (Transient); and
- Heads and fluxes for the period of October 2015. Head targets were supplemented with additional groundwater level data measured at other times to provide greater spatial coverage (Steady-State).
As discussed in Section 2.4.1, data from other time frames were included to provide spatial coverage. While these water levels may introduce some uncertainty in the calibration in the areas they represent due to seasonal fluctuations, the variation is likely to be small and these provide important calibration point locations.

### 4.1.1 2003 Steady-State Calibration Data Set

Appendix N presents 2003 steady-state calibration target values along with the dates they were measured. Head targets for the 2003 steady-state model were established from water levels measured primarily in January 2003. Several wells that were not monitored in January 2003 were also used as head targets to provide additional spatial coverage for calibration. For these wells, the groundwater elevation measured in 2002 that was closest to January 2003 was used as the target head value. A total of 107 head targets were used in the 2003 steady-state model, which are listed in Appendix N.

Estimated fluxes in the 2003 water budget (Table 2-5) were used as flux targets for the 2003 steady-state model. The water budget includes estimates of groundwater underflow, EHP seepage, areal recharge, groundwater capture (from drains and wells), and seepage from stock ponds.

In addition to the target head and flux data, the 2003 potentiometric surfaces discussed in Section 2.4.1 were used to qualitatively evaluate model calibration based on the observed closeness of fit between simulated and observed potentiometric surfaces maps.

### 4.1.2 February 2003 – December 2006 Transient Calibration Data Set

The transient calibration period includes the time when Cells F and H were flooded to enhance evaporation. This flooding led to an increase in groundwater levels in and surrounding the EHP as well as the formation of the SFCC Seep and West Seep. The period also includes response actions taken by Talen following the end of flooding in Cells F and H, when several surface and groundwater capture systems were constructed to capture groundwater that migrated beyond the cutoff wall as a result of flooding. This flooding and response action period represents an ideal transient calibration data set because there were substantial changes in inflows to and outflows from the groundwater system.

A total of 154 target locations with a total of 2,932 target head values were used in the 2003-2006 transient model for calibration. In addition to groundwater elevation targets, measured flux at the surface water capture systems installed at the West Seep and SFCC Seep were used as targets.

### 4.1.3 2015 Steady-State Calibration Data Set

Appendix O presents 2015 steady-state calibration target values along with the dates they were measured. Head targets for the 2015 steady-state model were established from water levels measured primarily in October 2015. The water level data set was taken from a time which exhibited relatively low precipitation and fairly stable groundwater elevations when transient stresses were at a minimum. The head target data set was supplemented with additional groundwater level data measured at other times in 2015 to provide greater spatial coverage. A total of 233 head targets were used in the 2015 steady-state calibration.
The calculated fluxes associated with the water budget for October 2015 (Table 2-5) were used as flux targets for the 2015 steady-state calibration. A description of the components of water budget for October 2015 is discussed in Section 2.6.

In addition to the target head and flux data, the 2015 potentiometric surfaces discussed in Section 2.4.1 were used to visually calibrate the observed closeness of fit between simulated and observed potentiometric maps.

### 4.1.4 Calibration Goals

A set of both quantitative and qualitative criteria was established as goals to assess how well the model was calibrated. Statistics of calibration residuals, or the difference between the model simulated and the observed target values, for each head target were used as goals, along with boundary fluxes and qualitative measures. Steady-state and transient goals for the steady-state models are summarized below.

**Steady-State Calibration Goals**

- The absolute residual mean for head targets (average absolute value of the difference between simulated and target head values) should be less than 2.0 feet (Quantitative);
- The residual mean for head targets (average difference between simulated and target head values) should be close to zero (Quantitative);
- The residual standard deviation divided by the range in head values should be less than 5 percent (Quantitative);
- The absolute value of residuals should be ≤ 5 feet (Quantitative);
- Simulated groundwater flux into and out of the model should be within the range of flux estimated as part of the conceptual model water balance (Quantitative); and
- Visual observations should reveal that the simulated and observed potentiometric maps are a close fit (Qualitative) taking into account the spatial distribution of observed data points used to develop the potentiometric surface maps.

**Transient Calibration Goals**

- Residual statistics should fall within criteria established for steady-state calibration described above (Quantitative);
- Simulated groundwater flux at the SFCC Seep and West Seep should generally match flux measured at surface water capture systems (Semi-Quantitative); and
- Hydrographs of simulated groundwater elevations vs. time should match those based on field-measured values in timing and magnitude of groundwater level changes (Qualitative).

### 4.2 Calibration Process and Results

During calibration, different input parameters are varied iteratively within a plausible range of values to minimize residuals, which are the difference between simulated and target values. Calibration was
achieved using both manual and automated techniques to vary input parameters based on field measurements and literature values described in Section 2.0. Results of each calibration simulation were then evaluated to determine if the input parameter adjusted during that run achieved a better or worse match to calibration targets. Calibration results were evaluated using both quantitative and qualitative methods and completed iteratively between the transient and steady-state models. Residuals and residual statistics were calculated after each model run and used as a measure of the overall match between simulated and observed conditions.

As discussed above, qualitative methods applied to the calibration process included visually comparing potentiometric surface maps or hydrographs generated by the model to those based on target values. The quality of the match through application of these comparisons was then judged by the modeler (Anderson et al., 2015).

Changes made to non-transient inputs that improved calibration statistics in one of the three calibration schemes were subsequently applied to the model for use in the other two calibration simulations. If the changes improved calibration in all schemes evaluated, the changes were retained and the calibration process continued. Particle tracking was performed intermittently to confirm particles released in the pond area (contaminant source area) traveled to areas of known contamination and did not travel to areas known to be free of contaminants.

Input parameters that were varied during calibration (listed in order of priority to model calibration) were as follows:

- Hydraulic conductivity (varied within ranges described for each hydrostratigraphic unit in Section 2.1.4);
- Conductance of head dependent (River Package) boundary cells representing EHP seepage (varied within ranges estimated to reflect changes in pond management);
- Capture well pumping rates (generally within ±50 percent of estimates provided by Hydrometrics in Appendix G);
- Recharge (varied within estimated range provided Section 2.6);
- Storage (only adjusted in transient calibration; varied within ranges reported from aquifer tests in Appendix A and literature values for similar lithologies); and,
- Cutoff wall permeability.

The most frequently adjusted parameter during steady-state calibration was hydraulic conductivity. The hydraulic conductivity component of the conductance of head dependent boundaries (River Package) representing EHP seepage was also adjusted within reasonable ranges. During transient calibration, pumping rates for some capture wells and storage parameters were adjusted most. Particle-tracking was periodically performed to check the match between simulated and observed movement of process pond-affected groundwater.
4.2.1 Calibrated Parameter Distributions

This section describes the distribution of parameters that remain constant in all model calibrations periods. The distribution of recharge, which varies for each calibration period, is described in Sections 4.2.2, 4.2.3, and 4.2.4 below.

Figure 4-1 through Figure 4-7 show the final calibrated distribution of horizontal hydraulic conductivity zones for Layers 2 through 8, respectively. Appendix P presents the horizontal and vertical hydraulic conductivity values and corresponding lithologic unit for each of these zones. Calibrated hydraulic conductivity values are the same for all model calibration periods. Final calibrated hydraulic conductivity values generally fall within the estimated range of values for the corresponding hydrostratigraphic units described in Section 2.0, as summarized in Table 4-1.

Table 4-1. Final Calibrated and Measured Horizontal Hydraulic Conductivity Values

<table>
<thead>
<tr>
<th>Aquifer Material</th>
<th>Calibrated Horizontal Hydraulic Conductivity of Zones Representing Various Aquifer Materials (feet/day)</th>
<th>Hydraulic Conductivity as Summarized in Table 2-1 (feet/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Min</td>
<td>Max</td>
</tr>
<tr>
<td>Alluvium</td>
<td>0.5</td>
<td>350</td>
</tr>
<tr>
<td>Rosebud/Clinker</td>
<td>1</td>
<td>5,000</td>
</tr>
<tr>
<td>McKay</td>
<td>0.001</td>
<td>20</td>
</tr>
<tr>
<td>Sub-McKay</td>
<td>0.001</td>
<td>125</td>
</tr>
</tbody>
</table>

* This is the geometric mean of the zone values used to represent this material in the model. It is not weighted spatially.

Ratios of horizontal to vertical hydraulic conductivity (K\textsubscript{h}:K\textsubscript{v}) in the model vary considerably. The K\textsubscript{h}:K\textsubscript{v} ratios used in most of the model range from 5:1 in unconsolidated sedimentary deposits (e.g., alluvium) to 250,000:1 for deeper bedrock, although there are some areas of the model where the ratio is as low as 1:1. The K\textsubscript{h}:K\textsubscript{v} ratios for coal (McKay and Rosebud) range from 1:1 to 5,000:1 and the K\textsubscript{h}:K\textsubscript{v} ratios for clinker range from 1:1 to 30,000:1. The clinker, while having increased permeability in places, also contains ash at its base as a result of the burning of the parent coal material. The ash results in a drastically reduced vertical hydraulic conductivity at the base of the unit. The K\textsubscript{h}:K\textsubscript{v} ratios incorporated into the model are typically supported by literature values. For example, Todd (1980) reported K\textsubscript{h}:K\textsubscript{v} ratios can range from 10:1 to 1,000:1 in alluvium. Anisotropy ratios of shales can range from 50:1 to 5,000:1 depending on the scale measured (Cosan et al., 1994), and are also reported to range from 1,220:1 (formations with thick and frequent shales) to 100:1 (sandstone formations with short, thin, and frequent shales; Burton and Wood, 2013). These values are also consistent with other numerical models of the area (Nicklen Earth and Water, 2011).

In the Fort Union Formation, vertical anisotropy is greatly influenced by bedding planes and the sedimentary processes that formed interfingered sandstone, shale, mudstone, and coal strata. The K\textsubscript{v} of a given section of the Fort Union Formation is primarily controlled by the units in that section with the lowest K\textsubscript{v} and its degree of lateral continuity, whereas the K\textsubscript{h} will be controlled by the higher permeable units. Nicklin Earth and Water (2014) estimated K\textsubscript{h}:K\textsubscript{v} in some of the Fort Union interbedded sandstone and mudstone units of as high as 2,000,000:1. However the presence of vertical fractures can greatly influence the anisotropy of the bedrock layers and reduce the K\textsubscript{h}:K\textsubscript{v} ratio.
Vertical anisotropy will typically vary between different hydrostratigraphic units. The Sub-McKay units have a range of $K_h$, dictated by whether there are greater amounts of sandstone or shale/mudstone. It was necessary to assign lower $K_v$ in order to match measured vertical hydraulic gradients between the shallow and deep Sub-McKay. The steep vertical gradients may be explained by the presence of thicker, more continuous low permeability layers (shale/mudstone) in the deeper Sub-McKay and thicker more continuous packages of sandstone in the shallower Sub-McKay.

Calibrated storage values for the transient model (Table 4-2) are within estimated ranges of values (Section 3.5). During the transient calibration, specific yield in several areas was adjusted to match the timing and magnitude of water level changes observed during the calibration period. Alluvium was initially assigned a specific yield of 0.10. Most alluvium has a calibrated specific yield value of 0.05. Alluvium in South Fork Cow Creek between wells 1021A and 608A, near the Drain Pit 5 trench and north of the Main Dam has specific yield of 0.10. A small area of alluvium in Layer 4 near wells 672A and 681A has a specific yield of 0.4. Rosebud/Clinker was initially assigned a specific yield of 0.05. Calibrated specific yield values in Rosebud/Clinker range from 0.01 to 0.4. The McKay unit was initially assigned a specific yield value 0.05. Calibrated specific yield values for the McKay unit ranges from 0.01 to 0.25. Sub-McKay bedrock was initially assigned a specific yield of 0.05. The calibrated range of specific yield for Sub-McKay material is 0.01 to 0.25.

Alluvium was initially assigned a specific storage value of $3 \times 10^{-5}$. A few areas of alluvium were adjusted to $5 \times 10^{-4}$ during calibration. Sub-McKay bedrock was initially assigned a specific storage value of $1.5 \times 10^{-5}$. These values were adjusted during calibration and the final calibrated storage parameters are presented in Table 4-2.

### Table 4-2. Final Calibrated Storage Parameter Values

<table>
<thead>
<tr>
<th>Unit</th>
<th>Specific Storage (unitless)</th>
<th>Specific Yield (unitless)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alluvium</td>
<td>$3 \times 10^{-5} - 5 \times 10^{-4}$</td>
<td>0.01 - 0.4</td>
</tr>
<tr>
<td>Coal</td>
<td>$1 \times 10^{-6} - 1.5 \times 10^{-3}$</td>
<td>0.01 - 0.25</td>
</tr>
<tr>
<td>Clinker</td>
<td>$5 \times 10^{-4}$</td>
<td>0.01 - 0.4</td>
</tr>
<tr>
<td>Bedrock</td>
<td>$1 \times 10^{-8} - 1.5 \times 10^{-3}$</td>
<td>0.01 - 0.25</td>
</tr>
</tbody>
</table>

As described in Section 3.4.4, the conductance for River Package cells is calculated from the width and length of the portion of the cell covered with water and the hydraulic conductivity and thickness of the saturated bed material (this can consist of flyash, paste or a combination). The conductance of River Package cells varies through time based on the extent of surface water and bed thickness at the time being simulated. Bed thicknesses were assigned based on bathymetric data. Hydraulic conductivity of the River Package cells representing the fly ash and/or paste was initially assigned a value of $2.83 \times 10^{3}$ feet/day. These values were adjusted during calibration and the final calibrated hydraulic conductivity of the fly ash ranges from $1.5 \times 10^{4}$ to $2.83 \times 10^{2}$ feet/day.

Drain Package cells representing the Valley and Main dam drains and various capture trenches around the EHP were assigned hydraulic conductivity of ranging from 1 to 200 feet/day and thickness ranging from 1 to 10 feet (Appendix M). Drain cell conductance was not adjusted during calibration. Hydraulic Flow Barrier boundaries representing the cutoff wall were assigned an initial hydraulic conductivity of 0.0283 feet/day and a thickness of 2.5 feet. Hydraulic conductivity values were adjusted during
calibration and final values range from 0 to 0.1 feet/day. **Figure 4-8** presents hydraulic conductivity values used for the cutoff wall for Layers 2, 3, and 4. The variability in hydraulic conductivity is the result of model calibration and particle tracking for various versions of the model, culminating in distribution shown in **Figure 4-8**. Variability in installation and possibly weathering of the bentonite amended concrete cutoff wall can account for variability in the permeability of the wall. A geophysical survey completed in 2005 detected two zones of high conductivity groundwater along the south slurry wall (Hydrometrics 2005). A high conductivity zone appeared at a depth just below the base of the slurry wall near wells 1006M and 1007R suggesting that impacted water may have seeped through the slurry wall at this location. Another zone of high conductivity water was detected from the water table down to a depth below the base of the slurry wall near wells 1000M and 1004M suggesting that impacted groundwater possibly seeped through and beneath the slurry wall in that area. The results of this survey indicate that the permeability of the cutoff wall can vary both laterally and vertical in different portion of the wall.

### 4.2.2 2003 Steady State Calibration

**Appendix N** contains calibration statistics resulting from the 2003 steady-state model, based on 107 head targets. All head target statistics and the other general components of the water balance met the steady-state model calibration goals. Further, visual comparison of the simulated and observed potentiometric maps show that, in general, groundwater flow directions and gradients were similar.

A total of 14 pumping wells were simulated as actively pumping in the 2003 steady-state calibration simulation. The pumping rates for these wells were established as the average pumping rate for three months prior to January 2003 presented in **Section 2.6.6**. **Appendix G** summarizes the pumping rates used in the model.

Calibrated recharge rates used in the 2003 steady-state simulation are presented on **Figure 4-9**. Calibrated rates are summarized below:

<table>
<thead>
<tr>
<th>Area</th>
<th>Rates</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clinker</td>
<td>$2.7 \times 10^{-4}$ feet/day to $3.4 \times 10^{-4}$ feet/day</td>
</tr>
<tr>
<td>Alluvium</td>
<td>$2.7 \times 10^{-4}$ feet/day</td>
</tr>
<tr>
<td>Background (spoils, bedrock)</td>
<td>$4.0 \times 10^{-5}$ to $5.0 \times 10^{-5}$ feet/day</td>
</tr>
</tbody>
</table>

#### 2003 Calibration to Head Data

The calculated residual mean of target head values for all target wells was -0.35. A small residual mean indicates model heads are not biased too high or too low (Anderson et al., 2015). The absolute residual mean of the target head values was 1.58 feet, which meets the calibration goals of less than 2 feet. The residual standard deviation divided by the range of observed heads is 0.6 percent. Many practitioners believe this statistic should be less than 10 percent and the calibration goal was less than 5 percent. The maximum residual was 4.18 feet and the minimum residual was -4.91 feet, which is within the goal of ±5 feet. **Figure 4-10** is a plot showing simulated vs. observed target values that are evenly distributed around a 1:1 line, demonstrating there is no groundwater elevation bias (Anderson et al, 2015) and that the model is well-calibrated to January 2003 groundwater elevations.
Figure 4-11 is a map of the simulated 2003 water table and Figures 4-12 through 4-18 are maps showing the simulated potentiometric surfaces for Layers 2 through 8, for the 2003 steady-state calibration. Visual comparison of the computed water table elevation contours (Figure 4-11) to those based on field measurements Figure 2-10) indicates a good match to heads and gradients. Comparison of Figure 2-11 to Figure 4-14 indicates a good match between simulated and observed heads and gradients within the McKay interval. Comparison of Figure 2-12 to Figure 4-15 indicates a good match between simulated and observed heads and gradients in Sub-McKay groundwater, with only slight differences between the observed and simulated potentiometric surfaces. For example, the observed and simulated Sub-McKay (Layer 5) potentiometric surfaces vary slightly in flow direction and gradient in and southwest of the EHP. However, the observed groundwater elevations in this area are sparse and hence flow directions and gradients based on observed data are somewhat uncertain.

Residuals at each target location are illustrated on Figure 4-12 through Figure 4-18, with positive (blue) values indicating the simulated head is less than the observed head and negative (red) values indicating the simulated head is greater than the measured value. In most areas positive and negative residuals shown on these figures are randomly distributed without large areas of spatial bias. A review of Figure 4-15 indicates that 25 of the 40 head values are over-predicted. In addition, in most areas there is a mix of over and under predicted values. Figures 4-14 and 4-15 indicate that the 2003 simulation generally under-predicts heads west of the EHP in Layer 4 and over-predicts heads west and south of the EHP in Layer 5, respectively.

Table 4-3 presents residual statistics by layer. Calibration statistics indicate that some model layers exhibit some spatial bias. Bias refers to the tendency to over- or under-estimate the value. Negative mean residual values indicate the heads are biased high and positive residuals indicate heads are biased low. Based on mean residuals, Layers 4, 5, 6, and 7 have slightly over-estimated groundwater elevations, while Layers 2 and 3 are slightly underestimated.

<table>
<thead>
<tr>
<th>Layer</th>
<th>Number of Targets</th>
<th>Absolute Residual Mean</th>
<th>Residual Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Layer 2</td>
<td>3</td>
<td>3.33</td>
<td>0.68</td>
</tr>
<tr>
<td>Layer 3</td>
<td>7</td>
<td>2.55</td>
<td>0.75</td>
</tr>
<tr>
<td>Layer 4</td>
<td>51</td>
<td>1.38</td>
<td>-0.31</td>
</tr>
<tr>
<td>Layer 5</td>
<td>40</td>
<td>1.58</td>
<td>-0.53</td>
</tr>
<tr>
<td>Layer 6</td>
<td>2</td>
<td>1.25</td>
<td>-0.79</td>
</tr>
<tr>
<td>Layer 7</td>
<td>2</td>
<td>2.71</td>
<td>-2.71</td>
</tr>
<tr>
<td>Layer 8</td>
<td>2</td>
<td>0.27</td>
<td>-0.14</td>
</tr>
</tbody>
</table>

2003 Calibration to Flux Data

The components of the 2003 steady-state water balance were compared to the components of the estimated water balance to ensure the model simulation incorporated the appropriate rates of flux. Table 4-4 presents the estimated water balance along with the corresponding simulated water balance. All the simulated flux values fall within the estimated ranges. Appendix Q contains the model water balance resulting from the calibrated 2003 steady-state model.
Table 4-4. Summary of Estimated and Simulated Water Balance for 2003

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
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<tbody>
<tr>
<td></td>
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<td></td>
<td></td>
<td>Simulated (feet$^3$/d)</td>
</tr>
<tr>
<td><strong>Inflows</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Underflow In</td>
<td>7,446</td>
<td>217,156</td>
<td>19,103</td>
<td>1,128</td>
<td>23,051</td>
</tr>
<tr>
<td>Infiltrating Background Recharge</td>
<td>3,087</td>
<td>9,262</td>
<td>6,175</td>
<td>48</td>
<td>4,751</td>
</tr>
<tr>
<td>Infiltrating Clinker Recharge</td>
<td>15,285</td>
<td>45,855</td>
<td>30,570</td>
<td>238</td>
<td>34,599</td>
</tr>
<tr>
<td>Infiltrating Regraded Area Recharge</td>
<td>54</td>
<td>161</td>
<td>107</td>
<td>0.3</td>
<td>62</td>
</tr>
<tr>
<td>EHP Ponds</td>
<td>26,525</td>
<td>106,099</td>
<td>53,049</td>
<td>551</td>
<td>37,954</td>
</tr>
<tr>
<td>Stock Ponds</td>
<td>26</td>
<td>103</td>
<td>52</td>
<td>0.1</td>
<td>70</td>
</tr>
<tr>
<td>Total IN</td>
<td>52,423</td>
<td>378,636</td>
<td>109,056</td>
<td>1,967</td>
<td>100,487</td>
</tr>
<tr>
<td><strong>Outflows</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Underflow Out</td>
<td>28,794</td>
<td>115,175</td>
<td>57,587</td>
<td>598</td>
<td>89,678</td>
</tr>
<tr>
<td>Capture System</td>
<td>7,839</td>
<td>24,075</td>
<td>19,597</td>
<td>125</td>
<td>10,797</td>
</tr>
<tr>
<td>Total OUT</td>
<td>36,633</td>
<td>139,250</td>
<td>77,185</td>
<td>723</td>
<td>100,475</td>
</tr>
</tbody>
</table>

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

The estimated groundwater capture rate for January 2003 ranged from 41 to 125 gpm. The simulated extraction rate from wells and trench systems was near the low end of this range (56 gpm). Rates for all wells were within the estimated range except at 604A and 605A-2 (Appendix G). MODFLOW SURFACT’s FWLS Package automatically reduced flow rates at two of the 14 pumping wells specified as FWLS Package wells (604A and 605A-2). The assigned pumping rate for these wells is (0.006 gpm, and 0.009 gpm, respectively, which is close to zero). During the simulation, the model automatically reduced the pumping rate in these wells to 0.003 and 0.004 gpm respectively. The extremely low specified pumping rate for these wells and the fact they were not pumping a number of months during the year at that time suggests that the resulting reduced steady-state rates are reasonable.

4.2.3 Transient Calibration

The transient simulation includes 47 stress periods representing the 47 months from February 2003 through December 2006. The Automatic Time Stepping (ATO) Package was used to automate the most efficient time stepping to reduce model run times. Output from the 2003 steady-state model was used as initial heads for transient calibration. Model inputs were adjusted in an iterative manner to improve the match between hydrographs based on field-measured data and those simulated by the model.

Pumping wells were simulated using estimated average monthly pumping rates from the period between February 2003 and December 2006. In some cases, pumping rates were adjusted during the calibration. Appendix R shows measured and simulated pumping rates for all capture system wells during this period.
Flooding of Cells F and H in 2003 and 2004 was simulated by increasing recharge in those areas. According to pond inventory records water was transferred Cell H between March and November 2003 and between May and September 2004; and water was transferred to Cell F between May and October 2003 and between April and August 2004. The background, Clinker and alluvium recharge rates were adjusted within plausible ranges to achieve the best match between measured and simulated groundwater elevations in areas affected by the flooding. In addition, recharge rates were varied seasonally in alluvium north of the Main Dam Sump and east of the Saddle Dam (near well 560A) to help match seasonal changes in water levels. Appendix S lists the calibrated monthly recharge values used for the 2003 through 2006 period for all the zones shown on Figure 4-19. The effect of variations in seasonal precipitation in terms of subsurface recharge varies spatially for a number of reasons, including permeability, land use, and topography. Overall, 7 of the 10 recharge zones were adjusted to simulate transient recharge.

Other boundary conditions used in the model including drains and constant flux boundaries were not adjusted for this simulation and are consistent with the 2003 simulation, with the exception of drains added to simulate the SFCC Seep and West Seep. These drains were placed in Layer 1 with drain elevations equal to ground surface. In addition, the majority of GHB cells are consistent with the 2003 simulation with the exception of a small section along the model domain north of the 560A drainage. Hydrographs for wells in this area, including wells 559A, 558A, 557A, 591A, and 596D, show a declining trend in groundwater elevations for the transient period. In order to calibrate the model to these wells, the stage used in the GHBs was adjusted in this area until reasonable matches were achieved between observed and simulated groundwater elevations.

The stage of River Package cells used to simulate Cells A, B, C, G, and the Old Clearwell was adjusted during the transient simulation based on measured stage elevations (Appendix S). The distribution of River Package cells is consistent with the 2003 simulation (Appendix I).

Simulated and field-measured hydrographs are displayed on Figure 4-20 through Figure 4-26 for the layers with observed data (Layers 2 through 8). The degree of fit was assessed primarily qualitatively by visual assessment of the match between simulated and observed hydrographs. When reviewing these hydrographs, the match of overall trends (increasing/decreasing) and the match to the short-term transient changes were evaluated. Responses to flooding of Cells F and H and subsequent groundwater capture were given top priority. Simulating the observed hydraulic responses in the deeper layers (7 and 8) was viewed as less important along with areas near the model domain that are further away from the EHP. However, the overall match of average values was also considered and the number of measured groundwater elevation measurements at each site was taken into account.

Wells in Layer 2 exhibited the greatest response in groundwater elevations as a result of flooding Cells F and H and subsequent groundwater capture. Evaluation of hydrographs presented in Figure 4-20 show that the model is capable of simulating responses in these wells and is well calibrated to transient events, particularly south and west of the EHP, where the largest changes in groundwater elevations occurred.

Simulated groundwater elevations in wells screened in the McKay (Layer 4, denoted with an M in the well nomenclature) show a reasonable match in timing and magnitude to observed changes in groundwater elevations (Figure 4-22a-c). South of the EHP (Figure 4-22c) simulated groundwater
elevations in a few wells (1004M, 1006M and 1012M) are generally lower than observed groundwater elevations.

Evaluation of hydrographs for Layer 3 and 4 wells screened in alluvium (denoted with an A in the well nomenclature) shows the model is capable of simulating a reasonable match in timing and magnitude of seasonal changes and changes related to installation of capture wells. Simulated groundwater elevations at a few wells in the upper Drain Pit 5 Drainage are generally higher than observed groundwater elevations (Figure 4-22a). Wells screened in alluvium in the Main Dam drainage and 560A drainage appear to show seasonal changes in groundwater elevations (Figure 4-22b). Recharge in these drainages was adjusted in order to achieve a better match between simulated and observed groundwater elevations (Figure 4-19 and Appendix S). In addition, several capture wells were installed in early 2005 in South Fork Cow Creek, which resulted in changing groundwater levels in monitoring wells in this area. Evaluation of hydrographs in this area show that the model is capable of simulating changes in groundwater elevations as a result of these capture wells (Figure 4-21c).

Evaluation of wells screened in the shallow Sub-McKay (Layer 5) shows the model is capable of simulating a reasonable match in timing and magnitude to changes in groundwater elevations, generally. Wells in Layer 5 show less response to flooding of Cells F and H but do show responses to pumping of capture wells in some areas. Wells (662D, 578D and 649D) east of the EHP, near capture wells 646D, 647D, and 648D, show a response to pumping from these capture wells. The model is able to reasonably simulate changes in groundwater elevations as a result of this pumping (Figure 4-23b). The two figures show hydrographs for 42 wells, the majority of which show a reasonably good match between simulated and observed. Observed water levels in well 612D exhibited a general increase between 2003 and 2006 and then declined (612D is the only Sub-McKay well in that area that exhibited this pattern), whereas simulated heads decrease between 2003 and 2005 then increase. The cause of the unique observed pattern in 612D is unknown and therefore not accounted for in the simulation. A cluster of wells located near the southeast corner of the EHP (565D, 566D, 575D, 576D) exhibited a general increase in groundwater elevations during the calibration period but the model simulated relatively stable heads in these wells(Figure 4-23b). The cause of the observed pattern in the wells is unknown and therefore not accounted for in the simulation. It was not anticipated that a perfect match would be achieved everywhere given the large number of wells and size of the model and uncertainty regarding pumping rates and seasonal recharge events. Overall the transient matches are considered adequate, especially given the fact that it is the steady-state model not the transient that is used for capture analysis and particle tracking.

Hydrographs for target wells in Layers 6, 7, and 8 (Figures 4-24 through 4-26) represent deeper intermediate to regional flow that exhibits minimal seasonal variation. Figure 4-24 indicates that in Layer 6, simulated and observed hydrographs match well in wells 596D and 563D, while simulated heads in wells 663D are 6 feet higher than measured heads. The simulated hydrograph for well 1009D is relatively flat while the observed data increase 2 feet between late 2005 and mid-2006. Observed groundwater levels in the two Layer 7 targets (wells 584D and 585D) decline slightly over the calibration period, but simulated heads remain relatively stable. Both simulated and observed heads in the two Layer 8 targets (595D and 599D) do not exhibit much change over the calibration period.

Hydrographs showing the observed and simulated water level changes for wells near the EHP demonstrate that the model is capable of simulating the magnitude and timing of mounding that
occurred in response to flooding of Cells F and H as subsequent drawdown after flooding stopped and capture systems were installed and operated.

The mean residual error for the long-term transient calibration is -0.20 and the absolute residual mean is 1.78. Table 4-5 presents the calibration statistics for the transient targets. The transient simulation provided a good match to both the timing and magnitude of stresses, including the flooding of Cells F and H. The relatively low absolute residual mean suggest this model is well calibrated to this large-scale long-term transient event.

Table 4-5. Transient Model Statistics

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Residual Mean (feet)</td>
<td>-0.20</td>
</tr>
<tr>
<td>Absolute Residual Mean (feet)</td>
<td>1.78</td>
</tr>
<tr>
<td>Residual Standard Deviation (feet)</td>
<td>2.2</td>
</tr>
<tr>
<td>Range of Observations (feet)</td>
<td>291.01</td>
</tr>
<tr>
<td>Standard Deviation/Range of Observations (percent)</td>
<td>0.8</td>
</tr>
</tbody>
</table>

Simulated flux at the West Seep and SFCC Seep generally match measured flux at the surface water capture systems. The surface water capture systems were installed in March 2005 and January 2005 for the West and SFCC seeps, respectively. The simulated flux for the initial measurement collected at these systems is within 50 percent of the observed measurement. After the initial measurement, measured flux varies substantially, which may be due to precipitation, snow melt, or other factors including initiation of groundwater capture (Figure 4-27). Thus, there is uncertainty in what portion of the measured flux is derived from flooding Cells F and H, which makes it difficult to directly compare the observed and simulated values.

4.2.4 2015 Steady-State Calibration

A total of 56 pumping wells were simulated as actively pumping in the 2015 steady-state simulation. Initial pumping rates for these wells were based on estimated average pumping rates for August-October 2015. Pumping rates for several wells screened in the clinker were adjusted using rates measured in September and October 2015. These adjustments were based on notes provided in pumping records that stated the well was not pumping or was temporarily turned off during the calibration time period. Appendix G lists pumping rates used in the 2015 calibration simulation.

Recharge rates used in the 2015 steady-state simulation are presented on Figure 4-28. Rosebud/Clinker recharge ranged from $3.5 \times 10^{-4}$ to $4.2 \times 10^{-4}$ feet/day. Recharge over alluvium was $3.5 \times 10^{-4}$ feet/day. Recharge over bedrock and spoils was $5 \times 10^{-5}$ feet/day. Recharge representing seepage from Cells B, F, and H was $1.8 \times 10^{-3}$ feet/day, $1 \times 10^{-3}$ feet/day, and $2 \times 10^{-4}$ feet/day, respectively.

Appendix O presents statistics resulting from the 2015 steady-state calibration. All head target statistics, and the general components of the water balance meet the steady-state model calibration goals. Further, visual comparison of the simulated and observed potentiometric maps show that groundwater flow directions and gradients were generally similar.
2015 Calibration to Head Data

The calculated residual mean for all target wells is -0.11 foot indicating that the overall model is not biased (Anderson et al., 2015). The absolute residual mean was 1.62 feet, which meets the calibration goals of less than 2 feet. The residual standard deviation divided by the range of observed elevations (310.29 feet) is 0.6 percent, which is less than the calibration goal of less than 5 percent. The maximum residual is 4.35 feet and the minimum residual is -4.91 feet, which is within the calibration goal of ±5 feet. Figure 4-29 is a plot showing simulated vs. observed target values that are evenly distributed around a 1:1 line, demonstrating there is no groundwater elevation bias (Anderson et al, 2015) and that the model is well-calibrated.

Figure 4-30 is a map of the simulated 2003 water table. Figure 4-31 through Figure 4-37 are maps showing the simulated potentiometric surfaces for Layers 2 through 8, for the 2015 steady-state calibration. Comparison of the computed water table contours (Figure 4-30) to those based on field measurements (Figure 2-13) indicates a good match between simulated and observed heads and gradients. Comparison of Figure 2-14 to McKay wells on Figure 4-33 reveals good match between simulated and observed heads and gradients in the McKay Coal. Comparison of Figure 2-15 to Figure 4-34 15 indicates a good match between simulated and observed heads and gradients in Sub-McKay groundwater.

Residuals at each target location are shown on Figure 4-31 through Figure 4-37, with positive (blue) values indicating the simulated head was less than the observed head and negative (red) values indicating the simulated head was greater than the measured value. The residuals posted on these figures allow for a spatial analysis of the calibration. Figures 4-33 and 4-34 indicate that the 2015 simulation generally over-predicts heads in the 560A drainage. Figures 4-33 and 4-34 indicate that the 2015 simulation generally over-predicts heads west and south of the EHP in Layer 4 and under-predicts heads in Layer 5 west of the EHP.

Table 4-6 indicates that model layers exhibit some spatial bias. Based on mean residuals, Layers 2, 4, and 6 have slightly over-estimated groundwater elevations, while groundwater elevations in Layers 3, 5, 7, and 8 are slightly underestimated.

<table>
<thead>
<tr>
<th>Layer</th>
<th>Number of Targets</th>
<th>Absolute Residual Mean</th>
<th>Residual Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Layer 2</td>
<td>24</td>
<td>1.7</td>
<td>-1.00</td>
</tr>
<tr>
<td>Layer 3</td>
<td>8</td>
<td>1.31</td>
<td>0.21</td>
</tr>
<tr>
<td>Layer 4</td>
<td>88</td>
<td>1.58</td>
<td>-0.48</td>
</tr>
<tr>
<td>Layer 5</td>
<td>91</td>
<td>1.69</td>
<td>0.54</td>
</tr>
<tr>
<td>Layer 6</td>
<td>17</td>
<td>1.55</td>
<td>-0.95</td>
</tr>
<tr>
<td>Layer 7</td>
<td>3</td>
<td>1.95</td>
<td>1.49</td>
</tr>
<tr>
<td>Layer 8</td>
<td>2</td>
<td>0.71</td>
<td>0.71</td>
</tr>
</tbody>
</table>
2015 Calibration to Flux Data

The components of the 2015 steady-state water balance were compared to the components of the estimated water balance to ensure the model simulation incorporated the appropriate rates of flux. **Table 4-7** presents the estimated water balance along with the corresponding simulated water balance. All the simulated flux values fall within the estimated ranges. **Appendix Q** contains the groundwater model water balance resulting from the calibrated 2015 steady-state model.

The estimated groundwater capture rate for October 2015 ranged from 73 to 288 gpm. The simulated extraction was near the low end of this range (105 gpm) due to adjustments made during calibration and MODFLOW SURFACT’s FWL5 Package automatically reducing flow rates to a few wells. Thirteen of the 59 pumping wells are simulated with FWL5 Package wells. Rates in 10 of wells were not reduced by the model (1026AM, 1039A, 1127D, 1153A, 592A, 605A-2, 645D, 680A, 687A/686A, 683A). The model reduced pumping rates in a fracture well representing three adjacent wells within one model cell (690A, 688A, and 689A) by 39 percent this difference is within the estimated range of error for pumping rates.

### Table 4-7. Summary of Estimated and Simulated Water Balance for 2015

<table>
<thead>
<tr>
<th></th>
<th>Min (feet³/d)</th>
<th>Max (feet³/d)</th>
<th>Estimate (feet³/d)</th>
<th>Min (gpm)</th>
<th>Max (gpm)</th>
<th>Estimate (gpm)</th>
<th>Simulated (feet³/d)</th>
<th>Simulated (gpm)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Inflows</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Underflow In</td>
<td>7,446</td>
<td>217,156</td>
<td>19,103</td>
<td>39</td>
<td>1,128</td>
<td>99</td>
<td>25,999</td>
<td>135</td>
</tr>
<tr>
<td>Infiltrating Background Recharge</td>
<td>3,065</td>
<td>9,195</td>
<td>6,130</td>
<td>16</td>
<td>48</td>
<td>32</td>
<td>5,889</td>
<td>31</td>
</tr>
<tr>
<td>Infiltrating Clinker Recharge</td>
<td>15,338</td>
<td>46,015</td>
<td>30,676</td>
<td>80</td>
<td>239</td>
<td>159</td>
<td>44,815</td>
<td>233</td>
</tr>
<tr>
<td>Infiltrating Regraded Area Recharge</td>
<td>54</td>
<td>161</td>
<td>107</td>
<td>0.3</td>
<td>0.8</td>
<td>0.6</td>
<td>11</td>
<td>0.6</td>
</tr>
<tr>
<td>EHP Ponds</td>
<td>17,922</td>
<td>71,690</td>
<td>35,845</td>
<td>93</td>
<td>372</td>
<td>186</td>
<td>33,764</td>
<td>175</td>
</tr>
<tr>
<td>Stock Ponds</td>
<td>26</td>
<td>103</td>
<td>52</td>
<td>0.1</td>
<td>0.5</td>
<td>0.3</td>
<td>70.2</td>
<td>0.4</td>
</tr>
<tr>
<td><strong>Total IN</strong></td>
<td>43,852</td>
<td>344,320</td>
<td>91,914</td>
<td>228</td>
<td>1,789</td>
<td>477</td>
<td>110,650</td>
<td>575</td>
</tr>
<tr>
<td><strong>Outflows</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Underflow Out</td>
<td>28,794</td>
<td>115,175</td>
<td>57,587</td>
<td>150</td>
<td>598</td>
<td>299</td>
<td>90,385</td>
<td>470</td>
</tr>
<tr>
<td>Capture Systems</td>
<td>14,116</td>
<td>55,443</td>
<td>35,290</td>
<td>73</td>
<td>288</td>
<td>183</td>
<td>20,262</td>
<td>105</td>
</tr>
<tr>
<td><strong>Total OUT</strong></td>
<td>42,910</td>
<td>170,618</td>
<td>92,877</td>
<td>223</td>
<td>886</td>
<td>482</td>
<td>110,648</td>
<td>575</td>
</tr>
</tbody>
</table>

Notes: feet³/d = cubic feet per day; gpm = gallons per minute.
The model automatically reduced rates in wells 1068A and 1136A to zero. The specified rate for 1068A is 36.5 ft³/d (0.19 gpm). Monthly records show that this well was either not pumping or pumping less than 10% of the time for most months in 2015 (July-Sept being the exception where pumping averaged about 30-40% of each month). The modeled pumping rate is representative of conditions during the fall of 2015, when little water was pumped from this well.

The specified rate for 1136A is 0.51 ft³/d (0.003 gpm). This well was not pumping a number of months in 2015. The extremely low specified pumping rate for this well and the fact it was not pumping a number of months during 2015 suggests that for a steady-state simulation a rate of zero is a reasonable representation of the degree of capture from this well in October 2015.

### 4.3 Calibration Results Summary

The Units 3 & 4 EHP groundwater model is well-calibrated and has been calibrated to several independent steady-state and transient data sets. Calibration statistics and good visual qualitative matches for the calibration data sets suggest this model is robust and adaptable to changing hydraulic conditions around the Units 3 & 4 EHP. Based on the results presented in this section, the numerical model is an appropriate tool to conduct predictive exercises including groundwater.
5.0 SENSITIVITY ANALYSIS

A sensitivity analysis was performed to quantify uncertainty in the calibrated model relative to uncertainty in model inputs. This type of analysis helps identify input parameters to which the numerical model is most sensitive and to verify the selection of parameters applied to the model to provide the best match to observed groundwater elevations. Methods used to complete the sensitivity analysis, along with the results, are described below. Additional sensitivity analyses of the model predictions regarding groundwater capture are described in Section 6.4.

The sensitivity analysis was conducted using the 2015 steady-state simulation by varying selected model input values within plausible ranges to document the effect on model calibration statistics. Parameters that appeared to have the greatest effect on residual statistics during manual and automated calibration were selected for analysis, including:

- Horizontal hydraulic conductivity in selected zones;
- Horizontal hydraulic conductivity by model layer;
- Vertical hydraulic conductivity in selected zones;
- Net recharge rate for clinker and alluvium;
- All recharge zones collectively;
- Seepage rates for Cells B, F, and H;
- Conductance of River Package cells simulating Cells C, G, and the Old Clearwell (Cell J);
- Capture well pumping rates; and
- Hydraulic conductivity of the cutoff wall.

Table 5-1 lists model input parameters tested in the sensitivity analysis for simulations where selected zones were varied.

The sensitivity analysis was completed using Groundwater Vistas Auto-Sensitivity function for most parameters. Analysis of capture well pumping rates was not completed using the Auto-Sensitivity function as the pumping rates were adjusted outside the function to a lesser degree than the other parameters.

The following is a summary of the ranges of values tested for the different types of input parameters in the sensitivity analysis:

- Horizontal and vertical hydraulic conductivity values were multiplied by 0.1, 0.5, 0.8, 2, 5, and 10;
- Net recharge rates were multiplied by 0.1, 0.5, 0.8, 2, 5, and 10;
- Cell B, F, and H seepage rates were multiplied by 0.1, 0.5, 0.8, 2, 5, and 10;
- River Package conductance was multiplied by 0.1, 0.5, 0.8, 2, 5, and 10; and
Simulated capture wells pumping rates were multiplied by 0.75 and 1.25.

The uncertainty associated with most of these parameters is estimated to be ± one order of magnitude and therefore most parameters were multiplied by factors within a range of 0.1 to 10 times for the sensitivity analysis. The uncertainty associated with pumping rates is estimated to be ± 25 percent, and pumping rates were therefore multiplied by factors of 0.75 and 1.25.

Table 5-1. Parameters Altered in the Sensitivity Analysis

<table>
<thead>
<tr>
<th>Horizontal and Vertical Hydraulic Conductivity</th>
<th>Pond Seepage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zone 5 Sandstone (Layers 5 and 6)</td>
<td>Zone 15 Cell F</td>
</tr>
<tr>
<td>Zone 11 Sandstone (Layers 2 to 8)</td>
<td>Zone 16 Cell B</td>
</tr>
<tr>
<td>Zone 28 McKay Coal (Layer 4)</td>
<td>Zone 17 H</td>
</tr>
</tbody>
</table>

All zones by Layer

<table>
<thead>
<tr>
<th>Vertical Hydraulic Conductivity</th>
<th>River Package Conductance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zone 8 Siltstone (Layers 3 to 5)</td>
<td>Reaches</td>
</tr>
<tr>
<td>Zone 17 Sandstone (Layers 5 and 6)</td>
<td>Reach 6</td>
</tr>
</tbody>
</table>

Pumping

All Wells were adjusted as a group

Recharge

<table>
<thead>
<tr>
<th>Zone 1 Clinker/Alluvium</th>
</tr>
</thead>
</table>

| All zones All areas |

Figure 5-1 through Figure 5-8 summarize results of the sensitivity analysis. These figures show the absolute residual mean for each sensitivity run as well as for the calibrated model. The relationships are important indicators of parameter sensitivity. Parameters that the model is most sensitive to show the greatest change in the absolute residual mean, while those that are least sensitive show little change in the absolute residual mean.

Results of the sensitivity analysis suggests the model calibration is most sensitive to changes in clinker and alluvium recharge, recharge in all zones (collectively), horizontal and vertical hydraulic conductivity, and pond seepage from Cell B, and River Package conductance in Cell C. The sensitivity analysis also shows that model calibration would not be improved by changes in any of the parameters evaluated. The following sections discuss these parameters (and others determined to be less sensitive) as they relate to the sensitivity analysis.

5.1 Horizontal and Vertical Hydraulic Conductivity

A sensitivity analysis was completed on five model hydraulic conductivity zones. Hydraulic conductivity values in zones selected for the analysis included those that comprise a relatively large portion of the model domain, or were observed to greatly influence model calibration. Both horizontal and vertical hydraulic conductivities within three of the selected zones were evaluated and vertical hydraulic conductivity for two additional zones was evaluated. In addition, horizontal hydraulic conductivity was
varied by model layer. Seven multipliers were applied for each analysis; results are shown on Figure 5-1 (horizontal hydraulic conductivity-selected zones), Figure 5-2 (horizontal hydraulic conductivity by model layer), and Figure 5-3 (vertical hydraulic conductivity-selected zones). The model zones referred to in this discussion are shown on Figure 4-1 through Figure 4-7 (Model layers 2 through 8).

The results show the model is more sensitive to increases and decreases in horizontal and vertical conductivity in Zone 11 than to changes in other zones evaluated during the analysis. Zone 11 showed a larger increase than other zones in the absolute residual mean when the calibrated model value was altered. This zone represents sandstone in the shallow and deep Sub-McKay and Interburden, and is present in Layers 2 through 8.

Order-of-magnitude changes of Zone 11 horizontal and vertical hydraulic conductivity resulted in an absolute residual mean greater than 3 feet. The model is much less sensitive to changes to horizontal and vertical hydraulic conductivity in Zones 5 and 28 with order-of-magnitude changes resulting in absolute residual means less than 3 feet.

When horizontal hydraulic conductivity is varied by model layer (Figure 5-2), the model is most sensitive to changes in Layer 5 and least sensitive to changes in Layer 2, 3, 7, and 8. Reducing $K_h$ in Layer 5 by an order of magnitude raised to absolute residual mean to almost 5 feet, and raising it by the same amount increased the mean to over 10 feet. In contrast, order of magnitude changes of $K_h$ in Layers 2, 3, 7, and 8 only raised the absolute residual mean to about 2 feet.

The calibrated model hydraulic conductivity values (multiplier of 1 in the sensitivity analysis) provided the smallest absolute residual mean for 46 of the 48 horizontal and vertical hydraulic conductivity analyses completed using selected zones, and for all analyses where $K_h$ was varied by model layer. Changes in vertical hydraulic conductivity in Zone 5 and horizontal hydraulic conductivity in Zone 8 resulted in an absolute residual mean slightly lower than the calibrated model value of 1.62 feet. However, the values with an improved mean were not incorporated in the calibrated model because the improvement in the absolute residual mean for these two zones was so small (1.60 to 1.61 feet), and the changes resulted in less favorable calibration (an increased absolute residual mean) in the 2003 steady-state model.

5.2 RECHARGE

Two sensitivity analyses were completed varying recharge. One analysis was completed on recharge Zone 1, which represents net recharge to alluvium and most of the clinker in the model domain. Seven multipliers were used for each analysis for this parameter, and results are shown on Figure 5-4. A second analysis was completed by varying all recharge zones collectively using the same multipliers, and the results are shown on Figure 5-5.

Results indicate that the model is more sensitive to increases in the recharge than for decreases both for when only Zone 1 was varied and for when all recharge zones were varied. Increases of 5 to 10 times the base recharge rate results in an absolute residual mean of 15.1 and 37.5 feet, respectively, when only Zone 1 is varied, and an absolute residual mean of 24.0 and 52.6 feet, respectively, when all recharge zones are varied. In contrast, decreases of 0.5 to 0.1 times the base recharge rate results in
less of an increase in the mean, ranging from 4.19 to 9.60 feet when only Zone 1 is varied, and 6.8 to 18.1 feet when all recharge zones are varied.

The analysis of recharge resulted in the absolute residual mean being the lowest for a multiplier of 1. This suggests the calibrated model recharge rates for these zones already incorporated into the model provide the best calibration statistics.

### 5.3 Pond Seepage

A sensitivity analysis was completed on recharge zones representing seepage from Cells B, F, and H. Seven multipliers were used for each analysis and the results are shown on Figure 5-6.

Results of the pond seepage sensitivity analysis indicate that the model is most sensitive to increases in seepage from model recharge in the following zones:

- Zone 16 – Cell B,
- Zone 15 – Cell F.

Increases of 5 to 10 times the base recharge rate for these two zones result in an absolute residual mean between 2.00 and 4.56 feet, approximately 0.34 and 2.89 feet higher than the calibrated value. In contrast, decreases of 0.1 to 0.8 times the base recharge rate results in less of an increase in the mean, resulting in a maximum value from 1.75 to 1.83 feet. The model is less sensitive to changes in the recharge rate for Zone 17 (Cell H), with changes in the absolute residual mean of less than 0.1 foot.

The sensitivity analysis of pond seepage zones suggests the calibrated model recharge rates for these zones already incorporated into the model provide the best calibration.

### 5.4 River Package Conductance

A sensitivity analysis was completed on conductance of River Package cells representing seepage from Cell C, Cell G, and the Old Clearwell (Cell J). The conductance term in these boundaries is determined by water level, cell area, thickness of fly ash, and hydraulic conductivity of fly ash. All of the components of this conductance term are relatively certain with the exception of the hydraulic conductivity of fly ash in the bottom of the cells. Seven multipliers were used for each analysis and the results are shown on Figure 5-7.

Results of the river package conductance (pond seepage) sensitivity analysis indicate that the model is most sensitive to changes in conductance for reaches representing Cell C. Decreases of 0.5 and 0.1 times the base conductance results in absolute residual means of 2.51 and 6.30 feet, respectively. In contrast, increases of 5 to 10 times the base conductance for reaches representing Cell C results in an absolute residual mean of 4.18 and 5.42 feet, respectively.

The model is also sensitive to conductance increases for Reach 6 (Old Clearwell), although to a lesser degree. An order of magnitude increase in this reach results in an absolute residual mean of 2.56 feet. The model is much less sensitive to decreases in conductance for this reach, where an order of magnitude reduction results in an absolute residual mean of 1.82 feet.
Of the three cells evaluated, the model is least sensitive to changes in the conductance for reaches representing Cell G. Order of magnitude increases and decreases in the conductance for these reaches results in absolute residual means of 1.73 feet and 1.68 feet, respectively.

The sensitivity analysis of River Package cell conductance (pond seepage) suggests the calibrated model conductance values for these reaches already incorporated into the model provide the best calibration. Only one of the analyses (Cell G 2x multiplier) resulted in an absolute residual mean lower than the calibrated value of 1.62 feet. However, the values with an improved mean were not incorporated in the calibrated model because the improvement in the absolute residual mean for the analysis was minimal (1.61 feet), and the changes resulted in an increased absolute residual mean in the 2003 steady-state calibration.

5.5 Pumping

A sensitivity analysis was completed on model pumping rates by applying rates of 0.75 and 1.25 times the calibrated model specified rates. Results of the pumping rate sensitivity analysis are shown on Figure 5-8.

The sensitivity results plot shows that the model is slightly more sensitive to an increase in pumping rates (which raises the absolute residual mean to 1.96 feet) than it is to a decrease in rates (which results in a mean of 1.86 feet). The calibrated model specified rates (multiplier of 1) provide the lowest absolute residual mean.

5.6 Summary of Sensitivity Analysis Results

Results of the sensitivity analysis show that the model is most sensitive to the following:

- Increases and decreases in clinker/alluvium recharge specifically and all recharge zones collectively;
- Increases in pond seepage at Cell B;
- Decreases in River Package conductance at Cell C;
- Increases and decreases in horizontal hydraulic conductivity in Zone 11 (Sandstone in Sub-McKay and Interburden),
- Increases in vertical hydraulic conductivity in Zone 11 –;and
- Increases and decrease in horizontal hydraulic conductivity in model Layer 5.

Of these four parameters, the model is most sensitive to changes in recharge in clinker and alluvium, where order-of-magnitude changes result in absolute residual means of up to 37.47 feet. The sensitivity to recharge is not surprising, given the large area of the model covered by the clinker and alluvium recharge zone.
Calibrated model values for the parameters to which the model is most sensitive are based on the data and calculations described in Section 2.0. For these parameters, the degree of uncertainty is relatively small, meaning that even though the model is sensitive to these values, they are reasonably well defined.

The model is least sensitive to pumping, pond seepage from Cell H, River Package conductance in Cell G, and vertical hydraulic conductivity in Zones 8 and 28, which show almost no change in the absolute residual mean over the range of plus or minus an order of magnitude. Although there is a large degree of uncertainty with some of these parameters due to an absence of field data, the sensitivity analysis shows that the uncertainty has little impact on model head-matching results.

For the majority of the parameters, zones, and reaches evaluated (146 total analyses completed), the absolute residual mean is lowest for the calibrated model specified values (a multiplier of 1 in the sensitivity plots). Two of the hydraulic conductivity zones, one of the pond seepage zones, and one of the River Package conductance reaches show a slightly better absolute residual mean for values different from those specified in the calibrated model. The improvement in the mean, however, is very small, and the necessary changes to hydraulic conductivity do not improve calibration for the 2003 steady-state model. Therefore, the sensitivity analysis shows that the parameter specifications for the calibrated model are the most appropriate for evaluating site conditions and for particle tracking described in the next section.
6.0 PARTICLE TRACKING AND CAPTURE ANALYSIS

Following calibration and sensitivity analysis, the numerical model was used to perform particle tracking to assess the effectiveness of the current groundwater capture system. This analysis should be considered an approximation and additional lines of evidence, such as field measurements of pumping drawdown and trends in water quality, should also be consulted in a weight-of-evidence approach.

Particle tracking simulates advective transport of dissolved constituents in groundwater. Advection is the transport of a solute by the bulk movement of groundwater, simulated by the movement of particles within flowing water at the average linear groundwater velocity. Particle tracking does not take into account other hydrodynamic processes that can affect the movement of solutes in groundwater including diffusion, dispersion, retardation (adsorption), or decay (chemical reactions).

The following subsections describe the methods and results of particle tracking performed to analyze capture system effectiveness.

6.1 CAPTURE ANALYSIS METHODS

MODPATH (Pollack, 1994) was used to complete particle tracking simulations to assess the effectiveness of the current groundwater capture system. The program was used to calculate particle pathlines based on advective flow. With the exception of capture rates (described in the next paragraph), hydraulic properties and boundary conditions from the 2015 steady-state calibration were used for the particle tracking analysis.

Capture well pumping rates listed in Table 6-1 were used for the particle tracking analysis and were selected following review of the last 2 years of capture system data in order to properly simulate long-term groundwater movement and capture. These represent adjustments of measured rates based on measurement uncertainty as previously described. Review of average monthly pumping rates for each well from 2014 through 2015 indicates that pumping rates used in the 2015 calibrated model generally represent current groundwater capture system operation. Pumping rates used in the 2015 calibrated model that did not represent current operation include Clinker pumping wells 694R, 695R, and 1031R. These wells were not pumping during the 2015 calibration but showed relatively consistent pumping rates between January and August 2015. The average pumping rate between January and August 2015 was used for these wells.

In 2015, the 552D Trench was constructed to capture shallow groundwater near the 552D seep (Hydrometrics, 2016b). In 2016, the 1172D Trench will be constructed to capture shallow groundwater near well 1123A. In addition, in 2016 wells 1120C and 1169R will be converted to capture wells (Hydrometrics, 2015b). Figure 2-46 shows the location of these capture wells and trenches. Capture trenches 552D and 1172D were added to the model as Drain Package cells, parameterized based on information in Hydrometrics (2016b) and Hydrometrics (2015c), respectively. The capture wells were added to the model as Well Package cells with pumping rates based on estimates provided by
Hydrometrics. Capture wells 1027A and 1028A are currently being bailed due to very low well yield and were therefore not included in the capture analysis.

Head (groundwater elevation) output from a steady-state simulation using the capture rates listed in Table 6-1 were used to generate velocity inputs for MODPATH.

**Table 6-1. Extraction Rates used in Capture Analysis**

<table>
<thead>
<tr>
<th>Well</th>
<th>Estimated Pumping Rate (gpm)</th>
<th>Well</th>
<th>Estimated Pumping Rate (gpm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1002R</td>
<td>6.86</td>
<td>1148D</td>
<td>0.12</td>
</tr>
<tr>
<td>1007R</td>
<td>0.85</td>
<td>1153A</td>
<td>0.16</td>
</tr>
<tr>
<td>1017R</td>
<td>2.25</td>
<td>1169R</td>
<td>4.00</td>
</tr>
<tr>
<td>1024AM</td>
<td>1.67</td>
<td>552D</td>
<td>0.14</td>
</tr>
<tr>
<td>1026AM</td>
<td>0.02</td>
<td>556D</td>
<td>0.02</td>
</tr>
<tr>
<td>1031R</td>
<td>1.70</td>
<td>565D</td>
<td>0.84</td>
</tr>
<tr>
<td>1034R</td>
<td>0.60</td>
<td>592A</td>
<td>0.06</td>
</tr>
<tr>
<td>1037R</td>
<td>0.94</td>
<td>605A-2</td>
<td>0.002</td>
</tr>
<tr>
<td>1039A</td>
<td>2.98</td>
<td>609D-2</td>
<td>0.04</td>
</tr>
<tr>
<td>1068A</td>
<td>0.19</td>
<td>610D</td>
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<tr>
<td>1080D</td>
<td>1.10</td>
<td>613D</td>
<td>0.50</td>
</tr>
<tr>
<td>1081D</td>
<td>0.15</td>
<td>616D</td>
<td>1.31</td>
</tr>
<tr>
<td>1083D</td>
<td>0.74</td>
<td>618D</td>
<td>0.27</td>
</tr>
<tr>
<td>1084A</td>
<td>0.02</td>
<td>619D</td>
<td>0.82</td>
</tr>
<tr>
<td>1087D</td>
<td>0.004</td>
<td>621D</td>
<td>0.60</td>
</tr>
<tr>
<td>1089D</td>
<td>0.26</td>
<td>644D</td>
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</tr>
<tr>
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<td>645D</td>
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<tr>
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<td>0.88</td>
<td>646D</td>
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<td>1095D</td>
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<td>647D</td>
<td>0.81</td>
</tr>
<tr>
<td>1097D</td>
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</tr>
<tr>
<td>1098D</td>
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<td>654A</td>
<td>5.41</td>
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<td>657M</td>
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<tr>
<td>1100D</td>
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<td>680A</td>
<td>0.02</td>
</tr>
<tr>
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<td>2.37</td>
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</tr>
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<td>1102D</td>
<td>0.12</td>
<td>687A/686A</td>
<td>4.97</td>
</tr>
<tr>
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<td>1.01</td>
<td>690A/688A/689A</td>
<td>1.41</td>
</tr>
<tr>
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<td>2.06</td>
<td>691A</td>
<td>4.77</td>
</tr>
<tr>
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<td>694R</td>
<td>0.68</td>
</tr>
<tr>
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<td>1.46</td>
<td>683A</td>
<td>0.02</td>
</tr>
<tr>
<td>1129D</td>
<td>0.53</td>
<td>695R</td>
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</tr>
<tr>
<td>1136A</td>
<td>0.003</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Rates are adjustments of the measured rates using the multipliers listed in Appendix G.
Effective porosity values were assigned to model cells in order to generate velocity inputs for MODPATH. Effective porosity values for different lithologies are within range of literature reported values presented in Table 3-1. Assigned effective porosity values are summarized in Table 6-2. The value assigned to McKay Coal is at the high end of literature values. Literature values of effective porosity were not available for clinker; it was assumed that clinker would have greater porosity than the parent rock (usually siltstone or sandstone) due to the highly fractured nature of clinker at the site.

<table>
<thead>
<tr>
<th>Unit</th>
<th>Effective Porosity (unitless)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alluvium</td>
<td>0.15 to 0.4</td>
</tr>
<tr>
<td>Clinker</td>
<td>0.1 to 0.4</td>
</tr>
<tr>
<td>Bedrock</td>
<td>0.01 to 0.25</td>
</tr>
<tr>
<td>McKay Coal</td>
<td>0.09</td>
</tr>
</tbody>
</table>

Five particle tracking simulations were completed, which included particles released from the presumed source area (EHP) and in saturated areas of the model exceeding BSLs in each of model Layers 2 through 5 (a small area of particles was added to Layer 6 in the Layer 5 simulation), shown in Figures 6-1 through 6-4, respectively (these figures are based on data presented in Figures 2-26 through 2-37). Areas with groundwater exceeding BSLs do not necessarily indicate impacts from the EHP. Several wells in the EHP area that were installed prior to EHP operation exhibited concentrations of indicator parameters that exceeded BSLs indicating that the BSLs calculated by Neptune (2016) may not adequately represent pre-EHP groundwater conditions. Particles were not released in Layers 7 through 8 because no wells in these layers currently exceed BSLs. Particles placement in each simulation is summarized below.

- **Source Area** – Particles were placed in active portions of Layer 2 within the cutoff wall, which represent saturated Rosebud/Clinker. Particles were also placed within River Package cells representing EHP Cells C, G, and the Old Clearwell (Cell J) in Layers 3 through 5.

- **Layer 2** – Particles were placed into saturated model cells representing the extent of groundwater exceeding BSLs in Layer 2 shown on Figure 6-1 (this figure shows saturated model cells within extents exceedances). This was delineated based on the maximum extent of indicator parameters in alluvium and Rosebud/Clinker exceeding BSLs shown on Figures 2-26 through 2-29. Particles were not placed in dry cells.

- **Layer 3** – Particles were placed into model cells representing the extent of groundwater exceeding BSLs in Layer 3 shown on Figure 6-2. This was delineated based on the maximum extent of indicator parameters exceeding BSLs in Interburden or alluvium inferred from Figures 2-26 through 2-33. Particles were not placed in dry cells.

- **Layer 4** – Particles were placed into model cells representing the extent of groundwater exceeding BSLs in Layer 4 shown on Figure 6-3. This was delineated based on the maximum extent of indicator parameters exceeding BSLs in the McKay (Figures 2-30 through 2-33) or alluvium (Figures 2-26 through 2-33). Particles were not placed in dry cells.
• Layers 5 and 6 – Particles were placed into model cells representing the extent of groundwater exceeding BSLs in Layers 5 and 6 shown on Figure 6-4 (there are only a few wells in Layer 6 located northeast of the 560A Trench that exceed BSLs for indicator parameters). This was delineated based on the maximum extent of indicator parameters exceeding BSLs in the Sub-McKay (Figures 2-34 through 2-37). Particles were not placed in dry cells.

For all particle tracking, particles were placed on 200-foot centers. Particle starting locations released within saturated areas of the model exceeding BSLs were set to the vertical center of model cells in Layers 2, 3, and 4. Particles released in Layers 5 and 6 were released at the top of the cell because generally only the upper portion of these layers contain wells exceeding BSLs. Forward particle tracking for each simulation was then completed, which involves moving the particles forward in time over a 50-year period using the steady-state groundwater flow conditions and tracking the path each particle takes over time.

6.2 Capture Analysis Results

Figure 6-5 through Figure 6-9 present animated particle tracks (click upper left corner of figure to activate animation; paper copies of this report contain a static image) resulting from the scenarios described in Section 6.1. Figure 6-5 shows the path for particles released in Source Areas in model Layers 2 through 5. Figure 6-6 through Figure 6-9 show particles released in model Layers 2 through 5 & 6 outside source areas as they move through the 50-year simulation. As the particles move into other layers, they are symbolized with different colors.

6.2.1 Source Areas

Figure 6-5 shows results of particle tracking for particles released within the EHP. Many particles released in Layer 2 within the EHP migrate south to the cutoff wall and then drop into Layer 3 (Interburden) and then into Layers 4 (McKay) and 5 (Sub-McKay). These particles migrate slowly to the south and southeast and are not captured within 50 years. Some particles released in Layer 2 migrate south, through the cutoff wall and are captured by wells 1002R and 1007R. Most particles released in Clinker in Layer 2 along the east side of the cutoff wall travel north and then northwest parallel to the cutoff wall. Most of these particles migrate to the Main Dam and then drop to deeper layers and migrate under the dam then north. Many of these particles are captured by the Main Dam Interception Trench or the 552D Trench. A few particles released in Clinker in Layer 2 along the east side of the cutoff wall travel east to the Saddle Dam and then drop to deeper layers beneath the dam; most of these particles are captured.

Some particles released in Layer 2 near Cell F migrate west through southwestern and west central portions of the cutoff wall; most of these particles then migrate into deeper layers and travel a short distance within the 50-year period. Other particles released in Layer 2 near Cell F migrate through the west central and northern portions of the west cutoff wall and are captured by the 656R capture system wells or drop to deeper layers and migrate north past the northwest corner of the cutoff wall, but do not migrate as far as Cow Creek within the 50-year simulation period.

Particles released near Cell B in Layer 2 migrate north or east to the cutoff wall and some migrate into deeper layers. Some of these particles are captured by wells in the 552D capture system or well 657M.
Other particles travel north in Layers 4, 5, or 6 but do not reach the northern model boundary within the 50-year simulation.

Particles released in most of Cell C within Layer 5 travel north or northeast. Many of these are captured by well 645D or the 556D capture system. Some travel as far as the northern model boundary without being captured within the 50-year simulation. Particles released in Layer 5 at the north end of Cell C and the Old Clearwell travel through Layer 5 (Sub-McKay) to the north and are captured by wells 646D, 654A, or the 556D capture system. Some travel northeast and are not captured. Particles released along the eastern margin of Cell C and in Cell G travel northeast below the Saddle Dam. Most of these are captured by wells in the 646D, 1039A, or 560A trench system. Some of these particles are not captured and travel as far as the northern model boundary in 50 years. Figure 6-5 suggests that with all the capture systems simulated, some groundwater from source areas will continue to migrate beyond capture systems immediately adjacent to the cutoff wall.

Some areas where BSL exceedances are currently mapped are not reached by source area particles by the end of 50-years simulation (such as southwest of the EHP). The particle tracking analysis is based on the current steady-state flow field, which is representative of current conditions including current operational practices, source control measures, and capture system configurations. The model predicts that under current conditions, migration pathways that previously brought groundwater from the EHP to areas exceeding BSLs that are not reached by source area particles in the capture analysis have been intercepted.

### 6.2.2 Particle Tracks by Layer

Figures 6-6 through 6-9 show results of particles released in groundwater in areas exceeding BSLs for specific model Layers 2 through 4 and combined Layers 5 and 6. These results are discussed below.

**Particles Released in Layer 2**

Results for particles within Rosebud/Clinker areas exceeding BSLs in Layer 2 (Figure 6-6) are similar to those released within the EHP discussed in **Section 6.2.1** above. Some particles released in Clinker west of the northwest corner of the cutoff wall are captured by the SP-15 north and SP-15 south interception trenches, and capture well 657M; a few particles are not captured and migrate northwest toward the Drain Pit 5 drainage. Particles released in Clinker south of the cutoff wall are either captured by South Fork Cow Creek capture wells or migrate westward in Layer 5 (Sub-McKay).

Some particles released in alluvium in Layer 2 in the Drain Pit 5 drainage are captured by the Drain Pit 5 interception trench, but a few particles are not captured and continue migrating downgradient in Cow Creek alluvium. Particles released in alluvium in Layer 2 in South Fork Cow Creek alluvium are captured by the South Fork Cow Creek capture system.

**Particles Released in Layer 3**

Particles released in Interburden in areas exceeding BSLs (Figure 6-7) migrate down into the McKay and Sub-McKay intervals. With the exception of particles captured by wells 1017R and 657M, particles released in Interburden southwest, west, and north of the cutoff wall travel northeast or north and are not captured. Particles released in Layer 3 Interburden east of the Saddle Dam migrate east and northeast. Most of these particles are captured in the Valley Drain and the 560A trench system.
Particles released in Layer 3 Interburden northeast of the Saddle Dam are not captured and migrate northeast.

Most particles released in alluvium in Layer 3 in the Drain Pit 5 drainage above the Drain Pit 5 Interception Trench are captured by the trench. Particles released in alluvium north of the interception trench are not captured and migrate a long distance east within Cow Creek alluvium. Particles released in Layer 3 alluvium in the South Fork Cow Creek are captured.

**Particles Released in Layer 4**

Results for Layer 4 particle tracking (Figure 6-8) are similar to Layer 3. Particles released in McKay in Layer 4 in areas exceeding BSLs migrate down into the Sub-McKay intervals. With the exception of particles captured by wells 1017R and 657M, particles released in the McKay in Layer 4 southwest, west, and north of the cutoff wall travel northeast or north and are not captured. Particles released in Layer 4 McKay east of the Saddle Dam migrate east and northeast. Most of these particles are captured by the Valley Drain and the 560A trench system. Particles released in Layer 4 McKay northeast of the Saddle Dam are not captured and migrate northeast. Particles released in Layer 4 McKay south and southeast of the cutoff wall migrate south and are captured by South Fork Cow Creek capture wells or migrate east uncaptured.

Particles released in alluvium in Layer 4 in the Drain Pit 5 drainage above the Drain Pit 5 Interception Trench are captured by the trench. Particles released in alluvium north of the interception trench are not captured and migrate a long distance east within Cow Creek alluvium. Particles released in Layer 4 alluvium in the South Fork Cow Creek are captured by wells. Some of the particles released in the Layer 4 alluvium north of the Main Dam are captured by 654A; some are not captured and migrate north.

**Particles Released in Layers 5 and 6**

Particles released in Layer 5 (Figure 6-9) south of the EHP are not captured but travel only a short distance in the 50-year simulation. Most of the particles released in Sub-McKay east of the Saddle Dam are captured by the 646D, 1079, and 560A trench capture systems. A few particles released in Layers 5 and 6 northeast of the 560A Interception Trench are not captured. A few particles released in Layer 5 northeast of the EHP are captured by the 556D capture system, but most particles are not captured and they migrate to the northeast. Some particles released in Layer 5 northeast of the EHP are captured by wells in the 644D/655D, Main Dam Sump, 552D Trench, 1087D, and 556D capture systems, though many particles migrate north beyond the capture systems. Most of the particles released in Sub-McKay northwest of the EHP are not captured, with the exception of particles captured by well 657M.

**6.2.3 Summary of Capture Analysis**

Figure 6-10 shows starting locations of particles released within source areas for all model layers that are not captured within the 50-year capture analysis time frame. Figure 6-11 through Figure 6-14 show starting locations of uncaptured particles originating in areas exceeding BSLs for model Layers 2 through 5 & 6. A summary of the uncaptured particles by specific model layer is as follows:

- **Layer 2:** Figure 6-11 suggests that in Layer 2, particles placed in a large portion of the Rosebud/Clinker of Layer 2 are not captured, but most particles placed in alluvium are captured.
• **Layer 3: Figure 6-12** indicates that particles released in most areas of Interburden exceeding BSLs are not captured, while particles released in most alluvium in South Fork Cow Creek drainage, the 560A drainage, and the Drain Pit 5 drainage upgradient of capture systems in those drainages are captured. Particles released in Layer 3 alluvium along Cow Creek and the downgradient end of the Drain Pit 5 and Main Dam drainages are not captured.

• **Layer 4: Figure 6-13** suggests that particles released in most areas of McKay coal exceeding BSLs are not captured, while particles released in most alluvium in South Fork Cow Creek drainage, the 560A drainage, and in the Drain Pit 5 and Main Dam drainages above capture systems in those drainages are captured. Particles released in Layer 4 alluvium in some of the Drain Pit 5, Cow Creek, and 560A drainages are not captured.

• **Layers 5 and 6: Figure 6-14** suggests that particles released in Sub-McKay north of the Main Dam and in most of the area east of the Saddle Dam are captured. Most particles released in Layer 5 northeast and northwest of the EHP are not captured.

The following is a summary of capture system effectiveness by system based on particle tracking results and other information. Capture systems are summarized in [Appendix G](#) and locations are shown on Figure 2-46.

**South Fork Cow Creek System**: Based on particle tracking results, the South Fork Cow Creek capture system is achieving complete capture.

**South Rosebud System**: Particle tracking and groundwater elevation data for wells in this area suggest that this system is capturing most of the groundwater in the Clinker south and west of the cutoff wall. Pumping rates have decreased substantially in many of these wells as the Rosebud/Clinker unit has been dewatered. In Clinker wells such as 697R, 1013R, 1016R, 1162R, groundwater levels have been drawn down below the contact between the Clinker and underlying Interburden by the capture system for at least part of the year. Particle tracking suggests that impacted groundwater in the Clinker may continue to migrate south beyond capture system wells, which is then captured by the South Fork Cow Creek System. However, several particles that originate in Rosebud/Clinker south of the cutoff wall migrate vertically into deeper layers without being captured. In addition, as groundwater levels in the Clinker have dropped, pumping has become much more intermittent in several wells or has stopped due to insufficient water in the capture wells to support continuous pumping.

**Well 656R System**: This system captures most of the groundwater that seeps through the northern portion of the west slurry wall. However, some groundwater in Clinker in this area is not captured and is migrating downward into McKay and Sub-McKay intervals. A portion of water in the McKay issues to the SP-15 North and South trenches.

**SP-15 North and South Trench System**: Groundwater in Clinker west of the Well 656R system is largely captured by the SP-15 North and South trench systems and well 657M. A few particles migrate beneath the trench in Sub-McKay.

**Drain Pit 5 Trench**: Particle tracking suggests this trench captures all of the groundwater exceeding BSLs in alluvium upgradient on the Drain Pit 5 Trench. A few particles migrate beneath the trench in Sub-McKay, and concentrations of indicator parameters in wells downgradient of the trench exceed BSLs.
Well 552D System: Particle tracking suggests that this system is capturing impacted groundwater migrating north of the cutoff wall just west of the Main Dam. However, particle tracking also suggests that impacted groundwater could be migrating beneath these capture wells. In addition, results suggest that particles slowly migrate north in McKay and Sub-McKay intervals between this system and the northwest corner of the cutoff wall. Sub-McKay wells 614D and 551D within this pathway have exhibited concentrations of indicator parameters exceeding BSLs.

Well 644D/645D System: These capture wells are capturing impacted groundwater on either side of the Main Dam. However, impacted groundwater may be seeping through and beneath the Main Dam between these two capture wells. Shallower groundwater in this pathway is largely captured by the Main Dam Valley Drain and Main Dam Interception Trench.

Main Dam Valley Drain and Sump Systems: These systems are capturing a large portion of impacted groundwater migrating north from the Main Dam in alluvium and Sub-McKay bedrock. Particle tracking suggests that some groundwater originating in Cell C may be migrating in deeper Sub-McKay layers and may not be captured.

Well 556D System: This system is capturing some groundwater migrating north and northeast from the northeast corner of the EHP. However, particle tracking and plume maps suggest that these systems are not capturing all impacted groundwater along these pathways in the Sub-McKay unit.

Saddle Dam Interception Trench and Well 646D System: This trench captures a small amount of shallow water seeping from the Saddle Dam area. Wells in this system capture much of the impacted groundwater in the Sub-McKay unit originating from the southern half of the Saddle Dam. Much of the impacted groundwater in the area is not captured by this system.

560A Trench System: Much of the groundwater in Alluvium and Sub-McKay northeast of the Valley Drain Trench and 646D system is being captured by wells and trenches in the 560A Trench system, which includes several capture wells and the 1051A, 1073, and 1079 interception trenches. Particle tracking suggests that impacted groundwater originating near the Saddle Dam is not being captured north of this system and some impacted groundwater could migrate slowly in intervals deeper than is intercepted by wells 1127D and 1148D.

The assessment of capture system effectiveness above is based on particle tracking and does not take into account COI concentrations or cleanup levels. Cleanup criteria will be determined in the Cleanup Criteria and Risk Assessment report (under review by DEQ). Capture system effectiveness will be further evaluated using solute transport modeling in the forthcoming Remedy Evaluation.

6.3 Uncertainty Analysis

Uncertainty associated with some model inputs lends uncertainty in model predictions such as the capture analysis described above. An uncertainty analysis was completed to evaluate how sensitive capture analysis results are to a set of input parameters that are anticipated to have a relatively high degree of uncertainty and also have an impact on predicted capture results. Parameters evaluated were those judged to have the greatest effect on capture analysis results, including pumping rates and effective porosity.
6.3.1 Reduced Pumping Rates

As described above, there is uncertainty associated with pumping rates in capture wells due to the difficulty in measuring flow rates at individual wells. Hydrometrics personnel indicate that scaling within the plumbing associated with the systems makes obtaining accurate flow measurements from the systems is problematic.

Model calibration and sensitivity analyses indicate that the model is somewhat sensitive to changes in capture rates of ± 25 percent. Therefore, one additional capture analysis was performed to help further evaluate the uncertainty described above as related to capture well pumping rates. Extraction rates used in the capture analysis were multiplied by 0.75. Particles were initiated at the same starting locations as described in Section 6.1. Forward particle tracking was then executed, and the particles were moved through the steady-state flow field.

Generally, uncertainty analysis indicates that with the lower pumping rates tested, there would be additional small areas of impacted groundwater that would not be captured. However, with both pumping rates, there are substantial areas of impacted groundwater that are not completely captured. The following observations result from comparison of Figures 6-15 through 6-18 to Figures 6-11 through 6-14:

- **Layer 2**: Areas of starting locations of uncaptured particles in Clinker and alluvium in Layer 2 are similar but there is decreased capture to the west of the EHP, and in a very small area to the northeast of the ponds.

- **Layer 3**: Areas of starting locations of uncaptured particles in Interburden and alluvium in Layer 3 are similar but there is a very slight decrease in capture along SFCC and along Cow Creek.

- **Layer 4**: Areas of starting locations of uncaptured particles in McKay and alluvium in Layer 4 are similar. Small additional areas of impacted groundwater within the McKay unit east of the EHP and in alluvium in the 560A drainage would not be captured.

- **Layers 5 and 6**: A few additional small areas of impacted groundwater in the Sub-McKay unit would not be captured north and east of the EHP. Otherwise lower pumping rates do not greatly affect capture in the Sub-McKay unit.

6.3.2 Effective Porosity

Time-of-travel predictions are sensitive to effective porosity because groundwater velocity is inversely proportional to effective porosity. Effective porosity is difficult to measure in the field, and site-specific data are not available. As discussed in Sections 3.0 and 4.0, the model was populated with what are considered to be standard literature-derived values for effective porosity.

Since effective porosity does not alter the flow field in any way, the same particles would be captured and with this analysis as presented in Section 6.2. However, effective porosity does impact the time-of-travel. With this in mind, the model was populated with a sparse set of particles, starting at locations that fell within the areas of BSL exceedance (presented in Section 6.1). The sparse set of particles allowed for easier visualization of the travel time along the particle trace. This analysis was also completed for a reduced period of time (10 years). Two additional simulations were designed and executed: a “low” effective porosity simulation and a “high” effective porosity simulation. For these two simulations, effective porosity in the major porosity zones were set to low and high values respectively,
according to the range in literature (Table 3-1). Table 6-3 below presents the effective porosity assigned to the major porosity zones in the model for these two scenarios, along with the values assigned in the standard case.

Table 6-3. Effective Porosity Values Applied to Uncertainty Simulations

<table>
<thead>
<tr>
<th>Material</th>
<th>Zone</th>
<th>Low Effective Porosity Scenario</th>
<th>Standard Effective Porosity</th>
<th>High Effective Porosity Scenario</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alluvium</td>
<td>2</td>
<td>0.2</td>
<td>0.25</td>
<td>0.35</td>
</tr>
<tr>
<td>Clinker</td>
<td>3</td>
<td>0.01</td>
<td>0.1</td>
<td>0.4</td>
</tr>
<tr>
<td></td>
<td>11 and 10</td>
<td>0.01</td>
<td>0.25</td>
<td>0.4</td>
</tr>
<tr>
<td>Bedrock</td>
<td>1, 4</td>
<td>0.01</td>
<td>0.1</td>
<td>0.4</td>
</tr>
<tr>
<td></td>
<td>27</td>
<td>0.01</td>
<td>0.2</td>
<td>0.4</td>
</tr>
<tr>
<td></td>
<td>28</td>
<td>0.01</td>
<td>0.3</td>
<td>0.4</td>
</tr>
<tr>
<td>Coal</td>
<td>5, 9, 29, 33</td>
<td>0.01</td>
<td>0.09</td>
<td>0.09</td>
</tr>
</tbody>
</table>

Figure 6-19 presents the results of the effective porosity uncertainty analysis. The most notable difference between the scenarios is that, under the lower effective porosity scenario, most particles that are not captured migrate to or near model boundaries along Cow Creek and South Fork Cow Creek within 10 years. With higher effective porosity, particles generally do not travel much beyond the existing extent of BSL exceedance within 10 years, with the exception of particles in alluvium.
7.0 MODEL ASSUMPTIONS AND LIMITATIONS

The numerical model described herein is capable of adequately simulating groundwater flow within the area of interest under a variety of conditions within a reasonable range. Calibration of the model to a variety of different aquifer stress conditions, as described in Section 4.0, improves the confidence in the model's abilities.

The numerical model is appropriate for assessing effects of changes in water management practices at the Units 3 & 4 EHP on groundwater flow and advective transport. It should be noted that because particle tracking (an advective transport analysis) does not take into account processes of attenuation (dispersion, retardation, and decay), it is not capable of quantifying the mass or concentrations of various solutes residing in the aquifer or the mass of solutes removed by capture systems.

Groundwater models are mathematical representations of groundwater systems and, therefore, are guided by certain assumptions and limitations. Those that pertain to MODFLOW include:

- Saturated-flow conditions exist throughout the model domain;
- Darcy's Law applies;
- The density of groundwater is constant; and
- The principal directions of horizontal hydraulic conductivity or transmissivity do not vary within the system; aquifer heterogeneity and anisotropy can be adequately represented with an appropriate choice of aquifer properties and grid spacing.

The model is also governed by other important assumptions:

- Specific equipotential contour lines used to assign GHBs and no-flow boundaries provide an accurate and reasonable representation of the flow field at the model boundaries;
- Steady-state boundary conditions, based on average pumping and recharge rates, result in representative flow fields. This assumes that transient aquifer stresses that are not simulated would not produce significantly different results;
- Estimated capture well pumping rates are representative of actual rates;
- Flow in fractured bedrock can be approximated as an equivalent porous medium;
- Vertical discretization within the model is fine enough to capture the depth-specific flow fields;
- The range of aquifer properties estimated from field-based data provides a reasonable range of site values that are representative of actual site conditions; and
- The elastic storage coefficient of the aquifer does not change.

There is a degree of uncertainty inherent in any model and its application. In this case, there is uncertainty associated with model inputs such as pond seepage rates, pumping rates, areal recharge, and hydraulic properties. The model includes an underlying assumption that the aquifer heterogeneity and anisotropy can be adequately characterized with an appropriate choice of aquifer properties and grid
size. Sedimentary processes that formed interfingered sandstone, shale, mudstone, and coal strata in the Fort Union Formation likely created changes in vertical and horizontal hydraulic properties on the scale of tens of feet or less. In addition, the model does not simulate any undocumented preferential flow paths that could be present. Interfingering of alluvial and colluvial units results in heterogeneity at tens of feet or less.

Groundwater models are by nature a simplification of the natural world. What we know about groundwater systems is typically insufficient to constrain the problem to one unique solution (Anderson et al, 2015). The set of input parameters used to calibrate the model is probably not unique, i.e., there are likely other combinations of input parameters that could be found that would produce results that would meet calibration criteria. The calibrated model described in this report is based on the identified conceptual model and based on available data and observations and is sufficiently discretized in space and time to meet the project objectives.

The ability of the model to accurately predict changes in groundwater flow and advective transport at the scale of tens of feet or less may be limited, especially in areas with complex flow characteristics. For these reasons, model predictions should not be viewed as certainties but as the best interpretation of likely outcomes based on available information and data. Additional lines of evidence, such as field-measurements of drawdown and trends in water quality, should be assessed along with the model predictions to evaluate capture system performance.
8.0 CONCLUSIONS AND RECOMMENDATIONS

Calibration of the numerical groundwater flow model described in this report demonstrates the 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 groundwater flow system in the Units 3 & 4 EHP area is complex and dynamic.
- Seepage from the EHP is a source of groundwater recharge within the upper Cow Creek drainage, and groundwater capture systems are points of discharge. Therefore, changes in water management at the EHP affects groundwater flow directions and gradients.
- Groundwater levels in several monitoring wells have increased by up to 40 feet since the filling of the EHP began in 1983.
- As groundwater elevations inside the cutoff wall increased, groundwater has seeped through and/or beneath the cutoff wall, the Main Dam, and the Saddle Dam.
- Groundwater flow is radially away from the EHP within the shallower hydrogeologic units (Rosebud/Clinker, McKay, and Interburden). Regional flow in the deep Sub-McKay is generally west to east.
- Vertical hydraulic gradients at paired wells are generally downward across the site with the exception of paired wells in alluvium along South Fork Cow Creek and Cow Creek where bedrock groundwater appears to discharge to alluvium in some areas.
- Most Sub-McKay wells and several McKay wells that have exhibited increasing water levels since 1983 do not contain concentrations of indicator parameters exceeding BSLs; this observation suggests that hydrostatic loading of the aquifer (i.e., an increase in hydraulic pressure due to aquifer compression) has occurred since the EHP cells have been filled.
- Joints, cleating, and fractures in coal and bedrock, and strata with varying permeability can create preferential flow and transport pathways such as in areas north of the Main Dam (near Seep 552) and south of the EHP (near the SFCC Seep and South Fork Cow Creek). Other preferential pathways have not been identified but may exist.
- Several wells in the EHP area that were installed prior to EHP operation exhibited concentrations of indicator parameters that exceeded BSLs. The presence of groundwater exceeding BSLs before the EHP ponds were in operation is an indication that the BSLs calculated by Neptune (2016) may not adequately represent pre-EHP groundwater conditions.
- It appears that groundwater quality has been influenced by seepage from the EHP as well as flooding of Cells F and H with process water in 2003 and 2004 resulting in pond water seeping through or under the cutoff wall. It appears that other releases of process water have also affected groundwater quality west of the EHP including releases from a fly ash slurry pipeline and
from a return water pipeline near Drain Pit 3. In addition, water seeping from mine spoils near the NP Cut west of the EHP appears to affect alluvial groundwater quality in the Drain Pit 5 drainage.

- The extent of saturation (and therefore impacted groundwater) in Rosebud/Clinker outside of the cutoff wall is smaller in 2015 than it was in 2005 following the flooding of Cells F and H. In addition, concentrations of indicator parameters in most Clinker wells south and west of the EHP decreased substantially between 2005 and 2015. This is attributable to changes in water management within the EHP as well as the installation and operation of groundwater capture wells south and west of the cutoff wall that have reduced the extent of saturation and cutoff the flow of water to the SFCC and West seeps.

- Installation of additional monitoring wells between 2006 and 2015 has further delineated the extent of impacted groundwater and identified some impacted zones unknown before 2006, including downgradient of the Drain Pit 5 Interception Trench, east of the Saddle Dam, and northwest of the EHP.

- Concentrations of indicator parameters in Sub-McKay wells 620D, 644D, 645D, 1115D, 1128D, and 1129D north of the EHP increased between 2003 and 2015. Most of these wells are immediately adjacent to capture wells. Observed increases in these wells may be attributable to growing zones of influence that capture more impacted groundwater; similar increases are not generally observed in downgradient Sub-McKay wells.

- Concentrations of indicator parameters in wells 556D, 610D, and 621D northeast of the EHP generally increased between 2010 and 2015. These wells are all capture wells. Concentrations of indicator parameters in 2015 samples from well 611D downgradient of the capture wells exceed BSLs for indicator parameters. Although concentrations measured in these wells were lower in 2015 than they were in 2010, the concentrations remain above BSLs, suggesting persistent process water impacts. Particle tracking suggests that this is the case. Transmissivity in this area is minimal, particularly at wells 611D and 612D, which limits the effectiveness of groundwater capture, which is reflected by the model.

- Concentrations of indicator parameters in wells 1047A, 1048A, 1126A, which are downgradient of the Drain Pit 5 interception trench continue to exhibit indicator parameter concentrations above BSLs, suggesting that the interception trench may not be achieving complete capture of impacted groundwater.

- Concentrations of indicator parameters above BSLs persist in wells 1121D and 1148D. Particle tracking suggests that pumping wells 1127D and 1148D is not achieving complete capture in this area. However, well 1146D shows no impacts.

Capture analysis suggests that the current capture system array intercepts much of the impacted groundwater east of the Saddle Dam and in the 560A, Main Dam, Drain Pit 5, and South Fork Cow Creek drainages. Particle tracking results suggest that some un-captured groundwater originating from beneath the ponds may be migrating north and northeast of the EHP. To the west and south of the EHP are areas that exceed BSLs for indicator parameters in McKay and Sub-McKay.

The assessment of capture system effectiveness described above is based on particle tracking and does not take into account COI concentrations or cleanup levels. Cleanup criteria will be determined in the
Cleanup Criteria and Risk Assessment report (under review by DEQ). Capture system effectiveness will be further evaluated using solute transport modeling in the forthcoming Remedy Evaluation.

Based on the modeling work described above, NewFields developed the following recommendations and identified data gaps.

- Impacted groundwater appears to be migrating north from the Main Dam area in alluvium and Sub-McKay bedrock. In the capture analysis, some particles migrate near the north model boundary in these units. Based on model simulations, capture of groundwater in the Sub-McKay near wells 1115D, 1087D, and 581D-2 is limited. Groundwater in a sandstone zone between approximately 3,140 to 3,190 feet amsl at wells 1115D and 1116D appears to be a conduit for impacted groundwater moving north from the EHP in the Sub-McKay unit. We recommend exploring options for increased capture from this interval, by possibly installing additional and/or deeper capture wells in the area.

- Particle tracking results and plume maps suggest that capture wells 609D-2, 556D, 610D, and 621D are currently capturing insufficient amounts of groundwater to capture particles migrating from the northeast corner of the EHP toward wells 611D and 585D. We recommend exploring options for increasing groundwater capture near these wells.

- Concentrations in wells downgradient of the Drain Pit 5 Trench that exceed BSLs. We recommend investigations to determine how groundwater downgradient of the trench might be captured more effectively.

- Particle tracking and plume maps suggest that groundwater in the McKay west and southwest of the slurry wall is not captured. We recommend further investigation in this area to evaluate capture of groundwater within the McKay unit.

- Particle tracking suggests that impacted groundwater may be migrating north from the northwest corner of the EHP. We recommend continued monitoring of water quality in Sub-McKay wells 614D and 1154D. If concentrations in these wells increase, wells should be used to capture groundwater.

- Particle tracking suggests that south of the EHP impacted groundwater may eventually migrate to McKay and Sub-McKay bedrock and move to the southeast. We recommend continued tracking of water quality trends in wells southeast of the EHP including well 1139M in the McKay and wells 589D and 1134D in the Sub-McKay If concentrations of indicator parameters increase, consider converting to capture wells.

- Particle tracking suggests that a major portion of impacted groundwater outside the cutoff wall flows from Clinker inside the cutoff wall. Capture of groundwater in Clinker inside the cutoff wall would greatly restrict seepage outside of the cutoff wall.

- Pumping of well 1085R suggests dewatering of the Clinker inside the cutoff wall may be effective at reducing seepage beneath and through the cutoff wall. We recommend converting wells 1003R, 1085R, and 1164R to capture wells after cells are lined or after paste reduces flow out of the cells so there is not constant recirculation of pumped water. Having accurate flow rate measurements is important for evaluating capture system effectiveness. We recommend evaluating and developing methods to provide more accurate measurements of instantaneous pumping rates from capture wells and trenches.
9.0 REFERENCES


Hydrometrics. 2006. Evaluation of 2005 Hydrologic Monitoring Data from Colstrip Units 1 through 4 Process Pond System Colstrip Steam Electric Station, Colstrip, Montana. Prepared for PPL Montana, LLC.

Hydrometrics. 2007. Email message regarding laboratory results for paste hydraulic conductivity. September 12.


Hydrometrics. 2015a. Personal communication with Al Hilty, Hydrometrics Inc. April 27.


Western Regional Climate Center. 2015. (Monthly and annual Average Pan Evaporation) Huntley Experimental Station (1911-2005) http://www.wrcc.dri.edu/htmlfiles/westevap.final.html#MONTANA.