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July 24, 2017

Sara Edinberg
Remediation Division, Hazardous Waste Cleanup Bureau
Montana Department of Environmental Quality
P.O. Box 200901
Helena, MT 59620-0901

RE: Final 3&4 EHP AOC Report

Dear Ms. Reynolds,

On behalf of Talen Montana, LLC, Hydrometrics is submitting the Final Revised Administrative Order On Consent, Units 3&4 Effluent Holding Pond (EHP) Site Report.

Enclosed are two bound copies which include:

- A CD with the report in electronic format;
- Hard copies of all of the Comments and Responses (without attachments); and
- A hard copy of MDEQ's approval letter.

Please contact Gordon Criswell with any questions or comments.

Respectfully submitted,

Al Hilty, P.G.
Hydrometrics, Inc.

Cc: Aimee Reynolds
Gordon Criswell, Talen Montana, LLC, 1 electronic copy
Steve Christian, Talen Montana, LLC, 1 hard copy including CD
Newfields Companies, LLC, 1 electronic copy
Geosyntec Consultants, 1 electronic copy

Enclosures

TALEN MONTANA, LLC
COLSTRIP STEAM ELECTRIC STATION
ADMINISTRATIVE ORDER ON CONSENT
UNITS 3 & 4 EFFLUENT HOLDING POND (EHP) SITE REPORT

Prepared for:

Talen Montana, LLC
P.O. Box 38
Colstrip, Montana 59323

Prepared by:

Hydrometrics, Inc.
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October 2013
Revised June 30, 2016
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TABLE OF CONTENTS

LIST OF TABLES iv
LIST OF FIGURES iv
LIST OF APPENDICES ix
EXECUTIVE SUMMARY E-1
1.0 INTRODUCTION 1-1
2.0 CLOSED LOOP SYSTEM DESCRIPTION, POND CONSTRUCTION, AND POND WATER QUALITY 2-1
2.1 CLOSED LOOP SYSTEM 2-1
2.1.1 Definitions 2-1
2.1.2 Facility-Wide Process Water Flow 2-3
2.1.3 Process Pond Storage and Water Management 2-4
2.1.4 Water Use and Measurement Difficulties 2-5
2.1.5 Best Management Practices for Water Management 2-6
2.1.6 3&4 EHP Pond Water Sampling 2-7
2.2 UNITS 3&4 EFFLUENT HOLDING POND 2-8
2.2.1 Pond Construction 2-8
2.2.2 Units 3 & 4 EHP Water Chemistry 2-10
2.2.2.1 Bromide 2-12
2.2.2.2 Reporting Limits and Method Detection Limits 2-13
2.3 POND SEEPAGE ESTIMATES 2-15
3.0 SUMMARY OF INVESTIGATIONS 3-1
3.1 SYNOPSIS OF PAST SPILLS, INVESTIGATIONS, MITIGATION, AND STATUS 3-1
3.2 PAST INVESTIGATIONS 3-1
3.3 CURRENT SITE CONDITIONS 3-1
3.3.1 Regional and Site Hydrogeology 3-1
3.3.1.1 Bedding Orientations 3-9
3.3.1.2 Presence of Groundwater 3-10
3.3.2 Distribution of Indicator Parameters 3-11

3.3.3 Groundwater Flow 3-21
3.3.4 Vertical Gradients 3-22
3.3.5 Simplified Conceptual Groundwater Model 3-27
3.3.6 Surface Water Quality.....3-32
3.4 DESCRIPTION OF COMPLETED AND ONGOING REMEDIAL ACTIONS 3-33
3.4.1 Operational Monitoring 3-33
3.4.1.1 Water Level Measurements 3-36
3.4.1.2 Capture System Monitoring.....3-36
3.4.2 Groundwater Mitigation Activities 3-37
3.4.3 Completed Units 3&4 EHP Mitigation Measures 3-39
3.4.4 Planned Mitigation Measures – Units 3&4 EHP 3-41
3.4.5 Best Management Practices 3-43
3.5 EFFECTIVENESS ASSESSMENT OF REMEDIAL ACTION 3-44
3.5.1 Area 1 – North of the 3&4 EHP Main Dam 3-47
3.5.2 Area 2 - East of 3&4 EHP Saddle Dam.....3-50
3.5.3 Area 3 - 560A/1051A Area.....3-53
3.5.4 Area 4 - EHP South and Southwest Side.....3-54
3.5.5 Area 5 - South Fork Cow Creek 3-56
3.5.6 Area 6 - EHP West and Northwest Side 3-58
3.5.7 Area 7 - Drain Pit #5 Interception Trench Area 3-60
3.5.8 Area 8 - Drain Pit #3 Interception Trench Area 3-60
3.6 ONGOING INVESTIGATIONS/ACTIVITIES.....3-61
3.7 SPECIFIC ACTIONS 3-63
3.7.1 Lining of F Cell.....3-63
3.7.2 Lining of B Cell 3-63
3.7.3 Moving Clearwell 3-64
3.7.4 H Cell Lining 3-64
3.7.5 Forced Evaporation.....3-64
4.0 GROUNDWATER MODEL RESULTS AND INTERPRETATION 4-1
5.0 IDENTIFICATION OF DATA GAPS 5-1

6.0 RECOMMENDATIONS FOR ADDITIONAL SITE CHARACTERIZATION 6-1
7.0 REFERENCES 7-1

LIST OF TABLES

TABLE 2-1. POND DESCRIPTIONS
TABLE 2-2. CHEMICAL PROFILES
TABLE 2-3A. SEEPAGE ESTIMATE FOR LINED B AND F CELLS
TABLE 2-3B. SEEPAGE ESTIMATE FOR H CELL DOUBLE GEOMEMBRANE LINER SYSTEM
TABLE 2-4A. CURRENT FLUX ESTIMATE FROM THREE EFFLUENT HOLDING PONDS; UNITS 3&4
TABLE 2-4B. 2013 FLUX ESTIMATE FROM THREE EFFLUENT HOLDING PONDS; UNITS 3&4
TABLE 3-1. SUMMARY OF RELEASES OF ACTIONS TAKEN
TABLE 3-2. SUMMARY OF WORK CONDUCTED AND FINDINGS
TABLE 3-3 GROUNDWATER QUALITY BACKGROUND SCREENING LEVELS
TABLE 3-4 FALL 2010 & FALL 2015 WATER LEVELS - UNITS 3&4 EHP
TABLE 3-5. AREA CAPTURE LOCATIONS AND START DATES

LIST OF FIGURES
(Included as ONE PDF file with bookmarks)

FIGURE 1-1. UNITS 3 & 4 EFFLUENT HOLDING POND AREA
FIGURE 2-1. COLSTRIP PROCESS WATER DIAGRAM
FIGURE 3-1. GEOLOGIC CROSS SECTION A-A'
FIGURE 3-2. GEOLOGICAL CROSS SECTION B-B'
FIGURE 3-3. GEOLOGIC CROSS SECTION C-C'
FIGURE 3-4. UNITS 3 & 4 EFFLUENT HOLDING POND AREA CAPTURE AND MONITORING WELLS
FIGURE 3-5. FALL 2015 SPECIFIC CONDUCTANCE IN SHALLOW AND ROSEBUD WELLS

FIGURE 3-6. FALL 2010 SPECIFIC CONDUCTANCE IN SHALLOW AND ROSEBUD WELLS
FIGURE 3-7. FALL 2015 SPECIFIC CONDUCTANCE IN SHALLOW AND MCKAY WELLS
FIGURE 3-8. FALL 2010 SPECIFIC CONDUCTANCE IN SHALLOW AND MCKAY WELLS
FIGURE 3-9. FALL 2015 SPECIFIC CONDUCTANCE IN SUB MCKAY WELLS
FIGURE 3-10. FALL 2010 SPECIFIC CONDUCTANCE IN SUB MCKAY WELLS
FIGURE 3-11. FALL 2015 SULFATE CONCENTRATIONS IN SHALLOW AND ROSEBUD WELLS
FIGURE 3-12. FALL 2010 SULFATE CONCENTRATIONS IN SHALLOW AND ROSEBUD WELLS
FIGURE 3-13. FALL 2015 SULFATE CONCENTRATIONS IN SHALLOW AND MCKAY WELLS
FIGURE 3-14. FALL 2010 SULFATE CONCENTRATIONS IN SHALLOW AND MCKAY WELLS
FIGURE 3-15. FALL 2015 SULFATE CONCENTRATIONS IN SUB MCKAY WELLS
FIGURE 3-16. FALL 2010 SULFATE CONCENTRATIONS IN SUB-MCKAY WELLS
FIGURE 3-17. FALL 2015 BORON CONCENTRATIONS IN SHALLOW AND ROSEBUD WELLS
FIGURE 3-18. FALL 2010 BORON CONCENTRATIONS IN SHALLOW AND ROSEBUD WELLS
FIGURE 3-19. FALL 2015 BORON CONCENTRATIONS IN SHALLOW AND MCKAY WELLS
FIGURE 3-20. FALL 2010 BORON CONCENTRATIONS IN SHALLOW AND MCKAY WELLS
FIGURE 3-21. FALL 2015 BORON CONCENTRATIONS IN SUB MCKAY WELLS
FIGURE 3-22. FALL 2010 BORON CONCENTRATIONS IN SUB MCKAY WELLS
FIGURE 3-23. FALL 2015 CHLORIDE CONCENTRATIONS IN SHALLOW AND ROSEBUD WELLS

FIGURE 3-24. FALL 2010 CHLORIDE CONCENTRATIONS IN SHALLOW AND ROSEBUD WELLS
FIGURE 3-25. FALL 2015 CHLORIDE CONCENTRATIONS IN SHALLOW AND MCKAY WELLS
FIGURE 3-26. FALL 2010 CHLORIDE CONCENTRATIONS IN SHALLOW AND MCKAY WELLS
FIGURE 3-27. FALL 2015 CHLORIDE CONCENTRATIONS IN SUB MCKAY WELLS
FIGURE 3-28. FALL 2010 CHLORIDE CONCENTRATIONS IN SUB MCKAY WELLS
FIGURE 3-29. FALL 2015 BROMIDE CONCENTRATIONS IN SHALLOW AND ROSEBUD WELLS
FIGURE 3-30. FALL 2010 BROMIDE CONCENTRATIONS IN SHALLOW AND ROSEBUD WELLS
FIGURE 3-31 FALL 2015 BROMIDE CONCENTRATIONS IN SHALLOW AND MCKAY WELLS
FIGURE 3-32 FALL 2010 BROMIDE CONCENTRATIONS IN SHALLOW AND MCKAY WELLS
FIGURE 3-33 FALL 2015 BROMIDE CONCENTRATIONS IN SUB MCKAY WELLS
FIGURE 3-34 FALL 2010 BROMIDE CONCENTRATIONS IN SUB MCKAY WELLS
FIGURE 3-35 OCTOBER 2015 ROSEBUD & ALLUVIUM POTENTIOMETRIC SURFACE
FIGURE 3-36 OCTOBER 2010 ROSEBUD & ALLUVIUM POTENTIOMETRIC SURFACE
FIGURE 3-37 OCTOBER 2015 MCKAY & ALLUVIUM POTENTIOMETRIC SURFACE
FIGURE 3-38 OCTOBER 2010 MCKAY & ALLUVIUM POTENTIOMETRIC SURFACE
FIGURE 3-39 OCTOBER 2015 SUB-MCKAY POTENTIOMETRIC SURFACE
FIGURE 3-40 OCTOBER 2010 SUB-MCKAY POTENTIOMETRIC SURFACE
FIGURE 3-41 HYDROGRAPHS OF PAIRED WELLS IN UNITS 3 & 4 EFFLUENT HOLDING POND AREA

FIGURE 3-42 UNITS 3&4 EHP SUB-AREAS AND SHALLOW/ROSEBUD GROUNDWATER FLOW DIRECTION
FIGURE 3-43 UNITS 3&4 EHP SUB-AREAS AND SHALLOW/MCKAY GROUNDWATER FLOW DIRECTION
FIGURE 3-44 UNITS 3&4 EHP SUB-AREAS AND SUB-MCKAY GROUNDWATER FLOW DIRECTION
FIGURE 3-45 WATER QUALITY GRAPHS FOR SELECT ALLUVIAL WELLS NORTH OF THE 3&4 EHP MAIN DAM (AREA 1)
FIGURE 3-46 2015 STIFF DIAGRAMS FOR ALLUVIUM AND BEDROCK WELLS NORTH OF THE 3&4 EHP MAIN DAM
FIGURE 3-47 WATER QUALITY GRAPHS FOR SELECT BEDROCK WELLS NORTH OF THE 3&4 EHP MAIN DAM (AREA 1)
FIGURE 3-48 WATER QUALITY GRAPHS FOR SELECT BEDROCK WELLS NORTH OF THE 3&4 EHP MAIN DAM (AREA 1)
FIGURE 3-49 WATER QUALITY GRAPHS FOR SELECT WELLS EAST OF THE 3&4 EHP SADDLE DAM (AREA 2)
FIGURE 3-50 WATER QUALITY GRAPHS FOR SELECT WELLS EAST OF THE 3&4 EHP SADDLE DAM (AREA 2)
FIGURE 3-51 2015 STIFF DIAGRAMS FOR WELLS EAST OF THE 3&4 EHP SADDLE DAM
FIGURE 3-52 STIFF DIAGRAM FOR WELL 1039A
FIGURE 3-53 WATER QUALITY GRAPHS FOR SELECT WELLS IN THE 560A AREA (AREA 3)
FIGURE 3-54 2015 STIFF DIAGRAMS FOR WELLS IN THE 560A AREA
FIGURE 3-55 STIFF DIAGRAMS FOR THE 1079A-TRENCH
FIGURE 3-56 STIFF DIAGRAMS FOR WELL 1099D
FIGURE 3-57 WATER QUALITY GRAPHS FOR SELECT WELLS SOUTH/SOUTHWEST OF THE 3&4 EHP (AREA 4)
FIGURE 3-58 WATER QUALITY GRAPHS FOR SELECT WELLS SOUTH/SOUTHWEST OF THE 3&4 EHP (AREA 4)
FIGURE 3-59 STIFF DIAGRAMS FOR WELL 694R

FIGURE 3-60 2015 STIFF DIAGRAMS FOR WELLS SOUTH/SOUTHWEST OF THE 3&4 EHP
FIGURE 3-61 WATER QUALITY GRAPHS FOR SELECT WELLS IN THE SFCC AREA (AREA 5)
FIGURE 3-62 WATER QUALITY GRAPHS FOR SELECT WELLS IN THE SFCC AREA (AREA 5)
FIGURE 3-63 2015 STIFF DIAGRAMS FOR WELLS IN THE SFCC AREA
FIGURE 3-64 STIFF DIAGRAM FOR WELL 1024AM
FIGURE 3-65 HYDROGRAPHS FOR WELLS 665A AND 666A
FIGURE 3-66 WATER QUALITY GRAPHS FOR SELECT WELLS WEST/NORTHWEST OF THE 3&4 EHP (AREA 6)
FIGURE 3-67 WATER QUALITY GRAPHS FOR SELECT WELLS WEST/NORTHWEST OF THE 3&4 EHP (AREA 6)
FIGURE 3-68 2015 STIFF DIAGRAMS FOR WELLS WEST/NORTHWEST OF THE 3&4 EHP
FIGURE 3-69 WATER QUALITY GRAPHS FOR SELECT WELLS IN THE DRAIN PIT #5 AREA (AREA 7)
FIGURE 3-70 WATER QUALITY GRAPHS FOR SELECT WELLS IN THE DRAIN PIT #3 AREA (AREA 8)

LIST OF APPENDICES
(Each Appendix is included as attachment to PDF of report)

APPENDIX A UNITS 3&4 EFFLUENT HOLDING POND GROUNDWATER CONCEPTUAL MODEL AND EXPANDED NUMERICAL MODEL

APPENDIX B UNITS 3&4 EHP PIPER DIAGRAMS, PROCESS POND DATA

APPENDIX C UNITS 3&4 EHP PARAMETERS AND REPORTING LIMITS COLSTRIP STEAM ELECTRIC STATION ADMINISTRATIVE ORDER ON CONSENT

APPENDIX D LITHOLOGIC LOGS

APPENDIX E WATER QUALITY TREND GRAPHS

APPENDIX F RAW DATA EXAMPLES

APPENDIX G TALEN WATER RESOURCES MONITORING PLAN

APPENDIX H RESPONSE DOCUMENTS - JANUARY 2017, APRIL 2017 AND OCTOBER 2017

TALEN MONTANA, LLC
COLSTRIP STEAM ELECTRIC STATION
ADMINISTRATIVE ORDER ON CONSENT
UNITS 3 & 4 EFFLUENT HOLDING POND SITE REPORT

EXECUTIVE SUMMARY

On August 3, 2012, PPL Montana, LLC (PPLM) and the Montana Department of Environmental Quality (MDEQ) entered into an Administrative Order on Consent (AOC) Regarding Impacts Related to Wastewater Facilities Comprising the Closed-Loop System at the Colstrip Steam Electric Station (Colstrip SES). On June 1, 2015, PPLM transferred ownership of their share of the Colstrip SES to Talen Montana, LLC (Talen); further, Talen assumed the role as operator of the facility. As required by the AOC, Talen committed to prepare Site Reports for the Plant Site, Stage I Evaporation Pond (SOEP) and Stage II Evaporation Pond (STEP), and Units 3&4 Effluent Holding Pond (3&4 EHP) areas.

Minimum requirements of the AOC Site Reports are:

- Identification of releases, if any, for each area and the source of the releases;
- A description of the investigations performed to date, including a list of reports resulting from the investigations and summary of the findings and results from the investigations;
- Groundwater models and results of modeling;
- A description of completed and ongoing remedial actions (including the sampling parameters and frequency of any ongoing monitoring);
- An effectiveness assessment of the remedial actions;
- For each area that contains a pond, a description of the construction of the ponds and of pond contents through time;
- For each pond, an estimate of seepage to groundwater beneath the pond;
- Identification of data gaps, if any; and
- Recommendations for additional site characterization, if any.

This Site Characterization Report provides information required in the AOC for the 3&4 EHP area.

Talen is the operator of the Colstrip SES, which consists of two 333-megawatt, and two 805-megawatt coal-fired steam electric generating units. Units 1&2 have been in service since 1975. Unit 3 has been in service since October 1983. Unit 4 went in to service near the end of 1985. The Colstrip SES is co-owned by Talen, PacifiCorp, Puget Sound Energy, Inc., Portland General Electric Company, Avista Corporation, and NorthWestern Corporation.

A closed-loop process is used at the Colstrip SES to minimize impacts to water resources in the area. Coal combustion residuals (flyash and bottom ash) from the generating plants are impounded in ponds designed and constructed to minimize seepage losses. The Plant Site pond system includes ponds that serve all four generating units in various capacities. Ash disposal does not occur at the Plant Site but rather in disposal ponds at separate locations. Ash from Units 3 and 4 are routed to the 3&4 EHP, located about three miles east-southeast of Colstrip.

Colstrip SES operators began routing scrubber slurry from Units 3 and 4 to the 3&4 EHP in 1983. The 3&4 EHP was originally lined with native soils amended with bentonite below an elevation of 3,200 feet to limit vertical seepage from the unit. A bentonite amended concrete cutoff wall (cutoff wall) was also constructed around the perimeter of the 3&4 EHP to limit horizontal seepage through baked shale that is present in the pond area. More recently, Talen has installed geo-synthetic liners in individual cells of the 3&4 EHP as they are rebuilt or modified. Since 2005, about 40% of the 3&4 EHP footprint has been lined with a synthetic liner (including Cells B, F, and H). Talen's current lining process includes dewatering cells, grading the pond bottom, covering with low permeability paste, and installing geomembrane liner systems. A summary of liner construction and function of each cell in the 3&4 EHP is as follows.

- A bentonite-amended concrete cutoff wall (cutoff wall) was constructed around the entire perimeter of the 3&4 EHP. The cutoff wall extends into competent bedrock below the McKay Coal on the northwest, north, and east sides, Main Dam, and Saddle Dam, and into competent interburden on the south and west sides. The cutoff wall was constructed to limit horizontal migration.
- A Cell –the cell is lined below an elevation of 3200 feet elevation with bentonite-amended soils, currently used to store dry bottom ash.
- B Cell (New Clearwell) – constructed with a Reinforced Polypropylene (RPP) composite liner over flyash/paste with a leachate collection system, also overlies a portion of the bentonite-amended soil liner (below 3200 feet elevation). Receives clear water from the paste plant and returns it to the scrubbers for re-use.
- C Cell – partially lined with bentonite-amended soils, currently used for flyash and paste disposal, excess water from this pond is pumped to H Cell.
- D&E Cells – currently contain dry coal combustion residuals (CCR). These cells are not lined. However, as indicated above, a bentonite amended concrete cutoff wall was constructed around the perimeter of the 3&4 EHP to limit horizontal migration.
- F Cell – constructed with a RPP composite liner and leachate collection system; used to store captured groundwater and excess pond water.
- G Cell – partially lined with bentonite-amended soils, originally used for scrubber slurry storage, now partially filled with paste.
- H Cell – constructed over existing dry scrubber slurry with double-lined RPP with leachate collection between each liner and below the liners; currently used for water management purposes.
- J Cell – lined with bentonite-amended soils, includes north half of original Cell G and former Clearwell, contains dry scrubber slurry/paste and will be geomembrane-lined to store CCR material. J1 was recently constructed over the topo of J Cell. The liner consists of a drainage layer installed over HDPE and clay liners.

The 3&4 EHP has a cumulative capacity of about 17,000 acre-feet at an elevation of 3,280 feet. An additional 1,200 acre-feet of retention space (free board) is available at an elevation of 3,283 feet. Embankments (dams) at the 3&4 EHP were constructed to a final elevation of

about 3,290 feet in 2012. A detailed description of each of the 3&4 EHP cells is presented in this report, including dates of service, use, capacity (volume), surface area, and liner construction information.

Estimates of pond seepage to local groundwater are presented in Section 2. Methods of seepage calculation appropriate for active geomembrane-lined ponds were applied to Cells B, H, and F; and Darcy's Law was used to estimate flow through earthen pond bottoms and the cutoff wall. The cumulative seepage estimate for the geomembrane-lined cells was calculated for this report at approximately 13.6 gpm. Flux through the pond boundaries calculated using Darcy's Law is attributable to active seepage from earthen-lined and geo-membrane-lined ponds, seepage of stored water between cells within the cutoff wall, and/or recharge from precipitation. Darcy Flux calculations were parameterized by existing water level, hydraulic gradient, and hydraulic conductivity data. The resulting flux calculated for this report of 243 gpm is an estimate of the upper limit of process water seepage. Similar design calculations were presented by Bechtel (1982) prior to construction of the 3&4 EHP. Design calculations were limited by available data; and several assumptions were made. The design calculations resulted in an initial seepage estimate of 275 gpm. Accounting for reductions in seepage attributable to actual water management and pond operations procedures, the current seepage estimate is consistent with the initial estimate. Seepage estimates based on a three-dimensional numerical groundwater flow model are also in agreement with the Darcy Flux calculations. The model predicted seepage of 196 gpm from the 3&4 EHP. The groundwater flow model report, developed by NewFields Companies LLC (NewFields, 2017), is in Appendix A.

Water quality data for each of the ponds including minimum, maximum, arithmetic mean, and median concentrations are tabulated in the report. Although numerous analytes have been evaluated for water from the 3&4 EHP, a smaller number of parameters are characteristic of water/waste of the Colstrip SES process. Specific conductance (SC) and elevated concentrations of sulfate, boron, and chloride are present in process water and residuals within the 3&4 EHP. These parameters are used as indicators for process water impacts in groundwater outside of the ponds. In addition, water from the 3&4 EHP has a

high concentration of magnesium in relation to calcium, which makes the ratio of these two parameters an important indicator parameter of process water impacts outside of the pond.

Water quality samples were collected by Talen at 349 monitoring sites in the spring of 2015 and 278 sites in the fall of 2015 around the 3&4 EHP. Monitoring sites include process ponds, monitoring wells, groundwater capture wells, interception trenches and dam sumps. Groundwater quality data are evaluated and further investigation and/or mitigation actions are conducted in areas showing process water impacts. The AOC provides for investigations and mitigation to be implemented via Interim Response Actions (IRAs). IRAs are implemented in response to circumstances identified through hydrogeologic evaluation and not because of an acute threat to human health or a recent spill. A summary of past releases of process water, a description of investigations and IRAs performed to date, a list of reports resulting from the investigations and IRAs, and a summary of the findings and results from investigations and IRAs conducted in the 3&4 EHP area are included in Section 3 of this report.

Impacted groundwater has been identified downgradient from the 3&4 EHP Main Dam, east of the Saddle Dam in multiple units, in clinker directly south of the 3&4 EHP, in South Fork Cow Creek (SFCC) alluvium, and in multiple units southwest and northwest of the pond. Mitigation activities, including groundwater capture, are currently ongoing in these areas, using groundwater interception trenches and pumping wells. Currently Talen captures process water or groundwater impacted by process water at 76 groundwater capture wells, 13 trenches, leachate collection systems between and below the pond liners, and in dam toe and chimney drains. Captured water is pumped to lined process cells in the 3&4 EHP for evaporation, or is piped to the Plant Site and treated for re-use via the Vibratory Shear Enhanced Process (VSEP).

A MODFLOW based numerical groundwater model was developed for the 3&4 EHP pond and surrounding area. The model was calibrated using existing monitoring well information, pumping test data, water level measurements, and capture system pumping rates. Model simulations are used to further evaluate existing interpretations of the hydrogeologic system

and to evaluate effectiveness of mitigation activities. The groundwater modeling predicts that the major portion of the impacted groundwater flow from the 3&4 EHP is or will be captured; however, the model report also identifies specific areas where capture may be incomplete. A complete description of model preparation and results is included in Section 4.

Data gaps, identified through review of new and existing groundwater quality data, groundwater flow patterns constructed from potentiometric monitoring, numerical groundwater modeling results, reports of past spills and/or releases, and reports of previous groundwater investigation or mitigation prepared subsequent to releases or independently as part of Talen's ongoing water resources monitoring effort, presented in Section 5. These include the need for more accurate flow data and additional hydrogeological information from specific areas. Recommendations to address data gaps are included in Section 6. General recommendations include continuation of current groundwater capture activities and expansion, if necessary;; continuation and refinement of groundwater monitoring; continuation of paste deposition; continuation of current lining practice to unlined cells in the pond, and continuation of Best Management Practices (BMPs) to further reduce water volumes and allow for improved water management. Updates to the groundwater model, that would include evaluation of any new capture systems or changes to existing capture systems, are also recommended on a periodic basis. Recommendations for specific areas surrounding the 3&4 EHP include but are not limited to: evaluating the need for increased capture in the 552D area (north of the main dam); evaluating water quality in the 624D area (also north of the main dam); evaluating capture efficiency of the 610D capture system (northeast of the 3&4 EHP); installing and evaluating a new well between 611D and 585D (northeast of the 3&4 EHP); installing and evaluating a new well near capture well 648D (east of the 3&4 EHP Saddle Dam); installing and evaluating several new wells south/southwest of the 3&4 EHP near 675M, 695R, and 696R; and installing and evaluating new wells between 615D and the South SP-15 Trench.

TALEN MONTANA, LLC
COLSTRIP STEAM ELECTRIC STATION
ADMINISTRATIVE ORDER ON CONSENT
UNITS 3 & 4 EFFLUENT HOLDING POND SITE REPORT

1.0 INTRODUCTION

The Colstrip Steam Electric Station (Colstrip SES) is located in Colstrip, Montana as shown in Figure 1-1. The Colstrip SES (Plant) consists of four, coal-fired, steam electric power generation units (Units 1 through 4) co-owned by Talen Montana, LLC, PacifiCorp, Puget Sound Energy, Inc., Portland General Electric Company, Avista Corporation, and NorthWestern Corporation.

Colstrip Units 1&2 are 333-megawatt units that have been in service since 1975. Colstrip Units 3&4 are 805-megawatt units adjacent to Units 1&2. Unit 3 has been in service since October 1983. Unit 4 went in to service near the end of 1985. A closed-loop process water/scrubber system is used at the Colstrip SES (Plant) to minimize impacts to air and water resources in the area; whereby, coal combustion residuals (CCR) from the generating units are impounded in ponds designed and constructed to minimize seepage losses. Ponds serving Units 1&2 were put into service in 1975. The pond system servicing Units 3&4 has been in use since 1983.

On August 3, 2012, PPL Montana, LLC (PPLM), the previous operator of the Colstrip SES, and the Montana Department of Environmental Quality (MDEQ) entered into an Administrative Order on Consent (AOC) Regarding Impacts Related to Wastewater Facilities Comprising the Closed-Loop System at the Colstrip Steam Electric Station (MDEQ/PPLM Montana, 2012). On June 1, 2015, PPLM transferred ownership of their share of the Colstrip SES to Talen Montana, LLC (Talen); and Talen assumed the role as operator of the Plant.

As part of the AOC, Talen is committed to prepare Site Reports for the Plant Site, Stage I Evaporation Pond (SOEP) and Stage II Evaporation Pond (STEP), and Units 3&4 Effluent Holding Pond (3&4 EHP, also referred to herein as "the pond") areas. These site reports are the basis for further remedial activities under the AOC. A fourth category of reporting, involving area process water associated spills or releases not included in one of the previously mentioned areas was also defined. All past spills and releases have fallen into one of the three areas defined earlier in this paragraph. This report provides information regarding past process water spills, pond seepage, and current conditions for the 3&4 EHP area in accordance with the AOC.

Minimum requirements of the AOC Site Reports are:

- Identification of releases, if any, for each area and the source of the releases;
- A description of the investigations performed to date, including a list of reports resulting from the investigations and summary of the findings and results from the investigations;
- Groundwater models and results of modeling;
- A description of completed and ongoing remedial actions (including the sampling parameters and frequency of any ongoing monitoring);
- An effectiveness assessment of the remedial actions;
- For each area that contains a pond, a description of the construction of the ponds and of pond contents through time;
- For each pond, an estimate of seepage to groundwater beneath the pond;
- Identification of data gaps, if any; and
- Recommendations for additional site characterization, if any.

Additional information has been added to this revised report at the request of MDEQ pertaining to area hydrogeology, process water flow and routing, and other aspects of Plant and process pond operation that are germane to the AOC. Note: The Background Screening Levels (BSLs) report (Neptune, 2017) was later updated based on MDEQ comments and submitted May 25, 2017. As agreed with MDEQ at the November 2016 meeting, BSLs referenced in this report are based on those presented in *Final Report on Updated*

Background Screening Levels, Plant Site, 1&2 SOEP and STEP, and 3&4 EHP Jan. 2016 (Neptune 2016).

References are cited in the text according to an author-year system; in which, sources are cited in parentheses by author and date (year) published. Each source cited in the text is listed first alphabetically by author and secondarily by date in a reference section (Section 7) at the end of the text. When two or more sources were prepared by the same author in the same year and same month, the documents are identified using an alphanumeric system; whereby, the first such source is followed by an "a", the second source is followed by a "b", and so forth. Where multiple cited sources in the reference list were prepared by the same author, only the first source is listed in the Reference section. Additional sources by the same author are assigned a blank place holder; and identified first by their date of publication.

2.0 CLOSED LOOP SYSTEM DESCRIPTION, POND CONSTRUCTION, AND POND WATER QUALITY

2.1 CLOSED LOOP SYSTEM

A closed-loop process water/scrubber system is used at the Colstrip SES (Plant) to minimize impacts to water resources in the area. Coal combustion residuals (CCR) from the generating plants are impounded in ponds designed and constructed to minimize seepage losses. The Plant Site pond system includes ponds that serve all four generating units in various capacities. Flyash and bottom ash disposal does not occur at the Plant Site but rather in disposal ponds at separate locations. Flyash from Units 3&4 is routed to the 3&4 EHP, located about three miles east-southeast of Colstrip. Table 2-1 contains descriptions of the 3&4 EHP.

2.1.1 Definitions

Several terms used in Table 2-1 and possibly in other portions of this report are defined as follows.

- Blowdown – A portion of water from the cooling tower which is removed and replaced with raw water containing lower concentrations of dissolved solids. The process is conducted to reduce the potential for scale buildup in the cooling towers.
- Boiler – structure where coal combustion occurs and steam is produced for the turbines. Pulverized coal is injected with air into the boiler resulting in combustion. The heat from the burned coal heats the water in the boiler tubes which generates steam to turn turbines and generate electricity.
- Bottom ash – a coarse grained residual from burning coal which falls to the bottom of the boiler where it is collected.
- Circulating water system – System of water used in the generation of electricity including raw water, makeup water, cooling water, bottom ash and flyash scrubber slurry, etc. The water is reused in various parts of the process.
- Coal Combustion Residuals (CCR) – Materials generated from the combustion of coal, including solid fuels classified as anthracite, bituminous, subbituminous and lignite, for the purpose of generating steam for the purpose of powering a generator to

produce electricity and other thermal energy by electric utilities and independent power producers. CCR includes fly ash, bottom ash, boiler slag, and flue gas desulfurization materials (EPA, April 2017). .

- Flyash – a residual of burning coal that is exhausted with flue gases through the scrubbers.
- Forced Evaporation – Mechanical processes used to enhance the rate of evaporation. Typically conducted by mechanical means through high speed fans, compressed air, and/or spray nozzles.
- HDPE – High Density Polyethylene – a synthetic material that is a polyethylene thermoplastic. HDPE has a multitude of industrial uses including pipelines and liners to name a few. HDPE resists deterioration from chemicals, weather, heat, and oxygen. HDPE has been used to line some of the ponds at the Colstrip SES since it is flexible and does not crack.
- Hypalon – A synthetic material that is a registered trademark for a family of chlorosulfonated polyethylene synthetic rubbers. Hypalon resists deterioration from chemicals, weather, heat, and oxygen, and is flexible. Hypalon has been used to line some of the ponds at the Colstrip SES.
- Leachate Collection – collection of fluids that has passed through a solid material such as liners, soil, or organic debris.
- Liner – An impermeable material (HDPE, Hypalon, reinforced polypropylene (RFP)), or material that exhibits very low permeability (clay, polymers, etc.) that is placed on the bottom of a pond, lake, canal, stream bed, etc. to retain water in the structure or to limit movement of fluids through the bottom of the structure.
- RFP – A synthetic material sometimes referred to as reinforced polypropylene (RPP), which is light weight, heat weldable, ultraviolet resistant polypropylene sheeting reinforced by sandwiching reinforcing fiber between polypropylene sheets. The material is commonly used for lining ponds due to its light weight, strength, UV resistance, chemical resistance, flexibility, and low expansion and contraction characteristics. RFP has been used to line some of the ponds at Colstrip SES.
- Scrubber – Pollution control equipment that removes SO_2, particulates, and other potential pollutants from the combustion flue gas.

- Vibratory Shear Enhanced Process (VSEP) - Reverse osmosis system for water treatment. A technology designed to reduce fouling and/or the buildup of particulates on the osmotic membranes.
- Wash Tray – a section of the scrubbers that helps remove SO_2 and particulates from the flue gas.

2.1.2 Facility-Wide Process Water Flow

Figure 2-1 is a schematic illustrating closed-loop process water flow for the Colstrip SES. Process water routing and facilities at the 3&4 EHP are shaded on this figure. Note that only ponds that are part of the current process water circuit are shown on Figure 2-1.

Up to 69 cubic feet per second (CFS) of raw water is piped from the Yellowstone River to Castle Rock Lake (also known as the Surge Pond). Water is then pumped to holding tanks on the Plant Site; where it is distributed for use in boilers, cooling towers as makeup water, the bottom ash systems, or the scrubbers. Process water that is routed to the Units 3&4 EHP is in the form of scrubber slurry (typically 10-15% solids).

Raw water is treated at the Plant Site by filtration, demineralization, and reverse-osmosis prior to being directed to the boilers. The majority of water used at the facility is in the cooling water systems. The cooling water systems are primarily used to condense the steam after it goes through the turbines so it can be sent back to the boiler to be re-used.

The Colstrip SES burns coal in the boiler where steam is generated from water contained in boiler tubes. The steam is used to rotate turbines that generate electricity. Exhaust and flue gases generated from burning coal are directed to the scrubbers. Flue gas scrubbers, the Plant's main pollution control equipment, are used to capture SO_2, particulates, and other potential pollutants generated from the combustion of coal.

Burning the coal leaves two residuals; bottom ash and flyash. Flyash, which is less dense than bottom ash, is exhausted with flue gases through the scrubbers. Scrubbers remove the particulates (flyash) creating scrubber slurry. The scrubber slurry is transported through

pipelines to paste plants located at the STEP and 3&4 EHP. The paste plants remove water from the scrubber slurry, creating a "paste" that is deposited in the STEP or 3&4 EHP. Water removed from the scrubber slurry (clear water) in the paste plants is sent to lined clearwells. Clear water is returned to the Plant Site for reuse in the scrubbers.

Bottom ash is coarser grained than flyash (pebble sized (4-64 mm)). Bottom ash falls to the bottom of the boiler where it is collected and piped as slurry to the bottom ash pond system corresponding to the given unit (either Units 1&2, or Units 3&4 Bottom Ash Ponds). The bottom ash settles out in the pond. Clear water decants into the adjacent Bottom Ash Clearwell (either Units 1&2 Bottom Ash Clearwell or Units 3&4 Bottom Ash Clearwell). Water from the clearwells is routed back to the bottom ash system at the Plant Site for reuse. Dewatered bottom ash is transported from the bottom ash ponds and deposited in final disposal ponds.

2.1.3 Process Pond Storage and Water Management

Process water is contained in cells of the 3&4 EHP before it is circulated back to the Plant Site to operate as a zero discharge facility. Water management is essential so an adequate amount of freeboard is maintained to account for upset conditions or to accommodate water introduced through precipitation. Management of the amount of water present in the ponds is complex because of plant operation and natural conditions. In some cases, it is necessary to re-direct process water to various ponds to allow for maintenance or to deal with unforeseen occurrences in the operations.

Furthermore, because of the large area associated with the facility, a significant amount of water volume is added through precipitation. For example, Colstrip receives an average of 15 inches (1.25 feet) of precipitation water each year. Water falling directly on ponds adds to pond volumes.

Deposition of flyash and bottom ash (about 10% of the coal volume burned) is a continuous process during electric generation. Scrubber slurry carrying flyash from Units 3&4 is currently directed to the 3&4 EHP. Placement of the ash in the ponds reduces the amount of

available storage for water. For this reason, it is necessary to reduce the amount of water at a rate faster than ash deposition and precipitation input rates to maintain sufficient storage. Colstrip SES uses best management practices (BMPs), to help manage water volumes (see Section 2.2.6).

2.1.4 Water Use and Measurement Difficulties

As indicated in a previous section, water is pumped to the Surge Pond at a rate up to 69 CFS, depending on plant operation and season. The majority of this water is used at the Plant Site. A portion is also used for domestic water supply to the City of Colstrip and at nearby coal mines. An estimate of water flow rates throughout the Plant process has been made, but detailed, accurate flow rates have not been determined because of difficulties with accurate flow measurement.

Difficulties in flow measurement throughout the process water circuit include the following.

- Some of the piping is not equipped with flow meters, some of the flow rates are estimated and general corrections, based on extensive site experience, professional judgment, and observations are made to some of the flow circuits.
- Where flow gages have been used, their accuracy and working life has been limited due to scale build up, corrosion, and other maintenance issues.
    - Scale build up in pipes and flow meters reduces the accuracy. Scale reduces the pipe inside diameter causing velocities to be higher than in a pipe void of scale. Flows measured by externally mounted flow meters results in overestimation of pumping volumes.
    - Furthermore, scale buildup on in-line flow meters creates inefficiencies, typically resulting in lower flow readings.
- The large slurry flows can contain solids which range from 0 – 20%. This variability in solids can lead to a significant error in flow measurement.
- Reuse patterns in the process water circuit are dynamic. That is, it is necessary to open and close values and redirect water during different processes which can introduce error in water balance calculations.

- The ponds have a large surface area, and therefore undergo relatively large amounts of evaporation. The amount of water being removed from the system through evaporation can be estimated but the margin of error is large.
- Similarly, the efficiency of forced evaporation used to reduce the amount of water in the process circuit is highly variable due to humidity and temperature. This variability causes difficulty in making an accurate estimate of water being evaporated.
- Impacted groundwater collected from capture systems is estimated using local measurements at the pumps. Because of scaling problems and pressure differential caused by pumping uphill to the ponds, the accuracy of the flow estimate is limited.
    - Use of flow meters was attempted early in the groundwater capture process. Severe scaling resulted in continued maintenance of the flow meters, inaccurate measurements, and meter failure.
    - Volumetric flow measurements (time to fill a container of known volume) are used as an alternative to using flow meters. Inaccuracies arise with this method since the flows are measured at individual well heads but pipeline pressures downstream of the capture wells vary. For example, flow may be measured at a well with a pipeline back pressure of 50 PSI, while the pressure at the well head is essentially zero. Flow in the pipeline is affected by the amount of back pressure. In this scenario, estimated pumping rates will be higher than flow rates actually occurring in the pipeline.

As a result of these flow measurement difficulties, some of the current flow rates are not being measured, some of the flow rates are measured (possibly with correction), and some of the flow rates are estimated.

2.1.5 Best Management Practices for Water Management

Talen institutes several BMP's to reduce water in the ponds. BMP's are upgraded when necessary to improve the methods used to reduce or contain water. In addition, new measures are periodically implemented to add new BMPs or improve existing facilities to improve water management. BMPs and site improvements are listed in the following bullets:

- Forced Evaporation;

- Education of facility employees regarding the importance of efficient water use;
- Weekly Pond Inventory;
- Multifunctional Water Management Team;
- Water Management Guidelines for Operation and Maintenance;
- Cooling Tower Water Management Cycle Optimization;
- Ongoing Water Reduction/Reuse Initiatives; and
- Review of current technologies with outside consultants.

Through these various practices the amount of excess water within the Colstrip SES process ponds has been reduced by about 1.7 billion gallons since 2006. These practices will continue to further reduce water within the pond. The reduction in the amount of water leads to lowering hydraulic head and reducing potential seepage from the pond.

2.1.6 3&4 EHP Pond Water Sampling

Ponds listed in the Colstrip SES Water Resources Monitoring Plan (WRMP) (Talen, 2015), are sampled at a minimum frequency of once every three years. Samples are collected from near the surface of the ponds at the approximate same location for each event. Actual sampling locations depend on site access, safety considerations, and pond levels. Grab samples are collected and the water sample preserved as needed, placed on ice, and transported to an analytical laboratory for analysis.

Metals within the pond samples are typically analyzed for dissolved phase concentrations in accordance with the MDEQ approved WRMP. However, pond samples have been analyzed for both total recoverable and dissolved phases of metals in some cases. The total analysis uses a digestion step to place both suspended and dissolved metals into solution. However, dissolved analysis is considered more applicable for the ponds since water leaving the ponds as seepage will enter groundwater or unsaturated media that typically have very slow groundwater flow velocities. The very low flow velocities and filtration characteristics of soil or clay liners make transport of solids from within the pond to groundwater very unlikely except under abnormal conditions. Furthermore, the Federal Ambient Water Quality Criteria

are based upon aquatic toxicity testing of the dissolved form of the constituent; further supporting that dissolved phase for metals is applicable to analysis of the pond water.

2.2 UNITS 3&4 EFFLUENT HOLDING POND

2.2.1 Pond Construction

The final design elevation of the Main Dam, Saddle Dam, and internal dikes is 3,290 feet, with a capacity of 17,000 acre-feet at an elevation of 3,280 feet. An additional 1,200 acre-feet of retention space (free board) is available at an elevation of 3,283 feet. The dams and dikes were constructed in phases. During the initial phases (1983 and 1984), the 3&4 EHP Main Dam and Saddle Dams were constructed to an elevation of about 3,260 feet and internal Dikes were constructed to an elevation of 3,290 feet (Bechtel, February 1985a). Final construction of the dams to an elevation of about 3,290 feet was completed in 2012.

A steep hydraulic gradient was expected from the pond through the 3&4 EHP Main and Saddle Dams. This was expected to result in an estimated 27 gpm flux through the Main Dam and 32 gpm through the Saddle Dam at full pool. A drain system was installed to capture the major portion of seepage through the embankments. Components of the drainage system included a chimney drain, an inclined drain, and a horizontal drainage blanket. Seepage entering the drains is conveyed to either the Main Dam Sump or the Saddle Dam Valley Drain Sump. Water entering the sumps is pumped to the 3&4 EHP (Bechtel, October 1982).

During initial construction, portions of the bottom of the pond below an elevation of 3200 feet, were treated with bentonite to seal the areas directly underlain by McKay Coal and sub-McKay strata. Treatment involved in-place mixing of the upper six-inches of soil with Wyo-Ben bentonite to a target 10% minimum bentonite. Treatment was conducted after the upper foot of topsoil and subsoil was removed. Spreading and compaction were completed after soil treatment. Portions of the pond floor that were too steep or too hard for in-place mixing were capped with an 8-inch layer of bentonite treated soil (mostly under C and the old Clearwell). An underdrain system, consisting of 6-inch slotted corrugated polyethylene pipe was installed above the bentonite treated soil. A clinker drain layer was placed around the

drain laterals. The underdrain system was designed to help dewater the pond in the future. The laterals for the underdrain system were connected to a sump located between the Old Clearwell (now J1 Cell) and C Cell (Bechtel, 1985a).

A bentonite amended concrete cutoff wall (cutoff wall) was installed around the perimeter of the pond to inhibit horizontal flow. The wall was installed through unconsolidated materials (mainly clinker) and at least five feet into "tight" bedrock. The wall was designed with a minimum wall thickness of two feet and maximum permeability of 1 X 10^{-7} centimeters per second (cm/sec). Laboratory testing was conducted to confirm that permeability specifications were met (Bechtel, February 1985b).

The pond was originally constructed with a series of cells to serve as settling basins. During original operations, flyash 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 directly inboard of the Main Dam. Clear water (water with solids settled out) was pumped to the Plant and reused in the Units 3&4 Scrubbers.

In late 2003, a paste plant was constructed and became operational at the 3&4 EHP. Scrubber slurry is piped to the paste plant where a flocculent is added to accelerate settlement of solids. Clear water from the paste plant is routed directly to the Clearwell and pumped back to the plant scrubbers for reuse. Paste from the paste plant is deposited around the perimeter of the pond or on exposed areas of clinker within the boundaries of the pond.

A 45 mil RFP liner, with underdrain system, was installed in F Cell in 2005 to serve as a storage pond for collected groundwater. F Cell is currently used to store excess process water and collected groundwater. In 2008, a 45 mil RFP liner, with underdrain system, was installed in B Cell. In 2009, B Cell became the New Clearwell and the Old Clearwell was taken out of service. H Cell was re-constructed in 2013 as a double-lined pond consisting of an upper 45 mil RFP liner, between liner collection, 36 mil RFP secondary liner, and under-liner collection. H Cell is currently used for water management. Work to construct a single cell (J Cell) on the footprint of the Old Clearwell and the north half of G Cell was initiated in

2014. J1 Cell was constructed over the footprint of the original J Cell is expected to be put in service in 2017.

2.2.2 Units 3 & 4 EHP Water Chemistry

Water quality samples are periodically collected from various cells in the 3&4 EHP. Table 2-2 shows minimum, maximum, mean, median, and most recent values for common ions and metals in samples collected from each cell. In some cases, a particular analyte may have only been analyzed once. In this case the minimum, maximum, average, and most recent result will all be the same. Data for organic constituents or other parameters that are not typically analyzed are included in Table 2-2, where available. Note that some of the data are for cells that are not currently in use or that have been closed. For example, E Cell has been out of service and has not contained free water for storage since about 1999. Additionally, H Cell was originally unlined and was filled with flyash. A new H Cell was recently constructed, using a double synthetic liner system, over the footprint of the original H Cell. Data shown in Table 2-2 are for the new H Cell.

Water quality for C Cell provides a representative range of chemicals typically found in the 3&4 EHP. Note, however, that concentrations of chemical constituents will vary depending on the overall amount of water, amount of precipitation water, the degree that evaporation has reduced water volumes, and number of times water has been recirculated through the scrubber system. Water in C Cell has very elevated specific conductance (SC) as well as higher concentrations of total dissolved solids (TDS), sulfate, boron, and selenium compared to background groundwater. In addition, the calcium to magnesium ratio is very low. These parameters or ratios are used as indicators for process water impacts outside of the ponds.

Graphs, showing concentrations of indicator parameters versus time; Piper diagrams which illustrate the cation and anions distribution with time; and pond water quality data are in Appendix B. Variation in the quality of process waters is illustrated on the graphs. The Piper diagrams show that the water in the ponds has remained as magnesium-sulfate type water throughout the monitoring period.

Changes in routing of process waters may occur for short periods of time for operational reasons. For example if a pond is going to be relined or rebuilt, the water from that pond has to be placed in different ponds. Water quality of the receiving pond may change following the transfer. In addition, various cells have changed from active or decant ponds to clearwells. Examples are G Cell which no longer receives flyash, and any water (e.g. precipitation) entering the cell is routed to either H Cell or the New Clearwell; Old Clearwell was taken out of service, drained, and is currently included in construction with the north end of G Cell, as the future J1 Cell; and B cell was converted to the New Clearwell.

A number of other factors also affect water quality within the various cells including:

- Evaporation of water from the pond surface results in higher concentrations of chemical constituents in the remaining water;
- Forced or passive evaporation efforts results in higher concentrations of chemical constituents in the remaining water;
- Precipitation results in dilution of waters in the ponds. All other things being equal, this results in a lowering of SC in ponds. Colstrip receives an annual average of about 1.25 feet of precipitation that falls directly on the ponds or that may flow to the ponds as runoff; and
- Introduction of water from groundwater capture systems is lower in concentrations of chemical constituents and reduces overall concentrations.

At the request of the MDEQ Major Facilities Siting Program, PPLM conducted a more detailed sampling and analysis of six ponds at the Colstrip SES in 2002 (Appendix B). The 3&4 EHP Old Clearwell was included in this sampling effort. Water from the 3&4 EHP New Clearwell (B Cell) was analyzed for a similar set of parameters in 2012. Clearwells were chosen for the additional analysis since they are most likely to receive chemical constituents in the event of on-site releases or upset conditions in containment features (e.g., oil/water separators at the Plant Site).

This 2002 and 2012 detailed sampling included analysis of samples for an extensive list of parameters including major constituents, hydrazine, nutrients, an extended metals list,

volatile organic constituents, semi-volatiles constituents, diesel range organics diesel range organics as diesel, total extractable hydrocarbons, total purgeable hydrocarbons, hydrocarbon fractions (aliphatic & aromatics), cyanide, oil and grease, ethylene glycol, and residual chlorine. Results of the analysis were submitted to the MDEQ Major Facilities Siting Program.

Hydrocarbons were not detected in the sample from the 3&4 EHP Old Clearwell in 2002. The Old Clearwell did contain elevated levels of fluoride (13.8 mg/L), detectable levels of cadmium (0.006 mg/L) and nickel (0.43 mg/L). Bromide was also present in the Old Clearwell at concentrations of 11 mg/L. Low concentrations of diesel range organics (0.39 mg/L) and Extractable Petroleum Hydrocarbons (0.56 & <0.306 mg/L) were reported in water sampled from the New Clearwell in 2012. Additional analyses were conducted for C5-C-8 aliphatics, C9-C10 aromatics, and C9-C12 aliphatic fractions based on the initial analysis; with all the concentrations below the detection limits. Fluoride concentrations were elevated at 28 mg/L. Metals concentrations were variable (See Table 2-2).

2.2.2.1 Bromide

Calcium bromide has been added to the combustion process as part of the mercury control system at the Plant Site since 2010. Calcium bromide causes mercury present in the flue gas to be oxidized and be captured in the scrubbers. Some bromide containing chemicals are also used as scale inhibitors in cooling towers. Typically, ponds that are directly connected to the scrubbers will have higher bromide concentrations. However, bromide concentration can be affected by factors other than the scrubber process. The amount of inventory in a pond also has an effect on the bromide concentrations in the ponds. Higher bromide concentrations result with more evaporation. Conversely, lower concentrations result from periods of high precipitation or if a substantial amount of raw water is added to the system. The highest concentration of bromide in an active cell at the 3&4 EHP has been 1,940 mg/L in the New Clearwell during May 2015.

Recently revised Background Screening Levels (BSLs) for bromide ranged from 5 to 10 mg/L for intervals existing in the 3&4 EHP area (Neptune and Company, 2016). Note that

these values were assigned based on the lowest non-detect, since results of bromide analysis did not meet statistical rules applied to the data (Neptune and Company, 2016).

2.2.2.2 Reporting Limits and Method Detection Limits

Water quality samples collected at the facility are submitted to commercial laboratories for analysis of parameters listed in the WRMP (Talen, 2015). Reporting Limits (RL) for individual analytes are also referenced. This includes pond water, samples from surface water, and from groundwater monitoring wells. RLs and method detection limits (MDLs) are described in this section and apply to surface water and groundwater analysis, but would also hold true for other types of laboratory analysis.

RLs are typically the lowest concentrations that a particular analyte can be detected by a laboratory and the concentration reported with a reasonable degree of accuracy and precision. These values are often the lowest standard on the calibration curve. RL's are generally driven by the client or regulatory guidelines and as such have changed over time. Less accurate laboratory methods in the past produce a greater variance in the calibration curves which may produce an artificial upward trend. Matrix interferences, caused by the presence of other chemical constituents in a particular sample may raise the level at which the concentration of a given analyte can be detected for reporting purposes in that sample. A simple, easy to use, protocol to evaluate the effects of matrix interferences and variations with reporting limits over time is not possible and a substantial amount of statistical interpretation is required. For this reason, any trends that are potentially artificial and may be associated with variations in laboratory analysis should be looked at on a case by case basis.

MDLs are the lowest concentrations that an analyte can be detected in a sample that does not cause matrix interferences using a particular analytical method. An analyte is considered detected when the instrument signal is at a statistically-derived value (defined in 40 CFR Part 136 Appendix B) greater than instrument signal background noise, also called the critical level. The MDL is essentially equal to the critical level. The critical level is where detection is considered positive, with an allowable false positive result of less than 1%. So the MDL is a value at which an analyte can be detected with at least 99% accuracy. However,

quantitation is less accurate compared to concentrations that are greater than the RLs. MDLs are evaluated using pure water blanks (water that contains extremely low or no analytes). In other words, MDLs are evaluated using the purest water available under the most ideal conditions. At no time is the MDL higher than the RL.

Water occurring in the environment, whether process or natural water, is generally far from pure. A relatively high number of false positives occur when analyzing a sample because of interference from additional analytes. This reduces the confidence level, and raises the MDL for a particular value. Actual detection levels then for water quality samples from ponds, surface water and wells are just above the point where a sample distribution barely intersects the blank sample distribution. Water with a high concentration of analytes tends to broaden the sample distribution and raise the level at which individual analytes can accurately be detected. This is referred to as matrix interference. The higher the degree of matrix interferences, the higher the detection limit will be for a given sample. Laboratories routinely perform MDL studies but MDLs can vary between sites due to site-specific sample matrix interferences.

Practical quantitation limits (PQL) are the lowest level that can be consistently achieved during routine laboratory conditions. The PQL is typically about two to five times the MDL (Van Buuren, B.H., 2011). The PQL may also be set at a level up to 10 times (one order of magnitude) higher than the MDL. A table listing available reporting limits through time, and recent MDLs evaluated at the analytical laboratory are contained in Appendix C.

Water samples from the Colstrip SES exhibit a wide range of concentrations of chemical constituents which frequently result in variations in the MDL and the RL. Samples that exhibit elevated levels of constituents may require a dilution by the laboratory for analysis. Dilutions are prepared by mixing the sample water with a known quantity of deionized water. Laboratory sample dilution raises the reporting limit.

2.3 POND SEEPAGE ESTIMATES

An estimate of seepage to groundwater beneath each pond or cell in the 3&4 EHP is required in this Site Report in accordance with Section VI.A.1(f) of the AOC. The 3&4 EHP includes cells that are lined with geo-synthetic liners and cells that are lined only with earthen materials. Practical engineering methods specific to construction of each cell were used to make a head-dependent calculation of seepage to groundwater from the 3&4 EHP. Specifically, empirical equations developed by Giroud et. al. (1989, 1992, and 1997) were used to estimate seepage from ponds with single or double geomembrane liners and Darcy's Law was used to estimate vertical flux through the earthen material liners as well as the horizontal flux through and under the cutoff wall. Parameter input for each liner type is variable; but seepage estimates were made using the same general procedure as follows:

1. A review of pond design and construction, including design seepage estimates, was conducted;
2. Lithology and hydrogeologic characteristics of sediments beneath the 3&4 EHP were examined;
3. Methods for calculating seepage were chosen and parameterized for each pond based on specific construction details and hydrogeologic setting; and
4. Seepage calculations were completed and compared to seepage estimates from other independent sources.

The 3&4 EHP currently has three cells that are lined with geo-synthetic liners (B, F, and H Cells). These cells impound most of the water that is stored within the 3&4 EHP. The 3&4 EHP was originally designed without geo-synthetic liners; instead, the first ponds were lined with native soils amended with bentonite below an elevation of 3,200 feet (Bechtel, 1985a). A cutoff wall was also constructed into bedrock to limit seepage through baked shale (clinker) that is present in the pond area. C Cell, which does not have a geo-synthetic liner, is actively used for flyash and paste deposition; but free water is pumped from this pond to lined F and H cells. G Cell and the Old Clearwell have recently been dewatered and the pond bottoms have been graded and covered with low permeability paste. Specifically, the north half of G cell and the Old Clearwell have been merged to form J Cell. J1 Cell will be

lined with a geo-synthetic liner for future operations; but it and the remaining cells in the 3&4 EHP (D/E, South G, and A) are currently dry. Further description of each cell is included in Table 2-1.

2.3.1 Pond Area and Water Levels

The area of each 3&4 EHP cell assigned to the seepage calculations was obtained from construction design specifications and/or by delineating the ponds as they appear in recent aerial photographs (Google Earth 5/21/2014 and National Agriculture Imagery Program, 2015). Therefore, the surface area used in the seepage calculation for each pond may not necessarily correspond to the design area of each 3&4 EHP cell summarized in Table 2-1. The wetted areas of lined B, F, and H Cells were assumed in the calculations.

Seepage from ponds, whether they are lined or unlined, is dependent on hydraulic head. Pond water levels are monitored by Talen on a weekly basis. Head on the geomembrane liners in each of cells B and F is assumed to be 20 feet, based on recent routine water level surveys. Head in H Cell is conservatively assumed to be the difference between the minimum pond bottom elevation (3,266 feet) and the pond crest (3,293 feet). As noted, flux through the 3&4 EHP boundaries was calculated using Darcy's law. Because the remaining cells within the 3&4 EHP do not have standing water, hydraulic gradients were calculated using the difference in water level elevations recently recorded at monitoring wells inside and outside the 3&4 EHP bentonite amended concrete cutoff wall. Water level elevations measured prior to dewatering unlined C and G Cells and the Old Clearwell were approximately 3,270 feet, 3,235 feet, and 3,235 feet, respectively. A comparison of flux through 3&4 EHP boundaries prior to and after the Old Clearwell and C, and G Cells were dewatered is made in Section 2.3.4.

2.3.2 Lithology and Hydraulic Conductivity

For geomembrane-lined cells, the hydraulic conductivity of the underlying flyash (or paste) layer is important to the function of the liners. Flyash hydraulic conductivity of $1x10^{-5}$ cm/sec (0.028 ft/day) was used in seepage calculations for lined 3&4 EHP cells based on

results of percolation tests conducted by Golder Associates (2002) and Hydrometrics, Inc. (Hydrometrics, Inc., November 6, 2008).

Design seepage (flux) estimates were made by Bechtel (1982) using Darcy's Law. The estimates were based on data gathered from geologic mapping and permeability testing at a series of exploration boreholes and monitoring wells drilled within the perimeter of the then proposed unlined ponds. Results of the evaluation indicated that lithology and permeability beneath the 3&4 EHP construction site is variable and may significantly affect the outcome of seepage estimates. A sequence of baked shale or clinker, interbedded siltstone, sandstone, claystone, and McKay Coal underlain by more interbedded siltstone, sandstone, and claystone was presented in the report. The hydraulic conductivity of thermally unaltered bedrock (i.e. sandstone, siltstone, claystone, and coal) ranged from less than 1 ft/year to 1,823 ft/year (Bechtel Power Corporation, 1982). Hydraulic conductivity of the clinker was inestimable by the test methods presented in the report; however, a review of aquifer testing results from clinker aquifers (Heffern & Coates, 1999) suggests a range of clinker transmissivity in the Powder River Basin from 35,400 ft^2/day to 1,482,400 ft^2/day. Based on testing at well 1002R and evaluation of initial startup pumping data, the hydraulic conductivity (ability of media to transmit water) was calculated to be 2,500 feet per day with a transmissivity of about 64,000 ft^2/day. A bentonite amended concrete cutoff wall was constructed around the perimeter of the pond to restrict horizontal flow through the clinker.

The lithology presented in cross sections of the 3&4 EHP Design Report (Bechtel Power Corporation, 1982) is similar to the current understanding of subsurface lithology in the 3&4 EHP area. A discussion of 3&4 EHP area lithology and current geologic cross sections are included in Section 3.3 of this report. In general, clinker from the Rosebud burn is at the surface, followed by Rosebud/McKay interburden consisting of interbedded siltstone, sandstone, and shale. The McKay Coal is present west and south of the 3&4 EHP. A whole section of the McKay Coal formation is approximately nine feet thick. Locally, it may be thinner depending on erosion, degree of burning, or due to depositional variation. More Fort Union Formation bedrock is present beneath the McKay. Cross sections (introduced as Figures 3-1 through 3-3 in Section 3 of this report) illustrate the depositional environment

beneath the ponds and extending from the ponds in each direction. Lithologic logs for select wells are included in Appendix D.

2.3.3 Seepage Estimates for Geomembrane-Lined Ponds

A geomembrane is a thin, flexible, low permeability material that is used as a fluid barrier (Giroud and Bonaparte, 1989). Ponds that have a geomembrane or dual geomembrane components have a much lower seepage potential than ponds constructed of earthen material alone; and the mechanisms for seepage through geomembrane liners differ from that through clay liners. The mechanisms of seepage through a liner system constructed with a geomembrane include permeation through the intact geomembrane liner and seepage through geomembrane defects. As noted previously, geomembrane liners used in the 3&4 EHP are constructed of RPP. Geomembranes installed in the 3&4 EHP are part of either a composite liner or a double liner system.

A composite liner is a single liner comprised of two or more low-permeability components in contact with each other (Giroud and Bonaparte, 1989). B Cell (New Clearwell) and F Cell are constructed with composite liners that consist of a 45 mil RPP liner over a 10-foot thick layer of flyash. A leachate collection system is in place in the flyash layer. The hydraulic conductivity of the lower layer is important to the function of the composite liner. As noted, a hydraulic conductivity of $1x\ 10^{-5}$ cm/sec (0.028 ft/day) was used in seepage calculations for the ash layer beneath lined ponds based on results of paste percolation tests conducted by Hydrometrics, Inc. (Hydrometrics, Inc., November 6, 2008) and laboratory studies of Golder (2002).

A double liner system includes two liners with a drainage layer to detect, collect, and remove liquids between the two liners (Giroud and Bonaparte, 1989). The 3&4 EHP H Cell is constructed with a double-liner system consisting of a 45 mil RPP primary liner, a geo-net/felt fabric drainage layer, a 36 mil RPP secondary liner, a thin geotextile cushion, and ten feet of compacted dry flyash. Giroud et al. (1997) evaluated the optimal configuration of a double liner system to minimize seepage. In that analysis, a method of estimating seepage through a double liner system with a primary geomembrane overlaying a geonet leachate

collection layer and a secondary composite liner was presented. The method (Giroud et al., 1997) includes calculating hydraulic head on the secondary liner that results from seepage through the primary liner into the leachate collection layer. Based on a comparative analysis, head on the secondary liner and seepage through the secondary liner decreases by at least four orders of magnitude compared to that of a single composite liner. The seepage estimate for the double-lined H Cell was made using a procedure consistent with Giroud et al. (1997) that considered the inherent decrease in hydraulic head on the secondary liner produced by the geo-net drainage layer.

Flow through a geomembrane is not purely by advection but occurs on the molecular level as either vapor transmission or liquid permeation (Giroud and Bonaparte, 1989). Vapor transmission only occurs when one side of the geomembrane is not saturated; while, liquid permeation occurs as the result of a large pressure head differential between liquids on both sides of the liner. Water vapor transmission through geomembrane liners is typically analyzed by standardized conformance testing (ASTM E-96) and results are provided by liner manufacturers. Based on available testing results, water vapor permeance of RPP and HDPE geomembrane liners ranges from 0.05 to 0.12 perms (1 grain of water vapor per hour per square foot per inch of mercury). A conservative estimate of seepage by permeation can be made for a given pond directly from the water vapor permeance results by: 1) converting the mass (grains) transfer rate to volume by assuming a density of water; and 2) multiplying the result by both the pond area and head on the liner. This was done for all 3&4 EHP cells constructed of either a geomembrane composite liner or geomembrane double-liner system. A conservative value of 0.1 perms was assumed in all seepage calculations for lined cells in the 3&4 EHP.

For each geomembrane-lined pond, the cumulative estimate of seepage includes flow through the liner from geomembrane defects. Seepage through defects is calculated using the equations and methods of Giroud and Bonaparte (1992), Giroud (1997), and Giroud et al. (1997). Specifically, Giroud's equations are used to calculate the rate of seepage through a single defect in a composite liner and are parameterized by the amount of head on the liner, the hydraulic gradient, the hydraulic conductivity of the low permeability soil beneath the

geomembrane, the area of the geomembrane defect, and the quality of the contact between the geomembrane and the underlying soil. As noted, there is an intermediate step that involves calculating the reduced head on the secondary liner for double-lined ponds.

The seepage rate through an entire geomembrane liner (double-liner or composite) is calculated by multiplying the rate of seepage through a single defect by the total number of defects present on the liner. For a geomembrane liner installed under strict quality assurance protocol, one to two liner defects per 4,000 m^2 (43,055.6 ft^2) can be expected (Giroud and Bonaparte, 1989); thus, a frequency of one defect per 4,000 m^2 (43,055.6 ft^2) is often considered by Giroud et al. (1994) for liner performance evaluation. These values are typical of a lined pond with a soil cover layer (such as a landfill) and may not be appropriate for ponds filled with water. To provide a more conservative evaluation of seepage, two defects per 4,000 m^2 (43,055.6 ft^2) were assumed for the 3&4 EHP pond liners. A defect area of 0.1 cm^2 (0.0155 in^2) is considered for a typical liner performance evaluation; however, a defect area of 1 cm^2 (0.155 in^2) is commonly considered for conservative design purposes (Giroud et al. 1994). The larger defect area (0.155 in^2) was assumed for 3&4 EHP seepage calculations.

The contact quality factor, C_q, is an empirical factor presented by Giroud and Bonaparte (1992) and Giroud (1997) to quantify the contact between the geomembrane liner and the underlying earthen liner. There are two possible values of C_q available in the calculations:

1. Good contact applies to a geomembrane that is installed with few wrinkles over a low-permeability soil that has been well compacted and is smooth. For good contact conditions, the C_q factor is equal to 0.21 (dimensionless).
2. Poor contact is assumed if a given geomembrane is installed with many wrinkles, and/or the soil has not been compacted, and/or the soil does not appear smooth. For poor contact conditions, the C_q factor is equal to 1.15 (dimensionless).

Cells with composite liners (B Cell and F Cell) were constructed directly on compacted dry paste; thus, the good C_q factor (0.21) was assumed for their seepage calculations. H Cell was constructed over a thin geotextile cushion; so the poor contact factor (1.15) was used in the

seepage evaluation of this cell. The poor C_q factor is roughly five times greater than the good C_q factor. This factor has a linear effect on seepage estimates through geomembrane defects; so assuming all other parameters are equal, seepage estimates through defects made using the poor C_q factor are roughly five times greater than those resulting from the good C_q factor.

Head on the geomembrane-lined cells of the 3&4 EHP is typically greater than the thickness of the underlying compacted flyash/paste. This factor is important to note because it dictates which form of the leakage equation Giroud and Bonaparte (1992) or Giroud (1997) is necessary for the liner seepage evaluation. Where head on the geomembrane liner is less than the thickness of the underlying layer, the hydraulic gradient term i_{avg} is assumed to be one (see Tables 2-3A and 2-3B for equations and variable assignments). Where head on the geomembrane liner is greater than the thickness of the underlying layer, the i_{avg} term must be calculated and included in the leakage equation. Note that the equations for liquid migration through defects (Giroud and Bonaparte 1992, and Giroud 1997) are semi-empirical and must be evaluated using the International System of Units (SI) where length is in meters (m), area in m^2, volume in m^3, and time is in seconds (s). Final seepage results were converted to gpm at the conclusion of the seepage calculation for each pond.

As noted above, calculating seepage through a double-lined pond filled with water is a two-step process whereby the reduced head on the secondary liner is evaluated based on the amount of seepage through the primary liner; then, the seepage rate through the secondary liner is calculated given the adjusted head (Giroud et al. 1997). To provide a conservative estimate of seepage from the primary liner to the geonet collection layer between the primary and secondary liners, singular defects are treated as orifices and free flow is calculated using Bernoulli's equation, rather than Giroud's equations. The assumption of free flow is satisfied by the relatively large hydraulic conductivity and abundance of pore space in the geonet.

As the secondary liner is in contact with underlying compacted flyash or paste, Giroud's equations are more appropriate for estimating final seepage through the secondary liner. Adjusted head on the secondary liner is a function of the hydraulic conductivity of the geonet, the slope of the leachate collection layer, the length of the pond, and the unit rate of

seepage through primary liner defects (q_i) (Giroud et al. 1997). The equation for adjusted head on the secondary liner is presented in Table 2-3B. For this evaluation, seepage due to permeation from the primary liner is added to q_i to obtain a conservative estimate of adjusted head. Note that the adjusted head (h_2) on the secondary liner of 3&4 EHP H Cell is 0.003 ft, as compared to 27 feet on the primary liner.

The final seepage rate through the secondary liner is calculated using the form of Giroud's equation (Giroud 1997) for small head on the liner (i.e. head is less than thickness of compacted clay layer). In this form of the equation (Table 2-3B), the hydraulic gradient is equal to one. Final estimates of seepage through defects are added to that estimated by permeation to obtain the total seepage rate through a double-lined cell.

Seepage due to permeation and defects from composite-lined B and F Cells is calculated in Table 2-3A. Seepage estimated from H Cell is evaluated in Table 2-3B. Current estimates of seepage from B and F Cells are 5.3 gpm and 8.2 gpm, respectively. Seepage estimated through double-lined H Cell is 0.009 gpm.

2.3.4 Flux Estimate Through 3&4 EHP Boundaries

Design seepage estimates for the 3&4 EHP were made prior to construction by Bechtel (Bechtel Power Corporation, 1982). Seepage rates were estimated using a seven step approach that included both an analytical method and a numerical model. The analytical method, developed first, was simply a summation of flux estimates for various flow paths around the perimeter of the pond. Flux was calculated by Darcy's law (Q = KIA); where K is hydraulic conductivity, I is the hydraulic gradient, and A is the cross sectional area perpendicular to groundwater flow. K and A were well parameterized with data gathered during exploration and permeability testing in the 3&4 EHP area. The hydraulic gradient was assumed based on a difference between full pool elevation of 3,280 feet and estimated elevations of presumed hydrologic boundaries and features at known differences from the pond. For example, the elevation of Cow Creek and its distance from the 3&4 EHP was commonly used. Several simplifying assumptions were made in the Darcy flux calculations, including: the pond is filled with water; no transient effects of pond filling; not accounting

for a reduction in hydraulic head by seepage of liquid through accumulated flyash; steady state conditions; no consideration for unsaturated flow conditions; and only horizontal flow was considered.

A numerical model was developed later by Bechtel and was used to refine seepage estimates by addressing some of the simplifying assumptions initially identified in the analytical method (Bechtel, 1982). The numerical model included a vertical flow component, addressed variable locations of the water pool within the pond, included effects of effluent material (flyash) on seepage rates, represented variations of permeability of various rock types, and accounted for transient effects. Calibration factors, calculated as the ratio of numerical model results to Darcy flux calculation results, were applied to yield final seepage estimates.

Bechtel (1982) calculated an initial seepage estimate (analytical method) of 275 gpm at the cutoff wall by applying the Darcy flux analytical method to a scenario where the entire 3&4 EHP was filled to an elevation of 3,280 feet. This initial seepage estimate was refined using the numerical model to produce a final seepage estimate of 90 gpm. Note that the accuracy of the numerical seepage model was limited by the data used as input. Limitations include representativeness of permeabilities determined by percolation tests and the lack of available data to validate transient model predictions.

Hydrometrics adapted the Darcy flux method used by Bechtel in design calculations to estimate a conservative groundwater flux at the bentonite amended concrete cutoff wall under the current dewatered condition of G, C, D/E, A, and J Cells in the 3&4 EHP. However, the lithology assigned to the calculations was based on an additional 30 years of observations, the hydraulic gradient used in the calculations was based on actual water level measurements made from monitoring wells both inside and outside of the 3&4 EHP boundary, and no calibration factors were applied to the results that would potentially reduce flux estimates.

Flux was calculated for four different flow paths, each originating at the 3&4 EHP and extending to the north, south, east, and west. These flow paths are consistent with flow perpendicular to the cross sections that Bechtel identified as AC, CE, IE, and IK in both the 3&4 EHP design report (Bechtel 1982) and the as-built report (Bechtel 1985a). The current flux calculations are presented in Table 2-4A. Flux estimated prior to complete dewatering of the Old Clearwell and C and G cells is presented in Table 2-4B. A description of each of the four flow paths and the resulting cumulative flux estimate at the bentonite amended concrete cutoff wall is as follows.

- North – This flow path is assumed to the north from the 3&4 EHP towards Cow Creek. It is analogous to flow through Cross Section AC (Bechtel Power Corporation, 1982). The lithology used to parameterize the estimate of flux for the north flow path is exemplified in Cross Section C-C', (Figure 3-3, Section 3 of this report), which was created approximately parallel to the direction of groundwater flow. Groundwater flux for the north flow path was considered as the sum of flow through the bentonite amended concrete cutoff wall and through a sequence of interbedded siltstone, claystone, and sandstone. The McKay Coal is generally absent along the north flowpath. When encountered, the coal is generally burned and a complete flow path through the unit does not appear to exist. For all flow paths, a cutoff wall thickness of 2 feet and hydraulic conductivity (K) of 0.1 ft/year were assumed. These are listed as minimum specifications in the slurry cutoff wall final construction report (Bechtel, 1985b). The first layer of interbedded siltstone was assigned a thickness of 60 feet based on lithology observations made at wells drilled just outside of the bentonite amended concrete cutoff wall (e.g. 1115D and 1080D). Hydraulic conductivity of the upper interbedded interval is assumed to be very low, as no saturated conditions have been observed in this interval during monitoring well drilling. A K value of 20 ft/yr (0.05 ft/day) was applied to this interval based on permeability tests by Bechtel (1982). An average K of 365 ft/yr (1 ft/day) was applied to sandstone north of the 3&4 EHP based on testing results at wells 1080D, 1081D, and 1082D that were 4 ft/day, 1.2 ft/day, and 0.04 ft/day, respectively.

  Current head against the cutoff wall was assumed to be 19 feet, based on the water level elevation of 3,229 feet at monitoring well 1173S and the cutoff wall bottom

elevation of 3,210 feet. Previously, twenty-five feet of head was assigned to the cutoff wall, based on October 2013 water level of 3,235 in the Old Clearwell. The current total flux estimated at the north flow path from the 3&4 EHP is 146 gpm (Table 2-4A). An estimate of 165 gpm was made based on the operating water level of 3,235 feet in the Old Clearwell (Table 2-4B). A comparison of the current and previous estimate indicates a reduction in flux of 19 gpm has been realized through this flow path by dewatering the previously active earthen-lined cells. For both the current and operating seepage estimates, flux through the cutoff wall along the northern boundary was less than two gpm; and the majority of flow along this pathway is attributed to sandstone bedrock units.

- East – The east groundwater flow path is best illustrated in Cross Section A-A', (Figure 3-1, Section 3 of this report) and considers flux through the bentonite amended concrete cutoff wall and underlying strata on the east edge of the 3&4 EHP. Current head on the cutoff wall is derived from the water level elevation in monitoring well 1164R and is consistent with operating heads of G Cell prior to dewatering. Head is assumed to be 3,237 feet; which is actually two feet higher than the water level elevation in G Cell before it was dewatered in 2013. Based on the cutoff wall as-built report, the bottom elevation of the cutoff wall ranges from approximately 3,185 to 3,200 feet (Bechtel Power Corporation, February 1985a) along this boundary. An average bottom elevation of 3,195 feet was assigned to the cutoff wall in the flux calculation. Hydraulic conductivities assigned to the interburden and sandstone at the east cutoff wall boundary were consistent with those used for the north flux estimate (K = 365 ft/yr for sandstone and K = 20 ft/yr for siltstone/claystone interburden). The hydraulic gradient was conservatively estimated for each unit as the difference in the water level elevation (3,237 feet) and the elevation of the hydrostratigraphic interval of interest at an assumed location 400 feet from the pond edge. Four hundred feet is the approximate distance from the edge of G Cell to well 1107D. Well 1107D is completed in the upper sandstone interval and has a water level elevation of approximately 3,181 feet. The same water level elevation was assumed for the upper interbedded siltstone/claystone interval. Head for the deeper interbeds was assumed to be equal to the bed thickness of 75 feet. The

current total flux estimate through the east boundary of the 3&4 EHP is basically unchanged from the flux estimate made while water remained in G Cell (54 – 57 gpm).

- West – Groundwater flux through strata beneath the west boundary of the 3&4 EHP was calculated as the summation of flow through the cutoff wall and a sequence of five bedrock intervals: 1) McKay Coal (~10 ft thick); 2) siltstone/claystone interbeds (~10 ft thick); 3) an upper sandstone unit (~ 20 ft thick); 4) a second interbedded unit (~ 15 ft thick); and 5) a deeper sandstone interval (~25 ft thick). Cross section B-B', presented in Figure 3-2 in Section 3 of this report, depicts the lithology parallel to this flow path. The estimate of flow through the bentonite amended concrete cutoff wall was parameterized by the water level elevation in well 1085R and an average cutoff wall base elevation of 3,225 feet. Concurrent with dewatering of C Cell, G Cell, and the Old Clearwell, well 1085R was pumped in late 2013 and early 2014 in an attempt to reduce water storage in clinker within the cutoff wall. Prior to pumping, the water level elevation in well 1085R was approximately 3,255 feet. The most recent water level elevation recorded in this well was 3,236 feet. The reduction in head resulted in a decrease in the flux estimate through the western boundary of 17 gpm. Prior to dewatering, the cumulative flow estimate through the western boundary was 44 gpm; the current flux estimate is just 27 gpm. Estimated flow through the cutoff wall was reduced from 2.3 gpm to 0.8 gpm for the 3,600-foot long west boundary after dewatering was conducted. Hydraulic gradients for the respective units were established by comparing water level elevations of wells inside the cutoff wall to water level elevations of wells outside of the cutoff wall. Not all of the strata considered in the calculation had paired wells on opposite sides of the cutoff wall. In this case, conservative estimates of head, based on best available data, were made. Water levels inside the cutoff wall were represented by well 1085R (for shallow units) and well 572D (for deeper units).

- South – Lithology used to conceptualize the groundwater flow path to the south of the 3&4 EHP is represented in the southern portion of Cross Section C-C' , (Figure 3-3, Section 3 of this report). This cross section is approximately parallel the direction of

groundwater flow to the south of the 3&4 EHP. The average elevation of the bottom of bentonite amended concrete cutoff wall is 3,220 feet. Well 674R is located just inside the cutoff wall. Well 674R had a typical groundwater elevation of about 3,260 feet while water was present in C Cell. However, the groundwater elevation in 674R has been reduced to approximately 3,249 feet. Head on the cutoff wall was calculated as the difference between the water level elevation in the nearby well (674R) and the wall bottom elevation. An estimated flux of six gpm was estimated through the cutoff wall while water was still present in C Cell; but the flux estimate was reduced to 4.4 gpm after dewatering. The estimated flux through the cutoff wall is higher along the south boundary than the other three boundaries because of the higher head and greater length of the flow boundary. Flux through strata below the bentonite amended concrete cutoff wall included that through an interbedded siltstone/claystone unit (~10 ft thick), the McKay Coal (~10 ft thick), a second interbed unit (~40 ft thick), and finally a sandstone bed (~50 ft thick). Hydraulic conductivities assigned to the respective units were consistent with those used along other flow pathways; and the hydraulic gradient was established using water level elevations and known distances between wells on opposite sides of the bentonite amended concrete cutoff wall. Flow through coal and bedrock units along this boundary is less than that evaluated at other boundaries due to the low hydraulic gradient. For example, the difference in head between well 572D (inside cutoff wall) and well 589D (outside cutoff wall) is just 2 feet. The wells are separated by an approximate distance of 1,000 feet; and both are completed in the deeper sandstone unit. Flow through the south 3&4 EHP boundary, including the bentonite amended concrete cutoff wall, was estimated to be 14 gpm based on head conditions observed in 2013 (Table 2-4B). Based on current conditions, flux through the south boundary was reduced to 12 gpm (Table 2-4A).

- Total – The current cumulative flux estimate for all flow pathways beneath the cutoff wall perimeter is 243 gpm; of which, flow through the cutoff wall is estimated to be 11 gpm (Table 2-3A). Cumulative flux estimated for conditions in 2013 that included free water in C Cell, G Cell, and the Old Clearwell was estimated to be 277 gpm (Table 2-4B).

Flux estimates were made using a pragmatic approach that employed basic groundwater flow dynamics and a dense network of monitoring and capture wells to parameterize subsurface lithology and groundwater potential along four distinct flow paths. Potentiometric surface maps of Rosebud Coal/Clinker, McKay Coal, and sub-McKay bedrock for fall 2015 in the 3&4 EHP area are presented in Figures 3-35, 3-37 and 3-39. These maps illustrate that, in general, the 3&4 EHP are centered above a zone of high groundwater potential in each of the respective units. The concept of four groundwater flow pathways is largely validated by applying the principle that the direction of groundwater flow is perpendicular to equipotential lines. A discussion of flow direction and other pertinent groundwater observations for each flow path is discussed as follows.

- North – Potentiometric contours on the north boundary indicate a groundwater flow in the shallow interval (Rosebud clinker or equivalent) that is to the north (Figure 3-42); although, very little groundwater is present in this interval. Note that wells completed in the clinker (e.g. 1060C and MD-12-17sp) are dry (Figure 3-35). Sufficient control to predict groundwater flow direction is obtained, however, by triangulating between shallow well 602S and downgradient alluvial wells. Dry conditions immediately outside of the bentonite amended concrete cutoff wall support the estimate made above that relatively little seepage flows through the cutoff wall to the north. As previously mentioned, the McKay Coal is generally absent (eroded) along the north flow path. When encountered, the coal is generally burned and a complete flow path through the unit does not appear to exist. The lack of a continuous coal seam is apparent in the potentiometric surface map (Figure 3-37) and in calculations presented above. The direction of groundwater flow in sub-McKay bedrock is perpendicular to the northern 3&4 EHP boundary and is nearly due north except where influenced by groundwater capture wells. The conservatively estimated rate of flux through the sub-McKay sandstone north of the ponds (146 gpm) was the highest of all flux estimates for individual units. Note from Cross Section C-C' (Figure 3-3) that there is little vertical separation between this sandstone unit and the bottom of C Cell and the Old Clearwell. Several groundwater capture wells are

present in this interval to mitigate process water impacts. Groundwater capture effectiveness is discussed further in Section 3.6.

- East – Groundwater flow in shallow bedrock, the McKay Coal, and sub-McKay bedrock trends to the east based on potentiometric contours in Figures 3-35, 3-37, and 3-39. Approximately 8 gpm is estimated to flow through the cutoff wall and shallow interbeds combined. This estimate is corroborated by the minimal amount of groundwater that is captured at the Saddle Dam Interception Trench. Note that the Saddle Dam Interception Trench also captures shallow recharge water that enters the system between the pond and the trench. The Saddle Dam Interception Trench is completed to the base of the McKay Coal stratigraphic interval (the coal is burned on the northeast side of the pond in the vicinity of the trench) and is designed to drain groundwater, by gravity, from the coal and overlaying units. The McKay Coal is found sparsely in the area east of the 3&4 EHP Saddle Dam and is typically either burned or partially burned. Flow through sub-McKay bedrock east of the Saddle Dam is currently estimated to be 36 gpm. Historic groundwater monitoring observations made prior to construction of the 3&4 EHP indicate that native groundwater was present in sub-McKay bedrock; thus, much of the flow in the deeper bedrock may not have originated at the EHP. Ongoing groundwater quality observations indicate that process water impacts in groundwater east of the ponds are dilute in comparison to pure pond water. A discussion of water quality and mitigation of process water impacts east of the 3&4 EHP Saddle Dam is included in Section 3.5.2.

- West – An examination of the groundwater flow direction west of the 3&4 EHP (Figures 3-42 through 3-44) indicates that flow is to the west in shallow intervals (i.e. clinker); but tends to be more northwesterly with depth. As such, the assumption of westerly flow from the 3&4 EHP west boundary may result in a conservative estimate of the length of the cross section perpendicular to flow and an overestimate of total flux in McKay and sub-McKay units. Low flux, in general, at all units west of the 3&4 EHP is consistent with observations made at the monitoring and capture well network in the area.

- South – Groundwater flow in upper strata south of the 3&4 EHP is to the south, which is consistent with the assumption of southerly flow used in the flux estimates presented in Table 2-4 (A and B). Flow in deeper units, however, tends to flow more toward the southeast. A slight inflection toward the southeast is seen in potentiometric contours of the McKay Coal (Figure 3-37); and flow is nearly due east in sub-McKay bedrock (Figure 3-39). The apparent easterly flow direction (Figure 3-44) would result in an overestimate of the flux contribution from the 3&4 EHP because flow in the calculation is assumed perpendicular to the mile-long southern boundary of the 3&4 EHP. Estimates of flux in sub-McKay intervals south of the 3&4 EHP cannot be solely attributed to seepage from the pond, which explains why very little process water impacts are present in deeper bedrock of the South Fork Cow Creek (SFCC) drainage. Process water impacts and mitigation of said impacts is discussed further in Section 3.5.2.

It is difficult to estimate seepage from the earthen-lined portion of the 3&4 EHP due to variable head and storage within the cutoff wall and uncertainty of pond bottom hydraulic conductivity that has likely changed with addition of flyash and/or paste deposition in the cells. All flow through the bentonite amended concrete cutoff wall is assumed to be impacted by process water or to have originated directly at the 3&4 EHP; likewise, flow through lined ponds is considered to be process water. Presently, flow through the cutoff wall is estimated to be 11 gpm; and the conservative estimate of flow through lined ponds is 14 gpm. The Darcy flux calculations presented herein account for all groundwater flow, which may include seepage from unlined ponds, seepage from lined ponds, and groundwater replenished by direct recharge from precipitation. By considering all groundwater flow, the resulting flux of 243 gpm is an estimate of the upper limit of process water seepage. Accounting for the reduction in water stored in earthen-lined cells at the 3&4 EHP, the present estimate is consistent with the calculated design flux of 275 gpm estimated by Bechtel (1982).

The previously discussed flux estimates were compared to pond seepage estimates derived from the calibrated numerical groundwater flow model of NewFields (2017) that is presented

in its entirety as Appendix A. Like the flux calculations, seepage simulated by the model is dependent on head in the unlined cells and hydrogeologic parameters of the underlying strata. Seepage from lined cells was considered to be zero in the numerical model. Modeling conducting in 2016 resulted in a simulated seepage rate of 196 gpm. The simulated seepage estimates are consistent with design flux estimates made by Bechtel (1982) and flux estimates presented in this report.

3.0 SUMMARY OF INVESTIGATIONS

3.1 SYNOPSIS OF PAST SPILLS, INVESTIGATIONS, MITIGATION, AND STATUS

Table 3-1 contains a list of incidents that resulted in confirmed releases, were suspected of causing releases, or potentially resulted in a release but information gathered after the observation did not confirm a release.

3.2 PAST INVESTIGATIONS

Numerous investigations have been conducted in the 3&4 EHP relating to process ponds activities groundwater and soil investigations, spills associated with the pipelines, or changes in water quality identified in operational groundwater monitoring. Table 3-2 contains a list of the reports, date of the report, and a short summary of the work conducted and findings of the investigations or studies. Appendix F contains examples of some of the types of data that have been collected at the site. These are provided as examples only. The actual amount of raw data collected and evaluated to define site conditions is exhaustive and beyond the scope of this report.

3.3 CURRENT SITE CONDITIONS

Site hydrogeologic descriptions have been presented in numerous previous site reports which are summarized in Table 3-2 and are listed in the reference section of this report. Hydrogeologic conditions are also discussed in the report on numerical modeling of groundwater flow in Appendix A. Regional geology is also presented in numerous reports that discuss the Fort Union Formation and coal resources in eastern Montana and the Powder River Basin. A brief overview is provided here for convenience.

3.3.1 Regional and Site Hydrogeology

<u>Regional Geology</u>

Colstrip is located in the northern portion of the Powder River Basin, an asymmetrical basin oriented northwest to southeast. This structural basin is responsible for the general regional orientation of bedding. “In general, Fort Union Strata dip very gently (less than a few

degrees) in easterly and southerly orientations from west to east across the coalfield, respectively. Locally, however, dips are steepened by high-angle faults that are present throughout much of the Colstrip area" (Roberts, et. al, 1999).

Stratigraphy in the Colstrip area 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 at the surface in the Colstrip area. The Lebo Shale, and then the Tullock Members are exposed to the north. At Colstrip, the total thickness of the Fort Union Formation is about 650 feet. The Lebo Shale is typically about 75-125 feet thick and is found at variable depths in the Colstrip area depending on the amount of erosion that the Tongue River member has undergone.

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. Colstrip is situated in an area that was deposited from streams. The fluvial systems were typically oriented northeast-southwest (Flores and Ethridge, 1985).

- Anastomosing streams are comprised of multiple channels within a single drainage. Individual floodplains of an anastomosing system may include braided or meandering, or straight characteristics. Deposition typically occurs under low energy conditions near a local base level (Makaske, 2000).
- Braided flow systems consist of a network of flow channels within a single floodplain or flow belt (Makaske, 2000). These channels have multiple thalwegs (deepest part of channel) that branch back and forth from single to multiple channels.
- Meandering streams consist of one or more individual channels that migrate back and forth across a single floodplain. Meandering channels consist of one thalweg.

Numerous coal seams are present in the Tongue River Member of the Fort Union Formation, the result of peat deposits which accumulated in swampy areas and channels. A tropical to

sub-tropical climate resulted in thick peat deposits within the swamps and bogs (Nichols and others, 1989, Flores, R.M. and others, 1999). Because of the depositional setting, the coal beds may pinch out laterally or stop abruptly. The main coal seams of interest near Colstrip are the sub-bituminous Rosebud (~ 24 feet thick) and McKay seams (~ 8-10 feet thick) which can economically be strip mined. These two coal seams merge into a single seam on the west side of the Little Wolf Mountains near the Absaloka Mine, approximately 20 miles southwest of Colstrip. The Rosebud Coal, however, is the only seam mined in the area due to 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. That is, they contain natural vertical fracturing generally oriented perpendicular to the bedding plane. Hydraulic conductivity of the coal seams is typically around one to three feet per day, but fluctuates locally.

The Rosebud Coal, and in some places, the McKay Coal has burned. This is most easily identified as red cap rock on hilltops around the region. Burning of the coal baked the overlying strata. As a result of the burning, the coal volume reduced either leaving a void for the overlying rock to collapse in or resulted in slow settling of the overlying rock into the space formerly held by the coal. The thermally altered rock is referred to as clinker or scoria. Collapse of the rock resulted in secondary porosity (fractures).

The depositional setting results in 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. Cementation, or the chemical binding of individual grains to one another, is highly variable within the units, mostly consisting of weak calcium carbonate cement although thin deposits with silica cementation also occur. Localized thin limestone beds may also exist. The combination of the depositional setting of the Fort Union Formation which resulted in lateral facies changes, variations in the lithologies of vertical sequences (sandstone, siltstone, shale), mining disturbances that have interrupted the original depositional setting, formation of highly fracture clinker from in situ coal burning, secondary porosity (minor fractures in bedrock) combined with erosion and deposition from the creek result in vertical and horizontal anisotropy (the condition of having different properties in different directions) and heterogeneities (variations through space

within a geologic formation). Although driven by potentiometric heads, because of the anisotropic and heterogeneous nature of the geology, groundwater flow may not always follow a direct path from high potentiometric heads to lower head areas.

Units 3&4 EHP Hydrogeology

Geology in the 3&4 EHP area generally includes shallow overburden bedrock, Rosebud and McKay Coal, clinker, and various deeper strata of the Fort Union Formation. Colluvium blankets the slopes in many areas and may grade into alluvial deposits which are present in many of the drainage bottoms. Spoil associated with area coal mining are also upgradient of the 3&4 EHP area in upper Cow Creek and South Fork Cow Creek (SFCC). Cross sections illustrating strata of the 3&4 EHP area are presented on Figures 3-1, 3-2 and 3-3 (Section 3.4.1.1). A general description of these deposits in approximate descending order follows.

- Alluvium – These deposits are present in drainage bottoms in the 3&4 EHP area. Major deposits are found in Cow Creek and SFCC. In Cow Creek, the alluvial deposits may be as much as 50 feet thick. In SFCC, the alluvium is typically less than 30 feet thick. Minor alluvial deposits are also present in some of the drainages tributary to Cow Creek and SFCC and the drainage below the 3&4 EHP Main Dam Valley Drain Sump and are typically less than 20 feet thick. The thickest alluvial deposits occur in the farthest downstream areas, with thinning of the deposits in an upstream direction.

  Alluvium in the 3&4 EHP consist of various mixtures of clay, silt, sand, and gravel. Thin deposits of basal gravels, overlying the bedrock contact, are present in the larger valleys of Cow Creek and SFCC. However, basal gravel deposits may be absent in the smaller drainages except in isolated cases. Where present, the basal gravel is primarily composed of clinker fragments. Gravel generally grades upward into poorly sorted sands and silts, as is characteristic of ephemeral channel and floodplain depositional environments. Nearer surface deposits include silty clay to clayey silt that are generally gradational with colluvium that lines the valley margins and blankets much of the valley bottoms. The result is an overall fining-upward grain size sequence.

Alluvial deposits typically exhibit lenses of coarser-grained deposits embedded within finer matrices, as the coarsest materials are deposited during higher energy water flow events and finer materials are deposited by shallower, lower energy water. Periodic storm events result in short-term high flows that deposit gravel and sand within the channel and flooding results in deposits of silt and clay in quiescent areas. These deposits are apparent downgradient of the 3&4 Main Dam Valley Drain Sump, where multiple thin, discontinuous coarser lenses were observed at different elevations and at different locations across the drainage.

Deposition during lower energy events result in finer-grain materials encompassing coarser-grained material. Migration of the valley channel during depositional times resulted in deposition of coarser grained materials in the finer matrix.

Rock fragments observed in the coarser grained deposits are typically angular to sub-rounded and are mostly comprised of clinker. The presence of the highly erodible and easily weathered clinker is indicative of the near source deposition which occurred.

Hydraulic conductivity of the alluvium varies greatly and is a function of overall grain size, degree of sorting, size of the interstitial spaces, grain orientation, and degree of cementation, if any. Alluvium with relatively large grain sizes, good connection between larger pore spaces, consistent grain orientation, and limited cementation exhibit higher permeability. In general basal gravels exhibit higher permeability than overlying sediments that exhibit mixing of grain sizes and lower overall grain sizes. Conversely, lower permeabilities are associated with small overall grain size, poor interconnection of pore spaces, and random grain orientation. Monitoring wells completed in the alluvium are designated with an “A”.

- Colluvium – Colluvium is a deposit of sediments which have been transported downslope by gravitational means to the point of deposition. In the 3&4 EHP, colluvium is most often a silty clay or clayey silt composition, although coarser rock fragments or deposits may be present locally. Colluvium deposited on the valley slopes tends to grade laterally into the alluvium at the valley margins. Colluvium also tends to be in gradational contact with underlying weathered bedrock when alluvium

is absent. Because of the stratigraphic position near ground surface and the general fine grain size of particles, hydraulic conductivities are typical very low(less than 1 foot per day) and little groundwater is transmitted. Probably the most significant contribution of colluvium in the Colstrip area is storage for precipitation water, which is released at varying rates to provide recharge to adjacent alluvial deposits and/or or springs.

- Rosebud overburden – Bedrock units of the Fort Union Formation are comprised of siltstone, claystone, shale, and fine-grained sandstone that typically overlay Rosebud Coal. In the majority of the 3&4 EHP area, the Rosebud Coal has been partially or completed burned. As this happened, sediments in the Rosebud overburden were altered to form clinker (see next bullet). Wells labeled with an "S" are generally completed in this unaltered overburden directly above the Rosebud Coal or in interburden, where the Rosebud has been removed. Yield of the shallow intervals are variable and are typically related to grain size and a supply of water to provide recharge. Wells with shallow local recharge typically exhibit low yields while those connected to recharge boundaries provide higher yield.

- Clinker – Also referred to as scoria, porcelanite (when semi-vitrified), and baked shale; clinker is comprised of thermally altered and collapsed overburden (sandstone, siltstone, shale, etc.) formed by the in situ burning of previously underlying coal. The degree of thermal metamorphosis varies depending on the temperature of the burn, thickness of the overburden, vertical fracture patterns, moisture, and duration of burn. As the coal burned, its volume decreased. As this occurred, or some period of time after burning concluded, the overburden collapsed into the void left by the burned coal. The result is a moderate to highly fractured interval of metamorphosed sedimentary rock. Ash layers and/or layers of unburned coal remain at the base of the clinker. Substantial amounts of clinker occupy the hilltops around the 3&4 EHP. A bentonite amended concrete cutoff wall was installed around the perimeter of the 3&4 EHP, through clinker deposits and into intact underlying bedrock, to inhibit horizontal flow of water from the pond through the clinker.

Clinker is generally quite permeable, a function of the secondary porosity caused by fracturing. Hydraulic conductivity in the clinker may exceed 2,500 ft/day due to its coarse grain size, interconnected pore space, and parallel orientation of rock fragments and gravels. Clinker is typically well drained due to the high permeability and rarely contains useable amounts of groundwater. If present, groundwater in clinker is typically "trapped" by structural low areas following periods of high recharge, either from precipitation or snowmelt. Wells completed in clinker are designated with the coal that the interval correlates with. For example, if the well is completed to the base of the former Rosebud Coal interval, it is designated with an "R".

- Rosebud Coal – Cleated coal with thickness on the order of 20 to 25 feet. This coal has burned in most of the 3&4 EHP near the pond, leaving clinker and ash in its place. Complete sections of Rosebud Coal are only present in a few isolated areas including; the northwest corner of the 3&4 EHP at well 659D; near the eastern extent of the saddle dam at well 621D; and southwest of the 3&4 EHP at wells 1010R. Rosebud Coal typically exhibits a relatively low hydraulic conductivity on the order of one to three feet per day. Unburned remnants of the Rosebud Coal are often found near the base of the clinker and range from zero to nearly full sections of coal. Wells completed in the Rosebud Coal or clinker occupying the former coal interval are designated with an "R".

- 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 SFCC, 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.

- Interburden – Typically comprised of siltstone and claystone which separate the Rosebud and McKay Coal seams. Interburden is present directly above the McKay

Coal (when present) and is either in contact with clinker or the Rosebud Coal (if present). The thickness of the interburden is highly variable, ranging from about one foot northwest of the 3&4 EHP, 13 feet northeast of the pond, and 30 feet or more south of the pond. Hydraulic conductivity of the interburden is variable depending on lithology. The interburden typically contains a shale or claystone layer that inhibits downward, or upward, flow of groundwater.

- McKay Coal – Cleated coal with thicknesses in the 3&4 EHP of typically about seven to ten feet. The McKay Coal is present around much of the perimeter of the 3&4 EHP, and under the pond in parts. However, the coal has been removed by erosion in the center and northern end of the pond and has undergone various degrees of burning in other areas. The McKay Coal is generally a complete, unaltered, unit along the southeast, south, and west sides of the pond. The McKay Coal is highly altered along the north and northeast of the pond. The cutoff wall was installed through the McKay Coal interval into tight bedrock on the north and east sides of the pond. The base of the cutoff wall is higher than the McKay Coal on the south and west sides of the pond. The McKay Coal was removed by erosion in the immediate vicinity of the 3&4 EHP at elevations below about 3,200 feet. Hydraulic conductivity in the coal is typically on the order of one to three feet per day. Wells completed in the McKay Coal or burned remnants/clinker correlative with the McKay Coal are designated with an "M".

- Sub-McKay – Fort Union strata consisting of interbedded claystone, siltstone, fine-sandstones, and thin coal seams. Channel sands are common, resulting in numerous lateral sedimentary facies changes. These depositional changes result in rapid variations in thickness and limit the lateral continuity of units. Sandstone is typically un-cemented or poorly cemented with calcium-carbonate. Hydraulic conductivity of the sub-McKay unit is variable (<1 to >20 feet per day) and is dependent on the amount of interconnected pore space, cementation, and grain size and grain orientation.

3.3.1.1 Bedding Orientations

Cross sections shown on Figures 3-1, 3-2, and 3-3 help illustrate the orientation of stratigraphic units in the 3&4 EHP, the laterally discontinuous nature of lithology, and the variation in the presence or absence of coal.

Cross section A-A' (Figure 3-1) was constructed approximately parallel to the local strike direction. As can be seen, a small unburned portion of the Rosebud Coal is present on the southwest end of the cross section, but is otherwise absent. Clinker has been formed over the remainder of the area. Both the coal and clinker have been eroded in the middle of the pond. Sub-McKay strata consist generally of laterally discontinuous deposits of sandstone and siltstone/shale. The Cow Creek alluvium is present at the northeast end of the cross section and is contact with sub-McKay strata.

Cross section B-B' (Figure 3-2) was constructed generally perpendicular to local strike direction (up and down dip). A slight high, forming a slight anticline, is centered over the northwest portion of the pond. Beds dip to the northwest on the northwest portion of the section and southeast on the southeast half of the cross section. A complete section of Rosebud Coal and McKay Coal is present at the northwest corner of the pond. However, the Rosebud is generally absent over the remainder of the area and this interval has been replaced with clinker. Both the Rosebud and McKay stratigraphic intervals have been removed by erosion in the middle of the pond and at the extents of the cross section. South Fork Cow Creek alluvium is present at the southeast end of the cross section. As shown on the cross section, the alluvium is in contact with the McKay Coal and sub-McKay strata.

Cross Section C-C' (Figure 3-3) extends north and south through the 3&4 EHP. Alluvium is present at both the north and south ends. The alluvium is in contact with sub-McKay strata at the north end of the cross section. The alluvium is in contact with the interburden and McKay Coal in the vicinity of the cross section. The Cow Creek alluvium is present on the north and the SFCC alluvium to the south. The Rosebud Coal is absent along the entire length of the cross section. Furthermore, it is eroded within the pond and at the north and

south ends of the section. The southerly dip of the beds is illustrated in the section by the elevation decline of the McKay Coal from the pond to SFCC. The McKay Coal is absent at the north end of the cross section line, the result of burning, erosion, or a combination.

3.3.1.2 Presence of Groundwater

Groundwater is present in the alluvium north of the 3&4 EHP Main Dam Valley Drain Sump, downgradient of the 3&4 Saddle Dam Valley Drain Sump, in Cow Creek, and in SFCC. Smaller volumes of water are present in drainages tributary to Cow Creek, including the one containing groundwater capture at the Drain Pit #3 Interception Trench and the Drain Pit #5 Interception Trench (see Figure 3-4). These drain pits are used to contain water drained from scrubber slurry and/or clear water return pipelines prior to maintenance.

Clinker in the area typically contains very little, if any, water due to its high permeability and the orientation of the floor of the deposit. The natural occurrence of groundwater in clinker in the 3&4 EHP is typically isolated and is likely associated with local low points at the lower contact. Residual water may also be present from pond losses that occurred in, or around late 2004. Clinker in the vicinity of the 3&4 EHP has been eroded and is present only on hill tops. The clinker is not an aquifer due to its lack of sufficient amounts of groundwater and lateral discontinuity.

The McKay Coal contains a small amount of groundwater. Yield from monitoring wells completed in this unit are typically quite low, generally one to two gallons per minute or less. Since the McKay Coal is eroded around its entire perimeter, it is not laterally continuous through the region. The McKay Coal is not targeted as an aquifer in the immediate 3&4 EHP area.

Water is present in the sub-McKay strata at various depths. Wells completed in these units typically exhibit low yields but can vary from less than a half-gallon per minute to more than ten gallons per minute. Water quality is variable, but this unit is frequently used as a stock water supply source in the 3&4 EHP area. Stock well, monitoring well, capture well, and capture trench locations, and sub-areas are shown on Figure 3-4.

3.3.2 Distribution of Indicator Parameters

Several indicator parameters are used to evaluate potential process water impacts to groundwater at the 3&4 EHP. These include total dissolved solids (TDS), specific conductance (SC), dissolved boron, chloride, sulfate, and the ratio of calcium to magnesium concentrations. SC, sulfate, dissolved boron, and chloride are good indicators of process water since the levels of these parameters are typically higher than background concentrations and each behaves in a conservative manner (mobile in the groundwater environment). The calcium to magnesium ratio is also useful as an indicator of process water in the 3&4 EHP area. This is due to the fact that magnesium is more concentrated in process pond water when compared to calcium. These parameters have been accepted as an evaluation method for process water impacts by Talen and MDEQ. Note, however, that chloride is considered as a secondary indicatory parameter because the chloride BSLs appear to be skewed low. This is based on the fact that chloride is very wide spread and there are multiple potential sources for chloride in the area. Because of the multiple potential sources, the screening of wells to be used in the BSL evaluation was extremely conservative, likely skewing the calculated values.

Background screening levels (BSLs) were recalculated in late 2015 (Neptune and Company, 2016). The update included use of data obtained since BSLs were last calculated in 2007 and 2011 (Arcadis 2007, Exponent 2011). Data from numerous groundwater sites from the Colstrip area were added to the BSL database and all areas (Plant Site, SOEP/STEP, and 3&4 EHP) were combined for calculation of BSLs that could be applied to all three AOC areas. In addition, the BSLs were calculated for a broader range of strata and constituents. For example, the original calculated BSLs for the 3&4 EHP were calculated for alluvium, coal, bedrock, and spoil. The recalculated BSLs included alluvium, clinker, coal related units (include strata from directly above the coal to the bottom of the McKay Coal, excluding clinker), spoil, and sub-McKay. All sites used for the BSL calculations were reviewed and accepted by the MDEQ. Completion units for each well used were evaluated for its stratigraphic position. Statistical evaluation was conducted on each of the intervals and BSLs were calculated.

Based on the statistical evaluation, BSLs for five intervals (alluvium, spoil, clinker, coal-related (Rosebud overburden, Rosebud Coal, Interburden, McKay Coal), and sub-McKay) were calculated. Intervals that were grouped together were either in direct contact with overlying or lateral units and data that were general similar. Background screening levels for units found in the 3&4 EHP area are included on Table 3-3 and detailed in Tables 5 and 8 of the updated BSL report (Neptune and Company, 2016). Note that spoil is not present in the immediate 3&4 EHP area but the BSL was included in Table 3-3 since water from the spoil could potentially influence the alluvium upgradient of the site or groundwater in the SFCC area. For example, water from the spoil potentially flows into the NP Cut and into the alluvium upgradient of Drain Pit 3.

It is important to emphasize that the recalculated BSLs combined data from all three areas (Plant Site, Stage I and II Evaporation Ponds, and the 3&4 EHP). Previous BSLs were calculated as two general areas, combining the Plant Site and Stage I and II Evaporation Pond areas as one group and the 3&4 EHP as another. In addition to combining areas, other data from areas in the vicinity of Colstrip were included to provide a more robust dataset. This includes additional wells from the Rosebud Mine, Big Sky Mine, Bureau of Mines and Geology, and U.S. Geological Survey.

The reason the 3&4 EHP was initially calculated separately was the fact that there was more geospatial variation in the data in this area. In particular, McKay Coal values tended to show elevated levels in areas that could not have been affected by process water, most notably directly south of the ponds. The variations point out the necessity to use multiple lines of evidence when evaluating data for process pond impacts. In other words, an exceedance of the BSLs for only one, or a few, parameters does not necessarily equate to process water impacts but may be a function of natural variation of groundwater in space and time.

Overall, the BSLs that were previously calculated for the 3&4 EHP separate from the other two areas were higher. By combining the three areas, the BSLs that are applied in this revised 3&4 EHP show many more wells with levels of indicator parameters that exceed the

BSLs. It is important to note that this does not represent a worsening of water quality in the area but is an artifact of the revised and lower BSLs that are being applied to the 3&4 EHP area.

BSLs are used in concert with the previously mentioned indicator parameters to provide a basis for comparing groundwater that may have potentially been impacted by process water to other waters in the Colstrip area that are considered to be un-impacted. Water quality in the Colstrip area and Fort Union Formation in general is highly variable. However, the BSLs are mainly used as a basis for comparison in areas where baseline data (data obtained prior to operations in the 3&4 EHP area) are not available. For example, groundwater in some upgradient areas of the facility may exceed calculated BSLs. In this case, impacts from the Colstrip SES are not possible and BSLs would not apply. Similarly, if baseline water quality data are available before pond operations at a particular well, then the baseline water quality is more applicable than the BSLs. An example of this is the area directly south of the 3&4 EHP where the McKay Coal exhibited levels higher than the BSL prior to any potential impacts from the pond. A thorough review of all indicators, local hydrogeology, and other factors must be considered in a multiple lines of evidence approach to evaluate impacts. Indicator parameters are used primarily to evaluate if groundwater is impacted by process water.

Measured SC values and concentrations of boron, sulfate and chloride are used in the following discussion to describe the distribution of chemical constituents at the 3&4 EHP area. Results for 2010 and 2015 are presented to facilitate an evaluation of potential changes through time. The distribution of these indicator parameters (SC, sulfate, boron and chloride) during the fall of 2015, as measured in wells completed in the shallow (alluvium and coal-related intervals) and sub-McKay hydrostratigraphic units, are presented on Figures 3-5, 3-7, 3-9, 3-11, 3-13, 3-15, 3-17, 3-19, 3-21, 3-23, 3-25 and 3-27 described below. Figures 3-6, 3-8, 3-10, 3-12, 3-14, 3-16, 3-18, 3-20, 3-22, 3-24, 3-26 and 3-28 were prepared to illustrate the distribution of indicator parameters based on fall 2010 analytical results. Note that the data set used for the 2010 maps is smaller since fewer wells were installed at that time, which results in variation of the position of contour lines. For this reason, comparison of the paired

maps sets need to be viewed with caution when drawing conclusions of expanding or shrinking areas of possible impacts. Iso-contour maps are divided by shallow (alluvium/Rosebud Coal and alluvium/McKay Coal related units) and sub-McKay which contain only data from wells completed at a deeper stratigraphic interval than the McKay Coal. Note also, that locations with concentrations exceeding the BSL's parameters are highlighted in red. Water quality discussions in the following sections are related to 2015 data. BSLs for each parameter and hydrostratigraphic unit (Neptune and Company, 2016) are also included in the discussion below. More detailed discussion of water quality in the various areas of the 3&4 EHP are in Section 3.5.

Overall, groundwater indicator parameter concentrations exceed BSLs near the pond in the Rosebud interval (clinker and Coal), the alluvium downgradient of past spills or releases, and in areas east, and north/northeast of 3&4 EHP in the sub-McKay unit.

Specific Conductance

SC is a measure of water's ability to conduct an electrical current. SC shows a strong correlation to TDS (Sterrett, 2007). Because SC is largely dictated by the ionic composition of groundwater it is a good indicator of overall water quality and is used as one of the indicators of possible process water impacts. SC in pond water at the 3&4 EHP ranges from 15,000 to 36,000 µmhos/com. SC exceeding the BSL of 4,270 µmhos/cm for alluvium, was present in groundwater in the drainage downgradient of the 3&4 Main Dam Sump (upgradient of capture), in the drainage downgradient of the 3&4 Saddle Dam Valley Drain sump (upgradient of capture), in a small tributary to Cow Creek at well 1123A (capture recently installed), in SFCC (capture installed), and in the tributary to Cow Creek below Drain Pit #5 and in alluvium tributary to Cow Creek below Drain Pit #3 (Figures 3-5 and 3-7). During fall 2015, the highest observations of SC in alluvium occurred in collection wells below the Main Dam Sump.

Laboratory SC exceeding the BSL of 5,310 µmhos/cm for the Rosebud Coal clinker was present in wells near the south and west sides of the 3&4 EHP cutoff wall. Northwest of the ponds the area of elevated SC extends about 2,000 feet from the 3&4 EHP to the Northwest

Secondary Sump (Figure 3-5). At this location, groundwater has flowed from the Rosebud interval to the McKay Coal and into the alluvium. Another area of elevated SC is present at well 1120C, northeast of the Saddle Dam. Groundwater capture has recently been initiated in this area. Note that a gravity drain trench that extends through the McKay Coal is also down gradient of this area.

The recalculated BSL for laboratory SC for the coal related intervals, which would include the McKay Coal, is 3,550 µmhos/cm with an SC of 3,550 µmhos/cm (field 4,130 µmhos/cm). McKay interval wells west and southwest of the 3&4 EHP had SC's above the BSL for SC in the McKay (Figure 3-7). Wells 632M and 633M, located east of the Saddle Dam also had SC values exceeding the BSL. The McKay Coal has been burned and mostly eroded in this area. A groundwater drain trench is installed downgradient of these wells to just below the base of the McKay. Full sections of the McKay Coal to the north and south of this area have SC values below the BSL. Note also, that the McKay Coal has exhibited elevated SC in wells south of the ponds since they were first installed in the early 1980's indicating the area has naturally occurring elevated levels of chemical constituents greater than BSL.

BSL's calculated for SC for the sub-McKay strata is 4,470 µmhos/cm. The highest observed SC values in the sub-McKay units are found in the areas north and east of the 3&4 EHP, below the Main Dam, the Main Dam abutment and the Saddle Dam (Figure 3-9). Multiple wells exceed the BSL's in these areas. The SC BSL is also exceeded at well 1008D, located directly south of the ponds, and at EAP-515 and 1071D, located to the west.

Sulfate

Sulfate concentrations in the 3&4 EHP pond water have ranged from 10,000 to 47,000 mg/L. Groundwater concentrations for the fall 2015 and 2010 are contoured on Figures 3-11 through 3-16.

The sulfate BSL calculated for alluvium in 2015 was 2,600 mg/L. Groundwater with sulfate concentrations exceeding the BSL is present in groundwater in the drainage downgradient of

the 3&4 Main Dam Sump (upgradient of capture), in the drainage downgradient of the 3&4 Saddle Dam Valley Drain sump (upgradient of capture), in a small tributary to Cow Creek at well 1123A (capture recently installed), in SFCC (capture installed), in the tributary to Cow Creek below Drain Pit #5, and in alluvium tributary to Cow Creek below Drain Pit #3 (Figure 3-11).

Sulfate BSLs are exceeded in the Rosebud interval at wells south and west of the ponds. Groundwater capture is being conducted in these areas. Elevated levels of sulfate are also present at well 1120C, located at the northeast edge of the ponds (Figure 3-11).

The sulfate BSL for coal related units is 2,061 mg/L. McKay interval wells west and southwest of the 3&4 EHP had sulfate concentrations above the BSL for sulfate in the McKay (Figure 3-13). Wells 632M and 633M, located east of the Saddle Dam also had sulfate concentrations exceeding the BSL. The McKay Coal has been burned and mostly eroded in this area. A groundwater drain trench is installed downgradient of these wells to just below the base of the McKay. As with SC, full sections of the McKay Coal to the north and south of this area have sulfate levels below the BSL. Note also, that the McKay Coal has exhibited elevated sulfate in wells south of the ponds since they were first installed in the early 1980's indicating the area has naturally occurring elevated levels of sulfate above BSL.

Several sub-McKay monitoring and capture wells north and east of the 3&4 EHP had sulfate concentrations above the BSLs (Figure 3-15). Four wells to the west and northwest and three wells south of the pond also had sulfate concentrations exceeding the BSL. Note that well 1152D is south of South Fork Cow Creek. There is a remote possibility that bedrock water in this area could be influenced by spoil to the south and/or west.

<u>Boron</u>

The highest concentrations of boron in the alluvium are similar to those of the other indicator parameters. That is, the highest concentrations of boron are present downgradient from the 3&4 EHP Main Dam Sump (generally upgradient of capture), east of the Saddle Dam at

trenches 1073A and 1079A, northwest of the ponds at the north and south interception trenches, and in SFCC (upgradient of capture).

Boron concentrations in the Rosebud Coal and clinker interval are highest directly west of the ponds where active capture is occurring. The major portion of this water is next to the cutoff wall. The exception is the southwest corner where water with elevated boron concentrations extends westward to capture well 694R. Well 1010R, which is completed in a full section of Rosebud Coal, and is downgradient of well 1017R, had a boron concentration of less than 1 mg/L in the fall of 2015. Well 1120C, located just east of the north end of the Saddle Dam has elevated levels of boron. Additional wells and groundwater capture has recently been installed in this area (see Figure 3-17).

The initial calculated boron BSL for the McKay Coal in the 3&4 EHP was 10.6 mg/L. The revised BSL, calculated for coal related units for all areas, is 1.1 mg/L. McKay wells located west of the 3&4 EHP had concentrations of boron ranging from 4.1 mg/L to 4.8 mg/L boron in fall 2015. Northwest of the pond, dissolved boron concentrations ranged from 1.1 to 4.3 mg/L. Groundwater capture has been installed in this area at well 657M. One McKay well, 675M, located south of the ponds, exceeded the BSL with a concentration of 13.7 mg/L (Figure 3-19). This concentration is similar to those observed at well 589M, since 1986. Well 675M was installed to replace 589M when it was concluded that the annular seal was not functioning properly. Boron exceeds the boron BSL at well 1149M in the SFCC drainage. This well is upgradient of capture wells that are installed in an area where the coal has been eroded and is in direct contact with the alluvium.

The highest concentrations of boron in sub-McKay units were observed in wells completed north, northwest, northeast and east of the 3&4 EHP, downgradient of the Main Dam, the Main Dam abutment and the Saddle Dam (Figure 3-21). The boron BSL (1.3 mg/L) was exceeded in several of these wells, with many of those completed as groundwater capture wells. Boron concentrations were generally less than 1 mg/L in sub-McKay groundwater south and along the southwest edge of the ponds. A pod of sub-McKay wells near the north

and south DP-5 trenches on the northwest side of the ponds have had boron concentrations above 2 mg/L.

Chloride

A weight of evidence approach is used when evaluating impacts attributed to process water. Chloride is given less weight compared to the other indicator parameters because calculated BSLs are skewed low. This is the result of the very conservative screening methods used to identify a dataset for BSL calculation. In addition, the extent of chloride concentrations greater than the BSL is different from the other indicators.

Chloride concentrations in the 3&4 EHP have ranged from 128 to 1460 mg/L. A general overall increase in chloride concentrations appears to have occurred between 2010 and 2015 (Figures 3-27 and 3-28). Increases are largest directly north of the ponds. Increases were also observed to the northwest and northeast of the ponds. Groundwater capture is being conducted or is planned in most of these areas. Additional monitoring and/or evaluation will be conducted in other areas where increases were observed to verify the changes in concentrations where pond related rather than normal variations in the hydrologic system. Chloride concentrations in the alluvium groundwater exceeded the BSL (45 mg/L) at alluvial wells in Cow Creek just downgradient of the Drain Pit #3 and Drain Pit #5. Multiple alluvial wells (mostly capture wells) in SFCC had chloride concentrations that exceeded BSL's in fall 2015. Alluvial deposits below the Main Dam and Saddle Dam also had chloride concentrations in excess of the BSL, with the highest concentration outside the cutoff wall observed east of the Saddle Dam at monitoring well 1073A, which is located up gradient of capture (Figure 3-23 and 3-25).

The chloride BSL of 34 mg/L for clinker is exceeded in wells completed in the Rosebud just south and to the west of the 3&4 EHP and in a clinker well (1120C) just below the Saddle Dam (Figure 3-23). The highest concentration of chloride in the Rosebud outside of the bentonite amended concrete cutoff wall is observed at capture well 656R, adjacent to the west side of the 3&4 EHP.

A value of 20 mg/L chloride was provided as a screening level for coal-related units, based on the maximum non-detect value in the dataset for chloride. Data for the coal-related units did not meet all the criteria used for calculating BSLs (Neptune, 2016). Several wells west, east, and south of the ponds exceeded 20 mg/L. The highest concentration of chloride in groundwater in the McKay Coal was observed in wells 657M and 1049M located northwest of the 3&4 EHP (Figure 3-25). A few McKay wells south of the cutoff wall also exceed 20 mg/L.

A chloride BSL of 24 mg/L was calculated for the sub-McKay. Many wells in the 3&4 EHP exceed this level. The highest concentrations of chloride in sub-McKay units were observed in wells completed downgradient of the Main and Saddle Dams and northwest of the pond at well 1071D (Figure 3-27). One well south of the ponds (1152D - 29 mg/L) and one along the southwest edge of the cutoff wall (EAP-515 – 133 mg/L) exceeded the BSL. Increases in concentrations of chloride were apparent in the SP-15 North area at wells 1069D, 1071D, and 1145D. Additional wells were installed between 2010 and 2015 to better define the area with indicator parameter concentrations exceeding BSLs. These additional wells provided data to allow more detailed contouring of the area. The additional data points give the impression that a larger area is affected by higher chloride concentrations. The actual size of the area with higher chloride concentrations may be a function of having more data points to contour rather than an actual increase in the size of the area. Note that groundwater capture is ongoing downgradient of this area at the Drain Pit #5 Interception Trench. The geology in this area lends itself to downward movement of waters through the stratigraphic intervals as a result of erosion of the upper intervals. For example, the Rosebud Coal has burned in most of this area and has been removed by erosion. This causes the groundwater to percolate downward into the thin interburden and McKay Coal. However, the interburden and McKay Coal have been altered by erosion and areas near the sub-crop or outcrops have weathered resulting in downward flow of groundwater to more readily occur. The major portion of the water in these intervals is being captured as suggested by the lower chloride concentrations to the northwest of the North SP-15 Trench.

Bromide

Bromide concentrations in 3&4 EHP pond water have ranged from 11 to 1940 mg/L. It was incorporated in 2010 as an additive at the Plant to remove mercury from flue gas, is also analyzed in water samples as a possible indicator parameter of more recent process pond water. Note, however, that bromide is also a constituent in anti-scaling chemicals that have been used in the cooling towers for some time. Also of note, is the fact that bromide was present in the 3&4 EHP Clearwell at a concentration of 11 mg/L in a sample collected in 2002. For this reason, evaluation of bromide in groundwater around the 3&4 EHP must consider the previous presence of the low concentrations since higher levels are likely associated with use of the chemical as an additive.

BSLs could only be calculated for the sub-McKay interval due to the variability in detection limits. The sub-McKay BSL is 5 mg/L. BSLs presented based on non-detect values were: 5 mg/L for the alluvium and 10 mg/L for the spoil and coal related units. Baseline concentrations were not clearly defined due to problems with analytical detection limits at the laboratory during baseline data collection. Bromide iso-concentrations for data collected in fall 2010 and fall 2015 are presented on Figures 3-29 through 3-34. Data for the fall 2015 are discussed briefly below. The 2010 maps are included for reference purposes.

Areas and wells with bromide concentrations exceeding BSLs were as follows:

- Alluvium – Capture wells 604A, 605A-2, and 1084A and monitoring well 582A, located directly downgradient of the 3&4 Main Dam Sump and upgradient of the lower interception trench had bromide concentrations above the BSL of 5 mg/L. No other alluvial wells exceeding the BSL.
- Rosebud Clinker – Bromide concentrations exceeded 10 mg/L at or near capture wells located adjacent to the northwest corner of the pond, at well 1002R, and at well 1120C, which recently had capture installed nearby.
- McKay Coal – No McKay wells had bromide concentrations exceeding 10 mg/L.

- Sub-McKay – Several capture wells immediately north of the Main Dam and one below the Saddle Dam (648D) had concentrations of bromide above the BSL of 5 mg/L. One monitoring well 1071D, located northwest of the pond had a value of 6.2 mg/L bromide. No other sub-McKay wells had concentrations near the BSL.

3.3.3 Groundwater Flow

Figures 3-35 and 3-36 are potentiometric maps of the alluvium and shallow bedrock (including Rosebud coal interval) monitored in areas near the 3&4 EHP; constructed using water levels measured in the fall of 2015 and 2010, respectively. Alluvial groundwater in Cow Creek and SFCC flows eastward or downstream towards Rosebud Creek. Very little groundwater is present in the alluvium directly downstream of capture in SFCC. Well 1030A was completed in SFCC alluvium about one-half mile downgradient of capture. Water quality and yield does not appear to be impacted at well 1030A by upgradient capture. Alluvium in drainages that are tributary to Cow Creek, and have been impacted by pond water, have very little groundwater flow toward the creek, due to ongoing groundwater capture. Very little groundwater is present in the clinker. Groundwater flow in the Rosebud clinker or coal is generally away from the 3&4 EHP, but is locally influenced by groundwater capture systems near the south and west sides of the 3&4 EHP, where impacted water is being captured and pumped to the EHP. Similar to the Rosebud, groundwater flow direction in the McKay during fall 2015 (Figure 3-37) is away from the 3&4 EHP toward Cow Creek and SFCC. The McKay Coal is absent north of the 3&4 EHP and is found sparsely in the area east of the 3&4 EHP Saddle Dam and is typically either burned or partially burned. Similar groundwater flow patterns were present in the McKay Coal in the fall of 2010 (see Figure 3-38). Water level data used for construction of the potentiometric maps are in Table 3-4.

Figure 3-39 and Figure 3-40 are potentiometric maps of groundwater in the sub-McKay constructed using water levels measured in fall 2015 and 2010, respectively. Sub-McKay groundwater generally flows to the north and east. Depressions in the groundwater table are

present near capture wells, a result of groundwater removal. Flow patterns were similar between 2010 and 2015.

3.3.4 Vertical Gradients

Groundwater flows from areas of higher potentiometric head to those with lower potentiometric head. It is critical, however, to understand that significant or even minimal groundwater flow may not occur between hydrostratigraphic units even though there may be a relatively large differential in potentiometric head at wells completed in various strata at roughly the same location. In fact, a large differential head at paired wells completed in different strata usually indicates a poor hydraulic connection, which inhibits vertical flow. In fact, it is not uncommon in the Colstrip area to encounter completely dry intervals between hydrostratigraphic units, indicating there is no vertical flow existing at these locations. Vertical hydraulic gradients, like horizontal hydraulic gradients, should be calculated using hydraulic head data from monitoring wells or piezometers completed in the same hydrostratigraphic interval. Calculation from different intervals may be misleading due to heterogeneities that may exist between the two intervals measured. However, the head differential between two wells completed in different strata may provide an indication of the potential for vertical migration of groundwater.

Actual vertical flow between separate saturated units is controlled by the hydraulic conductivity of the individual units, the hydraulic conductivity of the intermediate unit, and the difference in head between the units. Units with very low hydraulic conductivity, such as claystone, shale, and clayey siltstone, for example, will have very little groundwater flow through them, regardless of the head differential. Note that head differentials in individual wells may be affected by completion intervals and/or method of completion.

When a well is completed with perforations positioned over multiple water bearing intervals, the water level in the well will equilibrate such that it is not representative of the hydraulic head in one specific unit. For example, if a saturated interval of higher hydraulic head is not sealed off from a targeted saturated interval of lower head, the well water level may rise to a level consistent with the upper unit and not the targeted lower unit. Conversely, if the lower

targeted interval has a higher hydraulic head than the incompletely sealed upper interval, groundwater (head) from the lower unit will dissipate into the upper unit. Either case may occur when an upper saturated interval is not identified during drilling due to its extremely low yield.

Well completion methods have changed substantially throughout the life of the Colstrip SES. Initially, wells were completed by either placing neoprene packers above the perforated interval or by covering the perforations with a filter material, commonly pea gravel. The annular space above the packer or gravel pack was typically covered with about two feet of bentonite pellets; and the remainder of the annulus was filled with cuttings. Improper placement of well filter material (gravel pack), bentonite, or other annular seal material (i.e. cuttings) during well completion could result in bridging and a subsequently poor seal. A poor seal could also occur if cuttings used in the annulus were primarily coarse-grained. Later wells were completed using neoprene packers with bentonite seals placed above them to the surface. Packer failure was the primary concern with this method of well completion, as failed packers could potentially result in unstable seals and downward groundwater flow through the annulus. Currently, wells are completed by placing a filter pack, generally silica sand, outside of the perforations, and then backfilling with bentonite (chips or slurry) to the ground surface. A solid seal forms once the bentonite has hydrated. Note too, however, that high sodium content water may affect the bonding strength of bentonite, potentially weakening a seal.

Figure 3-41 contains hydrographs for various paired or nested wells in the 3&4 EHP area. The hydrographs illustrate the potentiometric head in each well and head differentials between separate units. Observations for the hydrographs (Figure 3-41) are included under the following bullets. Groups of wells or well pairs were chosen that would demonstrate gradients in areas that have minimal effects from pumping of groundwater capture wells. Where pumping effects are present, their influence on vertical gradient is discussed. In general, hydraulic head in the 3&4 EHP area is highest in hydrostratigraphic intervals with the highest elevation head; and hydraulic head decreases with formation elevations.

- 593A and 594D; 607A and 608D (north of 3&4 EHP Main Dam) – These paired wells are completed in alluvium or shallow sub-McKay bedrock north of the 3&4 EHP Main Dam at the locations shown on Figure 3-35. Alluvial well 593A is paired with bedrock well 594D and alluvial well 607A is paired with bedrock well 608D. Head in each of these wells may be artificially influenced to some extent by groundwater capture at the 3&4 Main Dam Lower Interception Trench (a.k.a. 3&4 Main Dam Interception Trench) or nearby well 654A. Similarly, head in all four of the shallow wells appears to fluctuate by as much as five feet. Despite fluctuations and a greater degree of capture system influences, water levels are higher in the alluvial wells than in the paired bedrock wells. Based on the measured hydraulic heads and difference in depth of the intervals of completion, a downward hydraulic gradient of about 0.74 is present between wells 593A and 594D; and a downward hydraulic gradient of about 0.36 is present at paired wells 607A and 608D.
- 590I, 590M, 565D, and 566D (East of 3&4 EHP Saddle Dam) – This well battery includes a well completed in interburden between the Rosebud and McKay Coal intervals (590I), a well completed in the McKay Coal (590M), and two wells completed at various depths in sub-McKay bedrock (565D and 566D). Well 565D was converted to a groundwater capture well in 2013. Prior to that time, these wells were relatively uninfluenced by groundwater capture. Hydraulic head observed in each of these wells prior to capture well startup was used to evaluate vertical hydraulic gradients. Hydraulic head is highest in the interburden well and declines with depth in the McKay and sub-McKay wells. A weak downward vertical gradient of 0.07 exists between the interburden and McKay Coal at this well battery. The downward gradients calculated between well 590M and bedrock wells 565D and 566D are 0.16 and 0.24, respectively. The downward vertical gradients between McKay Coal and sub-McKay bedrock in this area are lower than those typically observed in the 3&4 EHP area, likely due to the minimal amount of low permeability units (siltstone) that separate the completion intervals.
- 591A and 595D (Cow Creek, north of 560A Area) – These paired alluvium (591A) and bedrock (595D) wells are located in the Cow Creek drainage north of the area

known as the 560A Area. The head differential at this location is consistent with that observed elsewhere in the 3&4 EHP area and suggests a downward vertical gradient. However, the large thickness of separation between the alluvium and bedrock horizons, coupled with the presence of several low permeability intervals (i.e. siltstone and/or claystone), suggests that little or no hydraulic connection may be present between these wells. The approximate hydraulic head differential between 591A and 595D is 85 feet. The vertical distance of separation between total well depths at 591A and 595D is 180 feet. Assuming a hydraulic connection exists, the downward vertical gradient would be 0.47.

- 600M and 577D (Southeast of 3&4 EHP) – Hydraulic head in McKay well 600M is typically about 40 feet greater than in sub-McKay well 577D; and the vertical basal elevation difference of the units of completion is approximately 65 feet. The downward vertical gradient of 0.63 is typical of the gradient between McKay Coal and sub-McKay bedrock in the 3&4 EHP area.

- 1005R, 1004M, and 1008D (south of 3&4 EHP) – This well battery includes 1005R in the Rosebud Coal, 1004M in the McKay Coal, and 1008D in sub-McKay bedrock. These wells are outside of the 3&4 EHP concrete cutoff wall in a general area where the Rosebud clinker has been heavily targeted for groundwater capture. However, groundwater capture has not been initiated at this specific battery because it is at a structural high point that limits saturated water column thickness and well yield. In recent years, water levels at the McKay well (1004M) have declined; while the water level in the Rosebud well (1005R) has remained relatively stable. The declining water levels in 1004M are likely attributable to the decline in stored water inside the 3&4 EHP cutoff wall and reductions in seepage from the 3&4 EHP. The stable water level in 1005R indicates little or no connection to water on the inboard side of the cutoff wall. Nonetheless, an upward vertical gradient of 0.21 was calculated between the McKay and Rosebud Coal interval based on paired hydraulic head observations made in January 2009. Based on the most recent observations (October 2015), the vertical gradient between the Rosebud and McKay coals has shifted to a downward gradient of 0.13. Prior to pumping from the Rosebud interval in 2005 and currently,

the vertical gradient between the McKay Coal and the sub-McKay is approximately 0.76 downward. A downward gradient of about 0.06 was present between these units during groundwater capture in the Rosebud interval.

- WR-128, WI-109, WM-126, and 659D (west/northwest of 3&4 EHP) – This battery includes wells in the Rosebud Coal (WR-128), interburden (WI-109), McKay Coal (WM-126), and sub-McKay bedrock (659D). Hydraulic head in the Rosebud Coal interval in this area may be artificially influenced by multiple groundwater capture wells (e.g. 656R, 1031R, and 1037R). As such, it is common for a single pair of synoptic water level observations made at wells WR-128 and WI-109 to result in an upward vertical hydraulic gradient. In fact, the hydraulic gradient based on average water level observations presented in Figure 3-41 is 0.04 (upward). However, individual observations made in the Rosebud well (WR-128) may be as much as one foot greater than the paired interburden well. In the absence of nearby capture wells, it is likely that the vertical gradient would be predominately downward. Hydraulic head in the Rosebud and interburden units is very similar; and the vertical difference between completion intervals is only approximately three feet. A downward vertical gradient of 0.26 is calculated, based on recent water level elevations, between wells WI-109 and WM-126. The vertical gradient between McKay well WM-126 and sub-McKay well 659D is 0.67 (downward).

- 1158M and 1154D (northwest of 3&4 EHP) – These paired McKay and bedrock wells were completed in fall of 2013. Influences of groundwater capture are minimal in this area. The typical head differential between the paired wells is approximately 38.4 feet; and the vertical difference in the base of completion intervals is about 50 feet. The result is a relatively steep downward vertical gradient of about 0.77.

- 658R, 657M, and 1163D (northwest of 3&4 EHP) – These wells are also located northwest of the 3&4 EHP. Paired McKay and Rosebud wells 657M and 658R were installed in 2003 and 2004, respectively. Monitoring well 657M was converted to a groundwater capture well in 2015; however, monitoring well 1163D was completed in sub-McKay bedrock prior to capture in fall of 2013. Water levels recorded prior to conversion of well 657M were used to evaluate vertical hydraulic gradients between

these three wells. The approximate downward vertical gradient between well 658R and 657M, prior to capture conversion is 0.36. The downward vertical gradient between the McKay Coal and sub-McKay bedrock is 0.76.

Vertical gradients in the majority of the 3&4 EHP area are downward. The amount of downward flow, however, is mostly dictated by the stratigraphy and secondary porosity. Areas that have a weak downward gradient may have more vertical flow if the permeability is high enough to allow downward flow. For example, more downward flow will occur in areas where alluvium is in contact with fine-grained sandstone than where alluvium overlies shale. By contrast, strong downward gradients occur when water levels in shallow units are much higher than those in the deeper units. This difference is present because the hydraulic conductivity of the strata between the hydrostratigraphic units is low. The low hydraulic conductivity of these layers restricts downward flow. This is commonly the case between the base of the McKay Coal and the Sub-McKay.

3.3.5 Simplified Conceptual Groundwater Model

A detailed conceptual model for the 3&4 EHP area is included in the groundwater model report in Appendix A. The conceptual model in the groundwater model report contains graphics that allow the reader to better visualize the hydrogeological system in the area. A summary of a simple conceptual model is presented below.

Colstrip is located in Rosebud County in the northern portion of the Powder River Basin. Surficial geology is dominated by the Fort Union Formation, which dips at less than two degrees to the east, and unconsolidated sediments which occur in valley bottoms as unconsolidated alluvium and along hillslopes as colluvium.

The Fort Union Formation is comprised of an upper Tongue River Member, middle Lebo Shale, and lower Tullock Member. The 3&4 EHP are underlain by the Tongue River Member. The Tongue River Member of the Fort Union contains numerous coal seams. The Rosebud is the coal seam of economic interest in the 3&4 EHP area. The Rosebud Coal has been removed by mining south of the ponds in the headwaters of SFCC, east of the ponds in

the head waters of Cow Creek and tributaries which enter from the south. The Rosebud Coal is also being mined about 2 to 3 miles northwest of the ponds in the headwaters of Cow Creek and Pony Creek. Figures 3-1 through 3-3 illustrate the shallow geology at the 3&4 EHP.

The 3&4 EHP is situated on a divide between Cow Creek and SFCC. As such, this area provides recharge area for any water entering the clinker and to some degree deeper units.

Surface water in drainages that drain the area around the ponds are tributary to Cow Creek to the north, west and east of the ponds and SFCC to the south. Groundwater flow in the alluvium is in a downstream direction under a gradient similar to the topography, except where flow is interrupted by capture systems. Groundwater is withdrawn from the alluvium by capture wells and interception trenches in several of the drainages before reaching Cow Creek. In SFCC, groundwater is removed by capture wells installed on Talen property. Alluvial groundwater in Cow Creek and SFCC flows along the trends of the valley to their confluence. Below the confluence alluvial groundwater flows eastward in the Cow Creek alluvium to the confluence with Rosebud Creek (Figure 3-42).

Clinker, resulting from in situ burning of the Rosebud and in some places the McKay Coal, is extensive in the 3&4 EHP. It is commonly present on the tops of hills and is eroded away at elevations below about 3,230 feet mean sea level (msl), although the elevation varies depending on location and the local strike and dip. The clinker is well drained. As a result, groundwater is rarely found in useable quantities in the vicinity of the pond.

Groundwater at the site is present in alluvium and shallow bedrock, which may include Rosebud Coal in limited areas, Rosebud-McKay interburden, McKay Coal, and sub-McKay. Shallow groundwater found in alluvium is unconfined in the 3&4 EHP (Figure 3-42).

The Rosebud Coal is burned in most of the 3&4 EHP area. As such, clinker occupies the majority of the Rosebud Coal stratigraphic interval. The degree of burning varies from complete, in which case only ash remains at the base of the interval, to just a few feet. The

coal is very soft in areas where incomplete burning occurred. The most prominent areas of partially burned Rosebud Coal are directly south of the 3&4 EHP at well 1005R, where about 12 feet of unburned coal remains and northwest of the pond at well 1162R. There are three small areas where there are full unburned sections of Rosebud Coal; southwest of the 3&4 EHP at well 1010R, at the northwest corner of the pond at well 659D, and northeast of the pond at well 621D. Clinker is in lateral contact with the coal in all of these areas.

Groundwater is rarely present in the clinker. Groundwater that is present near the 3&4 EHP is residual from flow through, or under, the southern and northwest portions of the cutoff wall. A structural low exists along the southwest edge of the cutoff wall near capture well 1002R. The base of the clinker (old Rosebud Coal lower contact) appears to be in a structural low. Water in the Rosebud flows northward from wells 1013R, 676R and 586R since the base of the interval is higher at these wells than at capture well 1002R. Groundwater flow is also controlled by capture systems southwest and along the northwest edge of the pond (Figure 3-35). Groundwater flow in the alluvium and Rosebud interval for fall 2010 is illustrated on Figure 3-36.

Groundwater is found in the McKay Coal, which is present in full sections around the south, southwest, and southeast portions of the pond. The McKay Coal is absent, or been burned directly north of the pond and in the northeast area of the pond at wells 555M, 632M, and 633M. The coal dips to the southeast causing elevations of the base of the coal to vary from about 3,217 feet along the southwest side of the ponds to about 3,187 feet at well 1023AM. The coal, or remnants of the coal, subcrop at various places around the pond. To the northeast, the coal subcrops along the hills. The coal subcrops just west of the northwest corner of the pond upstream of the North SP-15 Trench, where groundwater from the coal flows to the alluvium. To the south, the coal subcrops into the alluvium in the vicinity of well 1019AM. Groundwater flows from the coal to the SFCC alluvium in this area. Groundwater is under confined conditions directly south of the pond but becomes unconfined near outcrops. Groundwater flow directions in the McKay Coal for fall 2015 and 2010 are shown in Figures 3-37 and 3-38.

Groundwater is present in the sub-McKay in channel sandstones. As mentioned in Section 3.3.1, the Fort Union Formation was deposited in channelized floodplains in a fluvial system of meandering, anastomosed and braided streams. This deposition resulted in a highly variable hydrogeologic setting with lateral facies changes. Water is contained in sandstone and siltstone of the sub-McKay. Where found, groundwater is typically under confined conditions. Groundwater flows generally north, northeast, and eastward. A hydrologic divide in the sub-McKay is evident southwest of the 3&4 EHP (Figure 3-39). Groundwater flow in the sub-McKay for fall 2010 is shown on Figure 3-40.

Hydraulic conductivity is variable in all hydrostratigraphic units of the 3&4 EHP as follows:

AQUIFER PROPERTIES FROM UNITS 3 AND 4 EHP AREA

Hydro-Stratigraphic Unit	Geometric Mean Transmissivity (feet^2/day)	Geometric Mean Hydraulic Conductivity (feet/day)	Minimum Hydraulic Conductivity (feet/day)	Maximum Hydraulic Conductivity (feet/day)	Geometric Mean Saturated Thickness (feet)	Geometric Mean Storativity
Alluvium	226	33	0.1	1,529	6.8	0.018
Rosebud/Clinker	8,379	1,207	55	10,720	6.9	0.047
McKay	7.1	0.9	0.0002	301	7.7	0.051
Sub-McKay	26	2.1	0.03	340	13.3	0.013

AQUIFER PROPERTIES FROM STUDIES[1] OF THE FORT UNION FORMATION

Hydro-Stratigraphic Unit	Transmissivity (feet^2/day)	Hydraulic Conductivity Range (feet/day)	Storage Coefficient
Alluvium[3]	1,900	0.00007 – 492	--
Rosebud	1.3 – 1,700	0.1 – 68	--
McKay	0.7 – 31	0.01 – 3.1	--
Sub-McKay[2]	0.7 – 31	0.01 – 3.1	--

N/A – not applicable
"--" – no data available.
1 – Rehm et al. (1980), Van Voast and Reiten (1988), and Van Voast et al. (1977).
2 - Assumes same values as McKay Hydrostratigraphic Unit.
3. – Quaternary alluvium – where present overlies Fort Union.

Variability in the hydraulic conductivity between hydrostratigraphic units in the 3&4 EHP area is a function of depositional environment, weathering, and degree and connectivity of secondary porosity, and the degree of cementation.

- Hydraulic conductivity of bedrock units (overburden, coal, interburden, sub-McKay) are influenced by lateral facies and the geometry of the deposits. Higher ranges in

hydraulic conductivity may have some fracture flow associated with it. However, most of the fractures in the area seem to have limited extent.

- Bedrock, other than coal, units typically show some degree of cementation. Areas or intervals with more complete cementation typically exhibit lower hydraulic conductivity.
- Hydraulic conductivity of the coal units is mainly dependent on presence or absence of cleating, degree of interconnectivity of the cleats, and weathering.
- The hydraulic conductivity of clinker varies by several orders of magnitude, but is typically higher than other water bearing units in the area. Recall that clinker forms as coal seams burn, thermally altering the overburden strata. The rock breaks into smaller rigid fragments as it collapses into the void. Very high hydraulic conductivity results when voids fill with highly angular fragments which creates large pores spaces with good connectivity. Lower hydraulic conductivities may be present, however, near the base of the clinker if water is contained in remaining unburned coal or ash.
- Hydraulic conductivity of the alluvium is dependent on the degree of sorting and overall grain size. Deposits with lower percentages of fines exhibit higher hydraulic conductivity.

Groundwater quality is variable and is discussed in Sections 3.3.2 and 3.5. Mitigation measures have been implemented in areas showing groundwater impacts. A portion of this includes groundwater removal using pumping wells. The pumping creates areas of local depressions (cones of depression). Other mitigation actions include pond reconstruction, lining, and improved water management practices.

Groundwater recharge in the area comes from precipitation, which averages about 15 inches per year. Recharge also occurs through pond seepage, estimated at about 181 (NewFields, 2017) to 243 gpm, some of which is precipitation water. Variations in the pond seepage estimates are reasonable for such calculations and computer simulations considering the variations in the hydraulic conductivity for various units, and the anisotropic and heterogeneous conditions that exist as the result of the depositional environment of the Fort Union formation. The range in estimates provide a good benchmark when evaluating the

reduction in seepage that may occur with various mitigation measures, particularly installation of double lined cells and depositional methods of ash.

Groundwater issues to the surface downstream of the facility in the lower Cow Creek where intermittent and occasional perennial flow occurs. Flow from bedrock into the alluvium may occur at places where erosion has caused direct contact between the two units. Discharge of groundwater also occurs through evaporation and removal by monitoring, capture or water supply wells.

3.3.6 Surface Water Quality

Surface water in the 3&4 EHP area is very limited, and consists of process ponds, stormwater containment ponds and overland flow in tributaries and drainages. Very rarely is surface water flow present in Cow Creek or SFCC, the main drainages in the 3&4 EHP area. When surface water flow does occur it is typically in the form of snowmelt or storm runoff, or residual from such events. The ephemeral nature of all the drainages in the 3&4 EHP area result in highly variable water quality that is very dependent on the conditions at, and prior to, the sampling event. For example, water quality is expected to be very good if water samples are collected under snowmelt conditions and flow is occurring over flowing frozen ground. Conversely, water quality may be very poor if water in the channel has been affected by evaporation or the overland flow has followed a period of heat and dry conditions that resulted in accumulation of soluble salts in the channel.

Surface water monitoring is conducted at sites along Cow Creek (CC2 – CC7) – see Figure 3-4. Sites CC3 and CC4 were sampled in spring and fall of 2015. All other sites were dry during monitoring events in 2015 and have typically been dry for the past 10 years (Hydrometrics, 2016). Water quality was within historical ranges observed at CC3 and CC4. Water quality graphs for CC3 and CC4 are at the end of Appendix E. The following table compares 2015 water quality data for indicator parameters at these sites to the previous ten years data in the following table. Note that the surface water BSLs provided in the table were calculated based on water quality derived from East Fork Armells Creek and are not applicable to the 3&4 EHP area due to the differences in surface water flow characteristics.

April 2015 Cow Creek Water Quality Compared to Previous 10 Years

	04/10/15	Min	Max	Ave	Surface Water BSL(1)
CC3					
Spec. Cond. Lab (µmhos/cm)	3470	2050	5810	3731	5,570(2)
Chloride (mg/L)	21	4	84	20	228
Sulfate (mg/L)	2130	1120	4100	2289	2,260
Boron (mg/L)	0.7	0.6	2.8	1.2	0.88
CC4					
Spec. Cond. Lab (µmhos/cm)	3420	2530	4730	3303	5,570(2)
Chloride (mg/L)	20	2	37	17	228
Sulfate (mg/L)	2010	3780	2980	1866	2,260
Boron (mg/L)	1.1	0.9	2.3	1.4	0.88

(1) Surface water BSL, Neptune 2016. Note: BSL's calculated on water from East Fork Armells Creek and are not applicable to ephemeral waters such as Cow Creek and South Fork Cow Creek.

(2) 90th percentile – no BSL assigned to surface water

3.4 DESCRIPTION OF COMPLETED AND ONGOING REMEDIAL ACTIONS

Talen conducts extensive activities associated with groundwater in the 3&4 EHP area. These activities include routine operational groundwater monitoring, mitigation measures, specific groundwater or surface water investigation, operational changes, and best management practices. Mitigation and/or specific investigations are conducted in response to changes detected through operational water quality monitoring indicating process pond seepage, and/or in response to past spills or releases. A summary of investigations conducted in 3&4 EHP area is contained in Table 3-2. Monitoring, mitigation measures, and best management practices (BMP's) are discussed in the following sections. The combination of the activities described below are based on current site conditions, and current or planned future activities that will be conducted to further improve groundwater conditions in the vicinity of the 3&4 EHP.

3.4.1 Operational Monitoring

Talen conducts operational groundwater monitoring in and around the 3&4 EHP at a network of monitoring and capture wells. The monitoring program is outlined in the Water Resources Monitoring Plan (Appendix G). The WRMP includes lists of monitoring wells, monitoring

frequency for ponds and wells, analytical parameters, and evaluation and reporting criteria. In 2015, water quality samples were collected from 349 monitoring sites during the first half of the year and 278 monitoring sites during the last half of the year. These sites included monitoring wells, groundwater capture wells and trenches, one spring (SP-14), surface water in Cow Creek, 3&4 EHP cells, dam drain sumps, Drain Pit #3 and Drain Pit #5 and selected ponds. An updated summary of groundwater monitoring sites and analytical parameter lists are in the WRMP (Talen, December 2015).

Well samples are most commonly analyzed for parameters which include SC, pH, TDS, total alkalinity as $CaCO_3$, bicarbonate, bromide, carbonate as CO_3, chloride, sulfate, and dissolved metals (boron, calcium, magnesium, potassium, selenium, and sodium), and ionic balance. Mercury is analyzed at a few select sites. Nitrate plus nitrite is also typically analyzed in newly installed wells. As described in Section 3.3.2, a set of indicator parameters (SC, boron, sulfate, chloride and the ratio of magnesium to calcium) are used as the main evaluation tool for changes in water quality. These parameters are concentrated in various process water and are relatively mobile. It is not necessary to evaluate other parameters to identify process water impacts since increases in the other parameters will not occur without an increase in the indicator parameter concentrations. However, the additional parameter concentrations are considered when evaluating water quality changes and will be used for risk assessment purposes.

Talen samples water from cells within the 3&4 EHP typically at least once every three years. Pond water samples have also been collected and analyzed for a more extensive list of parameters than that indicated in the WRMP. In 2015, pond water quality samples were collected from the 3&4 EHP C Cell and the New Clearwell. In addition, samples were collected from the 3&4 EHP Main Dam Sump and the Saddle Dam Sump. Data are included in Table 2-2.

The WRMP includes six surface water sites on Cow Creek (CC-2 through CC-7) and two on SFCC (SFCC2 and SFCC3). If water is present, a sample for water quality is collected; only CC-3 and CC-4 sites had water present in 2015. Surface water samples from Cow Creek

were analyzed for pH, SC, TDS, alkalinity as $CaCO_3$, sulfate, chloride, bromide, bicarbonate as $CaCO_3$, carbonate as CO_3, total boron, calcium, magnesium, potassium, selenium, and sodium (see Section 3.3.5).

All water quality samples are submitted to a certified commercial laboratory for analysis. Results of the analyses are validated through a quality control/quality assurance process and maintained in a project database. These validated data are provided to the MDEQ on an annual basis, following completion of the validation.

Results of operational monitoring for the previous years are summarized in annual hydrologic monitoring reports (see References, Section 7). These reports are typically issued in late spring/early summer of each year. Reports are submitted to the MDEQ for review. Upon review, MDEQ and Talen meet to discuss the findings of the monitoring program and to discuss activities that can be conducted to further evaluate a particular condition or to mitigate a condition if it is interpreted to be related to the 3&4 EHP process water operations.

Talen Environmental Compliance Department personnel review data on a routine basis. Additional evaluation is conducted in areas showing changes in water quality. In addition to investigations conducted in response to water quality variations, Talen also responds to operational occurrences which could potentially result in environmental impacts. Such events could include observations such as apparently affected vegetation, water issuing to ground surface in areas not previously observed, increases in water levels in wells that may or may not be accompanied by water quality changes, pipeline breaks, problems with drain pits such as overfilling, and other miscellaneous events.

Operational monitoring results are evaluated to identify changes in the groundwater system. Changes which are attributed to process ponds are further evaluated through continued monitoring, site investigation, implementation of mitigation activities, changing of normal processes, or a combination of the previous.

3.4.1.1 Water Level Measurements

Water levels in monitoring wells are typically measured either monthly, quarterly, semi-annually or every three years. Monitoring frequency depends on the density of wells in an area, previous observations in the area indicating wide variations in water levels, and relation to area capture wells. Talen measures water levels at most non-capture system monitoring wells on a monthly basis (see Section 3.4.1.2 for Capture System Monitoring). At a minimum, the wells listed in the WRMP (Talen, 2015) are measured. Water levels are measured in newly installed wells and evaluated for inclusion in the WRMP during periodic updates. Water levels are measured more frequently in connection with particular site activities, such as capture system startup or in conjunction with specific groundwater investigations.

Water levels are measured using electronic probes with calibrated tapes. The probes are lowered into the well until electrical contacts encounter water which activates an audible signal and an indicator light. The probe is moved up and down until the surface of the water is accurately located. The tape is then placed against a measuring point and the depth to water below the measuring point is recorded in a field book. The elevation of the groundwater for the well is then calculated by subtracting the measured depth to water from the surveyed measuring point elevation.

3.4.1.2 Capture System Monitoring

Capture wells are routinely monitored at least twice per month for operation, water levels, and pumping rate. Water levels in capture wells are measured to evaluate groundwater capture system performance and to identify adjustments to pumping rates, if necessary. Field SC is measured monthly. In addition, water quality samples are collected and submitted for laboratory analysis twice a year. Samples submitted for laboratory analysis are analyzed for Talen's standard list of analytes (Table 2 of the WRMP (Talen, 2015)).

In addition to informing operational changes, monitoring data collected at capture wells is reviewed to identify capture wells that could be shut down. Capture wells may be shut down

if: water quality improves to conditions that were observed prior to conversion for capture and it is concluded that process water impacts are no longer occurring; if water quality improves to below calculated BSLs, or; if water levels and yield drop in the area so capture from a specific well becomes impossible or impractical. Any capture wells that are shut down continue to be monitored for SC on a routine basis (monthly minimum) and sampled for laboratory analysis twice a year. Pumping at a given capture well or wells is re-initiated if water quality improvements are not sustained under shut down (static) conditions.

3.4.2 Groundwater Mitigation Activities

Groundwater mitigation in the 3&4 EHP area is conducted when/where process water impacts are interpreted through review of groundwater monitoring data. Mitigation activities include capturing potentially impacted groundwater and routing it to the 3&4 EHP, source reduction by paste deposition and pond lining, implementation of BMPs to reduce water inventory, and revegetation. Groundwater capture/containment is conducted at 91 sites in the 3&4 EHP area. Of these 91 sites, 78 are capture wells, eleven are interception trenches and two are dam sumps. A list of groundwater capture locations in the 3&4 EHP area and their respective dates of startup are listed in Table 3-5.

Locations of groundwater capture wells, trenches, and sumps are shown on Figure 3-4. Capture systems in the 3&4 EHP area target groundwater in multiple hydrostratigraphic intervals including alluvium, Rosebud Coal (mostly remnants of burned coal and clinker formed by burning coal), shallow interburden bedrock, McKay Coal (only in SFCC where the coal is in direct contact with alluvium), and some sub-McKay bedrock (mostly north and east of the 3&4 EHP where the McKay Coal is absent). Groundwater capture locations are present on all sides of the 3&4 EHP; but it can be seen from Figure 3-4 that they are not evenly distributed.

Capture system sites tend to be clustered because preferential groundwater flow pathways limit dispersal of impacted groundwater. Talen aggressively pursues remediation of groundwater in impacted areas by installing dense capture well networks when appropriate.

Groundwater capture wells are routinely monitored for flow, hours operated, water level and SC. Capture system monitoring is conducted to document depth to water in pumping wells, approximate pumping rates, adjust and maximize drawdown in the wells, and to identify problems with well function. Maintenance requests are made when problems are discovered and the necessary repairs are made. Data collected from the capture systems are documented in a project field book and maintained in an electronic filing system.

Persistent scaling problems have made it necessary to operate the majority of Colstrip SES groundwater capture systems without flow meters. Instead, pumping rates are measured through a sampling port at the wellhead of each capture well. This method may result in an overestimation of actual pumping rates in pressurized systems since discharge from the sample port is to atmospheric pressure conditions but actual pipeline pressures vary depending on scaling within the pipe, flow through the pipe, pipe size, pipeline length, hydraulic head differences between the sample port and end of line discharge point, and additional head attributed to operating parallel capture systems. For example, where a combined flow of all parallel capture systems was measured by instrumentation at the Saddle Dam Sump and compared to the sum of rates measured at individual wells, the rate measured at the sump was half of the sum of the individual pumping rates. However, there are contributions to the amount of water pumped at the sump that are not routinely gaged, such as the Saddle Dam Valley Drain Trench. Flow from this trench enters the Valley Drain Trench and flows to the sump. Based on the observed differences, and professional judgement, a correction factor for pumping rates of 0.75 was estimated.

Because pumping rates measured at individual wells are known to overestimate the actual capture rates, measured rates are multiplied by a factor of 0.75 to estimate the final capture rates. By applying the correction factor, the total calculated average rate of water collected at all capture systems in the 3&4 EHP area during 2015 was estimated at 241 gpm. Adjusted capture rates at individual wells are shown in Table 3-5.

3.4.3 Completed Units 3&4 EHP Mitigation Measures

Mitigation measures are actions, plans, or procedures that are intended or designed to eliminate, prevent, or reduce adverse effects of a process or situation. A mitigation measure may be implemented prior to an action, such as designing a lined impoundment to reduce potential seepage. Mitigation measures may also be implemented after an adverse situation has been discovered, such as pumping and treating affected groundwater.

Several activities have been conducted at the 3&4 EHP to assist with groundwater remediation and limit or contain impacts. Each of these activities and their potential influence on the groundwater system, and associated remedial activities are described hereafter. The list is not all encompassing of mitigation measures that have or will be conducted at the 3&4 EHP. The operators of the facility have conducted mitigation measures from the construction period through current operations to reduce potential impacts to water resources. These mitigation measures, which are beyond the scope of this report, include initial pond designs (cutoff wall, clay lining, and underdrain), pond construction methods, materials used in pond construction, piping design, upgrade, and maintenance, education of employees, refining the process water circuits which enabled certain ponds or processes to be closed, and numerous other actions. Additional mitigation measures will be developed during remedial evaluations and as closure and further operational plans are developed.

- Paste Plant - A paste plant was installed at the 3&4 EHP and began operating in late 2004. The paste process reduces the available free water by about 90% when compared to the direct flyash scrubber slurry disposal previously used at the 3&4 EHP. Paste technology along with forced evaporation and water management practices helps reduce the amount of water that is stored in the cells. In 2015, the excess water inventory at the 3&4 EHP was reduced by an estimated 64 million gallons. Since 2006, excess water inventory at the entire Colstrip SES has been reduced by 1.71 billion gallons. Reduction in the amount of water in the cells reduces the hydraulic head on the liners and consequently reduces the amount of potential seepage. The reduced head will lower the potential for liner failure and also would act to reduce losses if liner failures occur.

- Paste Deposition – The paste process indirectly mitigates process water impacts because paste deposition is more effective than the previous deposition of fly ash as scrubber slurry. The paste process allows for preferential deposition of CCR materials; whereas, the previous slurry materials could only be deposited diffusively. In exterior cells, paste was placed from the outer edges towards C Cell, causing free water to be moved away from the exterior of the pond. This created longer flow paths that will result in lower potential seepage rates. Paste was placed in interior C Cell over areas where clinker was exposed, or thought to be exposed in the cell, to reduce short circuiting from the cell and lower the permeability of the cell walls. Paste is currently being placed around the perimeter of the C Cell and a "sump" has been constructed by placing a dike within the cell. Free water from the paste flows through the dike and is pumped from the sump to lower water levels in the cell. This method of paste deposition used in conjunction with other water management practices has greatly reduced the amount of water in the pond. Currently, the vast majority of water in the 3&4 EHP is maintained in lined B, F, and H Cells, with a relatively small volume managed in C Cell.
- Forced Evaporation – The forced evaporation system is operated when environmental conditions are favorable (warm to hot temperatures and low wind). Enhanced evaporation reduces the amount of process water that must be contained in the cells.
- Geo-synthetic Pond Liners - F Cell, B Cell, and H Cell have been lined with geo-synthetic liners. These types of liners reduce the amount of water that enters the clinker adjacent to the cutoff wall and underlying bedrock, which subsequently reduces the amount of water that will seep from the pond.
- Management of water levels in G Cell – Water levels were maintained below a critical level following the discovery of leakage outboard of the Saddle Dam. The water level in G Cell is typically held below an elevation of 3,232 feet msl to prevent leakage under or through the cutoff wall to occur again. More recently, G Cell has been dewatered.
- Clearwell Relocation – The Clearwell was moved from its original location (Old Clearwell) against the 3&4 EHP Main Dam into lined B Cell (New Clearwell) and the Old Clearwell was dewatered. Dewatering the Old Clearwell reduced head against

the Main Dam and strata directly underlying the dam. The reduced hydraulic head reduces the groundwater flux from the pond. The liner of the New Clearwell has a much lower permeability than the Old Clearwell reducing the amount of seepage through the bottom of the cell.

- Water Reuse – Much of the groundwater collected by capture wells is routed to a vibratory shear enhanced processing (VSEP) reverse osmosis water treatment plant. The treated water is used in various facility processes reducing the amount of water that is routed directly to the ponds and in effect reducing the volume of water in the pond.
- Pipeline Replacement – The original scrubber slurry and clear water return pipelines were replaced with high-density polyethylene pipe. The HDPE results in fewer pipeline releases of either scrubber slurry or return water.
- Drain Pit Liners – Drain Pits 3 and 5 were drained and lined using synthetic materials. The synthetic liner has a lower permeability than the previous pond bottom, reducing seepage through the pond when water is present.
- Groundwater Capture Systems - Numerous wells have been converted or installed to capture groundwater that is interpreted to be impacted by process water. Groundwater interception trenches have been installed in shallow alluvial channels. The systems serve to intercept impacted groundwater thus limiting downgradient impacts (see Sections 3.4.2 and 3.5).
- Stock Water Well Recompletion – The casing in well PSW-1 was removed and the well was recompleted following observed water quality changes. Upon removal of the casing it was observed that holes had been drilled in each section to lift the string. These holes allowed shallow water to enter the well and change the water quality in the well. The well was pumped following the recompletion until water quality returned to its original character.

3.4.4 Planned Mitigation Measures – Units 3&4 EHP

Talen continues to improve best management practices, training, and facility upgrades to improve environmental conditions in 3&4 EHP area. The combination of these activities will assist in groundwater mitigation efforts and reduce the chance of creating new problems in

the future. Some of the activities that are planned, are being considered, or will continue in the future include the following.

- To reduce the volume of water that must be kept in ponds, groundwater from various groundwater capture systems is monitored for quality, treated, and routed to the various Plant water circuits. This approach takes captured groundwater out of the system inventory and will continue.
- New H Cell is double lined. The composite liner system incorporate two layers of synthetic liners; and a collection sump is situated between the liners and under both liners to collect water that possibly leaves the pond through liner breaches. Future cells (i.e. J1 Cell), when constructed, will incorporate a similar or more robust design. These ponds will be constructed to be in compliance with the Coal Combustion Residuals Rule (CCR Rule) that was promulgated in April 2015 (EPA, April 17, 2015).
- Future pond construction and paste management will be conducted in general accordance with details provided in the Remedy Evaluation Report. A Cell, B Cell, D Cell, E Cell, and G Cell are scheduled to be capped under the CCR Rule between 2017 and 2022. Following capping, new liners are scheduled to be installed in J Cell (J1 Cell), G Cell and a new clearwell is scheduled to be constructed. Paste and bottom ash is scheduled to be placed in C Cell in 2017 and 2018. Following capping G Cell and C Cell will be used for bottom ash and dry waste disposal. Paste will be placed in J1 Cell between 2017 and 2022. F and H Cell will be used to impound water, as necessary.
- Groundwater capture wells and trenches will continue to be operated into the foreseeable future. Pumping will be discontinued when water quality improves to levels acceptable to the MDEQ or in conjunction with alternative remedial approaches.
- Talen will continue to promptly respond to changes in water quality, spills, or other identified problems associated with the ponds, pipelines or pond operations. Responses typically include an internal evaluation and reporting to regulatory agencies, if required. Additional study and investigation is conducted if potential problems are identified and/or if regulatory agencies request more extensive

evaluation. Future investigation will be covered under guidelines of interim actions outlined in the AOC which include preparation of a work plan, regulatory review, conducting the investigation, evaluation, and reporting.

- Worker awareness training will continue so facilities operations can be conducted while reducing effects on the environment.
- Ecological and human health risk assessments will be conducted to evaluate potential exposure risk from the Units 3&4 EHP on potential receptors.
- A remedial alternatives evaluation will be performed to evaluate other potential methods of mitigating, eliminating, or managing impacts.

3.4.5 Best Management Practices

Best Management Practices (BMPs) is a term used to describe activities conducted to minimize or eliminate impacts to surface and groundwater. Talen implements multiple types of BMPs to reach this end. Many of the measures described in the previous sections are further examples of BMPs that are, or will be, implemented or used at the facility. Several other BMPs are described in the following paragraphs.

- Training and Education – Employees are educated as to the importance of water management and control at the facility. The goals of the training is to limit unnecessary uses of water, reduce the amount of water in the process circuit, and quickly respond when incidents occur to limits potential migration and to remove affected materials.
- Water management – Talen has made significant progress in reducing the amount of water at the facility. Reduction of the amount of water reduces hydraulic head and the amount of seepage that can occur. Methods used include forced evaporation and water reuse methods.
- Stormwater management – Site drainage control systems have been maintained to reduce flow of precipitation runoff onto the Colstrip SES pond system. Much of the 3&4 EHP area is at a higher elevation than the surrounding landscape, which limits the necessity for extensive run-on controls. However, run-on from any contributing area is controlled by berms and embankments around the 3&4 EHP. Dikes and ditches are also constructed within the 3&4 EHP to manage stormwater from direct

precipitation. Internal diversion ditches and dikes will remain in place and be continually maintained.

- Pond liner upgrades – As discussed previously, Talen is, has, or will be installing synthetically lined ponds with underdrain capture. Use of the liner/underdrain system reduces potential releases due to seepage through the liners if it occurs.
- Forced Evaporation – Forced evaporation is conducted during periods of relatively low winds and warmer temperatures. This methodology reduces wind drift and maximizes the effectiveness of the evaporation.
- Paste Plant – Scrubber slurry will continue to be dewatered using 3&4 EHP Paste Plant. Use of the paste plant makes reuse and handling of the process waters more efficient by reducing volume.
- Water Reuse – Efforts will be continued to reuse water to eliminate the amounts present in the ponds. This will include treatment of captured groundwater in various areas of the facility.

3.5 EFFECTIVENESS ASSESSMENT OF REMEDIAL ACTION

The effectiveness of the existing remedial measures should be evaluated in two ways. First, the effectiveness of existing source control measures such as pond liner upgrades can be evaluated based on trends in water quality for extraction wells and monitoring wells located downgradient of the pond source area. Second, the effectiveness of migration management measures such as hydraulic barriers produced by groundwater extraction wells farther downgradient can be evaluated using multiple lines of evidence. These lines of evidence include evaluation of hydraulic gradients that are induced toward capture wells and trends in water quality at monitoring and capture wells downgradient of the 3&4 EHP.

A description of hydraulic gradients and associated capture zones was presented previously in Section 3.3.3 of this report. Capture analysis is further discussed at length in the presentation of numerical modeling results in Appendix A; and a summary of the numerical capture analysis is included in Section 4.0.

The remainder of this section contains a discussion of trends in groundwater quality. Trends for the majority of wells discussed in this section are included in Appendix E. SC is used in this analysis as the primary indicator of water quality degradation by releases from the process wastewater system. SC is a function of the concentration and composition of dissolved electrolytes in a water sample and it is typically proportional to the concentration of dissolved major ion constituents (i.e. TDS). Depending on the concentration and strength of the dissolved electrolytes, TDS typically ranges from about two thirds to greater than one times the SC value. For example, a solution of dissolved sodium-chloride (a strong electrolyte) with a mass concentration of 5,000 mg/L at 20° C would have an SC of 8,200 µmhos/cm. In this case, the ratio of TDS to SC is 0.61. Contrarily, a solution of dissolved magnesium-sulfate (a weak electrolyte) with a mass concentration of 5,000 mg/L at 20° C would have an SC of 4,100 µmhos/cm. The ratio of SC to TDS in the magnesium-sulfate example is 1.22. For the process wastewater ponds at Colstrip, the major ions are sulfate and magnesium. These ions are highly mobile in groundwater and contribute substantially to the measured SC values. As such, sulfate concentrations, specifically reductions in sulfate concentrations, at capture and monitoring wells are discussed in relation to effectiveness of the ongoing remedial action. Finally, boron and chloride are other notable indicator parameters of process water impacts. The relative concentrations of these dissolved chemical constituents are typically at least an order of magnitude less than the concentration of TDS; thus, they do not contribute significantly to SC. However, declining concentrations of boron and chloride in wells near the 3&4 EHP are, in most cases, indicative of remedy effectiveness.

Talen evaluates capture system effectiveness by analyzing the potentiometric surface and water quality trends in monitoring and capture wells downgradient from and near the capture systems. Evaluation of indicator parameter trends provides additional lines of evidence of capture system effectiveness. In general, SC at monitoring and capture wells in the 3&4 EHP has shown improvement (decreased) compared to the highest observed SC previously measured at a given well. This improvement could result from the source control measures, migration management measures, or both.

The greatest reduction in SC (72 percent) was calculated at wells 696R and 1016R. Both of these wells are installed in Rosebud clinker near the perimeter of the 3&4 EHP. The highest SC measurement at well 696R was 14,900 µmhos/cm, compared to the most recent SC of 4,290 µmhos/cm (February 2015). Well 1016R was operated as a capture well from October 2005 to August 2006; during which time, the well all but dried up and water quality improved sharply (from SC 14,500 µmhos/cm to 6,930 µmhos/cm). To date, well 1016R is typically dry. The lower SC measurements and decreased occurrence of impacted water are attributable to significant source reduction including paste placement, pond lining, and water volume reduction.

As noted above, capture systems tend to be completed in groups or at least in common areas around the 3&4 EHP. Areas of grouped capture wells are reflected in Figures 3-42 through 3-44 as follows:

- Area 1 – North of the 3&4 EHP Main Dam;
- Area 2 – East of the 3&4 EHP Saddle Dam;
- Area 3 – 560A/1051A Area;
- Area 4 – South and Southwest of 3&4 EHP;
- Area 5 – South Fork Cow Creek (SFCC);
- Area 6 – West and Northwest of the 3&4 EHP;
- Area 7 – Drain Pit #5 Interception Trench Area; and
- Area 8 – Drain Pit #3 Interception Trench Area.

Flow arrows included in each of Figures 3-35, 3-37, and 3-39 illustrate the current approximate direction of groundwater flow in applicable hydrostratigraphic units of the 3&4 EHP area.

Effectiveness of remedial actions in each of the eight areas is discussed in the following sections. Boundaries of the areas identified on these figures are very loosely defined based on the general area that groundwater capture is occurring. The delineated areas include nearly all of the capture and monitoring wells surrounding the 3&4 EHP; but this does not imply that process water impacts are present at all wells. Graphs of SC, sulfate, boron, and

chloride trends for representative monitoring and capture wells in each of the eight areas near the 3&4 EHP are referenced in the following discussion. Dates associated with major pond operational changes and/or remedy implementation (including capture system startup dates) are included on the graphs, where applicable. Stiff diagrams, illustrating hydrochemistry of representative sites in each of the 3&4 EHP sub-areas are also used to evaluate remedy effectiveness. Specifically, the Stiff diagrams are used to identify changes in the hydrochemical character of groundwater around the 3&4 EHP in response to pond operations and/or subsequent mitigation actions. Stiff diagrams constructed of recent water quality data for multiple sites within a given area are indicative of the spatial distribution of potential process water impacts; while, Stiff diagrams constructed with data collected over time at a single site provide an indicator of the temporal trends in hydrochemistry.

3.5.1 Area 1 – North of the 3&4 EHP Main Dam

For the sake of the following discussion, this area includes all capture wells north of the 3&4 EHP. Capture systems in this area target the alluvium of the ephemeral drainage north of the 3&4 EHP Main Dam and/or impacted groundwater in bedrock below the bentonite amended concrete cutoff wall on the north edge of the ponds. The 3&4 EHP Main Dam Lower Interception Trench (a.k.a. 3&4 EHP Main Dam Interception Trench, or 3&4 EHP MDIT) was the first alluvial capture system in this area. This trench was supplemented by a drain trench that was installed in July 2001 directly upstream of the 3&4 EHP Main Dam Sump. Capture in the alluvium in this area is supplemented with three alluvial capture wells (604A, 605A-2, and 1084A) and modified well/Trench 654A. Most recently, a capture drain trench (552D-Trench) was installed parallel to the toe of the 3&4 EHP Main Dam in shallow bedrock directly beneath the alluvium. Several bedrock capture wells flank the 3&4 EHP Main Dam to the east and west. These include 552D, 613D, 618D, 619D, 644D, 645D, 1080D, 1081D, 1083D, 1087D, 1115D, 1128D, and 1129D.

Mitigation actions were started in this area at the Main Dam Sump in 1989 and are ongoing. A comparison of the most recent SC measurement (6,540 µmhos/cm on 8/14/2015) to the highest SC recorded at the 3&4 EHP Main Dam Lower Interception Trench (15,000 µmhos/cm on 11/21/2011) indicates a reduction in SC of 56 percent. Operation of the Main

Dam Lower Interception Trench, Main Dam Sump Interception Trench and other nearby capture wells has generally had a positive effect on water quality at downgradient monitoring wells (see 593A and 654A). Water quality trend plots for select monitoring and capture wells in the alluvium north of the 3&4 EHP Main Dam are presented in Figure 3-45. Stiff diagrams for representative capture and monitoring wells in bedrock or alluvium north of the 3&4 EHP Main Dam are shown in Figure 3-46.

A water quality trend plot for monitoring well 593A is included in Figure 3-45. Water quality at 593A and other alluvial monitoring wells north of the 3&4 EHP varies seasonally and with the operation of the Main Dam Sump. Specifically, values of process water indicator parameters (SC, sulfate, boron, and chloride) are lower in the spring than they are in the fall, as increased recharge in the spring provides a source of higher quality water to the shallow system. Recent (2015) increases in process water indicator parameters at well 593A and other alluvial capture wells in the drainage north of the 3&4 EHP Main Dam may be the result of lower than normal precipitation, down time at upgradient capture wells/systems, possible down time at the Main Dam Sump that would allow groundwater to flow past, or recent pulse of impacted groundwater from an unidentified pathway. Groundwater quality evaluation and mitigation are ongoing in this area.

Alluvial capture well 654A is located the farthest downgradient of all alluvial wells north of the 3&4 EHP Main Dam. Well 654A was constructed to maximize groundwater capture by installing a short trench across a portion of the alluvium. SC has decreased at well 654A from 5,760 µmhos/cm (9/29/2004) to 4,230 µmhos/cm (8/12/2015), a decrease of 26 percent. Water quality improvements and much lower SC at the downgradient well indicate effective capture is occurring despite seasonal and other temporal increases of process water indicator parameters upgradient (Figure 3-45).

Process water impacts in bedrock groundwater tend to be the greatest at wells nearest to the 3&4 EHP Main Dam and to the 3&4 EHP's northern boundary but decline through the bedrock capture well network and with increased distance from the 3&4 EHP. This trend can be seen in Stiff diagrams presented for multiple bedrock wells in Figure 3-46. Capture well

644D is located on the east abutment of the Main Dam. Well 644D recently had a peak SC measurement of 19,400 µmhos/cm (Figure 3-47). The higher SC levels at 644D are likely a function of higher concentrations in the upgradient cells resulting from a reduction in the amount of water in the pond and evaporative effects. Upgradient recharge to these wells is within the limits of the 3&4 EHP, making significant water quality improvement unlikely until final project remediation. Flow reduction through the unit can be accomplished, however, through water management practices that are currently being implemented (water volume reduction, pond lining, and paste placement around perimeter of cells and over exposed clinker). Well 644D was converted to a capture well in 2004. In the first years following its startup, average pumping from the well was 9.7 to 19.3 gpm. In the most recent three year period (2013 to 2015), the average pumping rate for this well ranged from 3.1 to 7.3 gpm. Possible causes for the reduction of flow at 644D are dewatering the Old Clearwell, G Cell, and most of C Cell, paste deposition in G Cell and future J Cell, and installation of a geomembrane liner in B Cell. Note, however, that pumping rates at well 645D, located on the west main dam abutment has had relatively constant pumping rates through this same time period. The difference in response to pond management may be a function of the amount of water held in the clinker in these areas and the communication of that interval with other parts of the pond.

Well 552D is a notable example of a monitoring well installed prior to construction of the 3&4 EHP with water quality that indicated process water impacts after operation of the ponds began. This low yield well (less than 1 gpm) has shown gradual improvements in water quality since the well was converted for capture. Capture well 618D, located west of well 552D, has also shown gradual improvement in quality since its conversion in November 2004. Additional water quality graphs for select bedrock capture wells near the northern boundary of the 3&4 EHP are included in Figure 3-47.

Water quality graphs for bedrock monitoring wells north of the 3&4 EHP Main Dam are presented in Figure 3-48. Bedrock wells farther downgradient, including those in the ephemeral drainage downgradient of the 3&4 EHP Main Dam, exhibit a lesser degree of process water impacts. Groundwater quality at monitoring well 602S showed a general

worsening trend from 1993 to 2009; but this trend slowed after capture began at wells 1080D, 1081D, 1083D and 1115D in 2010. Wells 594D and 603D exhibited a similar trend in water quality decline until the late 1990s, followed by an ongoing improving trend that coincided with startup of several capture wells (e.g. 552D, 604A, 613D, 605A-2, 616D, 618D, and 619D). More recently, groundwater at several bedrock and alluvial wells north of the 3&4 EHP Main Dam has shown increases in concentrations of process water indictor parameters (593A, 619D, 620D-P, 624D, 606A, 644D,1084A, 1118D, 1128D, WA-133) (Hydrometrics 2016). Groundwater capture in this area is currently under evaluation; and continued monitoring will be conducted in this area to provide an ongoing assessment of groundwater conditions and capture system effectiveness. Note that well 608D is located downgradient of all capture wells in the ephemeral drainage north of the 3&4 EHP Main Dam. Water quality at well 608D has been consistent since it was completed and has not indicated process water impacts.

3.5.2 Area 2 - East of 3&4 EHP Saddle Dam

Area 2, referred to as "East of the 3&4 EHP Saddle Dam", is delineated in Figures 3-42 through 3-44. In this assessment, the area east of the 3&4 EHP Saddle Dam includes all monitoring and capture wells installed between the dam crest and the 1073A-Trench in the east, capture well 565D in the south, and capture well 556D in the north. Groundwater capture locations east of the 3&4 EHP Saddle Dam include: the Saddle Dam Interception Trench; alluvial capture wells 1039A and 1073A Trench; and bedrock wells 556D, 565D, 609D-2, 610D, 621D, 646D, 647D, and 648D. Conversion of monitoring wells 1120C and 1169R to groundwater capture wells is ongoing at the time of this report. The new capture wells will be the first completed in the Rosebud Coal clinker interval on the east side of the 3&4 EHP Saddle Dam.

The Saddle Dam Interception Trench, a gravity drain, was constructed in early 2000 after process water was found issuing to the ground surface east of the Saddle Dam in December of 1999. The interception trench is still in operation and collects groundwater from shallow substrates at depths just below the base of the McKay Coal east of the Saddle Dam. This trench was installed by excavating a trench north to south from near well 633M to the 3&4

Saddle Dam Valley Drain, where water collected in the trench flows into the Saddle Dam Valley Drain pipe. The pipe conveys water to the 3&4 Saddle Dam sump, from which it is pumped to the 3&4 EHP. Note that water quality in the trench started to decline shortly after increasing concentrations of indicator parameters began to appear at well 632M. Groundwater quality in the McKay Coal interval east of the 3&4 EHP Saddle Dam is variable. For example, well 590M has exhibited no apparent process water impacts; while, an obvious trend of declining water quality is evident at well 632M, where only residual clinker from burning of the McKay remains (Figure 3-49). The Saddle Dam Interception Trench was constructed to, or through, the base of the McKay Coal interval; so shallow groundwater upgradient of the trench had not been the target of additional mitigation measures. Declining water quality at well 632M and the presence of process water impacts in the area of well 1120C led to the current decision to implement more capture upgradient of the trench. Specifically, monitoring wells 1120C and 1169R were recently converted to capture wells. The McKay Coal is absent downgradient of the Saddle Dam Interception Trench. However, water quality at bedrock wells downgradient of the Saddle Dam Interception Trench has remained unchanged or has improved as a result of capture in the trench. Water quality graphs for well 563D exemplify long-term water quality trends downgradient of the trench (Figure 3-49).

Groundwater quality impacts observed outside of the northeast end of the 3&4 EHP Saddle Dam are targeted for mitigation by capture wells 556D, 609D-2 (replaced 609D), 610D, and 621D. After startup of the capture system in this area in 1999, SC and other indicator parameters increased at the capture wells as pumping induced a flow path of impacted water from the source. By fall of 2013, SC at capture well 621D had decreased by 22% from the highest SC previously recorded in 2005. However, SC values and concentrations of other process water indicator parameters have increased in this area since 2014. Drawdown observed at the capture wells suggests that the impacted groundwater is still being collected; however, the declining water quality indicates a delayed flow path from the source or a decrease in the amount of precipitation recharge. It is possible that dewatering and paste deposition that has occurred adjacent to these capture wells on the inside of the cutoff wall (G Cell) has reduced the amount of recharge. Declining water quality observed northeast of

the Saddle Dam between 2014 and 2015 is accompanied by a decrease in system capture rates. Between 2010 and 2014, the cumulative capture rate of wells 556D, 609D (609D-2), 610D, and 621D ranged from 8.1 to 11.8 gpm. The cumulative capture rate was just 4 gpm in 2015 (Table 3-5). The decline in capture rate supports a probable decline in recharge, either locally or from the pond as a result of pond management practices. A plot of water quality at well 621D is included in Figure 3-49 to exemplify groundwater quality trends at the north end of the 3&4 EHP Saddle Dam.

Other mitigation measures between the Saddle Dam and the 560A Area include bedrock wells 646D, 647D, and 648D. Water quality graphs for these wells are presented in Figure 3-50; and indicate distinctly different trends in process water indicator parameters. Specifically, water quality at well 646D has improved since capture began; water quality at well 647D has been fairly consistent; and water quality at well 648D has generally declined throughout the period of record. The initial decline in groundwater quality at well 648D is not uncommon of a pumping well that is inducing flow from a source of process water impacts. The absence of the declining groundwater quality trend at nearby capture wells 646D and 647D and several monitoring wells suggests that the impacts at 648D are localized. Note that groundwater not intercepted in this area would flow into the alluvium near well 635A and would likely be captured at one of the downgradient capture wells (e.g. 1039A). The variable hydrochemical composition of groundwater in multiple hydrostratigraphic units of Area 2 is shown in Stiff diagrams in Figure 3-51.

Alluvial capture well 1039A was started concurrently with the 560A-Trench in 2008 but is located up-gradient of the 560A Area. Groundwater quality in the alluvium at well 1039A declined in response to the initial startup but has generally improved with the increased duration of capture. Water quality trends at 1039A are presented in Figure 3-50; and changes in the hydrochemical composition at this well over time are demonstrated via Stiff diagrams in Figure 3-52.

3.5.3 Area 3 - 560A/1051A Area

Extensive groundwater investigation and capture has been initiated in the 560A Area east of the 3&4 EHP Saddle Dam. The 560A Area is immediately west of Talen's easternmost property boundary as shown on Figures 3-42 through 3-44. Ongoing water quality mitigation efforts in the 560A Area have focused on both alluvial and bedrock groundwater, including operation of four capture interception trenches (560A, 1051A, 1079A, and 1172D Trenches) and 12 bedrock capture wells (1089D, 1090D, 1093D, 1095D, 1097D, 1098D, 1099D, 1100D, 1101D, 1102D, 1127D, and 1148D). Groundwater capture at the 1073A Trench also affects groundwater in this area. Water quality graphs of representative sites in the 560A Area are presented in Figure 3-53. Stiff diagrams for representative sites in the 560A Area are shown in Figure 3-54.

Well 560A has been monitored since 1982. Water quality observed at the well was fairly consistent until 2000; at which time, levels of process water indicator parameters began to rise gradually until 2007. A more pronounced increase in SC and other indicator parameters occurred in 2007; thus, the 560A-Trench was installed directly downgradient of well 560A in 2008. The 1051A-Trench was installed farther downgradient of the 560A-Trench in the same year as a backup measure. Groundwater at the 560A-Trench has exhibited a slightly improved water quality since capture at the trench began. The 560A-Trench has been proven effective by dewatering the impacted alluvium. The effectiveness of alluvial capture in this area is evident by the fact that the downgradient trench (1051A-Trench) has been dry since 2009.

Capture trench 1079A-Trench was installed in the alluvium of a separate ephemeral drainage that is parallel to the 560A/1051A drainage. Water quality has improved in this capture trench since it was started in 2009. Graphs of water quality trends at the 1079A-Trench are included in Figure 3-53. The changing Stiff pattern at the capture trench is presented in Figure 3-55.

The effectiveness of the current bedrock capture system in the 560A Area is exemplified by water quality graphs for capture well 1099D and monitoring well 1113D in Figure 3-53. Well 1099D was converted to a capture well and became operational in April 2010. Since that time water quality has shown an overall improving trend. For example, SC has dropped from 6,720 mg/L to 4,120 μmhos/cm, chloride from 46 to 25 mg/L, sulfate from 4,530 to 2,300 mg/L and dissolved boron from 5.2 to 1.8 mg/L (Figure 3-53). Evolving Stiff diagrams at well 1099D are shown in Figure 3-56. Well 1113D is downgradient of all bedrock capture in the 560A Area. Water quality improvement at the downgradient monitoring well is evident in trend plots for 1113D presented in Figure 3-53. Water quality improvements in bedrock of the 560A Area are attainable because this area has been cut off from the source by upgradient capture wells (i.e. those closer to the Saddle Dam) and because this area is at the leading edge of the impacted groundwater flow path. Groundwater pumping from the bedrock capture wells induces radial flow from un-impacted downgradient areas as well as the impacted upgradient areas.

The 1172D-Trench is the most recent capture system installed in the 560A Area. The trench was installed to target impacted groundwater that was observed at the shallow contact between alluvium and weathered bedrock at monitoring well 1123A (See Figure 3-4 for location). The 1172D-Trench was constructed in March 2016 and became operational in April 2016. Evaluation of the trench's initial capture performance is ongoing; and capture rates will be presented in Talen's annual water resources report for 2016.

3.5.4 Area 4 - EHP South and Southwest Side

Capture wells 694R, 695R, 1001R, 1002R, 1007R, 1016R, and 1017R are completed in Rosebud clinker and are operated outside of the bentonite amended concrete cutoff wall on the south and southwest sides of the 3&4 EHP. The wells were installed to collect process water that entered the Rosebud interval during 2004 (see Hydrometrics, June 2005). Upon startup in late 2005, the cumulative pumping rate of these wells was approximately 445 gpm. Because most of the groundwater in the Rosebud interval is attributed to storage from historic pond seepage or releases, and not a hydraulic connection to an active source of recharge, pumping rates in these wells have declined substantially in recent years. The

cumulative pumping rate reported for wells 694R, 695R, 1001R, 1002R, 1007R, 1016R, and 1017R was just 10.6 gpm in 2015. The water level at 1016R has dropped below the contact of the clinker and underlying bedrock, leaving the well essentially dry. Naturally occurring groundwater is minimal in the Rosebud interval in this area due to the high permeability and limited recharge. Because the Rosebud clinker is not connected to a regional or even a local source of groundwater flow, improvements to water quality rely almost exclusively on recharge from precipitation. Water quality improvements and declining capture rates are an indicator of source control and capture well effectiveness.

Water quality graphs for wells 696R, 1001R, 1002R, and 1007R are presented in Figure 3-57. Well 696R is located at the southwest corner of the ponds. This well showed pond water impacts when installed as part of the 2005 investigation of the SFCC Seep. SC at this well was initially 14,900 µmhos/cm. Water quality improved rapidly and significantly after groundwater capture started at the abovementioned wells. By June 2012, measured SC had dropped to 4210 µmhos/cm. Rapid water quality recovery at this well suggests an area of rapid precipitation recharge with limited horizontal flow through the area near the well (see also Section 3.3.1.2). The changes in water quality at well 696R were heavily influenced by groundwater capture at well 1002R given the rapid improvement in quality and lowering of the water levels shortly after pumping began. As previously mentioned, well 1002R is located on the south side of the 3&4 EHP cutoff wall. It was started for capture in September 2005. The base of the Rosebud Coal interval at well 1002R forms a small structural depression lending to effective capture in an unconsolidated unit.

Water quality graphs for monitoring wells 1036R and 588D and for capture well 695R are included in Figure 3-58. As indicated by the “R” designation, wells 1036R and 695R are completed in clinker of the Rosebud Coal. Water quality graphs for each of these wells indicate a high degree of process water impacts, albeit with a distinct trend of improvement. Water quality improvement in the area south/southwest of the 3&4 EHP is further exemplified by the shrinking polygon in the Stiff diagram for well 694R (Figure 3-59).

Stiff diagrams for multiple wells in Area 4, constructed using 2015 water quality data, are presented in Figure 3-60. The patterns indicate that hydrochemistry of groundwater in wells completed in deeper strata, such as the McKay Coal and sub-McKay bedrock, is dissimilar to that of process water or groundwater in the impacted Rosebud Coal wells. Well 588D is completed in sub-McKay bedrock. Throughout the period of record, groundwater at well 588D has remained un-impacted (Figure 3-58). The lack of impacts in sub-McKay bedrock southwest of the 3&4 EHP is possibly attributable in part to effective capture in upper hydrostratigraphic intervals.

3.5.5 Area 5 - South Fork Cow Creek

Extensive groundwater mitigation measures were put in place in the SFCC drainage south of the 3&4 EHP in response to the SFCC Seep that occurred in 2004 (Hydrometrics, June, 2005). The 22 capture locations installed in SFCC primarily target groundwater in alluvium and McKay Coal in direct contact with alluvium; these sites are listed in Table 3-5. Examples of groundwater quality trends in the SFCC drainage are presented in Figures 3-61 and 3-62.

Monitoring well WA-137 is installed in alluvium up-gradient of all SFCC capture wells. Water quality observations at the monitoring well are not indicative of process water impacts. Near the western extent of impacts from the SFCC Seep, the highest recorded SC values at capture wells 1019AM and 1024AM were 8,230 µmhos/cm and 8,640 µmhos/cm, respectively. Long-term reductions in SC have been observed at these (and other nearby wells) such that the most recent SC observations (fall 2015) were 6,010 µmhos/cm and 5,920 µmhos/cm at wells 1019AM and 1024AM, respectively. Improved water quality in this area indicates that the source of the seep has been effectively controlled. Also, the current hydrochemical classification of groundwater in alluvium, McKay Coal, and bedrock of the SFCC drainage is generally dissimilar to and much more dilute than process water. Stiff diagrams for select wells in the SFCC area are presented in Figure 3-63. The shrinking polygon in the Stiff diagram for well 1024AM is indicative of decreases in dissolved ions that have resulted since groundwater capture was started in SFCC (Figure 3-64).

Long term water quality records at monitoring well WA-136 and capture well 592A exhibit distinct changes in process water indicator parameters shortly after the SFCC Seep of 2004. Well WA-136 was not converted for capture due to the size of the casing (2 inches); instead, it was paired with capture well 1065A. SC peaked at 5,300 µmhos/cm at well WA-136 in fall of 2008 but began to decline after startup of well 1065A in 2009. SC measurements made in December 2012 at wells WA-136 and 1065A were 4,190 µmhos/cm and 4,370 µmhos/cm, respectively. The trend of improving water quality that was observed from 2009 to 2012 has since reversed, indicating residual process water impacts from the 2004 seep. Improvements in upgradient water quality at monitoring and capture wells between WA-136 and the 3&4 EHP suggest that the latest observations of process water impacts at WA-136 are likely from a pulse of impacted groundwater flow from storage and not from an active connection to the source. Note that capture well 1026A/M is approximately 2000 feet upgradient of WA-136. Well 1026A/M has operated since November 11, 2005. There have been three times when measured SC has increased following a period of declining or relatively stable values. Water from WA-136 has shown a similar trend with three periods of increasing SC following periods of relatively stable or decreasing values. The time periods between these peaks range between about 700 and 1000 days. Although there is some variability between the peaks, the time period is highly variable and is dependent on precipitation and/or snowmelt recharge, which varies substantially. Given these variations, it is likely the variations in water quality at WA-136 is a function of velocity of water moving between this well and the area around 1026AM/1065A. Relative to the density of other capture wells in the SFCC area, the distance between 1065A and the nearest upgradient capture well (1153A) is large. Typically, capture wells in the SFCC drainage are spaced much less than 500 feet apart; but the distance between 1153A and 1065A is approximately 1500 feet. Thus, it may take longer for pumping at well 1065A to influence the entire reservoir of stored upgradient groundwater. However, this does not imply that additional mitigation measures are necessary, as capture upgradient and downgradient of 1065A are effectively controlling process water impacts in SFCC. Additional capture in this area would, however, decrease the total time of remedial action that would be needed in this area.

Well 592A is one of a series of wells located near Talen's property boundary near the eastern (downgradient) extent of the SFCC capture system. In general, water quality in this area has improved and/or the alluvium has been pumped dry as a result of capture system pumping. The most recent SC at well 592A (August 2015) was 4,450 µmhos/cm, as compared to the highest recorded SC of 5,580 µmhos/cm. The difference in observations suggests an improvement of SC of 20 percent.

Effectiveness of SFCC capture systems is also measured by their hydrologic control on groundwater at the Talen property boundary. Hydrologic control is demonstrated in monitoring observations at wells 665A, 666A, 669A, and 670A; which are downgradient of the entire SFCC capture system. Each of these wells was installed in October of 2004 in response to discovery of the SFCC Seep. Water columns of approximately 3 feet were initially present at wells 665A and 666A. Wells 669A and 670A were dry when completed. Shortly after startup of the original SFCC capture system, wells 665A and 666A became dry. Wells 669A and 670A have remained dry throughout operation of the capture system. Recall, however, that water quality and yield at well 1030A is not impacted by process water. Well 1030A is installed about one-half mile downgradient of SFCC capture wells. Hydrographs for wells 665A and 666A are included in Figure 3-65. As noted, monitoring and capture well locations are shown in Figure 3-4.

3.5.6 Area 6 - EHP West and Northwest Side

For the sake of this discussion, the EHP West Side includes all monitoring and capture wells installed between the bentonite amended concrete cutoff wall on the 3&4 EHP west boundary and the SP-15 Trench capture system. The 12 capture locations included in this area are listed in Table 3-5 and include well 657M which was recently converted in 2015. Water quality graphs for select monitoring and capture wells west/northwest of the 3&4 EHP are included in Figures 3-66 and 3-67.

Groundwater capture in the Rosebud clinker interval outside the northwest corner of the cutoff wall is conducted from wells 656R, 1031R, 1034R, and 1037R. Water quality trends at 656R are shown in Figure 3-66. The plots demonstrate that although levels of process

water indicator parameters have declined in this area, water quality is still indicative of minimally diluted process water. As previously mentioned, naturally occurring groundwater is not typical of the Rosebud clinker; so water quality improvements are a reflection of the increasing ratio of recharge by precipitation to water from the 3&4 EHP. Head in the clinker inside the cutoff wall has declined in response to pond dewatering and lining practices, effectively resulting in less seepage outside of the pond. Monitoring wells 641P, 643P, and 642P, listed in order of distance downgradient of the Rosebud capture wells, have also shown improvements in water quality since 2006 (Figure 3-66).

Trends of process water indicator parameters are more erratic at the SP-15 trenches, owing to their shallow construction and influence from precipitation driven recharge. However, the SP-15 capture trenches have been effectively removing groundwater impacted by process water since 2006. SC and concentrations of other process water indicator parameters rose when North SP-15 was initially started because active pumping at the trench induced flow of groundwater impacted by process water. A period of decreasing SC was observed at North SP-15 from 2009 to 2011; likely because the source of impacted groundwater was becoming depleted and/or more dilute (i.e. from increased precipitation in spring 2011). The most recent SC observed at North SP-15 was 10,200 µmhos/cm; which is a reduction of 30 percent when compared to the highest measurement of record (14,600 µmhos/cm). Alluvial capture well 1068A intercepts shallow groundwater that may otherwise flow between the SP-15 Trenches. A trend of water quality improvement has occurred at well 1068A since it was started for capture (Figure 3-67).

A gradual increasing trend in concentrations of some process water indicator parameters was observed at McKay Coal monitoring well 657M (Figure 3-67). As noted, well 657M was converted to a capture well in 2015. Ongoing observations at capture well 657M and nearby monitoring wells completed in the McKay Coal interval will be used to gauge effectiveness of capture in this area.

The current groundwater hydrochemistry in Area 6 at wells completed in multiple hydrostratigraphic intervals is compared to the hydrochemical classification of process water

from the 3&4 EHP in Figure 3-68. Contrary to the shallow (Rosebud and McKay intervals) capture and monitoring well locations discussed previously, wells completed in sub-McKay bedrock in Area 6 do not exhibit an ionic composition that is consistent with process water. Continued capture in the shallow impacted intervals, coupled with pond management practices will reduce the likelihood of impacts reaching deeper strata in this area.

3.5.7 Area 7 - Drain Pit #5 Interception Trench Area

Groundwater capture began at the Drain Pit #5 Interception Trench in 2000 to mitigate potential process water impacts originating from Drain Pit #5. Well WA-135 was pumped to collect impacted groundwater from 1998 to 2000, prior to construction of the trench.

Monitoring well WA-142 is located downgradient of Drain Pit #5 but upgradient of the interception trench. Concentrations of process water indicator parameters at the upgradient monitoring well have shown a gradual increase since operation of the 3&4 EHP began. Well WA-135 is just downgradient of the Drain Pit #5 Interception Trench. Current groundwater quality at well WA-135 has improved compared to the highest concentrations of individual COIs (e.g. SC, sulfate, boron, and chloride) observed during the period between 2000 and 2005. The long-term improvement in water quality at WA-135 is thought to correlate to capture at the Drain Pit 5 Trench; however, restricted downgradient groundwater movement allowed by the capture trench created initial short term declines in groundwater quality at well WA-135. Water quality at well 617A-P has also improved since 2000. The most recent SC observed at the Drain Pit #5 Interception Trench was 5,170 µmhos/cm (9/8/2015); which is a reduction of 20 percent when compared to the highest measurement of record (6,540 µmhos/cm). Water quality graphs for sites in the Drain Pit #5 Interception Trench Area are included in Figure 3-69.

3.5.8 Area 8 - Drain Pit #3 Interception Trench Area

Groundwater capture began at the Drain Pit #3 Interception Trench in 2000 to mitigate potential process water impacts originating from a spill at Drain Pit #3 (Hydrometrics, April 14, 2000). The alluvium downgradient of Drain Pit #3 contains very little groundwater; as such, the interception trench typically yields less than two gpm (Table 3-5).

Monitoring well DP3-637A is located downgradient of Drain Pit #3 but upgradient of the interception trench. Concentrations of process water indicator parameters at well DP3-637A increased from 2000 to 2006, but have exhibited a continuous trend of improvement from 2006 to present. Concentrations of process water indicator parameters at the Drain Pit #3 Interception Trench also rose from 2000 to 2006; but have yet to recede. The discrepancy in water quality trends between the capture trench and up-gradient monitoring well may indicate that a pulse of impacted groundwater was/is flowing through alluvium of the Drain Pit #3 drainage. The pulse has already traveled beyond monitoring well DP3-637A and is actively being captured by the Drain Pit #3 Interception Trench. Low yield conditions in the alluvium may result in a long period of pumping before changes in water quality are apparent. Water quality observations made during semi-annual sampling at the Drain Pit #3 Interception Trench suggest process water impacts are increasing or remaining steady (Figure 3-70). However, the most recent SC observation made at the trench was 7,100 µmhos/cm (8/13/2015); which is a reduction of 13 percent when compared to the highest measurement of record (8,200 µmhos/cm). Well DP3-639D is completed in shallow bedrock downgradient of the Drain Pit #3 Interception Trench. Water quality at this well appears un-impacted by process water. Monitoring well DP3-638A is completed in alluvium farther downgradient of the Drain Pit #3 Interception Trench. Despite some routine seasonal fluctuation in water quality, concentrations of process water indicator parameters have remained below BSLs for alluvium at this site. This suggests that impacts have not migrated this far downgradient and/or have been controlled by the upgradient interception trench. Water quality graphs for sites in the Drain Pit #3 Interception Trench Area are included in Figure 3-70.

3.6 ONGOING INVESTIGATIONS/ACTIVITIES

Additional investigation is currently planned or is being conducted in the 3&4 EHP area. Talen is committed to preventing groundwater impacts through BMPs including the installation of double-lined ponds with leachate collection, paste processing to reduce seepage and water storage requirements, evaporation and water treatment to reduce inventory, extensive groundwater monitoring, and consultation with regulatory agencies.

Operational monitoring as discussed will continue. The monitoring program will be revised as additional wells are installed or in response to additional monitoring needs.

Current additional investigational and/or mitigation work that is being conducted or planned includes the following.

- Additional wells have been installed in water-bearing clinker adjacent to well 1120C, east of the 3&4 EHP Saddle Dam. Two boreholes were also installed in the sub-McKay unit (Hydrometrics, August 2015). Based on groundwater quality results at new and existing wells in this area, additional investigation and conversion of select monitoring wells to capture wells is planned.
- Design work and initial construction activities are currently being conducted on future J Cell. Note that J Cell was constructed within the footprint of the Old Clearwell and north portion of G Cell. J1 cell will be constructed over the footprint of former J Cell. J1 Cell will be a lined impoundment that meets or exceeds the requirements of the CCR rule, which requires a geosynthetic liner be placed over 2 feet of compacted clay with a permeability of $1x10^{-7}$ cm/sec or less. The bottom liner for J1 Cell will serve as the closure liner for J Cell. Different materials can be used under the geosynthetic liner provided it is equivalent or exceeds the clay liner requirements.
- A Cell is currently full of ash. Capping of the cell is currently planned by 2017.
- A new clearwell in a portion of A Cell is planned to replace the current operating clearwell (B Cell). The new clearwell is planned for construction in 2017; and will have a more robust liner system than B Cell. B Cell is planned to be capped in 2019
- C Cell is planned to be capped in 2023. A portion of C Cell is planned to be lined and used for future storage of CCR material. Removal of fluids from the cell and a cap that limits infiltration will reduce head on the underlying strata.
- D and E Cells are currently full of ash. Capping of the cells is currently planned by 2022.

- F Cell is planned to be used for water storage and eventually stormwater storage for the area..
- G Cell is planned to be dewatered, capped and lined for future storage of CCR material.
- H Cell is planned to be used for water storage and eventually stormwater storage for the area.

3.7 SPECIFIC ACTIONS

Several activities such as pond liner upgrades have been conducted to reduce the potential for seepage of process waters to groundwater. Actual measurement of seepage changes and effects on the groundwater system cannot generally be quantified. This section contains a list of actions conducted on ponds and the probable effect of the lining. In some cases, the actions were proactive, conducted to preclude liner failure, prior to observing actual changes.

3.7.1 Lining of F Cell

F Cell was originally intended to impound captured groundwater from the SFCC Seep and West Seep (Figure 1-1). However, the need for additional pond space and the fact that the rate and anticipated volume of captured groundwater from the Rosebud clinker diminished rapidly following the onset of pumping, allowed the pond to be incorporated into the overall water management circuit. The pond was constructed in 2005 using a single 45-mil reinforced polypropylene (RPP) synthetic liner placed over flyash. An underdrain system was installed as a series of laterals extending under the pond and sloping toward a common sump.

3.7.2 Lining of B Cell

B Cell was excavated and was rebuilt as a lined cell impoundment in 2008 to serve as the clearwell (decant water for return to plant for reuse). A 45-mil RPP liner was placed over at least 10 feet of dry paste, during construction of B Cell. An underdrain system consisting of laterals sloping toward a common sump was placed under the liner.

3.7.3 Moving Clearwell

The Old Clearwell was located adjacent to the Main Dam (Figure 3-4) and operated until 2009. In 2009, the clearwell was relocated to B Cell, which is now called operated as the Clearwell. Dewatering of the Old Clearwell began once the Clearwell started in service. Moving the water from the Old Clearwell reduces the head against the dam, and on the materials directly under the pond. This action will result in a decrease in flux through bedrock units under the pond. As mentioned in Section 3.5, lower yields at well 644D may be a result of the lower head.

3.7.4 H Cell Lining

H Cell was modified in 2013 using a double-liner consisting of an upper 45 mil RPP primary liner, between liner collection, 36 mil RPP secondary liner, and underliner collection system. Construction of the pond allows water from other cells to be directed to a lined impoundment to reduce head on the underlying material and reduce seepage directly into the underlying materials.

3.7.5 Forced Evaporation

Forced evaporation was initiated in 2006 to reduce the amount of water in the pond. Evaporation efforts are conducted under controlled conditions. Forced evaporation has been instrumental, along with other management practices, in reducing the amount of water held in the pond. Water and cell management practices have allowed the dewatering of the Old Clearwell, G Cell and the majority of C Cell. All of these actions reduce the amount of head on the underlying strata, thus reducing the potential flux from the pond.

4.0 GROUNDWATER MODEL RESULTS AND INTERPRETATION

Talen contracted with Geomatrix (2006) to develop a conceptual model of the hydrogeologic system in the 3&4 EHP area. NewFields refined the conceptual model and used it to design a numerical flow model (NewFields, 2013). The numerical model provides a tool for simulating groundwater flow patterns in the 3&4 EHP area and for assessing the effectiveness of existing groundwater capture systems. The conceptual and numerical models of the 3&4 EHP area were updated with groundwater information collected since the release of the 2013 model for inclusion in the revised AOC Site Characterization Report. The updated model report (NewFields, 2017) is included in its entirety in Appendix A.

The computer code MODFLOW-SURFACT (HydroGeoLogic Inc., 1998 and 2006) was used to process the Units 3&4 EHP numerical flow model because it allows for variable saturation (multiple water tables, steep gradients, overpumping scenarios, drying or wetting of cells, etc.). MODFLOW–SURFACT is a fully integrated flow and transport code based on the U.S. Geological Survey (USGS) groundwater modeling software. The USGS Code MODPATH Version 3 (Pollack, 1994) was used for groundwater capture simulations.

The model report (NewFields, 2017) provides a description of the model design including model limits, boundary conditions, flow layers, and hydraulic parameters. Hydrogeologic data from 2003-2006 were used for transient model calibration and data from 2015 were used to calibrate steady-state simulations. Calibration methods and results are presented. A capture zone analysis was conducted using steady-state and transient simulations. A sensitivity analysis was performed to identify which areas in the model were most subject to change through variations in individual parameters; and model limitations are discussed.

Particle tracking was applied to the numerical model of the 3&4 EHP to further evaluate capture system effectiveness. Particles were not only applied to the 3&4 EHP source area but more conservatively to all areas interpreted to have concentrations of process water indicator parameters above a BSL. This is a very conservative approach since an exceedance

of a BSL does not necessarily indicate process water impacts. Results of capture (particle tracking) analysis from the 2016 numerical model simulation (NewFields, 2016, Appendix A), indicates groundwater in certain areas of the 3&4 EHP with concentrations above a BSL are not intercepted by the current capture systems. Based on conservative particle tracking analysis, areas where current capture systems may not be completely capturing impacted groundwater and/or groundwater with constituent concentrations exceeding the BSLs are discussed as follows.

- Most of the groundwater in the clinker south and west of the cutoff wall is being captured. Modeling simulations suggest that some water may flow to the South Fork Cow Creek alluvium, where capture occurs. However, the model also simulates flow of some particles from this Rosebud interval into deeper units where they are not captured.
- Groundwater may be migrating in McKay and/or sub-McKay intervals northwest of the 3&4 EHP between capture well 657M and the 552D Capture System.
- Most of the groundwater in the Rosebud interval outboard of the northwest cutoff wall is captured. However, some groundwater in Clinker northwest of the 3&4 EHP may be migrating downward into McKay and sub-McKay intervals. Most of this groundwater appears to be captured by the North and South Interception Trenches. Particle tracking results suggest groundwater in the alluvium upgradient of the Drain Pit #5 Trench will be captured. However, concentrations of indicator parameters exceeding BSLs are present downgradient of the trench and are not captured.
- Some water may be flowing under the Main Dam between wells 644D and 645D. However, the majority of this water in the shallower portion of this interval is captured, either by sub-McKay wells, alluvial wells, or interception trenches.
- Some groundwater may be uncaptured northeast of the pond in the sub-McKay in the vicinity of capture wells near 609D.
- Particles originating from the southern portion of the Saddle Dam were not entirely captured by the Saddle Dam Valley Drain Trench (identified as Valley Drain Interception Trench in Appendix A) and/or 646D capture system in the model.

- Impacted groundwater north of the 560A Area, between capture wells 1127D and 1148D, may not be completely captured. This may include groundwater in intervals deeper than 1127D.

It is important to emphasize that the capture zone analysis performed using particle tracking provides a very conservative estimate of the migration of potentially impacted groundwater, as not all of the uncaptured particles used in the capture analysis originate at source areas. Capture zone analysis involved placing particles in areas where BSLs for indicator parameters are/were exceeded. BSLs are a statistical measure of baseline groundwater quality; and not all BSL exceedances are necessarily indicative of process water impacts. Furthermore, final cleanup concentrations for some constituents may be higher than the BSLs. Capture systems are operated to extract groundwater that contains, or has been interpreted to contain process water, not necessarily all groundwater that exceeds a particular BSL. Further, as recently updated statistical analysis resulted in universally lower BSLs (Neptune 2016), particles are assigned to a very broad non-source area. For this reason, it would be expected that not all particles assigned to non-source areas would be captured; and not all un-captured particles would be representative of groundwater impacted by process water. Finally, particles are an advective tracer and are not assigned a particular concentration of any indictor parameter. It is impossible to predict concentrations of indicator parameters at any point in the model using particle analysis.

Data gaps and recommendations identified through the recent modeling efforts are included in Sections 5.0 and 6.0 of this report.

5.0 IDENTIFICATION OF DATA GAPS

Bulleted items listed below are data gaps identified through review of new and existing groundwater quality data, groundwater flow patterns constructed from potentiometric monitoring data, numerical groundwater modeling results, reports of past spills and/or releases, and reports of previous groundwater investigation or mitigation prepared subsequent to releases or independently as part of Talen's ongoing water resources monitoring effort. Many of these data gaps, described as follows, are the basis of recommended additional work described in Section 6.

- Flow rates at the majority of capture wells are measured from a sample port at the well head. This method may result in an overestimation of the actual amount of water captured because it does not account for total dynamic head of the system attributable to pipe friction losses and differential elevation between the wellhead and the 3&4 EHP. More accurate measurement of flow is necessary to better evaluate system performance.

- The understanding of hydrogeologic conditions would benefit by obtaining more data from the area between well 615D and the SP-15 South Trench. As noted in Section 3.5.6, water quality in the SP-15 trenches is erratic due to shallow precipitation inputs; but an improving water quality trend has yet to be established. Further, particles originated at 3&4 EHP source areas in the numerical model (Appendix A) suggest there may be a westerly flow path of impacted groundwater from the source. Wells in this area would provide data for identifying potential flow paths from the 3&4 EHP.

- The potential for impacted groundwater to migrate vertically from the Rosebud interval to the deeper McKay and/or sub-McKay strata southwest of the 3&4 EHP is not well understood. Some particles released in Layer 2 of the numerical model near F Cell migrated west through southwestern and west central portions of the cutoff wall. Model simulations suggest that most of these particles then migrated into deeper layers but only traveled a short distance during the simulation (NewFields 2017). New wells and additional groundwater quality evaluation of McKay and/or

sub-McKay intervals south of well 696R and west/southwest of well 695R would fill this data gap.

- Well 675M, located south of the 3&4 EHP, shows elevated levels of indicator parameters. It should be noted that well 589M, located near well 675M, and installed prior to pond use, exhibited concentrations of indicator parameters greater than BSLs prior to pond use. Well 1149M, also shows elevated indicator parameter levels and is located between 675M and the 1023A/M area where groundwater capture is being conducted. Note however that NewFields (2017) identified several particles in the numerical model that originate in Rosebud/Clinker south of the cutoff wall but migrate vertically into deeper layers without being captured. Wells in the McKay coal of this area would provide additional information regarding potential vertical flow paths. Note that wells 1000M and 1004M do not show indications of process water impacts, although chloride levels have recently been increasing at 1000M.
- Additional data are needed regarding potential capture near wells 1047A and 1048A.
- The numerical groundwater flow model (NewFields 2017) suggests that an insufficient amount of groundwater capture is present to intercept particles outside the northeast corner of the EHP between wells 611D and 585D. Very little groundwater was encountered in the first sub-McKay interval of a plugged borehole (PH-1106-01) in this area (Hydrometrics, September 30, 2011); thus, a data gap remains.
- A data gap is present at bedrock capture wells 646D, 647D, and 648D, located east of the 3&4 EHP Saddle Dam, because they have exhibited variable water quality and particle tracking analysis suggest incomplete capture. Specifically, water quality has improved at wells 646D and 647D but has declined at well 648D. The absence of the declining groundwater quality trend at nearby capture wells 646D and 647D and several nearby monitoring wells suggests that the impacts at 648D are localized. It is likely that any impacted groundwater flow beyond this capture system is collected by downgradient wells; but some particles originating at source areas migrated beyond the 646D/647D/648D capture system in the model (NewFields 2017).

6.0 RECOMMENDATIONS FOR ADDITIONAL SITE CHARACTERIZATION

The following recommendations are made either as general enhancements of Talen's ongoing water resources evaluation and mitigation practices or to address specific data gaps outlined previously. General recommendations are as follows.

- Evaluate data from capture systems on an ongoing basis and make adjustments to various capture systems, or individual wells, to increase the effectiveness of mitigation efforts. It is recommended that groundwater wells showing improvement to BSLs, or better, be considered for shutdown. However, it is further recommended that the wells be maintained as operational capture points. If water quality deteriorates at these wells, indicating further process pond impacts, they should be restarted. Data from the capture systems should also be evaluated to identify areas that may require additional capture.

- Continue to evaluate groundwater potentiometric surfaces as they relate to groundwater flow near, or upgradient, of groundwater capture systems. This activity is routinely conducted as part of annual reporting and is essential for ongoing site characterization.

- Continue operational groundwater and surface water quality monitoring. Convert wells for groundwater capture, and if necessary, add additional monitoring wells to evaluate capture effectiveness. Maintain capture wells as part of the sampling and analysis program.

- A select number of wells in various areas should be instrumented with flow meters to develop a relationship between measured and actual flow rates. Note that flow meters are currently being installed in a limited number of new capture wells at the facility to test their utility in terms of accuracy, operation, and maintenance considerations.

- Conduct further evaluation to better define groundwater capture system volumes through the long-term use of flow meters, particularly in areas where excessive scaling problems have not occurred. This will allow better calibration of groundwater models for capture system analysis.

- Continue to address changes in water quality identified during operational monitoring and associated with spills or other releases by conducting further evaluation, monitoring or investigation. Evaluations should consider potential migration pathways, vertical migration, as well as the fate and transport mechanisms. Mitigation measures should be taken, if necessary.
- Consider updating the groundwater model in the future using data obtained since the previous update if it would be beneficial for further evaluating groundwater remediation alternatives or for other site characterization purposes.
- Consider further characterization of BSLs to address geospatial variations since some pre-operational data exceed BSLs and may be too conservative.
- Evaluate the length of time to dewater or drain the flyash or paste following completion of disposal activities or as it would apply to long term groundwater trends under the pond.
- Continue to monitor water levels inside of the cutoff wall. Consider periodic pumping of the underdrain and/or dewatering wells so data can be gathered to evaluate the amount of water that may be flowing into the clinker. Continued paste disposal and cell lining will reduce the amount of water flowing to the clinker. Data obtained from the water level measurements and pumping can be used to evaluate when more aggressive dewatering inside of the cutoff wall will be most beneficial.
- Review and revise the groundwater monitoring program, in coordination with MDEQ, to reduce the number of monitoring wells in the current program. Several of the wells in the current program could be removed or sampled on a less frequent interval, or for fewer parameters. The review will also include evaluation of the well locations to monitor impacted and unimpacted areas, completion intervals and chemical characteristics prior to making recommendations to eliminate wells from the program.

Recommendations for well installations or groundwater evaluation to address data gaps in specific areas surrounding the 3&4 EHP are as follows.

- Two to three additional wells are recommended along the railroad right of way south of well 675M. The wells should be installed in the McKay Coal and positioned at the two main drainages between 675M and 1149M. This is a potential pathway for water flowing to the area around well 1023A/M. Additional well installation in this area is planned for 2016.
- Capture in the vicinity of well 552D, north of the Main Dam, should be further evaluated and expansion considered. Capture well density in this area may need to be increased or alternative methods of containing groundwater flow in the sandstone considered. Water quality is quite poor and, with the exception of well 618D, only minor, if any, improvements in water quality have been observed. The shallow poorly consolidated sandstone, which correlates to the sandstone underlying the pond, should be targeted.
- Further evaluate the TP624-2 and well 624D area north of the Main Dam. This area is north of the 552D capture system.
- Additional well completions are recommended in first groundwater between well 615D and the South SP-15 Interception Trench to better identify groundwater flow paths.
- It is recommended that two pairs of McKay/sub-McKay wells be installed: 1.) southwest of well 695R; and 2.) south of well 696R. These wells will address the potential for impacted groundwater to migrate vertically from the Rosebud interval to the deeper McKay and/or sub-McKay strata southwest of the 3&4 EHP that was identified by the numerical model. This work is planned for 2016.
- Install a well between 611D and 585D, targeting the first groundwater in sub-McKay strata. The well should target strata between 3,050 and 3,090 elevation. Also, wells are recommended in the Rosebud clinker and McKay Coal if these units are encountered and contain groundwater. This recommendation addresses data gaps identified through previous field investigation and numerical modeling efforts.
- Install additional monitoring wells in the vicinity of well 648D and evaluate them for potential capture conversion. Water quality at well 648D has declined. Any water

flowing beyond capture well 648D would likely subcrop in the alluvium and eventually be intercepted by well 1039A or the 560A Trench; or it may be captured by deeper bedrock wells downgradient. The new wells would be used to evaluate the extent of process water impacts in the area; and if converted to capture wells, the increased capture density in this area may provide better capture efficiency and expedited remediation.

- Increased capture density is recommended near well 610D. Groundwater quality in this area appears to be declining.
- Monitor wells in the Drain Pit #5 area, specifically wells WA-222 and WA-145, to evaluate changes in water quality, if any, following the installation of lining in the drain pit. In this same area, but slightly to the east, continue to track water quality trends in wells 1140D, 1141D, and 1142D.
- Install a monitoring well into first groundwater downstream from the North SP-15 Secondary Trench. It is recommended that the well be installed as far upstream of the confluence of the drainage with the drainage holding Drain Pit #5 as access allows. This will allow detection of impacted groundwater, if any, that may bypass the upgradient interception trenches and secondary containment system.
- Evaluate the area near wells 1047A and 1048A for potential groundwater capture. Groundwater capture is occurring up gradient of the wells with multiple interception trenches and wells and very little water is flowing down the drainage based on observations at up gradient wells 1027A and 1028A (passive capture is being conducted at these wells due to their low yield and water quality is improving slowly). However, water quality at these wells has shown little improvement over the past five years. Long-term (1-2 weeks) pumping at one of the wells, while monitoring SC and water levels at both wells, is one option to consider.
- Groundwater capture has recently been installed at Rosebud clinker wells 1120C and 1169R, located near the northeast edge of the Saddle Dam. Water levels should be monitored following startup and the effectiveness of capture evaluated.

- A groundwater interception trench (1172D-Trench) has been installed in near well 1123A. Data are being obtained from the initial startup. This area should continue to be monitored and the effectiveness of groundwater capture evaluated after sufficient data have been collected.
- Additional investigation of the McKay Coal is suggested along the cutoff wall on the west side of the pond in the vicinity of wells 652M and 653M.

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TABLES AND FIGURES

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