TALEN MONTANA, LLC
COLSTRIP STEAM ELECTRIC STATION
ADMINISTRATIVE ORDER ON CONSENT
UNITS 1 & 2 STAGE I AND II EVAPORATION PONDS SITE REPORT

Prepared for:

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

Prepared by:
Hydrometrics, Inc.
5602 Hesper Road
Billings, Mt 59106

May 2013
March 2016 – Revised
June 2017 – Revised
October 2017 – Revised

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TALEN MONTANA, LLC
COLSTRIP STEAM ELECTRIC STATION
ADMINISTRATIVE ORDER ON CONSENT
UNITS 1 & 2 STAGE I & II EVAPORATION POND AREA

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 Evaporation 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 SOEP and STEP 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 local water resources. Coal combustion residuals from the generating plants are impounded in ponds designed and constructed to minimize seepage losses. Ponds that service Colstrip SES Units 1 and 2 are located approximately 1.5 miles west-northwest of Colstrip. The Stage I Evaporation Pond, or SOEP, was constructed with a partial clay liner and began serving Units 1 & 2 in 1975. The SOEP received fly ash, transported as scrubber slurry, for final disposal. The SOEP was full in 1997; and the reclamation program for this pond was completed in 2002.

Colstrip SES operators began routing scrubber slurry from Units 1 and 2 to the STEP in 1992. There are currently five cells constructed in the STEP; and each has a specific function. At a minimum, STEP cells were lined with a single geo-synthetic liner. The function of each cell and summary of liner construction is as follows:

- Cell A – constructed with single High Density Polyethylene (HDPE) liner, received scrubber slurry for final disposal, full and no longer active;
- Cell E – constructed with single High Density Polyethylene (HDPE) liner, formerly received scrubber slurry, actively receives paste;
- Old Clearwell – constructed with single HDPE liner, received clear water from the settling portion of the STEP and will eventually be filled with paste;
- Cell B (New Clearwell) – constructed with a Reinforced Polypropylene (RPP) double-liner and redundant leachate collection system, receives clear water from the paste plant and returns it to the scrubbers for re-use; and

- Cell D – constructed with a Reinforced Polypropylene (RPP) double-liner and redundant leachate collection system, receives clear water or paste, as needed.

A detailed description of each of the SOEP and STEP area ponds is presented in this report, including dates of service, use, pond capacity (volume), surface area, and liner construction information. In addition, water quality data for each of the ponds including minimum, maximum, arithmetic mean, and median concentrations for up to 92 analytes are tabulated in the report for each pond. Although numerous analytes have been evaluated for water from the SOEP and STEP, a smaller number of parameters are characteristic of water/waste of the Colstrip SES process. Increased specific conductance (SC) and elevated concentrations of sulfate, boron, and chloride are present in process water liquids/solids within the SOEP and STEP compared to background groundwater concentrations. These parameters are used as indicators for process water impacts in groundwater outside of the ponds. In addition, water from the SOEP and STEP 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 ponds.

Estimates of pond seepage to local groundwater are presented in Section 2. A HYDRUS 2D variably-saturated numerical flow model was used to estimate seepage from the reclaimed SOEP. Methods of seepage calculation appropriate for active geomembrane-lined ponds were selected for analysis of the STEP cells. Because the SOEP was reclaimed with an evapotranspiration (ET) cap, seepage estimates are based on annual precipitation. Estimates of recharge to groundwater though the SOEP averaged 1.44 inches per year or about 8.8% of annual average precipitation during the 10-year simulation period (equivalent 4.1 and 10.3 gallons per minute). The cumulative estimate of seepage to groundwater from the five geomembrane-lined ponds in the STEP is approximately 17 gallons per minute (gpm).

Water quality monitoring is conducted routinely by Talen at a network of over 216 monitoring sites in the SOEP and STEP area. Monitoring sites include process ponds, monitoring wells, private wells, groundwater capture wells, surface water, sumps, and ponds. Water quality data are evaluated and further investigation and/or mitigation actions are

conducted in areas showing process water impacts. Groundwater with process water impacts has been identified downgradient of the SOEP and STEP. As of the end of 2015, 60 groundwater capture wells, four process pond under-liner secondary collection systems, and chimney and toe drains installed in the face of the STEP Main Dam are operated by the Colstrip SES to capture impacted groundwater in the SOEP and STEP areas. Impacted groundwater is pumped to lined process ponds or treated via the Vibratory Shear Enhancement Process (VSEP). Evaluation of water quality and water level data at capture wells and paired monitoring wells indicates that the existing capture system is largely effective to date as a source control measure and hydraulic gradient control.

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 SOEP and STEP area are included in Section 3 of this report.

Groundwater modeling analyses required by the AOC are introduced in Section 4 of this report. The complete report is included as Appendix A. A preliminary conceptual groundwater model was developed for the Plant Site and SOEP and STEP areas in 2004 (Maxim, 2004). Maxim (2005) further summarized the conceptual model, described the initial numerical model design, and discussed model calibration methods and results. The initial model was developed using the USGS code MODFLOW-2000 (Harbaugh et.al, 2000). Geomatrix (2007) updated the conceptual model to include water level and water quality data at new capture and monitoring wells installed since the inception of the initial modeling effort. A more robust code, USGS MODFLOW-SURFACT Version 3 (HydroGeoLogic, 1998) was used in the updated model to allow for variable saturation. The current model report for the SOEP and STEP areas (NewFields 2017, Appendix A), describes expansion, calibration, steady-state and transient groundwater flow simulation, sensitivity analysis, and capture system evaluation. Capture analysis was conducted in the current model using

particle tracking via MODPATH Version 3. Particle tracking is analogous to advective transport; and the results do not indicate constituent concentrations or account for chemical transformation, sorption, diffusion, or dispersion. Results of the conservative capture analysis from prior simulations and the current model indicate that the majority of potentially impacted groundwater in the SOEP and STEP areas is captured by the existing capture system. Based on 50-year particle tracking simulations, complete capture of groundwater originating where an indicator BSL is currently exceeded may not be occurring in the following areas.

- Particles originating beneath the north and northwestern portion of the SOEP source area. These particles migrate very slowly to the north.
- Particles released beneath the southwest area of the SOEP source area. These particles migrate very slowly northeast under the SOEP Dam.
- Particles originating in the southern portion of the SOEP source. Particles originating in this area travel slowly to the northeast.
- Particles released in a small area of Layer 2 within the SOEP Dam. These particles remain within the SOEP Dam after 50 years due to the relatively low permeability of the dam material.
- Particles originating along the northern edge of Cell A (these particles represent residual impact and not seepage from Cell B). These migrate slowly north.
- Particles originating in the northwest corner of Cell E. These particles travel very slowly northeast and east.

Particles were also release outside of source areas at locations showing concentrations of some indicator parameters above the BSL. Model simulations suggest the following areas with uncaptured particles after 50 years.

- A few particles released in an area east of the SOEP in Layers 2, 3, and 4. These particles travel very slowly northeast and end up under Cell E, the Old Clearwell, or Cell D after 50 years.
- Particles originating along the north and northwest margin of the SOEP in Layers 3 and 4. These particles migrate north less than 2,500 feet within 50 years.

- An area of groundwater west of the SOEP source area is uncaptured. Groundwater in this area travels northeast under the SOEP Dam.
- Particles originating in Layer 4 north of the SOEP and Cell A and beneath Cell B. These particles travel less than 2,000 feet north of the SOEP and STEP within 50 years.
- Particles originating in an area north of Cell A (in Layer 5) and beneath Cell B (in Layer 5 and Layer 6). The uncaptured particles released north of Cell A migrate approximately 2,500 feet north and northwest within 50 years and the uncaptured particles released beneath Cell B migrate to the north and northeast and travel less than 600 feet within 50 years

Data gaps identified through the modeling effort are outlined in the 2017 model report (NewFields 2017, Appendix A). Additional data gaps identified through evaluation of SOEP and STEP area groundwater monitoring data are included in Section 5. These data gaps include the need for more accurate flow data from capture wells, additional hydrogeological information from specific areas, additional groundwater capture at, or near, well 903D, and further documentation of activities.

Recommendations to address noted data gaps are included in Section 6. These recommendations include:

- continuation of current groundwater capture activities and expansion, if necessary;
- continuation of groundwater monitoring and possible expansion of monitoring network;
- continuation and refinement of groundwater modeling, including consideration of fate and transport modeling;
- continuation of Best Management Practices (BMPs);
- continuation of annual synoptic runs on East Fork Armells Creek (the Creek);
- continuation of water balance refinement;
- further study of scaling problems in capture systems; and
- evaluation of pond liner permeability.

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UNITS 1 & 2 STAGE I & II EVAPORATION POND AREA

1.0 INTRODUCTION

Talen Montana, LLC (Talen) is the operator of the Colstrip Steam Electric Station (Colstrip SES), located in Colstrip, Montana (Figure 1-1). The Colstrip SES (Plant) is co-owned by Talen, PacifiCorp, Puget Sound Energy, Inc., Portland General Electric Company, Avista Corporation, and NorthWestern Corporation.

Colstrip Units 1 & 2, which are two 333-megawatt, coal-fired steam electric generating units, have been in service since 1975. Colstrip Units 3&4 are 805-megawatt generating units adjacent to Units 1 & 2. Unit 3 has been on line since October 1983. Unit 4 came on line near the end of 1985 and began producing commercial power in April of 1986. 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); further, Talen assumed the role as operator of the facility.

As part of the AOC, Talen is committed to prepare Site Reports for the Plant Site, Stage I Evaporation Pond (SOEP), Stage II Evaporation Pond (STEP), and Units 3&4 Evaporation Holding Pond (3&4 EHP) 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 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 (Appendix A);
- A description of completed and ongoing remedial actions (including the sampling parameters and frequency of any ongoing monitoring) and 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 report provides information required as listed for AOC Site Reports for the SOEP and STEP areas.

2.0 POND CONSTRUCTION AND CLOSED LOOP SYSTEM DESCRIPTION

2.1 CLOSED LOOP SYSTEM

A closed-loop process water/scrubber system is used at the Colstrip SES to minimize impacts to water resources in the area. Water-based liquid wastes 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 disposal is not conducted on the Plant Site but rather in holding ponds at separate locations. Flyash from Units 1 and 2 are, or were, routed to the SOEP and STEP, located northwest of Colstrip. The SOEP and STEP ponds presently servicing Colstrip Units 1 & 2 have been in use since 1975 and 1992 respectively. Details of the SOEP and STEP ponds are described in the subsequent sub-sections. Table 2-1 contains descriptions of the SOEP and STEP ponds. Table 2-2 contains pond and pipeline nomenclature for the SOEP and STEP area for correlation purposes.

2.1.1 Definitions

Several terms used in Table 2-1 and throughout this report require defining 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.

- Forced Evaporation – Mechanical processes used to enhance the rate of evaporation. Typically conducted by mechanical means through high speed fans, compressed air, and/or Venturi types of spray nozzles.
- Flyash – a residual of burning coal that is exhausted with flue gases through the scrubbers.
- 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 have passed through a solid material such as solid waste, liners, soil, or organic debris.
- Liner – An impermeable material (HDPE, Hypalon, reinforced polypropylene (RFP or RPP)), 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.
- Paste Plant – A process facility used to dewater scrubber slurry reducing the amount of water that must be managed in ponds. Creates a "paste" consisting of over 65% solids while binding the majority of water.
- RFP – A synthetic material sometimes referred to as reinforced polypropylene (RPP), which is lightweight, 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. RPP has been used to line some of the ponds at Colstrip SES.
- Scrubber – Pollution control equipment that removes SO2, particulates, and other potential pollutants from the combustion flue gas.

- VSEP – Vibratory Shear Enhancement Process – Reverse osmosis system for water treatment. A technology designed to reduce fouling and/or the buildup of particulates on the osmotic membranes.

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 STEP are shaded on this figure. Note 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 can then be pumped to the holding tanks on the Plant Site. Water is then distributed for use in the boilers and cooling towers as makeup water, or used in the bottom ash systems or the scrubbers. Process water that is routed to the STEP (and previously the SOEP) is the scrubber slurry.

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 gas are generated from burning of the coal and is directed to the scrubbers. Air scrubbers, the Plant's main pollution control equipment, are used to capture SO2, 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 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 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 a slurry to the bottom ash pond corresponding to the units (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 normally routed back to the bottom ash system at the Plant Site for reuse. Bottom ash is transported from the bottom ash ponds and deposited in holding ponds.

2.2 SOEP AND STEP PONDS

2.2.1 Stage I Evaporation Pond (SOEP)

The SOEP was designed to store 10 years of flyash (Bechtel, May 1976). Construction included a partial liner consisting of natural clay. The bottom was prepared by grubbing vegetation from the ground surface, grading and compacting the existing clay. The crest of the Units 1 & 2 SOEP Dam is at an elevation of approximately 3,308 feet above mean sea level (msl) and the total height is about 70 feet above the original ground surface. Maximum pool elevations were approximately 3,300 feet above msl. With the partial clay lining, seepage was estimated between 85 and 115 gpm, assuming a full pond, saturated conditions, limited fractures in bedrock, and steady state conditions (Bechtel, May 1976). The SOEP was constructed with chimney drains, a blanket drain, and toe drain. Water from the drains was routed to a sump which returned seepage water to the pond. Copies of design drawings for the SOEP are included in Appendix K.

The pond was operated between 1975 and 1997. During its operation, flyash slurry was pumped from Plant Site Units 1 & 2 A/B Pond through a fiberglass pipeline to the SOEP. Flyash settled in SOEP and the water was periodically pumped back to the Plant Site for use as process water through the same pipeline. Reclamation involved staged installation of an evapotranspirative cover. The cover was completed in 2002.

2.2.2 Stage II Evaporation Pond (STEP)

The STEP was constructed directly down the drainage from the SOEP (Figure 1-1). It consists of five cells (A, B (New Clearwell), D, E, and Old Clearwell) which are synthetically lined with either high density polyethylene (HDPE) or reinforced polypropylene (RPP). Copies of construction plans and drawings are included in Appendix K.

Cell A, located at the toe of the Units 1 & 2 Stage I Main Dam, is essentially full and no longer receives flyash scrubber slurry. Cell A no longer receives captured groundwater nor passive evaporation system water as of October 19, 2015 and no water is impounded within the cell.

Cell E is currently the active cell. This cell originally served as a decant pond receiving water from Cell A. Scrubber slurry was routed to the pond after Cell A was filled until the paste plant was completed and began operations. Flyash slurry from Units 1 & 2 is routed to a paste plant that was constructed directly south of Cell A in 2008 and began operations in 2009. Paste from the plant is then piped to Cell E.

Cell B was constructed in 2006 to provide additional space to store process water. In 2001, Cell B was equipped with pumps and converted to the New Clearwell. The Old Clearwell, located adjacent to the Units 1 & 2 STEP Main Dam is now used for water storage and will eventually be filled with paste. Cell D was constructed in 2011 and is currently used for water management. Cell C is a future cell, planned for construction north of Cell E.

During operation of the SOEP, STEP Cell A, and early phases of Cell E, flyash scrubber slurry was piped through a single pipeline to the ponds. Periodically, the piping was changed so clear water could be pumped back to the Plant for reuse. A new flyash scrubber slurry pipeline was installed in 2002. The new piping system consisted of one HDPE pipeline to convey flyash scrubber slurry to the STEP and a second for return water to the Plant Site to be reused in the scrubbers.

2.2.3 Surge Pond (Castle Rock Lake)

The Surge Pond is not a Plant process pond. Rather, the Surge Pond is a water supply reservoir that stores water for use by Plant operations, the City of Colstrip, and nearby coal mines. Therefore, discussion of the Surge Pond will be limited to its effects on the groundwater table in the vicinity of the SOEP and STEP.

Water for the Surge Pond is supplied by the Yellowstone River via a 29-mile long pipeline originating at the Nicols pump station west of Forsyth, Montana. Water in the Surge Pond is either routed to the City of Colstrip Water Treatment Plant and distributed, or piped to the Power Plant. Water levels in the Surge Pond are regulated between an elevation of about 3,280 feet above msl in the summer and 3,284 feet above msl in the winter months. The quality of the water is generally good and reflects the river water quality.

2.2.4 Process Pond Storage and Water Management

Process water in the STEP is contained in ponds and 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. Relatively large portions of water falling on portions of the Plant Site also enter the ponds through stormwater runoff control measures.

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 1 & 2 is currently directed to the STEP paste plant. Scrubber slurry has not been directed to the

SOEP since the mid 1990's. 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).

2.2.5 Water Use and Measurement Difficulties

Text contained in this section has been revised from the AOC Plant Site Report (Hydrometrics, July 2015) and relates to the entire facility and not just the SOEP and STEP area.

The majority of water from the Surge Pond is used at the Plant Site. However, a portion is also is also used at nearby coal mines and as domestic water supply to the City of Colstrip. An estimate of water flows 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 has been limited due to scaling buildup, 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- the process water circuit is not static. 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.
- The volume of 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, or 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 those 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.

2.2.6 BMP's 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;
- Weekly Pond Inventory;
- Multifunctional Water Management Team;
- Water Management Guidelines for Operation and Maintenance;
- Cooling Tower Water Management Cycle Optimization;
- On-going Water Reduction/Reuse Initiatives; and
- Review of current technologies with outside consultants.

2.2.7 SOEP and STEP Process Pond Sampling and Water Quality

Water quality samples are periodically collected from cells at the STEP. Samples were also collected from the SOEP pond during its operation. This section describes sampling from the ponds and chemistry of the water in the ponds obtained through sample analysis. Potential reasons for variations in the pond chemistry are also described.

2.2.7.1 <u>Pond Sampling</u>

Ponds listed in the project monitoring plan (Appendix B), 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 monitoring plan. 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. Therefore, dissolved phase of analysis is applicable to analysis of the pond water.

2.2.7.2 SOEP and STEP Pond Water Quality

Table 2-3 shows statistics for pond water quality including the most recent pond sample collected through 2015. 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. Note that some of the data for pond water quality is for ponds that are not currently in use (SOEP), method of use has changed (from Clearwell or decant ponds or visa-versa) or that have been closed. Data for the SOEP is included on Table 2-3 although it has been out of service and has not contained free water at the surface since about 1995.

Note also, that pond water quality depicted for Cell A includes data collected both before and after the cell was active. STEP Cell A is essentially full and flyash scrubber slurry and/or paste are no longer introduced to the pond. Water entering the pond decants into the New Clearwell or Cell E. Concentrations for more recent samples from Cell A are elevated due to the extreme evaporative effects associated with the pond and evaporation pad. Note that Cell A no longer impounds water.

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 C. Variation in the quality of process waters is illustrated on the graphs. The Piper diagrams show that the water in the ponds has remained magnesium-sulfate type water throughout the monitoring period. Note also that only median concentrations for cations and anions were plotted for the SOEP Piper diagram but no time/concentration graphs were

prepared because the sample points within the pond were not differentiated. For this reason the Piper diagram represents the median water chemistry in the SOEP as a whole and does not represent individual areas within the pond through time. Water quality in the SOEP and STEP ponds varies (varied) for a number of factors including, but not limited to the following.

- Changes in routing of process waters may change for short periods 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. Two examples are Cell E which was initially a decant pond from water exiting Cell A and Cell B which was initially a secondary decant pond and is now used as a clearwell. Water periodically may be transferred between ponds at the facility.
- Evaporation of water from the pond surface results in higher concentrations of chemical constituents in the remaining water.
- Force 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 flows to the ponds as runoff.
- 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. Included in this sampling was the STEP Old Clearwell. Water from the STEP New Clearwell 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 (oil/water separators at the Plant Site).

Samples were analyzed 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 are included in data routinely submitted to the MDEQ Major Facilities Siting Program.

Hydrocarbons were not detected in the sample from the STEP Old Clearwell in 2002. Low concentrations of diesel range organics (DRO - 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.

2.2.7.3 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 STEP has been 576 mg/L in Cell E. Water collected from water above the flyash in Cell A has shown a maximum concentration of 746 mg/L. Cell A is no longer part of the process water circuit and no longer impounds water.

Recently revised Background Screening Levels (BSLs) for bromide ranged from 5 to 10 mg/L for intervals existing in the SOEP and STEP 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). Bromide was detected in several wells in both the SOEP and STEP areas, but all at concentrations of 3 mg/L or less. The low bromide concentrations suggest that current seepage from the ponds is minimal, which is consistent with the assertion that the approach to estimating seepage is conservative.

2.2.7.4 Reporting Limits and Method Detection Limits

Water quality samples collected at the facility are submitted to commercial laboratories for analysis of parameters listed on a table referenced from the site monitoring plan. Reporting limits are also referenced in the Water Resources Monitoring Plan (WRMP) (Appendix B). This includes pond water, samples from the Creek, and from groundwater monitoring wells. Reporting limits (RL) and method detection limits (MDL) are described in this section and apply for 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 curves which may produce an artificial upward trend. Matrix interferences, caused by the presence of other chemical constituents may raise the level at which the concentration of a given analyte can be detected for reporting purposes. 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 a value has been defined at a concentration that the analyst is almost positive

is not background, 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 the additional interfering substance that is present. This reduces the confidence level, and raises the MDL for a particular sample. Actual detection levels 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 interfering substances tend 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 D.

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. 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

In accordance with Section VI. A.1(f) of the AOC, estimates of pond seepage to groundwater are presented herein for the SOEP and STEP. SOEP seepage estimates include design seepage estimates applicable to the operational pond and seepage estimates based on the current reclamation and evapotranspiration cover. Seepage estimates for the STEP are based on actual geo-synthetic liner construction; but a comparison is made to prior seepage estimates (Hydrometrics 1985) that considered native earth or clay-lined pond construction.

2.3.1 Stage I Evaporation Pond Operational Seepage Estimates

Design seepage estimates for the SOEP were made prior to construction by Bechtel (May 1976). The SOEP design seepage estimates were based on permeability data gathered from a series of exploration boreholes and monitoring wells drilled within the perimeter of the then proposed unlined SOEP. Seepage rates were calculated for three individual sections of the SOEP with observed differences in hydraulic gradient: 1.) the northwest rim; 2.) the east rim; and 3.) the Units 1 & 2 SOEP Dam section. Permeability calculated from the exploration program and assigned to the seepage model ranged from 100 ft/year for the Units 1 & 2 SOEP Dam section to 300 ft/year for the northwest and east sections. Bechtel (1976) based their seepage estimate on Darcy's Law and made several simplifying assumptions; their projection of seepage from the SOEP during operation was 130 gpm. These calculations assumed a full pool to 3300 foot elevation and a mound formed under the pond.

2.3.2 HYDRUS Model Simulations of Percolation Through Stage I Flyash

A HYDRUS-2D numerical model (HYDRUS 2012) was used to simulate recharge rates to groundwater through the SOEP soil cover and underlying fly ash. The HYDRUS model is appropriate for evaluating percolation through the SOEP soil cover, as HYDRUS is one of the few model's that simulates both saturated and unsaturated flow conditions. HYDRUS applies the Richards equation to solve for unsaturated flow. As noted in Albright, Benson & Waugh (2010) regarding modeling of unsaturated flow, "the most important attribute is that

the model must be based on a solution of the fundamental partial differential equation governing water flow in unsaturated soil, namely, the Richards equation". Further, MDEQ lists HYDRUS as an acceptable model for simulating unsaturated flow in their Guidance on Final Alternative Cover Demonstrations (MDEQ, 9/22/11). Therefore, HYDRUS is one of the few tools widely accepted as appropriate for evaluating percolation through a soil cover. It is unclear what analytical methods would be appropriate for simulating long-term percolation from unsaturated flow through such a cover.

The SOEP no longer holds surface water. An engineered cap was installed to balance the water storage capacity of the cover soil with the ability of vegetation to extract, utilize, and transpire infiltrating precipitation. Based on measurements in test pits excavated in different portions of the SOEP in 2012 by Hydrometrics, the engineered cover is comprised of three distinct material types or layers. These included an upper topsoil layer about 15 cm (6 inches) thick, an underlying subsoil layer averaging about 45 cm (18 inches) thick, and a bottom layer of clinker or porcelanite intended to act as a capillary break and ranging in thickness from 20 cm (8 inches) to 43 cm (17 inches). Underlying the porcelanite layer is the fly ash fill material approaching 50 feet in thickness in central portions of the impoundment. The cap thickness and material properties are described in the HYDRUS model Technical Memorandum (Hydrometrics December 2013 – Stage One Evaporation Pond Soil Cover Hydrologic Evaluation). Reclamation Research Group (RRG) also conducted exploratory trenching in the soil cover and reported an average cap thickness of 96 cm (37.7"), including 20 cm (~7.8") of topsoil, 50 cm (~19.7") of subsoil and 26 cm (~10.2") of porcelanite (capillary break), (RRG Phase 1 Ash Disposal Ponds report, Castiglione and Jennings, 2010).

This cover was designed to restrict infiltration of precipitation and thereby reduce or eliminate the amount of water that could enter the flyash and percolate to groundwater which is present at a depth of about 25 to 30 feet below ground surface (bgs).

Well 966A is completed near the deepest part of the SOEP and data from this location provide an indication of site hydrogeologic conditions. The flyash at this location is underlain by narrow, alluvial deposits that were present in the drainage bottom prior to pond

construction. Alluvium encountered in the 966A borehole ranged from poorly sorted, sub-angular to angular, sandy silty clay to sandy gravel. The current ground surface elevation at well 966A is about 3,304 feet above mean sea level (msl). The bottom of the flyash at this location is at an elevation of about 3,253 feet above msl. The elevation of the groundwater table at the time of installation was about 3,279.3 feet above msl. This equates to approximately 26 feet of saturated flyash at this location at the time of installation. The saturated thickness decreases peripheral to 966A due to increasing elevation of the native ground surface outward from the historic drainage centerline. The flyash above the water table is slightly moist to moist (unsaturated).

Since a free water surface is not present on the pond, the pond was modeled using existing site-specific data to simulate flow through the engineered cap and predict the amount of precipitation that may reach groundwater in the flyash. Based on this hydrogeologic scenario, water infiltrating through the cap and flyash to a depth of 20 feet is considered equivalent to potential seepage from the pond since this water will reach the groundwater table.

Movement of water through the SOEP evapotranspiration (ET) cap was modeled using the HYDRUS 2D/3D unsaturated flow numerical model (HYDRUS, 2012). The model discretizes the cap into finite elements and numerically solves the Richards equation for variably saturated flows. Model output includes percolation, soil water content, evaporation, root water uptake, and numerous other fields. Mesh lines may be inserted in the model to observe flux at specified locations. For this analysis a two-dimensional (2D) model was constructed for vertical water movement through a defined cap profile.

2.3.2.1 Model Input Parameters

Model inputs include geometric properties, time and iteration criteria, soil hydraulic model parameters, root water uptake parameters, initial and boundary conditions, and climate data. As the model was refined, analyses were performed on the effects of modifying several of the model inputs. Sensitivity analyses were conducted during modeling and focused on soil layer thickness, saturated hydraulic conductivity (Ksat), and potential evapotranspiration

(PET). These are the parameters typically addressed in a sensitivity analysis due to their strong influence on unsaturated flow and, in the case of the latter two, their high level of variability. Once the base model was developed and calibrated to field measured soil moisture contents, each parameter was adjusted independently to determine the model sensitivity to that particular parameter. In addition to the primary sensitivity runs, additional model runs were performed while varying other parameters related to the three primary sensitivity parameters. For instance, once the PET sensitivity analysis was completed, additional model runs were performed while varying PET, rooting depth and leaf area index to look at the combined effect of these transpiration-controlling variables. Overall, the sensitivity analysis showed the model to be most sensitive to PET and least sensitive to soil cover thickness. The sensitivity analysis results are described in Appendix E (Hydrometrics December 2013 – Stage One Evaporation Pond Soil Cover Hydrologic Evaluation).

As indicated in the previous section, the SOEP ET cap layers vary in thickness throughout the site, and a cap thickness of 20 cm (8 inches) of topsoil, 50 cm (20 inches) of subsoil, and 26 cm (10 inches) of porcelanite (clinker) was chosen based on information from the Reclamation Research Group (RRG) Phase 1 Ash Disposal Ponds Report (Castiglione and Jennings, 2010) and test pit observations. These parameters were based on test pit measurements as well as observations made by RRG. Soil samples of each cap component (topsoil, subsoil, porcelanite) were collected from each test pit and submitted to Daniel B. Stephens & Associates Soil Testing & Research Laboratory in Albuquerque, NM for complete hydraulic testing. Each sample was tested for a full suite of hydrologic parameters including saturated hydraulic conductivity (Ksat), gradation analyses, porosity, bulk density, residual and saturated moisture content, and the van Genuchten parameters alpha and n. Soil water characteristic curves were also developed for each sample equating moisture content to varying matric potential. The test pit and lab data are included in the HYDRUS model Technical Memorandum (Appendix E) (Hydrometrics December 2013 – Stage One Evaporation Pond Soil Cover Hydrologic Evaluation).

The underlying ash was modeled to a depth of 20 feet (610 cm) bgs. Water reaching the 20-foot depth most likely continues vertical flow downward until encountering groundwater.

The ten year period from 2003 to 2012 was modeled so that results could be compared to data collected at the site during that same time period. HYDRUS default and recommended values were used for iteration criteria. Soil hydraulics were modeled using the van Genuchten-Mualem model, which estimates unsaturated conductivities. Soil parameters required for the model are residual water content, saturated water content, saturated hydraulic conductivity (Ksat), a pore-connectivity parameter, and two empirical coefficients that define the shape of soil hydraulic functions. Samples were collected and analyzed for each layer at three test pits in the Units 1 & 2 SOEP cap area. Initially, an average of the results for each layer was used. This approach was of limited value due to the interdependence of parameters, and subsequent models used soil parameters from individual test pits. Additionally, Ksat was increased by an order of magnitude in each layer to better correlate with the flux response observed at the site (Pokorny, Franklin & Jennings, 2012).

The Ksat value for the model was increased from the laboratory-measured values for two reasons. First, detailed studies conducted under the Alternative Cover Assessment Program show that laboratory-measured Ksat values are typically lower than Ksat under field conditions due to fissures, burrows, and other micro/macro conduits that develop in soil profiles. According to Albright et al. (2010), regardless of permeameter testing results, most soils range from 10^{-3} to 10^{-5} cm/sec after a few years of field exposure. Therefore, the laboratory values were increased by an order of magnitude to better represent the expected existing conditions in the soil cap. Second, the Ksat values utilized in the model were determined in part by comparison of the model results to field-measured soil moisture contents. Soil moisture monitoring conducted by RRG over the past several years provides a unique opportunity to calibrate the model to actual field conditions, lending an added level of confidence in the results not typically available for unsaturated flow models. The calibration process and results are presented in Appendix E.

Increasing the Ksat value over the lab values is considered a conservative element (i.e., increases percolation) in the model since a higher K will result in a higher percolation rate. In addition, averaging the Ksat values is not appropriate. Because virtually all of the hydrologic properties governing unsaturated flow, including Ksat, Kunsat, and the van

Genuchten parameters alpha and n are interrelated, using average values or different parameters from different samples will lead to erroneous results.

Soil parameters for test pit TP-1209-02 are shown in Table 2-4. These parameters were based on field observations and laboratory analytical results. Hydrologic properties for the topsoil, subsoil and porcelanite cap components were determined from laboratory testing on soil samples submitted to Daniel B. Stephens & Associates Soil Testing & Research Laboratory. Complete hydrologic analyses were performed on three samples of topsoil, subsoil and porcelanite, each, for a total of nine sample analyses. In addition, four archived intact flyash core samples were submitted to the lab for complete hydrologic testing.

Root water uptake parameters define the upper and lower pressure heads and optimum range at which plants can remove water from the soil, as well as the vertical root distribution. Root water uptake parameters are given in Table 2-5. The HYDRUS model includes a number of default crops to choose from including alfalfa, corn, pasture grass, etc. For the SOEP cap, pasture grass was used. A crop coefficient correction factor was applied to the PET data from the AgriMet station to adjust the alfalfa-based PET values to pasture grass. The crop coefficient accounts for varying crop conditions throughout the year.

HYDRUS model default options assume a mature crop. The vegetative cover density is controlled through the leaf area index (LAI) input parameter. LAI was set to zero from November 1 through April 1, increased linearly to one on May 15, remained at one until September 18, and decreased linearly to zero on October 31, equating to a moderate vegetation density. A moderate density is consistent with Hydrometrics observations of the site and vegetative cover characteristics reported by RRG. The LAI was also adjusted during the model sensitivity analysis which showed the model is not particularly sensitive to the LAI value within the range of typical LAI values.

Initial soil water contents for the ten year model runs were determined from a three year simulation using climate data from 2003, which was a typical year during the 2003 to 2012

period. An atmospheric boundary condition was applied at the surface and a free-draining boundary condition was applied at 20 feet bgs.

The HYDRUS model requires precipitation, potential evaporation, and potential transpiration input data. These climate data were developed from multiple sources. Daily precipitation and Hargreaves PET at the Colstrip weather station were downloaded for 2003 to 2012 from the Utah Climate Center (Utah, 2013). Precipitation during the 10-year simulation period averaged 42.0 cm (16.5 inches). For comparison, average annual precipitation at Colstrip since 1928 is 37.5 cm, and the 30-year average from 1980 through 2010 is 36.1 cm. The wettest and second wettest years on record were 2011 and 2005.

A correction factor was developed to adjust the available Hargreaves PET to the more accurate Modified Penman PET. Both Penman and Hargreaves PET were available for Terry, Montana, which is located about 90 miles northeast of Colstrip. Modified Penman PET data were downloaded from the Terry AgriMet station (US DOI, 2013), and Hargreaves PET at Terry was downloaded from the Utah Climate Center. Monthly correction factors were calculated as the ratio of Penman to Hargreaves PET and applied to the Colstrip Hargreaves PET to estimate Penman PET for the Colstrip site. The results are comparable to, and somewhat less than, Penman PET values from other locations in the region:

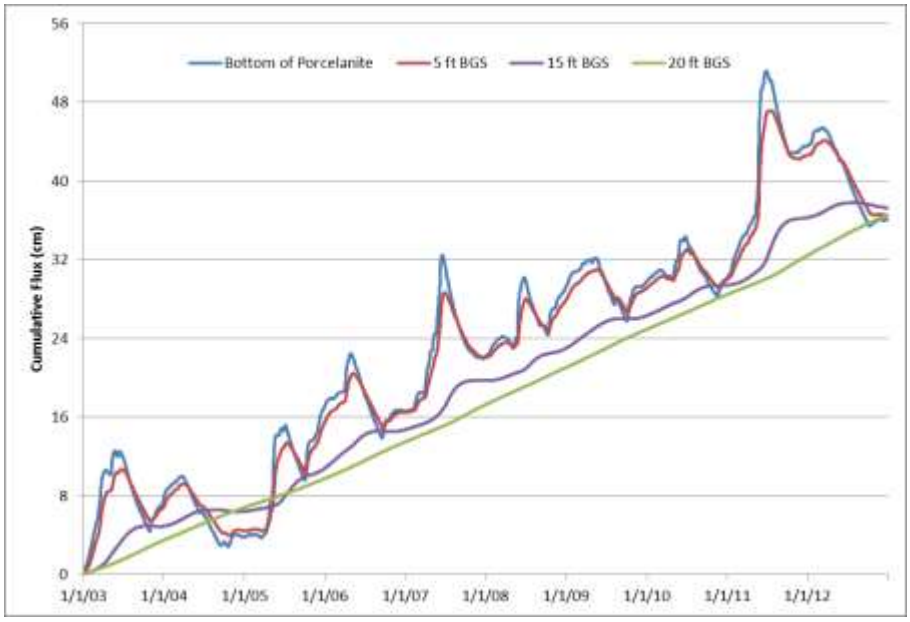
Location	**Distance (mi)**	**PET* (cm)**	**Precipitation* (cm)**	**Source**
Colstrip, MT	-	121.8	42.0	Described in Section 3.1.7
Badger Peak, MT	19	125.9	33.5	Desert Research Institute WRCC
Terry, MT	89	128.3	32.1	AgriMet
Melstone, MT	91	133.4	35.7	AgriMet
Glendive, MT	116	127.0	31.8	AgriMet
Beach, ND	142	156.4	32.7	NDAWN
Bowman, ND	154	155.8	32.7	NDAWN
Harlowton, MT	161	149.0	29.5	AgriMet

*Average annual values 2003-2012.

AgriMet Penman PET uses alfalfa as a reference crop, so a daily crop coefficient for pasture grass was applied to generate a more appropriate PET. The crop coefficient has a maximum value of 0.68 (during peak growing season) and minimum value of 0.25 (during non-growing season). Applying the pasture grass crop coefficient reduced PET from 121.8 cm to 70.2 cm of potential actual ET annually. Potential actual PET was partitioned into PET and potential transpiration using the Ankeny function ($PT=0.52*PET*LAI^{0.5}$). Leaf Area Index was set to zero from November 1st through April 1st, increased linearly to one on May 15th, remained at one until September 18th, and decreased linearly to zero on October 31st. The ten year simulation period averaged 42.0 cm per year of precipitation and 70.2 cm per year of actual PET.

2.3.2.2 HYDRUS Model Results

The HYDRUS model was constructed to 20 feet bgs and it is assumed that any water percolating beyond that depth reaches groundwater. Over a ten year period the average percolation was 3.65 cm per year, or 8.7 percent of average precipitation. The minimum and maximum annual percolation values at 20 feet were 2.95 cm (2005) and 4.12 cm (HYDRUS 2012). The minimum percolation followed the dry year of 2004, while the maximum percolation followed the wet year of 2011. The percolation lag was significantly reduced at shallower depths. At the bottom of the porcelanite a net upward flux was observed in 2004, while 2011 resulted in the largest downward flux observed during the simulation period. Estimated annual evaporation averaged 27.9 cm while actual root water uptake averaged 10.7 cm. The following chart illustrates the cumulative fluxes at various depths for the model duration. Increasing cumulative flux represents a downward flow of water.



Model simulations indicate the effects of precipitation and ET are evident at shallower depths, while the fluxes are dampened as depth increases. Changes in soil water content account for the difference between precipitation and the sum of modeled ET and percolation. Mass balances computed within the HYDRUS model show a relative percent error of less than 0.2 percent at the end of each month, with most values less than 0.03 percent.

Estimates of recharge to groundwater based on HYDRUS model analysis range from 0.6 to 1.5 inches per year, or 3.6% to 8.8% of average annual precipitation. The ten-year average simulated recharge to groundwater was 1.4 inches per year. The footprint of the SOEP covers approximately 133 acres as measured at the perimeter run-on capture ditches. This results in a conservative estimate of actual area. Based on the HYDRUS calculated recharge rates and pond area between 4.1 and 10.3 gpm of recharge to groundwater is occurring through the cap of the SOEP, with a 1-year average of 9.9 gpm.

The current numerical groundwater flow model of the SOEP and STEP areas was calibrated in steady state to 2014 water level elevations (NewFields 2017, Appendix A). Calibration was achieved using a SOEP recharge rate of 14 gpm. Note that the SOEP is no longer used and water levels are well below the ground surface. Current potential seepage through the

cap and flyash are assumed to be attributable to recharge from direct precipitation on the cap. Run-on is still managed by ditches that divert water around the perimeter the SOEP.

2.3.3 STEP Lined Cells Seepage Calculations

Prior to construction, Hydrometrics, Inc. made seepage predictions for the STEP (1985) similar to those made previously by Bechtel for the SOEP (1975). Hydrometrics' calculations were based on a conceptual plan of operation for the 176-acre STEP and included transient analysis of both an unlined pond configuration and implementation of a low permeability clay liner. Maximum percolation estimates for the clay-lined pond and unlined pond were 146 gpm and 161 gpm, respectively. Note, however that the model (Hydrometrics 1985) only predicted increases in baseline groundwater flux downgradient of the pond of 10.9 gpm (for the lined pond) and 12.9 gpm (for the unlined pond) at the end of 26 years of simulation. Storage in pore space beneath the STEP accounted for the remainder of the percolated budget in the calculations.

Design seepage rates for the unlined or clay-lined pond were not favorable to operation; thus, the STEP was constructed with synthetic liners. A design seepage estimate of 5 to 15 gpm (Hydrometrics, 1985) was suggested for the 176-acre lined pond based on manufacturer's specifications. This design estimate does not reflect actual pond development and operation. In accordance with Section VI. A.1(f) of the AOC, an estimate of seepage to groundwater from each of the five active cells of the STEP is made herein.

Each of the STEP cells is lined with a geomembrane liner (e.g. High Density Polyethylene (HDPE) or reinforced polypropylene (RPP)), as specified in Table 2-1. 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. Further, geomembrane-lined ponds at the STEP consist of either a single composite

liner or a double-liner system. Practical engineering methods specific to each liner type (single or double-lined) were used to make a head-dependent calculation of seepage to groundwater from each pond. Specifically, empirical equations developed by Giroud et. al. (1992, 1994, and 1997) were used to estimate seepage from ponds with single or double geomembrane liners. Parameter input for each liner type is variable; thus, seepage estimates for STEP ponds are listed in Table 2-6A for ponds with single composite liners and Table 2-6B for ponds with double liner systems. Pond dimensions, water levels, and parameter assignments used in the seepage estimates are included in the tables.

A composite liner is a single liner comprised of two or more low-permeability components in contact with each other (Giroud and Bonaparte, 1989). Cells with composite liners at the STEP are Cell A, Cell E, and Old Clearwell. Each of these ponds is constructed with a geomembrane component overlaying compacted native soil or conditioned bedrock (blanket layer installed over exposed bedrock). 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). STEP Cells B and D are constructed with double-liner systems. The double liner system at each of these two ponds consists of the following, from top to bottom:

- A 45-mil reinforced polypropylene primary geomembrane liner;
- A geosynthetic drainage layer (~0.03 ft thick) constructed of a geonet between two geo-synthetic cushions;
- A 36-mil reinforced polypropylene secondary geomembrane liner;
- A geosynthetic cushion layer; and
- Compacted native soil/conditioned bedrock.

Giroud, Soderman & Badu-Tweneboah (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 decrease by at least four

orders of magnitude compared to that of a single composite liner. Seepage estimates for the double-lined B and D Cells were made using a procedure consistent with Giroud et al. (1997) that consider the inherent decrease in hydraulic head on the secondary liner produced by the geo-net drainage layer. Note that there is also collection under the secondary liner which would serve to further reduce the potential of pond releases.

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, Badu-Tweneboah & 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. For double-lined ponds, there is an intermediate step that involves calculating the reduced head on the secondary liner. 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.

Flow through a geomembrane is not purely through defects but also 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 (grain/ft^2*hour*in-Hg). 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 STEP ponds constructed of either a geomembrane composite

liner or geomembrane double-liner system. A conservative value of 0.1 perms was assumed in all calculations.

Note that the equations for liquid migration through defects (Giroud et al. 1992, and Giroud 1997) are semi-empirical and must be evaluated using the International System of Units where length is in meters, area in m^2, volume in m^3, and time is in seconds. Final seepage results were converted to gpm at the conclusion of the seepage calculation for each pond. Estimates of seepage from STEP ponds with composite liners is calculated in Table 2-6A. Estimates of seepage due to permeation and defects from STEP ponds with double-liner systems is calculated in Table 2-6B. The estimates are parameterized by the frequency and size of liner defects, head above the liner, pond acreage, and thickness and permeability of soil beneath the liner. The cumulative estimate of seepage from all STEP cells is approximately 17 gpm. A discussion of model input, results, and sensitivity of parameters is as follows.

2.3.3.1 Parameterization of Liner and Defects

Liner inspections have been conducted and/or liner defects have been documented for each of STEP Cells A, B, E, and the Old Clearwell.

- A leak was discovered in the STEP Cell E in February 2006. The water level in the pond was lowered rapidly to decrease the amount of head on the suspected lead area. Leak Location Services, Inc. of San Antonio Texas was contracted to perform a liner inspection to locate any liner defects that may be responsible for the leak. A single semi-circular puncture approximately one-inch in diameter was found in the liner just above the prevailing water level at the time the inspection. This puncture was submerged before the pond water level was lowered; and it is suspected that it was the sole source of the leak. Leakage rates slowed as head above the puncture was reduced; and the leak stopped when the puncture was repaired. Cell E was returned to service at operating levels above the puncture after it was repaired.
- Major liner failure occurred at Cell A after its installation. The cell was drained and repaired/replaced in 1996 (URS 2000). A small tear was documented in STEP Cell A

in December of 2006. The tear was above the current water level of the inactive pond.

- The Old Clearwell was struck by a barge in 2007; and some seepage was observed beneath the liner. The liner was repaired and well 955D was installed to capture the released water. Note that well 955D was abandoned prior to construction of Cell D but replaced with capture well 2019D.
- The most rigorous liner inspection was performed on the STEP B Cell in 2007. The inspection was prompted by the presence of water in the between-liner collection system. Several defects ranging from minor punctures (<1 cm^2) to a bad seam weld were discovered during the inspection. The cell was drained and repairs were made.

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). Two defects per 4,000 m^2 (43,055.6 ft^2) were assumed for the STEP pond liners, based on Talen's site experience. A defect area of 0.1 cm^2 (0.0155 in^2) is often considered for liner performance evaluation; and a defect area of 1 cm^2 (0.155 in^2) is considered for conservative design (Giroud, Badu-Tweneboah & Soderman, 1994). The more conservative figure was used to evaluate STEP pond seepage. Seepage calculations presented herein are based on liner defects that could reasonably be expected to be present during routine operation of the ponds. These defects are differentiated from major liner tears or malfunctions that result from infrequent extreme events, such as the liner tear in the Old Clearwell caused by a collision with the barge. Seepage losses resulting from extreme events may be significant, but are at the same time temporal and reparable. Past releases are tabulated in Table 3-1. As noted, all known defects found in the STEP have been repaired. Further, ongoing monitoring of cells with between-liner collection systems indicates that little or no water is present between the liners (pers. Comm. Mike Holzwarth); thus, all calculated estimates of seepage through the STEP are conservative estimates.

An empirical contact factor (C) is included in the equations of Giroud (1994, 1997) to further parameterize the quality of liner installation. A liner in good contact with underlying sediments is assigned a C value of 0.21. Alternatively, a liner in poor contact with the

underlying sediments is assigned a C value of 1.15. The empirical factor has a linear effect on seepage results; thus, Giroud's equations are very sensitive to the assignment of this parameter. Assuming equal values of all other parameters, seepage estimates made with the poor C factor are greater than five times those made with the good C factor.

The C value for good contact is assumed for STEP Cells A, E, and the Old Clearwell, due to the weight of overlying low permeability fly ash deposited in the pond bottoms. Solids in the pond bottom likely bridge any liner defects. The C value for poor contact (1.15) is assumed for seepage estimates from STEP Cells B and D because a thin geotextile separates the secondary geomembrane liners from the underlying soil. Further, less fly ash is present in Cells B and D to bridge defects. Although the contact factor increases the seepage estimate from these two cells by five times, the modern double liner system still reduces seepage by at least two orders of magnitude compared to single liners.

2.3.3.2 Head on Pond Liner

Head on each of the STEP liners is assumed to be 30 feet, based conservatively on maximum operational depths. This assumption will result in an overestimate of pond seepage because not all STEP cells are full of free water. There is currently impounded water in Cell A. However, for calculation purposes a maximum of approximately six feet of standing water in Cell A was used for calculations and the remainder of the pond is filled with ash. This approach results in a conservative estimate of seepage. Similarly, water depths in Cell E range from zero to 24 feet; and the water is impounded over a variably thick layer of ash. For these seepage estimates, the ash is assumed to be saturated and all heads are assigned a maximum value of 30 feet. However, it is likely that the ash layer further limits the flow of water through the pond. The hydraulic conductivity of ash is on the order of $1x10^{-5}$ cm/sec (0.028 ft/day) (Hydrometrics, 1985); and Cells A, B, E, and the Old Clearwell have a layer of ash beneath impounded water.

Head on the geomembrane-lined STEP ponds is typically greater than the thickness of the underlying compacted silt/clay soil. This factor is important to note because it dictates which form of the leakage equation Giroud et al. (1992) or Giroud (1997) is necessary for the STEP

liner evaluation. Where head on the geomembrane liner is less than the thickness of the underlying soil layer, the hydraulic gradient term i_{avg} is assumed to be one (see Tables 2-6A and 2-6B for equations and variable assignments). Where head on the geomembrane liner is greater than the thickness of the underlying clay layer, the i_{avg} term must be calculated and included in the leakage equation.

As noted above, calculating seepage through a double-lined pond filled with water is a two-step process whereby the head on the secondary liner is evaluated; then, the seepage rate through the secondary liner is calculated given the reduced head (Giroud et al. 1997). To provide a conservative estimate of seepage from the primary liner to the between-liner leachate collection layer, 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. 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 (qi) (Giroud et al. 1997). The equation for adjusted head on the secondary liner is presented in Table 2-6B.

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 2-6B), 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 each of the double-lined ponds.

2.3.3.3 <u>Pond Areas</u>

The area of STEP Cells A and E assigned to the seepage calculations were determined by delineating the approximate wetted perimeter of the pond observed during a recent bathymetric survey (Dowl, April 2015). The design area of Cells B, D, and the Old Clearwell were assumed in the calculations. Pond acreages used in calculations are summarized in Tables 2-6A and 2-6B.

2.3.3.4 Lithology and Hydraulic Conductivity

An assessment of lithology beneath the STEP, directed at evaluating liner suitability of native materials, was conducted by Northern Engineering and Testing (1985). Soil types encountered and tested in the evaluation ranged from sand to claystone. The permeability of undisturbed soils ranged from 5 x 10^{-7} cm/sec to 1 x 10^{-4} cm/sec (0.0014 to 0.28 ft/day). Native materials that were remolded or amended with bentonite exhibited permeabilities as low as 4 x 10^{-8} cm/sec (1.13 x 10^{-4} ft/day). Additional field testing from on-site monitoring wells has been conducted for saturated horizons beneath the ponds (Table 2-7). All of the aquifer tests were conducted after construction of the STEP; and the saturated test intervals are not immediately beneath the liner.

A range of hydraulic conductivity from0.0002 to 0.0005 cm/day (0.6 to 1.4 ft/day) was calculated at well 921A (located between Cell A and Cell E). The clayey silt/silty sand tested at well 921A is present at an elevation from 3,203.9 feet to a basal elevation of 3,189.9 feet. The bottom of Cell E is at elevation 3,220 feet, which implies that roughly 17 feet of clay/silt embankment fill separates the pond liner from the underlying aquifer. Note that the hydraulic conductivity of alluvium at capture well 922A is much greater than that for alluvium or shallow bedrock at any of the other wells completed within the STEP. Alluvium logged at wells 921A and 922A is very poorly sorted clayey silt to silty sand. However, a sub-angular to rounded clinker gravel, up to ¼-inch, was logged near the base of the alluvium at well 922A. The coarser grained material in 922A likely accounts for the difference in calculated hydraulic conductivity. However, the limiting permeability is that of the clay above the alluvium. Based on lithology at capture well 922A, approximately 10 feet of low permeability clay overlays the alluvium. For each seepage estimate, the thickness of the low permeability soil layer (t_s) beneath the liner is assumed to be 10 feet.

A hydraulic conductivity of 1 x 10^{-5} cm/sec (~0.03 ft/day) was assigned to the soil/sediment layer beneath the liner in the calculations included in Table 2-6A and 2-6B. This conservative variable assignment is one to two orders of magnitude lower than horizontal hydraulic conductivities resulting from aquifer tests conducted on saturated sediments beneath the STEP; but the assigned K is consistent with the upper range of K expected for

fine-grained materials as tested by Northern Engineering and Testing (1985). Also, it should be noted that Cells A, B, E, and the Old Clearwell have a layer of ash beneath impounded water. The hydraulic conductivity of ash is on the order of $1x10^{-5}$ cm/sec (~0.03 ft/day) (Hydrometrics, 1985). Test results for wells within or near the STEP are included in Table 2-7. Lithologic logs for the wells listed in Table 2-7 are in Appendix F.

2.3.3.5 Discussion of Results

As previously stated, the total seepage estimate from geomembrane-lined ponds (composite lined ponds and double-lined ponds) in the STEP is approximately 17 gpm. A seepage estimate of 161 gpm was previously made for the STEP (Hydrometrics 1985), assuming a pond area of 176 acres and no geo-synthetic liner. This estimate suggests a potential seepage rate of 0.91 gpm/acre. The geomembrane-lined ponds have a cumulative design area of 110 acres, resulting in an estimated seepage rate of about 0.15 gpm/acre. Single composite lined ponds (Cells A, E, and the Old Clearwell) have a cumulative design area of 71 acres and account for nearly all of the estimated seepage. The estimated seepage rate from the double-lined cells (B and D) is just 1.5×10^{-3} gpm/acre. Seepage from double-lined ponds is two orders of magnitude less than for single-lined ponds. The reduction in seepage from double-lined ponds indicates that the current technology is an effective source control. The primary and secondary leachate collection systems at STEP Cells B and D collected no water in 2015 (pers. comm. Mike Holzwarth), which validates these estimates.

3.0 SUMMARY OF INVESTIGATIONS

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

Table 3-1 provides a list of past releases, date of the release, estimated amount of release, action taken to address the release, the fate of the released process water, and any reports prepared specifically for the release. Information provided in Table 3-1 is not inclusive of non-process water related spills such as chlorine, petroleum hydrocarbons, or other operational chemicals which have not been introduced into the process water or are not intended to be part of the process water circuit.

3.2 PAST INVESTIGATIONS

Table 3-2 contains a chronological listing of events on the SOEP and STEP area that have been, or are being investigated. The table includes the approximate date of the report, report title, general topic, and a summary of results or findings. The reference section of this report (Section 7) contains a complete listing of the reports outlined in Table 3-2. Examples of data data collected during past investigations are included in Appendix J.

3.3 CURRENT SITE CONDITIONS

Site hydrogeologic descriptions have been presented in numerous previous site reports. 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, Wolf & Pocknall, 1989; Flores, Ochs, Bader, Johnson & Vogler, 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 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, groundwater flow may not always follow a direct path from high potentiometric heads to lower head areas because of the anisotropic and heterogeneous nature of the geology.

Alluvium is present along many of the drainage bottoms throughout the region. The most prominent deposit in SOEP and STEP area is along East Fork Armells Creek. Alluvial deposits of clay, silt, sand and gravel reach a maximum thickness of about 38 feet. A basal gravel, comprised of mostly of clinker, is often present in the alluvium. Clinker fragments are typically also found throughout finer-grained alluvial deposits.

As mentioned previously, 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). Permeability of the clinker varies but is typically very high (exceeding 2,500 ft/day) and depends on the amount of fine grained sediments that have moved vertically into the available pore spaces and the degree and nature of fracturing. Clinker is present along most of the higher ridgetops in the SOEP and STEP area. The base elevation of the clinker is typically above the top elevation of both the SOEP and STEP ponds and above the groundwater table in nearly all locations.

SOEP and STEP Hydrogeology

Geology in the SOEP and STEP area generally is comprised of alluvium, colluvium, shallow bedrock, coal, clinker, and various strata of the Fort Union Formation. Spoil associated with area coal mining are also present south and west of the SOEP area. Figures 3-1, 3-2 and 3-3 are geological cross sections that illustrate the relationship of various units in the STEP and SOEP area. Monitoring and capture well locations are shown on Figure 3-24. A general description of these deposits in approximately descending order follows.

- Alluvium – These deposits are present in drainage bottoms under the SOEP and STEP and along East Fork Armells Creek. The alluvium generally consists of various mixtures of clay, silt, sand, and gravel. The most significant alluvium is present along East Fork Armells Creek and is represented by a fining-upward depositional sequence. That is, basal gravels typically overlie the Fort Union Bedrock. Gravel generally grades upward into poorly sorted sands and silts. Near surface deposits include silty clay to clayey silt and are generally gradational with colluvium that lines the margins and much of the valley bottom. The ancestral East Fork Armells Creek has eroded through the bedrock units to below the McKay Coal and basal gravels are typically in contact with sub-McKay strata.

A relatively small deposit of alluvium still exists coincident with the drainage bottoms under the valley in which the SOEP and STEP were constructed. Alluvium in this drainage is finer grained that that under East Fork Armells Creek. Deposits range from very poorly sorted clayey silt, to silty sandy gravel. Rock fragments are angular to sub-rounded and are mostly comprised of clinker. The presence of the clinker is indicative of the near source deposition which occurred.

Groundwater flow in the alluvium follows the drainage, generally at gradients that are similar to the topographical gradient. A small deposit of alluvium, with a limited extent, is present below the SOEP. The alluvium downgradient the SOEP is cutoff by the Stage I Dam (see Figure 3-1). Water levels measured in wells completed in the alluvium rise into the overlying flyash. This is a function of a direct hydraulic connection between the flyash in the SOEP and the underlying alluvium. No distinct confining layers are present between the base of the flyash and the alluvium. Horizontal groundwater flow in the alluvium under the STEP is cutoff by the grout curtain and core trench of the STEP Dam (see Figure 3-1).

A deposit of alluvium of limited extent is also present below the lined STEP, directly east of the Stage I Dam. The alluvium was removed for construction of the STEP Main Dam core trench. Dam core material cut off horizontal groundwater flow in the alluvium. Water levels in the alluvium below the STEP are above the upper alluvial contact in embankment materials. This condition is a function of confinement by the overlying pond liners and damming by fine-grained dam core construction materials.

Alluvium is present directly east of the STEP Main Dam. A relatively small amount of groundwater is present in this alluvium due to the reduced recharge area. Water in this alluvium is derived from the local precipitation recharge and bedrock. Groundwater in the alluvium flows eastward contributing to the East Fork Armells Creek alluvium.

East Fork Armells Creek alluvial groundwater flows northward. There are gaining and losing reaches in the Creek suggesting that groundwater is contributing to the flow in some areas and receiving recharge from the Creek in some areas. Hydraulic conductivity of the East Fork Armells Creek alluvium is generally an order of

magnitude higher than in tributary drainages, a function of larger overall grain size of the alluvium.

- Colluvium – Colluvium is slope wash deposits which have been transported downslope by fluvial or gravitational means. In the SOEP and STEP area, colluvium is most often a silty clay or clayey silt composition, although coarser deposits may be present locally. Colluvium deposited on the valley slopes tends to grade into the alluvium at the valley centers. Colluvium also tends to be in gradational contact with underlying weathered bedrock. Hydraulic conductivity of colluvium, where groundwater is present, is typically low, less than one foot per day.
- Rosebud overburden – Bedrock units of the Fort Union Formation are comprised of siltstone, claystone, shale, and fine-grained sandstone that typically overlay Rosebud Coal. Groundwater is present in the overburden south of the SOEP. Overburden has been removed by erosion north and east of the SOEP and STEP. Hydraulic conductivities of the overburden are typically on the order of one to three feet per day.
- Rosebud Coal – Cleated coal with thickness on the order of 20 to 25 feet. It has been eroded north and east of the SOEP and STEP. This coal has burned in the southern portion of the SOEP and STEP, leaving clinker and ash in its place. Cleats are defined as systematic fractures that have a common spatial orientation. Orientation and the interconnection of fractures generally dictate the hydraulic conductivity of the coal. Groundwater flow paths within the coal are also dictated by hydraulic pressures and cleat orientation. The Rosebud Coal lies stratigraphically above the McKay Coal and is separated by interburden (see below). Hydraulic conductivity of the coal is typically low, on the order of one to three feet per day, although areas of higher and lower permeability exist locally. The Rosebud Coal is burned in the SOEP and STEP areas (see clinker below).
- Clinker – Also referred to as scoria and baked shale – Comprised of thermally altered and collapsed overburden (sandstone, siltstone, shale, etc.) that is formed by the burning of previously underlying coal. The degree of thermal metamorphism of the sediments overlying the coal varies depending on the temperature of the burn,

thickness of the overburden, 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 highly fractured interval of metamorphosed sedimentary rock. Ash layers and/or layers of unburned coal sometimes remain below the clinker.

Clinker is generally quite permeable, a function of the secondary porosity caused by fracturing. Hydraulic conductivities at the facility have been tested at over 2,500 ft/day, although much higher values have been documented regionally. Groundwater flow in the clinker may be preferential in a direction parallel with the original bedding planes. Fracturing is generally widespread and interconnected making vertical and horizontal permeability nearly equal. However, most groundwater flow is parallel to the hydraulic gradient. Because of the high permeability, clinker is generally capable of transmitting large quantities of groundwater. Groundwater is rarely contained in the clinker in the Colstrip area, however, due to its presence on hilltops and ridges where it readily drains. If present, groundwater in clinker in the Colstrip area is typically found in structural low areas following periods of high recharge, either from precipitation or snowmelt. Clinker is present on many of the ridgetops in the SOEP and STEP area.

- Spoil – Spoil consists of silt, clay, sandstone, coal fragments, formerly overburden units that have been used to backfill areas where the Rosebud Coal was mined. The spoil is the result of strip mining of the Rosebud Coal seam. Strip mining involves removing overburden material (sedimentary rocks that overlie the coal) and placing it in the previously mined pit. The coal is then removed. The overburden placed in the previous pit is referred to as spoil.

  Spoil does not exist in the STEP or SOEP area but is present upgradient of the SOEP (see Figure 1-1). Groundwater levels in spoil start to recover once backfilling begins. Recharge may occur from precipitation, flow into the unit from the adjacent spoil or coal, and ponds constructed on or near the spoil. Recharge typically takes many years. For this reason, groundwater flow directions may vary as the spoil recharges. Spoil is typically mineralized and initially exhibits higher concentrations of dissolved

constituents than before mining. Spoil may serve as a groundwater supply source following recharge.

- Interburden – Typically comprised of sandstone, siltstone and claystone which separate the Rosebud and McKay Coal seams. Interburden is present south of the ponds, but generally absent north of the drainage center due to erosion. The absence of the Rosebud and McKay Coal north of the ponds is a function of the dip and erosion and/or much less likely due to a normal fault that may exist in the valley bottom. The location of this fault in relation to the SOEP and STEP are shown on the inset of the following page. The downthrown block of this normal fault on the south meaning that strata north of the fault is higher relative to the south side of the fault. Note, however, that the fault and potential associated fractures do not show clear evidence of preferential flow pathways for groundwater. The fault has not been mapped in the study area and has not been identified in any borings or through field observations. Although faults may sometimes act as preferential flow pathways, the converse is also often the case due to the buildup of fine-grained fault gouge along the fault. Faults can cause a damming affect whereby groundwater levels are higher on one side of the fault than the other. This condition is also not observed at the site.

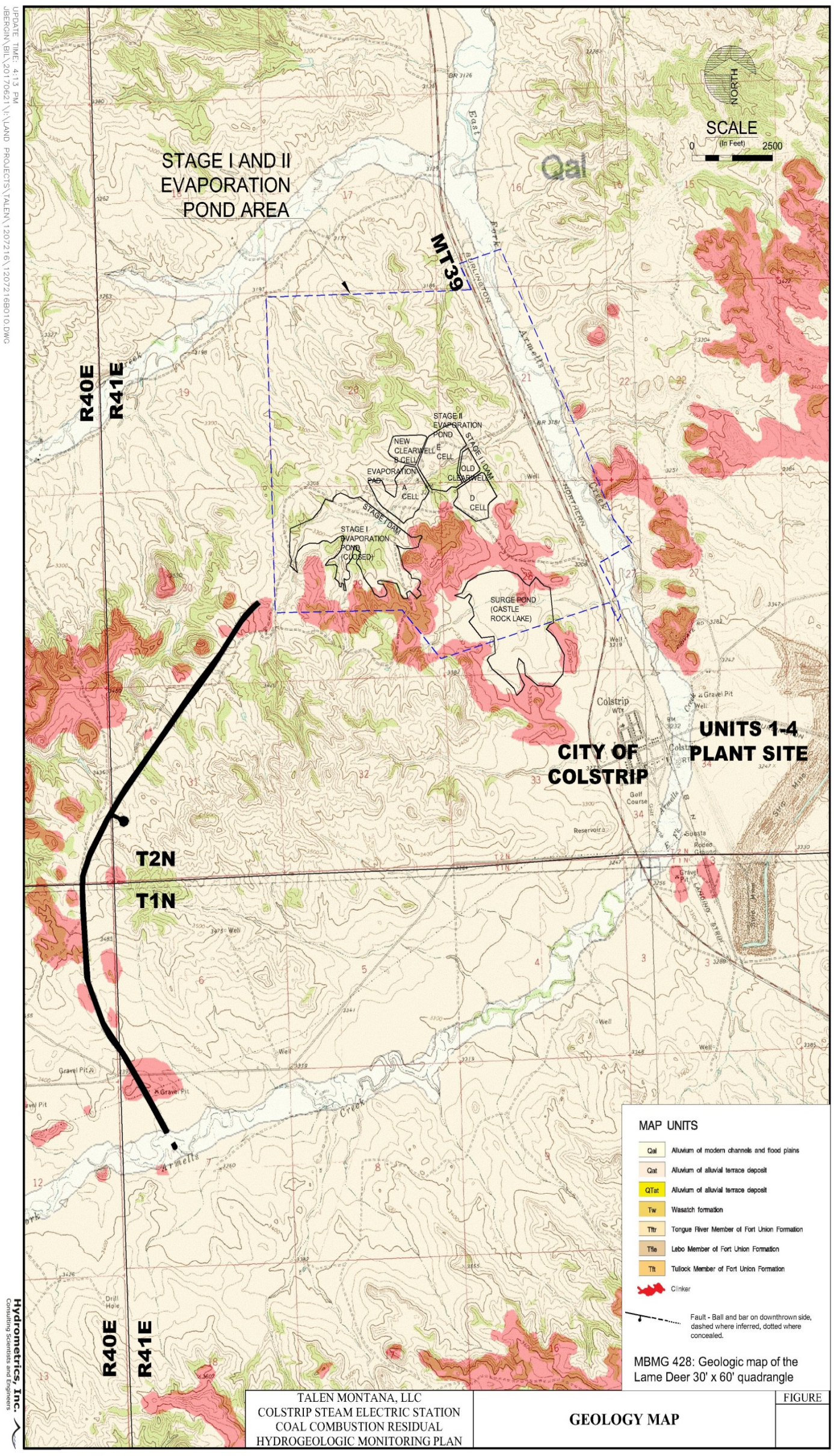
Fractures and formation of joint sets may result during or after faulting or in response to regional stresses. These structures can act as preferential flow paths which typically occur at various orientations to the faults depending on the type of faults, and the stresses that cause the faulting. No evidence of preferential groundwater flow paths associated with larger scale (laterally extensive) fracture or joints has been observed in either the interburden or McKay Coal that is described below. An area where some fracture flow is suspected occurs in the sub-McKay, in the vicinity of capture well 380D. However, groundwater yield in this area is relatively low, suggesting only a small scale fracture system (if any) is present. Groundwater in the interburden is contained in sandstone that is in direct contact with the McKay Coal, such as at well 948M.

- McKay Coal – Cleated coal with a thickness of 7 to 14 feet. Thickness of the coal in the SOEP and STEP area is typically 7 to 9 feet thick, although a thickness of about 13 feet was logged at well EAP-121. Fifteen feet of coal was logged in well 121-2,

although the actual position of the upper and lower contact are suspect since circulation was lost or poor when this replacement well was drilled. The McKay Coal is present in the SOEP and STEP area only south of the ponds. The coal is likely not present north of the ponds due to the dip of the beds. A normal fault, with the downthrown block to the south, is mapped west-southwest of the area with a terminus about 1.8 miles from the Units 1 & 2 STEP Main Dam (Vuke, Heffern, Bergantino & Colton, 2001 (revised 2007). The trend of this fault would bring it through the drainage near the Units 1 & 2 STEP Main Dam if the fault extends that far to the east. Groundwater flow in the McKay is towards the east northeast. Groundwater flowing through the McKay Coal may contribute to the water present in the alluvium. The McKay Coal receives recharge regionally, but also from the Surge Pond since it crops out in the pond approximately 700 feet west of the Surge Pond Dam.

- Sub-McKay – Fort Union strata consisting of interbedded claystone, siltstone, fine-sandstones, and thin coal seams. Channel sands are not uncommon 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. Water in the sub-McKay units flows east northeast. Water flowing in the sub-McKay units either issues to the alluvium or flows further northward below the Creek. Impacts to groundwater in the alluvium and shallow units east of the STEP Main Dam are mostly derived from sub-McKay flow. The hydraulic conductivity in the sub-McKay strata are variable, although it is most often less than 2 feet per day.

Monitoring wells are coded with a letter to identify the completion interval. In general, the following well designations apply: A=Alluvium, S=shallow unconsolidated or interburden, I=Interburden, R=Robinson Coal or clinker in this interval, C=Clinker, M=McKay Coal, D=Sub-McKay Strata, SP=Spoil. These designations are true in the majority of cases, although the reader should reference the well logs for verification of the completion unit if there is doubt. An example of where this nomenclature does not apply are at wells 368D and 976D, which are actually interburden wells.



Fault location in relation to SOEP and STEP

Groundwater is found in the alluvial deposits, interburden south of the ponds, McKay Coal, and sub-McKay. Groundwater is generally absent from the clinker due to its stratigraphic position, elevations, and high hydraulic conductivity which results in rapid drainage. Hydraulic conductivities observed on the SOEP and STEP area are highly variable. Alluvial deposits along East Fork Armells Creek alluvium, under the ponds, is also variable but generally exhibits lower hydraulic conductivity than the East Fork Armells Creek alluvium. Bedrock units typically exhibit lower hydraulic conductivity values, depending on the degree of sorting, grain size, presence of secondary porosity, and cementation.

3.3.2 Distribution of Indicator Parameters

Several indicator parameters are used to evaluate potential process water impacts to groundwater at the Colstrip SES. These include specific conductance (SC), dissolved boron, chloride, sulfate, and the ratio of concentrations. SC, sulfate, dissolved boron, and chloride are good calcium to magnesium indicators of process water since the levels of these parameters are typically high and each behaves in a conservative manner (mobile in the actual environment). The calcium to magnesium ratio is also useful as an indicator of process water. This is due to the fact that magnesium is typically more concentrated in process pond water when compared to calcium. An exception is Units 3&4 Bottom Ash Ponds at the Plant Site, which has higher calcium concentrations when compared to magnesium. All of the water contained in the STEP exhibits a calcium to magnesium ratio that is well below 1, typically less than 0.3. Most ambient waters in the Colstrip area have calcium to magnesium ratios that range from a little less than, to above 1. These indicator parameters have been accepted as an evaluation method for water quality by Talen and MDEQ. All analytical parameters used for routine groundwater monitoring at Talen Colstrip SES through 2015 are in the WRMP (Appendix B).

Background screening levels (BSLs) were updated in late 2015 (Neptune and Company, 2016). The update included use of data obtained since BSLs were last calculated in 2007 (ARCADIS, 2007). 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. All background sample sites used were reviewed and accepted by the MDEQ. Completion units for each well used was 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. Baseline screening levels (BSLs) for units found in the SOEP and STEP are included on Table 3-3 and detailed in Tables 5 and 8 of the updated BSL report (Neptune and Company, 2016) which is included as Appendix G. Note: The BSL report 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 (*Appendix G). Note that spoil is not present in the SOEP or STEP area and were therefore excluded from Table 3-3.

Clinker in the SOEP and STEP area is typically dry. Groundwater is occasionally present in wells completed in the clinker, however, following high precipitation or snowmelt events. Any groundwater present in the clinker, however, is very localized and not laterally extensive.

BSLs are used 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 unimpacted by the closed loop wastewater system. 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 STEP area) are not available. Note that an exceedance of a BSL does not necessarily indicate that there are definitive groundwater impacts. For example, groundwater in alluvium upgradient of the Plant Site may exceed calculated BSLs. In this case, impacts from the Colstrip SES are not possible. 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 collectively used 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 SOEP and STEP. 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 Spring of 2015, as measured in wells completed in the shallow (alluvium and coal-related intervals) and sub-McKay hydrostratigraphic units, are presented on Figures 3-4, 3-6, 3-8, 3-10, 3-12, 3-14, 3-16 and 3-18 described below. Results from water quality samples collected in the spring were used since a larger number of wells are sampled during that monitoring period. BSLs for each parameter and hydrostratigraphic unit (ARCADIS 2007) are included in the discussion below. Figures 3-5, 3-7, 3-9, 3-11, 3-13, 3-15, 3-17 and 3-19 were prepared to illustrate the distribution of indicator parameters based on spring 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 (which includes data from wells completed in alluvium and coal-related units) and sub-McKay which contain only data from wells completed at a deeper stratigraphic interval than the McKay Coal. More detailed discussion of water quality in the various areas of the SOEP and STEP are in Section 3.5.

Overall, a reduction in impacted areas is apparent in the alluvium downgradient of the STEP Main Dam, including the tributary and East Fork Armells Creek. The reduced area is due to efforts to control source areas, capture groundwater near the source, and from groundwater capture within areas interpreted to have process water impacts.

Figures 3-1 through 3-3 are geologic cross sections in the SOEP/STEP area. Indicator levels have been added below the cross sections on each figure. The profiles provide a visual indication of indicator parameter levels below the ponds and at monitoring wells along the

cross section. Sample depths for each well are coincident with the position of the well perforations.

Specific Conductance

Calculated BSLs for laboratory SC for the various intervals of interest in the SOEP and STEP area are 4,270 µmhos/cm (field SC BSL – 4,314 µmhos/cm) for alluvium, 3,550 µmhos/cm (field SC BSL – 4,120 µmhos/cm) for coal-related intervals (overburden, Rosebud Coal, Interburden, McKay Coal), and 4470 for sub-McKay(Neptune 2016). Note that the BSL calculated for field measured SC is often higher than those measured in a laboratory. SC shown on the following figures represent laboratory values. Although clinker is present in the SOEP and STEP area the BSL is not pertinent since the unit is almost always dry.

Figures 3-4 and 3-5 present SC values for the alluvium, and coal-related intervals that occur beneath and to the south of the ponds for spring 2015 and 2010, respectively. Wells with groundwater exceeding the updated BSL for either alluvium or the coal-related units are highlighted in red. Coal related units represented in the map appear in the southwestern portion of the figures near well 368D, also referred to as Area 1. Coal related units are absent north of the south edge of the STEP. Discussion of SC values proceeds from the South of the SOEP (Area 1) to areas downgradient of the STEP Main Dam (Area 6). Sub area locations are shaded on Figure 3-4.

SC exceeding the pertinent BSLs were present at six wells southeast of the SOEP (Area 1) in spring 2010 and spring 2015, although only four wells exceeded the BSL in both events. The highest value was reported in water from 366S in 2015. Values slightly higher than the BSLs were present south of 366S at wells 374S, 977A, 978S, and 979S. Bedrock groundwater in this area flows to the northeast, although gradients are very flat (see Figures 3-20 and 3-21). Water levels used to construct the potentiometric maps are shown in Table 3-4. Note that shallow groundwater flows away from the Surge Pond towards capture well 389A-P.

Water level elevations in the Surge Pond typically range from about 3280 during summer months to about 3284 in the winter. This fluctuation also influences groundwater flow in the immediate vicinity of the Surge Pond. SC decreases northwest of 366S before increasing again at interburden wells 368D and 976D. SC below the BSL is observed at wells 926S, 389A-P, 949D, 388D, and 390D-P. Water quality at 366S is believed to be influenced by local variations in water levels induced by the Surge Pond, the completion interval and location at the base of burn, rather than the SOEP. A complete flow path between the pond and the 366S area has not been identified.

SC exceeding the BSL of 4,270 µmhos/cm for alluvium is observed under both the SOEP and STEP. A thin, narrow alluvial deposit is present under both ponds. However, the alluvium was removed under the SOEP and STEP main dams, effectively blocking downgradient flow. Groundwater capture is conducted from the alluvium in both the SOEP and STEP. SC under the SOEP in spring 2015 was similar or lower than SC observed in spring 2010, while the values were generally slightly lower under the STEP for this same period.

Several wells completed in the alluvium directly east of the STEP Main Dam (Areas 4 and 5 exceed the BSL). Extensive groundwater capture is being conducted in this area. Groundwater downgradient of well 982A, in the tributary drainage east of the STEP Main Dam, and in East Fork Armells Creek alluvium to wells nested around 944A has generally shown improvement since the fall 2010. Most of the wells within this reach are near or below the BSL for SC in alluvium. SC in the vicinity of well 944A was similar in 2015 when compared to 2010. SC at these wells is about 7 to 40% higher than the BSL.

Wells 948M and 957M are completed in the McKay Coal north of the Surge Pond. Both of these wells show SC values less than 4,000 µmhos/cm. Water from well 948M shows probable effects of the Surge Pond, with an SC of less than 1,500 µmhos/cm. Well 957M does not show these influences. The McKay Coal crops out in the Surge Pond approximately 700 feet west of the Surge Pond Dam potentially providing a route of direct recharge to the coal.

The updated BSL for SC for the sub-McKay is 4,470 µmhos/cm. Figures 3-6 and 3-7 are iso-contour maps illustrating SC in the sub-McKay for spring 2015 and 2010, respectively. Measured SC in the sub-McKay were the highest directly north of the SOEP and STEP, under the Old Clearwell and Cell D (Capture Well 2019D), the area east of the Units 1 & 2 STEP Main Dam and at capture well EAP-119 (Figure 3-6). See Sections 3.5.2.2 and 3.5.2.3 for further explanation. Sub-McKay wells directly east of the STEP Main Dam have shown improved water quality, while those directly north of the SOEP have shown a slight decline in quality. Monitoring wells have not been installed through the SOEP into the sub-McKay Strata.

Sulfate

Figures 3-8 through 3-11 are iso-contour maps of shallow and sub-McKay units for spring 2010 and 2015. Sulfate concentrations exceeding the updated BSLs for alluvium and coal-related strata were similar to SC and are present directly south of the SOEP, in alluvium under the ponds, east of the STEP Main Dam and directly north of the golf course. Water from one well point (SP3), completed in colluvium south of the golf course also exceed the BSL. The number of wells in the alluvium exceeding the BSL east of the STEP was lower in 2015 than in 2010.

The distribution of wells with concentrations of sulfate exceeding the sub-McKay BSL (2,200 mg/L) was generally similar to SC and consistent between 2010 and 2015. A notable difference is the area north of the ponds where additional wells have been installed. Several new wells were installed since 2010 to further characterize groundwater conditions. Some of these wells exhibit concentrations of sulfate above the BSL. These levels of sulfate may have been present in 2010 but were not detected until installation of the new wells.

Dissolved Boron

Figures 3-12 through 3-15 are iso-contour maps of dissolved boron for shallow and sub-McKay units for spring 2010 and 2015. Areas with concentrations exceeding the BSL for dissolved boron in the shallow bedrock and alluvium are under the ponds east of the Units

1 & 2 STEP Main Dam, under the SOEP, historically in shallow well SPN which is located near the North 1AD Pipeline Drain Pond, southeast of SOEP, and in portions of East Fork Armells Creek alluvium. The concentration gradient for boron southeast of SOEP is different from that described above for SC and sulfate, potentially indicating that the SC and sulfate are not site-related.

BSLs are exceeded in the sub-McKay in the area directly north of the SOEP, east of the STEP Main Dam, and in isolated areas southeast of the SOEP and directly north of the New Clearwell. The distribution of boron was generally similar in 2010 and 2015 but less extensive than SC and sulfate. More discussion of boron concentrations is contained in Section 3.5

Chloride

Figures 3-16 through 3-19 are iso-contour maps of chloride for shallow and sub-McKay units for spring 2010 and 2015. Chloride concentration distributions were similar or covered a slightly larger area in the fall of 2010. Many wells were installed between 2010 and 2015. The additional wells allowed chloride concentrations to be more accurately delineated. In some cases, the new data identified areas that had not previously been mapped as having chloride concentrations exceeding BSLs. However, the extra delineation does not necessarily indicate an increase in the area that has had concentrations of chloride exceeding BSLs, but is a function of a broader monitoring network. Chloride concentrations exceeding the BSL in alluvium and coal related bedrock units were observed under the ponds, east of the STEP Main Dam, and at a few locations in the alluvium of East Fork Armells Creek. Chloride concentrations exceeding the BSL for chloride were present north of the SOEP, east of the STEP Main Dam and in isolated areas north of the New Clearwell (STEP Cell B) and the Surge Pond.

3.3.3 Groundwater Flow

Water levels are periodically measured at the facility in monitoring wells and capture wells using commercial water level meters equipped with calibrated tapes. Groundwater elevations are calculated by subtracting the depth to water (pumping or static) from the measuring point

elevation. Water levels measured in monitoring wells represent static conditions. Water levels measured in capture wells represent pumping water levels, or levels measured during some portion of "recovery" when pumps have turned off. Water levels inside a pumping well are often lower than those in the surrounding formation due to frictional losses caused by drilling and well completion processes. Multiple types of head losses occur in and around a pumping well. These are formation losses, disturbed zone losses, and well losses. Formation head losses are a function of the rate at which water is removed from a well and the hydraulic conductivity of the formation in the well completion zone. Head losses also occur at the interface between the formation and the portion of the formation that is disturbed during the drilling process. This "disturbed zone" may have lower permeability than the surrounding formation from an accumulation of drilling fluids, fines pushed into the formation during drilling, or other effects of the drilling process. A head loss will occur where the hydraulic conductivity at the interface between the two media is lower than that of the adjacent water bearing formation. Well losses are a result of the well installation itself and are a function of restrictions of groundwater flow to a well. These may be caused by the presence of a filter pack, size and amount of perforations, type of flow into the well (turbulent versus laminar), and post-construction factors such as scaling of perforations causing blockage. Any or all of these factors may restrict flow to a well, causing water levels inside a well to be lower than those in the adjacent formation. Water levels measured inside a pumping well are typically an overestimate of actual drawdown affects outside of the pumping well because of the head losses not associated with the formation. Therefore water levels from capture wells that are used for potentiometric map construction represent an estimate of actual conditions.

Water levels are measured in select monitoring wells during the first 10 days of each month. A broader set of water levels are measured twice a year, typically in late spring and fall. Water levels measured in shallow units are typically higher in the spring than in the fall. However, the effect on groundwater flow direction is negligible.

Measured water levels are used to construct figures that illustrate the elevation and configuration of the water table (unconfined) or potentiometric surface (confined). These

figures are typically referred to as either water table or potentiometric maps. For the purposes of this report, all figures depicting groundwater surfaces are referred to as potentiometric maps. Potentiometric figures are constructed by plotting water level elevations for multiple wells within the same hydrostratigraphic unit on a map; then, lines of equipotential (lines representing equal groundwater elevations) are interpolated between known water level elevations in wells. Water level data used during map construction are selected from a narrow temporal window, such that potentiometric surfaces are representative of a specific point in time. However, the frequency of water level measurements may vary at each well. Spatially, some areas have a smaller density of wells than others. The number of wells used to construct a map is dependent on the density of wells in an area which are completed in similar hydrostratigraphic units. Calculated water table elevations are used for all available wells, except when data appear erroneous or there are multiple wells in close proximity to one another with similar water level elevations. In order to make the potentiometric figures more legible, only one well may be used in an area when a high density of wells are present that exhibit similar water level elevations. In these cases, the location of contour lines are not affected.

Figures 3-20 and 3-20A are potentiometric maps constructed using water levels measured during fall 2015 and fall 2010, respectively, for the shallow groundwater horizon of the SOEP/STEP areas. This horizon consists of alluvium and shallow bedrock associated with Rosebud and McKay Coal beds. The Rosebud Coal is missing (burned) southeast of the SOEP and immediately west of the Surge Pond; so first groundwater is either found in Rosebud-McKay interburden or the McKay Coal. Groundwater at this location exists under unconfined conditions and is laterally continuous with alluvium that is present beneath the SOEP and STEP. Shallow bedrock and alluvial groundwater elevations are the highest west of the Surge Pond and the area southeast of the SOEP. Water levels west of the Surge Pond indicate groundwater flow towards the SOEP.

Alluvial groundwater flows eastward under the SOEP and STEP but is interrupted by the Stage I and II Dams. Alluvial groundwater directly east of the Units 1 & 2 STEP Main Dam

flows east towards the East Fork Armells Creek alluvium. Flow in the East Fork Armells Creek alluvium is northward. The shallow groundwater intersects the Creek.

Figures 3-21 and 3-21A are potentiometric maps constructed of water levels measured in the sub-McKay hydrostratigraphic interval during fall 2015 and fall 2010, respectively. Sub-McKay groundwater generally flows to the north-northeast; this includes groundwater underneath and north of the SOEP and STEP ponds. Flow near the Surge Pond is more northward. Depressions in the potentiometric map are centered at active capture wells. The potentiometric depressions suggest that the pumping wells create localized influence on hydraulic gradient and direction of groundwater flow.

Under normal conditions, that is when capture wells are not pumping, groundwater flow in the shallow units (i.e. alluvium and coal-related intervals) of the SOEP and STEP areas generally mirrors surface topography. Alluvial groundwater of an ephemeral tributary drainage flows eastward under the SOEP, STEP, and directly east of the Units 1 & 2 STEP Main Dam towards the East Fork Armells Creek alluvium. Flow in the East Fork Armells Creek alluvium is northward.

The direction of flow in sub-McKay bedrock on the west side of East Fork Armells Creek is generally to the east/northeast. Where the sub-McKay bedrock sub-crops in East Fork Armells Creek alluvium, groundwater flow from the shallow bedrock issues to the alluvium. Alternatively, deeper sub-McKay bedrock strata that does not sub-crop in the alluvium may follow a more regional groundwater flow path towards the northeast. Note that regional groundwater flow in the Tongue River Member of the Fort Union Formation has been reported to be generally eastward (Van Voast, W.A., and Reiten, J.C. 1988). Flow beneath the SOEP/STEP area is generally in a northeast direction but may turn more eastward outside of the area.

3.3.3.1 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. 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 separating them, 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 unless there are enhanced secondary porosity resulting from interconnected fractures. 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 either 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.

Accepted 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; 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, over the perforations, and then backfilling with bentonite (chips or slurry) to the ground surface. A solid seal forms once the bentonite has hydrated with formation water. Note too, however, that high sodium content water may affect the bonding strength of bentonite, potentially weakening a seal.

Figure 3-22 contains hydrographs for various paired or nested wells, or for wells in very close proximity to one another. The hydrographs illustrate the potentiometric head in each well and head differentials between separate units. Observations for the hydrographs (Figure 3-22) 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 STEP area is highest in hydrostratigraphic intervals with the highest elevation head; and hydraulic head decreases with formation elevations.

- 389A-P, 390D-P, and 950D (south of SOEP) – These wells are located southeast of the SOEP (see Figure 3-24). Well 389A-P is completed in first groundwater coincident with shallow weathered sandstone. Stratigraphically, the shallow interval at this location is equivalent to the Rosebud-McKay interburden but it exists under unconfined conditions. The Rosebud Coal is missing at this location. Well 390D-P is completed in the first water-bearing sub-McKay bedrock; and well 950D is the completed in an even deeper sub-McKay interval. Groundwater capture is being

conducted in the interburden horizon at well 976D and in the first sub-McKay horizon at well EAP-119; but capture well pumping in this area does not affect the prevailing vertical flow direction. Hydraulic head is greatest in the shallowest well (389A-P), intermediate in the middle saturated interval (390D-P), and lowest in the sub-McKay at well 950D. Assuming a hydraulic connection between the three intervals, the vertical gradient is downward.

- 374S and 979S (South of SOEP) – These paired wells are completed south of the SOEP and west of the Surge Pond. Both wells are completed at different depths in a common hydrostratigraphic interval that includes the McKay Coal. Based on well completion depths and typical water level elevations, a vertical hydraulic gradient of approximately 0.025 exists at this well pair. The direction of flow is downward.
- 397D, 398D, and 399D (north/northwest of SOEP/STEP) – A battery of three wells (397D, 398D, and 399D) was completed in successively deeper intervals of sub-McKay bedrock north of the SOEP/STEP areas. Specifically, well 398D was completed in the shallowest sandstone bedrock interval from 3,174.3 feet to 3,212.8 feet of elevation; well 399D was completed in the intermediate interval from 3,141.6 feet to 3,160.6 feet of elevation; and 397D was completed in the deepest unit from 3,063.2 feet to 3,087.2 feet. Hydrographs for these wells, included in Figure 3-22, indicate a hydraulic head differential of approximately 32 feet between the upper (398D) and intermediate (399D) sandstones. A differential of about 22 feet of head exists between the intermediate (399D) and deepest (397D) sandstones. The differences in hydraulic heads between the wells at this location indicate there is likely very little vertical connection between units.
- 921A and 958D (STEP Cell E) – These paired alluvium (921A) and bedrock (958D) wells are located on the dike between STEP Cell E and Cell A. Based on groundwater quality impacts observed at well 958D, there may be a hydraulic connection between the shallow alluvium and the bedrock unit. The head differential at this location is consistent with that observed elsewhere in the STEP area and suggests a downward vertical gradient. Well 958D was converted to a groundwater capture well in 2010. Prior to the start of pumping in the bedrock well, the vertical gradient was approximately 0.3. The already steep vertical gradient was increased to

greater than one after pumping began. Note that a vertical gradient greater than one can likely only be achieved by artificially lowering hydraulic head (i.e. pumping) in the downgradient unit.

- 2029D and 2030A (East of STEP Main Dam) – These paired wells were installed east of the STEP Main Dam to monitor groundwater in alluvium and shallow bedrock. A hydraulic connection is thought to exist between alluvium and bedrock at this location because shallow bedrock sub-crops in the East Fork Alluvium east of this well pair; and water level trends at 2029D and 2030A are nearly identical. Based on well completion depths and the hydraulic head differential between the wells, a downward vertical gradient of 0.01 is typical at this location.
- 972D and 913A; and 919D and 918A (Downgradient areas east/northeast of STEP Main Dam) – These well pairs are located east of Colstrip SES. Each of these well pairs targets sub-McKay bedrock and alluvium of East Fork Armells Creek. Unlike well 2029D, the bedrock completion interval at wells 972D and 919D is deep and not directly hydraulically connected to the alluvium. The lack of hydraulic connection is evident by the lack of water level response in well 972D when the water level in nearby well 913A was drastically lowered due to capture system pumping. Under static (non-pumping) conditions, hydraulic head in alluvial wells 913A and 918A is greater than that in the underlying bedrock.
- 995DD, 951D, 2037D and 2038A (Industrial Park Area, East of STEP) – These wells are located near Talen's eastern property boundary; on or west of the former Moose Lodge property. Wells 951D and 995DD are completed in hydrostratigraphic intervals that are deeper than any active capture wells in the area. Well 2037D is completed in the first water-bearing sub-McKay interval that is subject to groundwater capture by nearby wells such as 927D, 928D, and PW-704D2, among others. Well 2038A is completed in alluvium on the margins of the East Fork Armells Creek alluvial deposit. Nearby capture wells in the alluvial interval include 377A and 378A. Hydrographs for wells 2037D and 2038A exhibit some variability in response to pumping at nearby wells; however, a comparison of hydraulic head between each of the four completion intervals targeted by 2038A, 2037D, 951D, and

995DD indicates a general trend of declining head in successively deeper strata (i.e. a downward vertical gradient).

3.3.4 Hydraulic Parameters

Hydraulic properties of SOEP/STEP Site hydrostratigraphic units are listed below. The parameters were used in development of the groundwater flow model documented in Appendix A. The geometric mean was used to calculate the average transmissivity, hydraulic conductivity, and storativity of SOEP/STEP area hydrostratigraphic units. Geometric mean was calculated by multiplying the values in a data set together and then taking the nth (number of values in data set) root of the product. A geometric mean indicates the central tendency or typical value of a set of numbers by using the product of their values (as opposed to the arithmetic mean which uses their sum). For aquifer parameters that vary by more than two orders of magnitude as well as those with log-normal distributions (e.g. hydraulic conductivity), the geometric mean is often thought to be more representative of average values than the arithmetic mean (Fetter, 1988).

Aquifer Properties from SOEP, STEP, Plant Site, and Colstrip Townsite Areas						
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	225	18.3	0.15	355	12	0.0003
Rosebud	149	12.5	0.9	65	12	N/A
Interburden	13	1.1	0.02	39	13	N/A
McKay	26	2.3	0.06	9.3	10	N/A
Sub-McKay	41.5	2.5	0.03	242	14.1	0.0008

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	1,900	0.00007 – 492	--
Rosebud	1.3 – 1,700	0.1 – 68	--
Interburden	28	0.9	--
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.

3.3.5 Surface Water – East Fork Armells Creek

Talen has conducted 18 synoptic runs on East Fork Armells Creek (the Creek) in 1993, 1994, 1996, 2000, 2003, 2004, 2005, 2007, 2008, 2009, 2010, 2011, 2012, 2013, spring 2014, fall 2014, spring 2015, and fall 2015. A synoptic run, also referred to as a seepage run, consists of surface water monitoring along a reach (section of a stream between two designated points) of a creek or river to characterize flow and water quality conditions. Synoptic run monitoring sites within the SOEP/STEP area are shown in Figure 3-23. Locations for synoptic run sites upstream of the SOEP/STEP area are in Appendix H, which contains a technical memorandum for the Spring 2015 synoptic run. Synoptic run sites on East Fork Armells Creek are as follows.

- AR-12 – Upstream of Plant Site and directly upstream of Highway 39.
- AR-5 – Directly upstream of the culvert located on Currant Drive. This location is west of the Units 1 & 2 A and B Ponds and northwest of Units 1 & 2 Blowdown Pond C North and South Ponds.
- AR-4 – Directly upstream of the culvert on Willow Avenue. This site is a very short distance west of the Units 1-4 Sediment Retention Pond.
- AR-3 – Upstream and upgradient from the City of Colstrip Wastewater Treatment Plant settling ponds.
- AR-2 – Also known as the South Flume, this site is located downgradient and downstream of the two easternmost City of Colstrip Wastewater Treatment Plant settling ponds and adjacent to the westernmost pond (North Sewage Effluent Pond).
- AR-1 – Also known as the North Flume, this site is located downstream from the City of Colstrip Wastewater Treatment Plant settling ponds, downstream of a tributary that drains the town site, downgradient from the Surge Pond, and downstream from Power Road. This site is also downgradient from the boundary between the Plant Site and Units 1 & 2 Stage I and II areas.
- AR-9 – Located about midway between AR-1 and the Ponderosa Butte Golf Course.
- AR-8 – Located on Ponderosa Butte Golf Course upstream from the irrigation holding pond. This pond receives treated water via pipeline from the City of Colstrip Wastewater Treatment Plant.

- AR-7 – Located on Ponderosa Butte Golf Course downstream from the irrigation holding pond and upstream from the confluence of the tributary that holds the SOEP and STEP.
- AR-6 – Located downstream from the City of Colstrip sports fields (baseball, softball, soccer, etc.) and downstream from the confluence of the tributary that holds the SOEP and STEP.
- AR-11 – Located on the Ponderosa Butte Golf Course between sites AR-6 and AR-10.
- AR-10 – Also known as the Pine Butte Road Flume this site is located at the northern edge of the golf course and upstream of Pine Butte Road.

As shown on Figure 3-23 synoptic run sites AR-1, AR-9, AR-8, AR-7, AR-6, AR-11, and AR-10 are within the area defined as the STEP/SOEP Site for the purposes of this and subsequent AOC reports. A small tributary, known as the Power Road Tributary, is also included in the reach of the Creek within the STEP/SOEP Site boundary. This site is typically dry. The first sites on the Creek upstream of the STEP/SOEP Site are AR-2 and AR-3. These upstream sites are adjacent to the City of Colstrip Wastewater Treatment Plant settling ponds.

Synoptic runs have routinely been conducted in the spring of the year before the golf course begins irrigation and/or fertilization practices, and before vegetation growth is sufficient to cause significant evapotranspiration effects on stream flow and water quality. More recently, two synoptic runs have been conducted in the spring and fall of the year (October of 2014 and 2015). In October, golf course irrigation practices have concluded for the year and most vegetation has gone dormant. The timing of spring and fall synoptic runs is intended to monitor the stream during “baseflow” conditions. Baseflow conditions exist when the Creek flow is the result of groundwater contributions and are not affected by precipitation or artificially caused runoff events. Synoptic runs are conducted over a short period of time to minimize diurnal flow variations. Higher flows, attributable to runoff from snowmelt, typically occur between February and March. Runoff is magnified due to rain on snow events and/or when snowmelt cannot infiltrate due to frozen conditions. Lowest flows

typically occur in late summer and early fall due to evapotranspiration affects. Short term high flows also occur in response to intense rainfall and runoff events.

Stream reaches may be defined as gaining (increasing in flow) or losing (decreasing in flow) based on flow measurements. Gaining reaches are supplied by groundwater inflow; while, surface water recharges groundwater in losing reaches. Occasionally, groundwater levels and quality are also monitored in association with the synoptic run. Groundwater levels higher than the Creek are indicative of areas that are likely flowing into the Creek (gaining); conversely, lower groundwater levels are suggestive of places where surface water is recharging groundwater (losing). In some reaches, groundwater levels are higher than the level of the Creek on one side and lower than the level of the Creek on the other side. This indicates that groundwater is flowing into the Creek from the bank with higher groundwater levels; and water is flowing out of the Creek toward the side with lower groundwater elevations. This flow pattern is typical at meander bends, where the Creek flow is temporarily perpendicular to the direction of groundwater flow.

Average surface water discharge measured during synoptic runs conducted since 1993 show a losing reach near the southern boundary of the SOEP and STEP area, between the North Flume (synoptic run site AR-1) and AR-9, which is about 1,250 feet downstream of AR-1 (see Figure 3-20). Average flows downstream of AR-9 are relatively constant, although slight losing and gaining reaches are observed. The variations are generally within the margin of error for the stream gaging conditions along the Creek (Hydrometrics, 2012).

3.3.5.1 Synoptic Run Results - Current Conditions

Current conditions of East Fork Armells Creek are summarized herein based on results of the Spring 2015 synoptic run. During the Spring 2015 synoptic run event, 14 surface water sites were monitored, including 12 sites on the Creek, one tributary, and one pond. Water quality samples were collected and flows were measured at twelve sites on the Creek. A sample was also collected from the City of Colstrip Wastewater Treatment Plant settling pond. Standing water was present in the Power Road Tributary; but no sample was collected. Groundwater elevations were measured at boreholes adjacent to the Creek at 19 sites; the groundwater

elevations were paired with surface water elevations to evaluate gaining and losing patterns. In addition to groundwater and surface water observations, sediment samples were collected from the streambed at 12 sites (AR-1 through AR-12, see Appendix H) along the Creek in 2015. All of the samples were analyzed for an extensive list of parameters (Appendix H). A copy of the March 2015 East Fork Armells Creek Synoptic Run Technical Memorandum is included in this report as Appendix H. Appendix H also includes figures showing losing and gaining reaches of the Creek based on flow measurements between 2005 and 2015 and trend plots of SC, sulfate, boron, chloride, and the calcium to magnesium ratio for all synoptic runs through spring 2015.

Figure 3-23 shows the synoptic run monitoring sites within the SOEP/STEP area that were monitored during the March 2015 (spring) synoptic run. Appendix H contains a technical memorandum with results of the synoptic run and maps showing the location of each site. Flows measured during the Spring 2015 synoptic run were above average; however, flow gaining and losing patterns for the Spring 2015 synoptic run were similar to patterns observed during previous events. That is, flow increased across reaches where it normally increases, and decreased over reaches where it normally decreases. Flow is typically the lowest at upstream site AR-12 and increases in a downstream direction. During recent years, however, flow has increased between AR-12 and AR-5, decreased between AR-5 and AR-3, and increased downstream of AR-2. Decreases in flow between AR-5 and AR-3 are likely the result of groundwater capture conducted on the east side of the Creek on the Plant Site. In spring 2015, a slight increase in flow was observed between AR5 and AR-4. Flow patterns in the reach of the Creek within the STEP and SOEP Site boundary in spring 2015 were similar to previous years. Flow decreased between AR-1 and AR-9; and an overall gradual increase in flow occurred from AR-9 to AR-10.

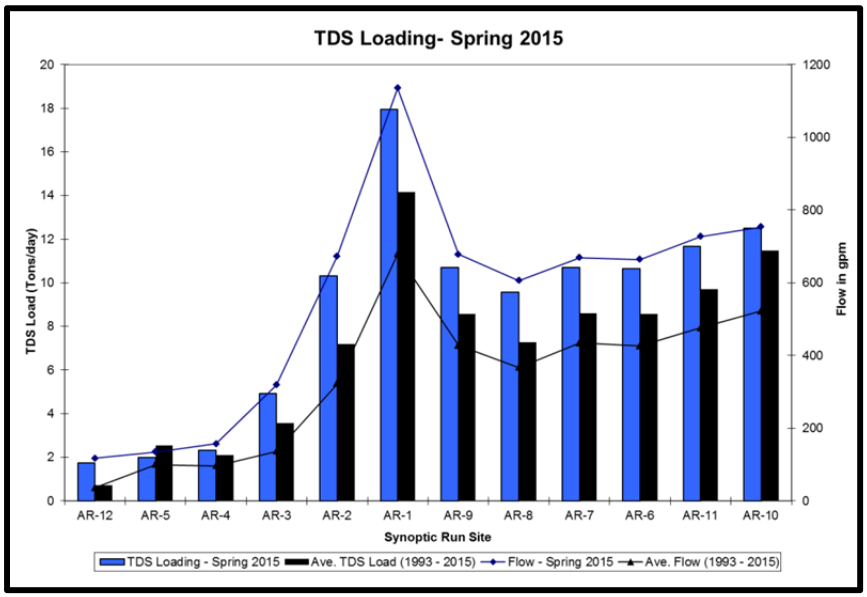
Groundwater elevations were measured at 19 sites and compared to adjacent surface water levels in the Creek. About half of the sites showed likely gains and about half showed likely losing conditions. The data from the stream gaging and water level measurements demonstrate that the Creek has multiple areas that either gain or lose water; however, results

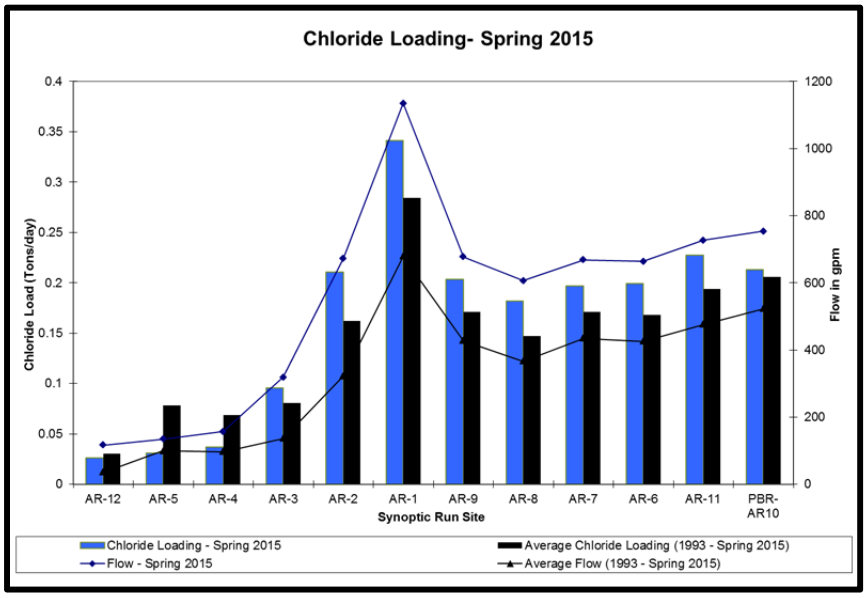
for spring 2015 were consistent with stream flow observations and indicate that overall the Creek shows a net increase in flow (gain) through Colstrip.

Graphs of chemical constituent concentrations for the various indicator parameters at synoptic run sites are in Appendix H. In general, concentrations of indicator parameters have declined with time in the reach of the Creek adjacent to the Plant Site and STEP/SOEP area. Improvement in water quality through this reach is likely the result of ongoing groundwater capture efforts, best management practices by Talen, water management practices of the City of Colstrip, and improved water quality from upstream.

The load or loading rate of a chemical constituent in surface water is a function of volumetric flow rate and the concentration (mass per volume) of a given chemical constituent in the water. An equal loading rate can be achieved for a stream with either high or low concentrations of a given constituent, provided that the flow rate changes in proportion to the difference in concentration of the chemical constituent. Thus, loading can either be dictated by high concentrations and low flow or by low concentrations and high flow. Loading rates are seen to increase in the downstream direction in East Fork Armells Creek. Because there is only slight variation in concentrations of chemical parameters between sites, loading increases are driven by increasing flow rates. The following two charts illustrate loading versus flow in the stream for Total Dissolved Solids (TDS) and chloride in spring 2015. TDS is used for this comparison since it is a concentration value available for simple load calculations. SC and TDS values typically show parallel trends so use of TDS as an indicator for comparison of loading is reasonable.

TDS concentrations were the highest (2,760 mg/L) at site AR-10; however, loads were the highest at AR-1 (TDS – 2,630 mg/L) because the flow rate is greater at AR-1, as influenced by the wastewater lagoons and the Surge Pond. Chloride concentrations were generally very similar at all sites on the Creek in spring 2015 (ranging from 38 mg/L to 52 mg/L); however, the chloride load increased in the downstream direction in accord with increases in flow. Other indicator parameters (sulfate, boron, calcium, and magnesium) showed trends very similar to those illustrated as follows.





Although groundwater quality samples were not collected in spring 2015, previous synoptic run results suggest that shallow groundwater along the Creek is primarily a magnesium-sulfate type. Surface water of the Creek is also of a magnesium-sulfate type, which supports a conclusion of a connection between groundwater and the Creek. Constituent concentrations in shallow groundwater vary in relation to adjacent surface water sites. In general, groundwater samples near the upstream creek sites exhibit higher constituent concentrations than the adjacent creek samples; and groundwater samples along the lower

creek sites have constituent concentrations generally similar to or lower than the adjacent creek.

Twelve sediment samples were collected during the Spring 2015 synoptic run from upstream of the surface water sample locations along the Creek. Soil textures were not evaluated in 2015; but results of textural analysis from previous synoptic runs indicates that surface stream sediments range from silty loam to sandy loam. Soil pH ranged from 7.4 to 7.8; and sodium adsorption ratios (SAR) ranged from 1.63 to 3.63 in spring 2015. Metals concentrations were variable. Ranges of concentrations of select trace metals reported for sediment from synoptic run monitoring sites in the SOEP/STEP area were:

- Arsenic - 0.9 to 3.0 mg/Kg;
- Beryllium – 0.11 to 0.46 mg/Kg;
- Cadmium - <0.5 to 0.16 mg/Kg;
- Copper – 3.9 to 10.1 mg/Kg;
- Lead – 2.52 to 8.04 mg/Kg;
- Mercury - <0.1 mg/Kg;
- Nickel – 4.4 to 10.6 mg/Kg; and
- Selenium – 0.2 to 0.4 mg/Kg.

Full results of the sediments analysis are included in Attachment 1 of the technical memorandum in Appendix H.

3.3.6 Simplified Conceptual Groundwater Model

A detailed conceptual model for the STEP and SOEP Site 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 SOEP/STEP 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 SOEP and STEP areas 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 south and west of the STEP and SOEP areas; but this seam is absent from the SOEP and STEP area proper. Clinker, resulting from in situ burning of the coal (Rosebud and McKay) is present in the southwestern extent of the SOEP area. The cross sections in Figures 3-1 through 3-3 show typical SOEP and STEP area geology.

Groundwater at the site is present in alluvium and shallow bedrock, which may include Rosebud-McKay interburden, McKay Coal, and sub-McKay. Shallow groundwater found in alluvium is typically unconfined, although some semi-confined conditions exist where fine-grained sediments overlie coarser grained water-bearing sediments. Groundwater in the McKay Coal and Rosebud-McKay interburden is typically unconfined. Confined conditions are common in deeper sub-McKay units found in the SOEP and STEP areas.

Hydraulic conductivity is variable in all hydrostratigraphic units of the SOEP and STEP areas. The alluvium typically exhibits the highest hydraulic conductivity (avg. ~ 18 ft/day or less); while, shallow units related to the coal seams (excluding clinker) and sub-McKay bedrock typically exhibit relatively low hydraulic conductivity (1.1 to 12.5 ft/day). Hydraulic conductivity of the clinker varies but is typically very high (exceeding 2,500 ft/day) and depends on the amount of fine grained sediments that have moved vertically into the available pore spaces and the degree and nature of fracturing. Because clinker is so well drained, it is not a significant groundwater reserve in the STEP and SOEP areas. Flow through clinker is not considered in either the conceptual groundwater flow model or the numerical groundwater flow model presented in Appendix A.

Groundwater in the coal related intervals south of the SOEP and west of the Surge Pond flows in a northerly direction and is laterally continuous with flow in alluvium of an ephemeral tributary drainage that travels eastward under the SOEP/STEP. Flow in the alluvium in the drainage is blocked by the SOEP and STEP Main Dam. Flow from alluvium

of the ephemeral drainage flows east of the Units 1 & 2 STEP Main Dam towards the East Fork Armells Creek alluvium. Flow in the East Fork Armells Creek alluvium is generally northward. The direction of flow in sub-McKay bedrock on the west side of East Fork Armells Creek is generally to the east/northeast. Groundwater flow from the sub-McKay bedrock flows to the alluvium where the bedrock sub-crops in East Fork Armells Creek alluvium. Alternatively, sub-McKay bedrock that does not sub-crop in the alluvium may follow a more regional groundwater flow path towards the northeast. As noted previously, natural vertical gradients between units are universally downward in the STEP and SOEP areas. Reductions in hydraulic head caused by capture system pumping may potentially reduce the downward gradients.

Groundwater quality is variable and is discussed in detail in Section 3.3.2. 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, infiltration of domestically used water (lawn water) east of the STEP, infiltration from the Creek in losing reaches, minor percolation through the closed SOEP, seepage from the lined STEP, City of Colstrip Sewage Lagoons, and seepage from Castle Rock Lake (a.k.a. the Surge Pond). The Surge Pond supplies the majority of the water used at the facility, town, and the Rosebud Mine. It is considered to be a major source of recharge in the STEP and SOEP areas. Groundwater discharges include flow to the Creek, evapotranspiration, and extraction from groundwater supply wells and capture wells.

Surface water (other than ponds) is limited to East Fork Armells Creek, which flows from south to north adjacent to the SOEP and STEP areas. East Fork Armells Creek is a gaining reach from the upstream end of town at the Highway 39 road crossing to the northern end of Ponderosa Butte Golf Course, located two miles north of Colstrip. Increases in flow to the Creek are from groundwater on both sides of the Creek, from the City of Colstrip Wastewater

Treatment Plan settling ponds, and from surface water additions from minor tributaries. Flows vary seasonally in response to precipitation, urban uses, and upstream activities.

3.4 DESCRIPTION OF COMPLETED AND ONGOING REMEDIAL ACTIONS

Talen conducts extensive activities associated with groundwater in the SOEP and STEP area. These activities include routine operational groundwater monitoring, groundwater mitigation, 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. These actions are discussed in the following sections. The combination of the activities described below provide a summary of current site conditions, and current or planned future activities that will be conducted to further improve groundwater conditions in the vicinity of the SOEP and STEP process ponds.

3.4.1 Operational Monitoring

Talen conducts operational monitoring in and around the SOEP and STEP at a network of monitoring and capture wells. The monitoring program is outlined in the site monitoring plan (Appendix B Talen Montana, December 2015, WRMP). The monitoring plan includes lists of monitoring wells, monitoring frequency for ponds and wells, analytical parameters, and evaluation and reporting criteria. New wells are sampled and evaluated for addition to the monitoring program when the monitoring plan is updated. In 2015, 382 wells were sampled; 214 during the first half of the year and 168 during the last half of the year. Many of the wells are sampled twice a year with the largest sampling being during the first half of the year.

Sampling frequency has been determined in coordination with the MDEQ and is designed so changes in water quality are identified. Biannual sampling is conducted at most of the wells to allow seasonal variations to be documented. Wells that are considered critical for detection monitoring or to evaluate current water quality conditions are generally monitored twice a year. Less frequent monitoring is conducted at wells that are located in less critical locations or in areas where sampling intervals are less critical to the evaluation of

groundwater conditions. Less frequent monitoring is also conducted on wells that have been installed for specific investigational purposes but are not critical for the overall evaluation of an area, typically because of the high density of wells.

Well samples are most commonly analyzed for 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. With the exception of selenium, these parameters are present in the process water at relatively high concentrations. Hence, many of these parameters are used as indicators of the presence of process waters. Broader spectrum analyses were conducted from the mid 1970's to the mid 1980's. The analytical parameter list has been modified to the current list based on discussions with MDEQ and results of prior analysis. Mercury is analyzed at a few select sites. These sites are at locations that are considered as "sentinel" type wells, that is, they are in locations that would likely be most susceptible to impacts from efforts to remove mercury from the flue gas.

Talen samples pond water from cells within the STEP typically at least once every three years. Pond samples have also been collected and analyzed for a more extensive list of parameters than indicated in the monitoring plan. In 2015, samples were also collected from four cells in the STEP and from the Units 1 & 2 STEP Main Dam Sump. Data are included in Table 2-3.

East Fork Armells Creek is the only natural surface water body in the SOEP/STEP Area. The monitoring plan includes three surface water sites along East Fork Armells Creek (South Flume – AR-2, North Flume – AR-1, and the PBR Flume – AR-10). However, samples are collected independent of the operational program from several sites on East Fork Armells Creek during periodic synoptic runs. Synoptic runs began in 1993 and have been conducted annually in the spring since 2007 (see Section 3.3.5 and Appendix H). A total 12 sites along East Fork Armells Creek are sampled during the synoptic runs. This includes the South Flume – AR-2, North Flume – AR-1, and the PBR Flume – AR-10. Spring and fall synoptic

runs were conducted in 2015. In 2015, each of these sites was monitored for flow and water quality samples were collected if water was present. Surface water samples from East Fork Armells Creek were analyzed for dissolved oxygen, pH, SC, TDS, alkalinity as $CaCO_3$, nitrate plus nitrite, sulfate, chloride, bromide, bicarbonate as $CaCO_3$, carbonate as CO_3, total boron, calcium, magnesium, potassium, mercury, selenium, and sodium. Groundwater samples have been collected as part of past synoptic runs. Groundwater samples were not collected during 2015 synoptic runs although groundwater elevations were surveyed. Appendix H contains the memorandum for the Spring 2015 synoptic run.

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 year are summarized in annual 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 SOEP and STEP 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 surface 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.

Evaluations of these data are used to identify changes in the groundwater system. Any changes in the system are evaluated to identify those that may be caused by process pond activities. 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. Groundwater mitigation is initiated following the identification of impacted waters as indicated by increases in concentrations of indicator parameters or levels of indicator parameters in new wells. Other factors, such as location, groundwater flow paths, and historical use of an area are also considered when evaluating impacts.

3.4.1.1 Water Level Measurements

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 Appendix B of the WRMP (Talen, 2015) are measured. Newly installed wells may also be monitored on a monthly basis until official inclusion in the updated monitoring plans.

Monitoring wells are typically measured on either a 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. Water levels will be measured more frequently in connection with particular site activities. For example, water levels in wells may be measured more frequently if investigations are being conducted that require additional information for construction of potentiometric figures. Note also, that water levels are measured in some wells that are not routinely sampled for quality. These wells are typically associated with the Surge Pond.

Water levels in the wells are measured using electronic probes with calibrated tapes. The probes are lowered into the well until electrical contacts encounter water at which time the meter provides an audible signal and a light comes on. 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 Water Resources Monitoring Plan – Appendix B). These data (field and laboratory) are reviewed prior to shutting down any capture well. 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 or 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 will be resumed if data indicate worsening water quality.

3.4.2 Groundwater Mitigation Activities

Groundwater mitigation in the SOEP and STEP area is conducted where groundwater has been interpreted to be impacted by process water. Sixty groundwater capture wells were in service at the end of 2015. Wells 910A, 913A, 938A, and 940A are not currently pumping. 910A and 913A were turned off after pumping resulted in improved water quality at the wells (see Section 3.5). Wells 939A and 940D (capture) were shut down due to improved water quality following initial startup. Monitoring continues at any wells that are turned off due to improved water quality and are started again if water quality declines or if it is concluded that additional capture is needed in a specific area based other conditions in the area (water quality, pumping performance, etc.).

The New Clearwell and Cell D were constructed with underdrain collection. Water was not present in either of these systems in 2015. The STEP Main Dam was constructed with chimney drains (vertical drains along the face of the dam) and toe drains (pipe placed along the toe of the dam to collect seepage and water entering the chimney drains). Water that enters the drains flows by pipe to the STEP Main Dam Sump. Water entering the STEP Main Dam Sump is pumped to Cell E. Table 3-5 is a summary of the wells, the date the wells began collecting water, where the water is piped, and estimated pumping rates since 2009. Monitoring wells used to evaluate the various collection areas are listed in Table 3-6.

The majority of groundwater capture wells are located east of the Units 1 & 2 STEP Main Dam and are completed in shallow bedrock or alluvium. Locations of groundwater capture wells are shown on Figures 3-24 and 3-25. Groundwater capture wells are routinely monitored for flow, hours operated, water level, and SC. Monitoring of the capture systems is conducted to document depth to water in pumping wells, approximate pumping rates, make adjustments to maximize drawdown in the wells, and to identify problems. Maintenance requests are completed when problems arise and repairs are made by a contractor. Data collected from the capture systems are documented in a project field book and then maintained in an electronic file.

The average collection rate for all SOEP/STEP capture wells for 2015 was 183 gpm. An additional four gpm was collected by the Units 1 & 2 STEP Main Dam collection system at the Units 1 & 2 STEP Main Dam Sump and is pumped into Cell E. Note that the volume of water captured is overestimated to some degree. Scaling problems have made it necessary to operate the majority of systems without flow meters. Flow is measured at the well head through a sampling port. Therefore, flow is measured without the back pressure that is present on the system under normal operating conditions. Less water is pumped when the system is back pressured, resulting in an overestimate of measured flow and calculated capture volumes. Higher pipeline back pressures result in a higher margin of error. In some cases the overestimate can be 100 percent or more. For these reasons, the pumping rates presented in Table 3-5 have been adjusted to 75% of the measured values to compensate for backpressure effects.

3.4.3 Completed SOEP and STEP Site Mitigation Measures

Several activities have been conducted on the SOEP and STEP to assist with groundwater remediation. Each of these activities and their potential influence on the groundwater system, and associated remedial activities are described hereafter.

- Installation of an engineered cap during reclamation of the SOEP. The cap is designed to limit infiltration of storm water into the flyash and consists of upper soil layers and a capillary break above the flyash. Vegetation has been established to provide evapotranspiration. Managed grazing has been used since the early 2000's to further enhance vegetative growth and establishment of native communities. Studies have been conducted that indicate the cap is generally successful at limiting infiltration. Furthermore, model simulations using HYDRUS analytical software and input parameters gained through site study, indicate infiltration to groundwater through the cap is on the order of 0.6 to 1.5 inches per year (3.6% to 8.8% of average annual precipitation, or approximately 4.1 to 10.3 gpm). Therefore the cap is preventing approximately 90 to 95% of the precipitation from infiltrating the cap and reaching groundwater.
- Installation of double-lined cells (New Clearwell (Cell B) and Cell D) with RPP and leachate collection in 2006. The double liner system allows capture of process water from between the liners. In addition, the presence of water under the upper liner is an indicator of potential liner problems that can be addressed to further limit the potential for losses of process water. Water was not pumped from between the liners of either the New Clearwell or Cell D in 2015 indicating that the upper liners were intact. Cell A, Cell E, and the Old Clearwell were lined with HDPE in 1992.
- Utilization of paste - a paste plant was installed at the STEP in 2008 and began producing paste in 2009. The paste process reduces the available free water by about 90% when compared to the original design and operation of the STEP. Use of the paste plant along with forced evaporation and water management practices help reduce the amount of water that is stored in the cells. 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 also lower the potential for liner failure and would act to reduce losses if liner failures occur.

- Evaporation of process water is conducted when climatic conditions allow (low winds and warm or hot temperatures). Enhanced evaporation reduces the amount of process water that must be contained in the cells.
- City water is supplied to residences and businesses east of the Units 1 & 2 STEP Main Dam to limit the potential for exposure. Private wells without well logs or completions that suggest a potential for downward movement around the annulus, will be abandoned. Well PW-704 was abandoned and replaced in 2012. There currently are no wells that are considered at risk. However, monitoring continues in late spring and fall at remaining private wells to identify changes that could be attributed to the process ponds.
- Installation of new scrubber slurry and clearwater return pipelines to replace the original pipeline. The original pipeline transported scrubber to the ponds from the Plant Site and periodically was used to return clearwater to the Plant Site. Installation of the new piping system reduces the potential for pipeline releases.

3.4.4 Planned and Continuing SOEP and STEP Site Activities

Talen continues to improve best management practices, training, and facility upgrades to improve environmental conditions in the SOEP and STEP area to aid in groundwater mitigation efforts, and to 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.

- Monitoring the Stage 1 Evaporation Pond (SOEP) Cap performance has been on-going since construction was completed in 1998. The MSU Reclamation Research Group initiated the study with test plots on the SOEP in 1990. In the 10 year summary report of 1990 to 2000 that was submitted to the Montana Department of Natural Resources and Conservation (DNRC), study results are presented with plans to manage the SOEP reclamation area for cattle grazing and wildlife habitat. Ponds are monitored for moisture movement, monitored for boron and salt movement in the cap soils and the cap vegetation, and the cap vegetation monitored for plant diversity.

Currently, these annual studies of moisture movement, vegetation performance and vegetation diversity are being conducted and the reports are being sent to the MDEQ. The SOEP will continue to be monitored for cap performance. In addition, dewatering will continue within the footprint of the SOEP to help reduce process water effects.

- Groundwater is currently being pumped from capture well 966A in the SOEP. This well encountered alluvial sediment at the base of the SOEP. Additional wells may be converted for pumping to enhance dewatering.
- Runoff from precipitation uphill or up the drainage from the SOEP will continue to be diverted around the pond. This will reduce the amount of water potentially entering the ash.
- 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.
- The New Clearwell and Cell D are double lined. The composite liners 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.
- Water will continue to be pumped from alluvium below the Old Clearwell, Cell E and the dike between the Old Clearwell and Cell D.
- Cell A, Cell E, and the Old Clearwell are lined with HDPE. These liners seem to be containing water based on analytical results at capture wells 922A, 924A, and 2019D. Groundwater sampled from these wells show low levels of bromide even through water in the ponds contain elevated levels of bromide.
- Talen will continue to promptly respond to changes in water quality, spills, or other identified problems associated with the ponds 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 minimizing effects on the environment.
- Ecological and human health risk assessments will be conducted to evaluate potential risk from the SOEP and STEP 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 goal of the training is to limit unnecessary losses of water, reduce the amount of water in the process circuit, and quickly respond when incidents occur to minimize 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 on the liner 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 SOEP. These diversion ditches and associated diversion dam will remain in place and 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.

- Scrubber slurry will continue to be dewatered using STEP Paste Plant. Use of the paste plant makes reuse and handling of the process waters more efficient by eliminating volume.
- 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 nearby (but downgradient from) 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 the induced hydraulic gradients toward the capture well using potentiometric figures and trends in water quality for monitoring and capture wells.

The induced hydraulic gradients and associated capture zones are discussed in Sections 3.3.3 and Appendix A. Results of capture analysis from the 2017 50-year model simulation (NewFields 2017, Appendix A), indicates groundwater in most areas of the SOEP and STEP with concentrations above a BSL are currently intercepted by the current capture systems. Areas where current capture systems may not be completely capturing impacted groundwater in the future include the following.

- Particles originating beneath the north and northwestern portion of the SOEP source area. These particles migrate very slowly to the north.
- Particles released beneath the southwest area of the SOEP source area. These particles migrate very slowly northeast under the SOEP Dam.
- Particles originating in the southern portion of the SOEP source. Particles originating in this area travel slowly to the northeast.
- Particles released in a small area of Layer 2 within the SOEP Dam. These particles remain within the SOEP Dam after 50 years due to the relatively low permeability of the dam material.

- Particles originating along the northern edge of Cell A (these particles represent residual impact and not seepage from Cell B). These migrate slowly north.
- Particles originating in the northwest corner of Cell E. These particles travel very slowly northeast and east.

Particles were also release outside of source areas at locations showing concentrations of some indicator parameters above the BSL. Model simulations suggest the following areas with uncaptured particles after 50 years.

- A few particles released in an area east of the SOEP in Layers 2, 3, and 4. These particles travel very slowly northeast and end up under Cell E, the Old Clearwell, or Cell D after 50 years.
- Particles originating along the north and northwest margin of the SOEP in Layers 3 and 4. These particles migrate north less than 2,500 feet within 50 years.
- An area of groundwater west of the SOEP source area is uncaptured. Groundwater in this area travels northeast under the SOEP Dam.
- Particles originating in Layer 4 north of the SOEP and Cell A and beneath Cell B. These particles travel less than 2,000 feet north of the SOEP and STEP within 50 years.
- Particles originating in an area north of Cell A (in Layer 5) and beneath Cell B (in Layer 5 and Layer 6). The uncaptured particles released north of Cell A migrate approximately 2,500 feet north and northwest within 50 years and the uncaptured particles released beneath Cell B migrate to the north and northeast and travel less than 600 feet within 50 years.

Note that these areas are not source areas; they are migration pathways with constituents that may have been derived from source areas. However, these are areas where it has been interpreted that process water from source areas has migrated into and are currently being mitigated or are targeted for additional investigation, and if necessary, expand mitigation.

It is important to note at this point that the capture zone analysis performed using the groundwater model in Appendix A provides a very conservative estimate of particles that

may not be captured. Capture zone analysis involved placing particles in areas where water quality results suggest BSLs for the indicator parameters are exceeded. The inference from this may be that if a BSL is exceeded, then the water must be impacted. This is not necessarily the case. The effect is to place particles over broader area than have actually had identified impacts. Capture systems are intended to extract groundwater containing a portion of process water, not necessarily all groundwater that exceeds a particular BSL. For this reason, it would be expected that more particles would bypass the capture systems than estimated in previous model versions when BSL values were higher.

The remainder of this section has descriptions of trends in groundwater quality. Trends for the majority of wells discussed in this section are included in Appendix I. SC is used in this analysis as an overall indicator of water quality degradation by releases from the process wastewater system. Under normal conditions, SC is proportional to the concentration of dissolved major constituent ions in a water sample (i.e. total dissolved solids). Generally, depending on the concentrations of chemical constituents in the water, particularly sulfate, TDS can range anywhere from about 2/3 to 1 times the SC value. In other words, in normal water an SC of 1,000 µmhos/cm would have an approximate TDS of around 650 mg/L. As sulfate and some other constituents increase, the relationship becomes closer to 1 to 1 ratio. Therefore, in evaluating overall trends in groundwater quality in response to remedial measures, SC is a very useful indicator of the concentration of process wastewater constituents of interest (COIs).

For the process wastewater ponds at Colstrip, the major ions are sulfate and magnesium. Sulfate is highly mobile in groundwater and contributes 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 SOEP and STEP are indicative of remedy effectiveness. Note, however, that

chloride concentrations do not decrease in all wells near the SOEP and STEP. Increasing or stable chloride concentrations which are elevated in relation to BSLs are not necessarily indicative of process water influences.

Talen evaluates capture system effectiveness by analyzing water quality trends in monitoring and capture wells downgradient from and near the capture systems. Evaluation of indicator parameter trends provides an additional line of evidence of capture system effectiveness if source area control measures are working well. In general, SC at monitoring and capture wells near the SOEP and STEP 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.

A comparison is made of highest SC measurements in capture wells to current groundwater quality data collected during routine capture system monitoring. This comparison provides a snapshot and general indication of overall capture system effectiveness. Calculated improvements in groundwater quality based on SC ranged from 2 to 64 percent (reduction in SC). The least amount (2 percent) of improvement is present at capture well 987D. The greatest amount (64 percent) of improvement has occurred at capture well 958D, where SC was reduced from 10,300 µmhos/cm to 3,870 µmhos/cm. An overall reduction in SC of 29 percent has occurred in wells in the SOEP and STEP Area. Late in 2008, the overall reduction in SC was on the order of 21 percent. The reduction in SC is an indicator that mitigation measures being taken in the area are effective where monitored. However, capture wells are placed and or converted from monitoring wells at locations that have known process water impacts and hydraulic properties (i.e. hydraulic conductivity) that are conducive to groundwater capture effectiveness. Observed increases in concentrations of dissolved constituents are not uncommon at capture wells, since the flow of groundwater with higher concentrations of process water indicator parameters is induced toward the pumping wells.

Effectiveness of remedial actions in each of seven areas, shown in Figures 3-26 and 3-27, 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. As such, a well is shown within a particular area does not in itself indicate that the well is impacted by process water. Since the boundaries are loosely defined, there is overlap with adjacent areas. Graphs of SC, sulfate, boron, and chloride trends for representative monitoring and capture wells in each of the seven areas near the SOEP and STEP are included 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.

3.5.1 Stage I Evaporation Pond

Actions taken to address source control during operation of the SOEP included a partial clay liner and chimney, blanket, and toe drains designed to capture and return water to the pond. As noted in Table 2-1, the pond was full in 1997 and completely reclaimed in 2002. Source control at the reclaimed pond includes an engineered ET cap and groundwater capture systems (EAP-119, EAP-205, EAP-208, 369D, 375D, 376D, 966A, 976D, and 2024D-2).

Groundwater capture systems associated with the SOEP area are generally located north and south of the reclaimed pond, as the STEP was constructed downgradient (east) of the SOEP, considering the natural direction of groundwater flow. The capture well network at the SOEP is not as extensive as that found east of the STEP. It is possible that most of the impacted water captured in the cross-gradient wells flowed from the SOEP under mounding conditions created during pond operation. Groundwater capture areas north and south of the SOEP are shown in Figures 3-26 and 3-27. Groundwater quality trends in the SOEP capture areas are discussed as follows.

3.5.1.1 <u>Southeast of the SOEP (Area 1)</u>

Water quality graphs for wells southeast of the SOEP are included in Figure 3-28. Groundwater capture south of the SOEP began at well EAP-119 in December 1998. Water quality improved substantially at this well immediately after pumping began. Since mitigation actions were initiated, a reduction in SC of 46 percent has been observed at EAP-119. Well 366S, located south of the SOEP but nearer the Surge Pond, has been the

subject of much discussion and evaluation over the years. Based on extensive study in the area this water appears to be from a local source, possibly from wetting of the nearby clinker following the filling of the Surge Pond. Monitoring well 366S has shown little or no change in water quality since pumping began at capture well EAP-119 (Figure 3-28). In addition, groundwater flow direction is currently northward, from the area of 366S towards capture well EAP-119.

Capture well 976D is located near the southeast corner of the SOEP. Capture began at this well in March 2007. A reduction in SC of 27 percent has been observed at 976D since capture began. Observation well 368D is paired with well 976D. Wells 368D and 976D are listed as sub-McKay completions, as indicated by the "D" designation. However, both of these wells are actually completed in the interburden interval directly above the McKay Coal. This stratigraphic setting makes the potential for flow from the SOEP into this area more feasible. Groundwater quality improved rapidly at observation well 368D in responses to pumping at well 976D. Specifically, a 61 percent reduction in SC was observed at 368D less than a year after capture at 976D began. However, water quality at 368D has begun to decline in recent years, as evidenced by increases in SC, sulfate, boron, and chloride. SC is currently only 20 percent less than the highest observation on record at well 368D. Wells 976D and 368D are completed very close to the southeast corner of the SOEP. Although, there has been some operational down time at 976D, the reason for the increase in concentrations at the nearby observation well is not clearly understood. One possible scenario is that groundwater capture at 976D has created a capture zone that results in impacted groundwater flowing through well 368D. Additional investigation is planned for this area in 2016.

Note that monitoring well 949D was installed in shallow bedrock to evaluate potential flow from the 368D area to the southeast. Well 949D does not show any evidence of process water impacts; water quality trends for this well are included in Appendix I. Talen submitted a Work Plan to further investigate groundwater quality in the 368D/976D area in 2016. The intent of the investigation is to evaluate the extent of process water impacts observed at well 368D and identify the need, if any, for additional groundwater capture south of the SOEP.

Stiff Diagrams depicting the current (2015) major ionic composition of groundwater in wells south of the SOEP (Area 1) are included in Figure 3-29. The Stiff Pattern for water previously contained in the SOEP during its operation is also included in the figure. Process water from the SOEP was of a magnesium-sulfate hydrochemical character. A similar pattern, albeit with lower concentrations (meq/L) of magnesium and sulfate ions, is exhibited at monitoring well 368D, capture well EAP-119, and 366S. As noted previously: conditions at 368D are under further investigation; groundwater quality at well EAP-119 has improved greatly in response to pumping (Figure 3-27); and dominant ions present at well 366S are thought to be from an isolated local source, most likely the base of the burned coal. The Stiff diagram in Figure 3-29 suggests that groundwater south of the SOEP tends to be dominated by magnesium and in some cases calcium-magnesium cations and sulfate anions, regardless of whether process water impacts are present.

3.5.1.2 North of the SOEP (Area 2)

Figures 3-30 and 3-31 show water quality graphs for capture wells in Area 2, north of the SOEP. Concentrations of indicator parameters, including SC, sulfate, boron, and chloride in well EAP-205 showed an increasing trend beginning in about 1987. Groundwater capture was initiated at this well in 1995. Groundwater quality continued to decline (higher concentrations of constituents) after pumping began at capture well EAP-205. Groundwater quality at EAP-205 exhibited a varied response to pumping between 1997 and 2001 but quasi-stabilized at near maximum concentrations for each of the process water indicator parameters from 2001 to 2009. Levels of indicator parameters decreased, indicating water quality improvement between 2009 and 2014; but the most recent water quality observations at EAP-205 do not exhibit the improving trend. Groundwater capture began at wells 375D and 376D in 2001. These wells are located on either side of well EAP-205. Water quality in these capture wells has been highly variable. However, several observations of SC and sulfate have been at or below BSLs since capture was initiated at both 375D and 376D; and concentrations of boron and chloride below BSLs have occasionally been observed at well 375D.

Capture well 369D (Figure 3-31) is located northwest of the SOEP and began pumping in December 1998. Water quality improvements have been observed at 369D coincident with the start of pumping and final SOEP reclamation. Current values of SC and chloride are below BSLs. Similar groundwater quality trends have been observed at monitoring well 391-D, which is located downgradient of capture well 369D. Both wells are completed in sub-McKay sandstone. Note that well 391D-P was originally only used to monitor water levels; so water quality data are only available since 2006.

Capture well EAP-208 is located west of EAP-205 and is positioned very close to the northwestern boundary of the SOEP. Groundwater capture was initiated at this well on September 27, 2001. A gradual improving trend in water quality, evidenced by decreasing levels of process water indicator parameters (i.e. SC, sulfate, boron, and chloride) has been observed since pumping began. Further, evaluation of groundwater was conducted north of well EAP-205 in 2012. Based on results of that investigation, well 2024D was converted as a capture well. Well 2024D was replaced with 2024D-2 after the original well was damaged.

Monitoring well 929D is located north of the SOEP. Groundwater at 929D does not show definitive evidence of process water impacts. Except for the most recent groundwater quality observations, a slight increasing trend in SC and sulfate has occurred at this site. Chloride concentrations exhibited the opposite trend, declining steeply throughout the period of observation. It is unclear if trends observed at 929D are a function of natural long term fluctuations in water quality or impacts from process water.

Stiff Diagrams for monitoring and capture wells located north/northwest of the SOEP (Area 2) are presented in Figure 3-32. The Stiff Pattern of process water from the SOEP, characterized prior to pond closure, is included in the figure for comparison to well water quality. Stiff Patterns for capture wells in Area 2 (i.e. EAP-205 and EAP-208) are consistent with the ionic composition of the SOEP. Wells 354D, 355D, and 370D located north of the SOEP exhibit ion distributions that are generally dissimilar to the magnesium-sulfate pattern of the SOEP. However, similar to Area 1, it is common for groundwater in Area 2 to exhibit a magnesium-sulfate character even though process water impacts are not present. Temporal

changes in the amount of dissolved cations and anions at capture well 369D are shown via multiple Stiff Diagrams in Figure 3-33. The shrinking area of the Stiff diagram is indicative of decreased concentrations of dissolved constituents in the capture well.

3.5.2 Stage II Evaporation Pond

As noted in Section 2.2.2, each of the STEP cells is constructed with a geo-synthetic liner to control seepage at the source. Liner technology used at the STEP has evolved from single lined Cells A, E, and the Old Clearwell to the more recently constructed double-lined Cells B and D. Redundant leachate collection systems (between and below liners) were also included in the double-lined cells. In addition to pond liners, water that has seeped from the ponds is controlled by groundwater capture wells installed downgradient of and within pond boundaries and chimney and toe drains installed in the face of the Main Dam. Approximately 4 gpm was captured at the Units 1 & 2 STEP Main Dam Sump in 2015. This sump is connected to drains designed to lower water pressure in the face of the Units 1 & 2 STEP Main Dam and collect water potentially seeping through the dam and into chimney or toe drains. Water from the Units 1 & 2 STEP Main Dam Sump is pumped to Cell E. A discussion of remedy (source control and groundwater capture) effectiveness in each of the capture areas associated with the STEP delineated in Figures 3-26 and 3-27 is as follows.

3.5.2.1 <u>STEP Cell E and Old Clearwell Area (Area 3)</u>

There are four capture wells that operate within the STEP boundary on the perimeter of Cell E and the Old Clearwell in Area 3. These include 922A, 924A, 958D, and 2019D. Capture system effectiveness at removing impacted groundwater from well 958D was discussed previously in Section 3.5. As implied by the "D" designation, well 958D is completed in sub-McKay bedrock. Rapid improvement in water quality at well 958D following the conversion to a capture well in 2010 suggests that either the source or pathway of process water impacts is limited in sub-McKay bedrock at the well location. Well 2019D was installed southeast of the Old Clearwell in summer 2011 and was converted to a capture well early in 2012. Well 2019D was specifically installed to replace historic capture well 955D. Prior to being abandoned in 2011, well 955D was located within the footprint of current Cell D. The initial levels of process water indicator parameters at well 2019D were slightly

greater than the final levels observed at well 955D. The discrepancy is attributable to the fact that well 2019D is located closer to the source than was 955D. Process water indicator parameter trends at 2019D indicate gradual water quality improvement since pumping began. Water quality graphs for wells 958D and 2019D are presented in Figure 3-34.

Water quality in monitoring wells 959D, 974D, and 975D, completed in bedrock directly north of the STEP, does not exhibit process water impacts. This suggests that the source of impacts is controlled from creating a flow path to the north (by mounding). Water quality trends at well 974D are included in Figure 3-34. Water quality trend plots for 959D and 975D are included in Appendix I.

Groundwater quality at alluvial capture wells 922A and 924A, completed on the perimeter of Cell E, has not shown the same level of improvement as that at well 958D. Process water indicator trends for well 922A are included in Figure 3-34. The relative lack of improvement in water quality at these wells is attributable to the lower thickness of separation and greater hydraulic connection between impacted water held in storage from previous liner tears, minor pond seepage and the shallow alluvial sediments. Although water quality has not improved in the STEP alluvial capture wells, pumping at capture wells 922A and 924A limits the flow of impacted groundwater that travels in alluvium beyond the STEP.

Stiff Diagrams constructed of 2015 groundwater chemistry observations for wells in Area 3 are compared to the Stiff Pattern of STEP Cell E water quality in Figure 3-35. Consistent with water quality observations discussed previously, the Stiff Patterns for groundwater at wells 922A and 924A most closely resemble that of Cell E, although concentrations are substantially lower. Groundwater at bedrock wells in Area 3 has a Stiff Pattern that is contrary to the extreme magnesium-sulfate dominance seen in STEP process water. The Stiff Diagrams for wells 958D, 974D, 959D, 2011D, 351D, EAP-411, and 971D illustrate the geochemical signature for groundwater in this portion of the site. Note that the groundwater for these wells does not seem to exhibit a dominant cation or anion.

3.5.2.2 East of Units 1 & 2 STEP Main Dam (Area 4)

As presented in Figures 3-26 and 3-27, Area 4 is delineated east of the Units 1 & 2 STEP Main Dam and includes wells installed between the dam crest and Talen's east property boundary. Area 4 is limited longitudinally to the narrow alluvial channel that extends eastward from beneath the STEP Main Dam and the limited northern margins of the alluvium. This area has been the focus of numerous investigations and on-going mitigation efforts; and several capture wells have been installed to collect groundwater from the alluvium and shallow bedrock. Capture wells in this area include (from the Main Dam eastward): 970D, 969D, 962D, 963D, 911D, 985A, 984D, 987D, 905D, 906D, 2013A, 2016A, and 2021D. Some of these capture wells and nearby monitoring wells are discussed individually in evaluation of the general effectiveness of groundwater capture in this area. Water quality trends in this area also inform the effectiveness of upgradient source control.

Groundwater quality trend plots for capture wells 905D, 911D, and monitoring well EAP-413 are presented in Figure 3-36A. The longest record of groundwater quality in this area occurs at monitoring well EAP-413. Levels of process water indicator parameters at this monitoring well increased gradually throughout the period of record but increased more rapidly from 2004 to 2010. More recently (2010 to 2015) water quality has improved at EAP-413. The observed water quality improvements lag behind but are generally consistent with initiation of groundwater capture at nearby wells (i.e. 905D, 906D, and 911D) and implementation of the paste plant process that led to more storage of free water in double-lined Cells B and D as opposed to active Cell E. Levels of process water indicator parameters increased sharply after pumping began at well 911D but have remained at nearly consistent levels from 2005 to present. This pattern suggests the well is effectively removing impacted groundwater but also may be indicative of a continued upgradient source area. Recent water quality improvements at EAP-413, which is downgradient of 911D, suggest that the pumping well is intercepting impacted groundwater.

Monitoring well 906D was converted to a capture well in 2006; and 905D was converted to a capture well in 2008 in response to observations of increase concentrations of indicator parameters. Values of process water indicator parameters have generally remained lower at

906D since capture was initiated. Further increases in concentrations, as evidenced by increases in SC, sulfate, boron, and chloride levels, was observed in 905D following the start of capture. Levels of these parameters have plateaued and are beginning to drop. Monitoring well 904D was installed east of the STEP Main Dam at the same time as 905D. Boron concentrations at well 904D have remained below levels that would suggest source impacts; but levels of SC, sulfate, and chloride were above the recently updated BSLs between 2005 to 2010. Recent observations of SC, sulfate, and chloride at monitoring well 904D are all at or below BSLs. Water quality graphs for wells 904D and 906D are shown in Figure 3-36B.

Well 985A was installed in fall 2007 near bedrock well 905D on the margin of the alluvial channel downgradient of the STEP Main Dam. Initial water quality observations from the well indicated that process water impacts were present. Groundwater capture by pumping began at 985A in February 2008. Levels of SC, sulfate, boron, and chloride at the capture well have remained relatively constant and indicative of impacts since pumping began. The relatively consistent water quality at 985A suggests a continued upgradient source is feeding the area immediately around the well. Water quality graphs for well 985A are presented in Figure 3-36B.

Alluvial groundwater capture wells 2013A and 2016A and bedrock capture well 2021D were installed downgradient of 985A, farther east of the STEP Main Dam. Capture was initiated at both alluvial wells in early 2012. Capture began at well 2021D in fall 2012. As seen in Figure 3-36C, levels of SC, sulfate, chloride, and boron were elevated in all three wells prior to the start of pumping. With the exception of chloride, levels of process water indicator parameters have declined rapidly, indicating an improvement in water quality. The water quality improvements suggest that the impacted water captured by these wells was held in storage within the subsurface and that the upgradient source of impacts is not persistent. It is likely that the source is controlled by upgradient capture wells, described previously. Higher than expected chloride concentrations may be indicative of a local source other than process water.

Current Stiff Diagrams for bedrock and alluvial wells are presented in Figure 3-37; and temporal changes of the ionic makeup at well 2021D in response to capture system pumping is presented in Figure 3-38. The current Stiff Diagrams are presented from top to bottom in order of increasing distance from the STEP. In general, groundwater in Area 4 exhibits a magnesium-sulfate most similar to process water at wells near the STEP; but the magnesium-sulfate dominance is muted or non-existent at the downgradient boundary of the area. Note that several wells in Area 4 do not have a Stiff Pattern indicative of a dominant ionic species (e.g. 358D, 359D, and 2029D). Further, overall water quality has improved at well 2021D, although the rate of improvement has slowed since the original pumping. Water quality at this well has continued to show decreases in TDS, SC, and sulfate levels and slight decreases in chloride, while dissolved boron concentrations have remained relatively steady.

3.5.2.3 Industrial Park Area (Area 5)

As considered in this discussion, the Industrial Park Area (Area 5) includes capture and monitoring wells that are located between Highway 39 and the STEP but south of the alluvial channel that underlies the STEP Main Dam. Area 5 is shaded magenta on Figures 3-26 and 3-27. A light industrial park borders Talen property in this area. Water quality trend plots for wells in the Industrial Park Area (Area 5) are included in Figures 3-39A through 3-39C.

Capture well 934D is located at the north end of the Industrial Park Area. This well was completed as a monitoring well in 2003 but was converted to a capture well in 2004. SC, sulfate, boron, and chloride concentrations increased in the well from 2004 to 2007 in response to pumping. Then, a general decline in process water indicator parameters (improvement in water quality) was observed from 2007 to present. Water quality trends for well 934D are presented in Figure 3-39A. Observed improvements at 934D were coincident with the start of capture well 988D, nearby. Monitoring well 988D is located near 934D, on the southern margin of the tributary alluvial deposit. This well was advanced through shallow dry alluvium and completed in first water-bearing bedrock in October 2007. Groundwater quality in the well exhibited process water impacts; and it was converted to a capture well in 2008. SC, sulfate, boron, and chloride trends, plotted in Figure 3-39A indicate that water quality has improved at this well since capture was started.

Wells 927D and 928D are capture wells and well 990D is a monitoring well located east of the STEP Main Dam. The wells are about 100 feet apart. Each of these three wells are completed in sub-McKay sandstone to elevations of about 3,100 feet msl. Wells 927D and 928D both began capturing groundwater in March 2004. Water quality has shown a slight improvement at 927D. Water quality at 928D improved rapidly after pumping began to levels similar to those observed in well 990D. The spring 2013 sample from 928D indicated an increase in indicator concentrations but are lower than prior to pumping. Water quality graphs for wells 927D and 928D are presented in Figure 3-39A. Water quality at 990D has not shown indications of process water impacts and has remained relatively constant throughout the monitoring period (Figure 3-39B).

Well 377A is one of several capture wells completed in alluvium on the East Fork Armells Creek valley margins in the Industrial Park Area. Well 377A was installed and has been a capture well since 1998. Groundwater quality at well 377A exhibited variability but no consistent trend until steady improvements began in around 2010 (Figure 3-39B). Well 382A is completed in alluvium downgradient of capture wells 377A, 378A, 991A and 994A. This well was converted to a capture well and began pumping in April 2004. Water quality has improved at this well; and SC, TDS, and sulfate levels are currently at or below BSLs (Figure 3-39B). Higher concentrations of chloride at 382A may be the result of influences from a nearby septic drain field. Dissolved boron concentrations at 382A have dropped from 14 mg/L in 2004 to 4.3 mg/L in fall 2015. The timing of water quality improvements preceded those observed at upgradient wells (e.g. 377A) by about two years. More rapid improvement at 382A is attributable to upgradient source control. Some of this improvement may be the result of the cessation of operations at the Moose Lodge and the associated septic system.

Well 998A is located the farthest south of the alluvial wells completed in the Industrial Park Area. Like the other alluvial wells, water quality has improved at 998A since pumping began in December 2008. Specifically, SC, sulfate, and boron concentrations have declined since 2008. SC and sulfate values were consistent with the BSLs at time of the original

report submittal (Figure 3-39C). However, values for these constituents have increased back to above the BSL, likely a function of variability of transport of impacted groundwater. Bedrock capture wells 2000D and 2003D were completed near 998A in the southern portion of the Industrial Park Area. Water quality at each of these wells has exhibited a general trend of improvement; but improvements are more pronounced at well 2000D. Since 2010, SC decreased from 6,860 µmhos/cm to 5,220 µmhos/cm at well 2003D. A decrease in SC from 6,080 µmhos/cm to 4,010 µmhos/cm was observed at well 2000D between 2008 and 2015 (Figure 3-39C).

Stiff Diagrams for Area 5 wells are shown in Figure 3-40. Current Stiff Patterns for most of the selected wells in Figure 3-40 are inconsistent with the highly magnesium-sulfate dominated water found in STEP Cell D. Changes in Stiff Patterns for wells 988D, 382A, and 2000D through time are presented in Figures 3-41, 3-42, and 3-43, respectively. These three wells were selected to demonstrate water quality changes in the north and south halves of Area 5 in both the alluvium and bedrock intervals. The shrinking magnesium-sulfate base of each of the Stiff Pattern polygons indicates decreased contributions of process water in local groundwater and signifies effectiveness of groundwater capture wells in this area.

3.5.2.4 Downgradient Areas (Area 6)

Figures 3-44A through 3-44C contain water quality graphs for shallow alluvium wells further east of the Units 1 & 2 STEP Main Dam. This area is named Area 6 and extends from the east Talen property boundary to East Fork Armells Creek and northward to Pine Butte Road at the north end of the Ponderosa Butte Golf Course. Area 6 is shaded gold on Figures 3-26 and 3-27.

Wells 910A and 913A are completed in alluvium directly west of Highway 39. Well 910A is 36 feet deep and 913A is 40 feet deep. Both wells are located at the confluence of the tributary drainage that holds the SOEP and STEP and East Fork Armells Creek. Groundwater capture started in June 2002 at well 910A and April 2004 at 913A. Boron, sulfate, and SC levels at both of these wells have improved to values at or below BSLs (Figure 3-44A). Conversely, chloride concentrations at 910A and 913A have increased.

These wells are relatively close to Highway 39 where salt is used for winter road maintenance and a Montana Highway Department facility where salt is sometimes stored. Salt applied to local roadways, parking lots, and work yards may enter the shallow system that are downgradient of this facility. Capture well 940A was installed in 2004; and levels of SC, sulfate, and boron have consistently been below BSLs at this well. Chloride concentrations at well 940A have been variable throughout the period of observation; but a general increasing trend in chloride concentrations is evident from 2012 to 2015. Higher chloride levels at this well could be associated with operations around the ball fields. Because other process water indicator parameters have not shown a trend of increasing concentration, chloride concentrations at well 940A are more than likely attributable to a source other than the SOEP or STEP. Well 940A is very near Highway 39 and the Ponderosa Butte Golf Course. Note that well 940A is no longer pumping.

Monitoring well 938A and capture well 939A are paired alluvial wells located on the Ponderosa Butte Golf Course. Water quality trends at both wells are nearly identical. Water quality graphs are presented in Figure 3-44B. Values of SC, sulfate, and boron have remained below the BSLs throughout the period of record at these wells. However, like other alluvial wells east of the STEP, chloride concentrations at wells 938A and 939A are greater than the BSL of 48 mg/L. Elevated chloride levels at these sites are not necessarily indicative of process water impacts. Many potential sources for chloride exist upgradient of these wells including water transported by East Fork Armells Creek from treated roadways on the highway and townsite, and from golf course maintenance of parking lots and access roads. Capture well 938A has been shut down because of the noted water quality improvements.

Capture well 916A is located about 360 feet downgradient of monitoring well 939A on the west edge of the golf course. Well 916A was originally installed as a monitoring well in East Fork Armells Creek alluvium to a depth of 17 feet bgs during July 2000. Capture began at well 916A in March 2004. Since capture began, water quality has noticeably improved. A reduction in SC from 8,100 µmhos/cm in 2002 to 4,820 µmhos/cm in 2014 has been observed at capture well 916A. Water quality graphs for 916A are shown in Figure 3-44B.

Well 935A was installed during July 2003 in the East Fork Armells Creek alluvium at a depth of about 13.5 feet. This well is on the west edge of the Ponderosa Butte Golf Course and about 800 feet north of the Colstrip baseball field. Well 935A is about 500 feet downgradient of capture well 916A, 900 feet downgradient of capture well 913A, and 1,350 feet downgradient of capture well 910A. Water quality graphs for well 935A are included in Figure 3-44B. Water quality at well 935A has shown improvement since the well was installed. This is indicated by a reduction in SC, TDS, and sulfate levels. The most recent levels of these parameters are below calculated BSLs. Boron and chloride concentrations have also declined at well 935A; but recent observations are still slightly above BSLs. The boron concentration at well 935A was 1.9 mg/L, compared to the BSL of 1.6 mg/L. The most recent chloride concentration was 56 mg/L, compared to the BSL of 48 mg/L. This well is also in a location that may have other influences besides pond water including golf course and ball park facility maintenance.

Capture wells 943A, 944A, and 945A are operated in East Fork Armells Creek alluvium north of Pine Butte Road. These wells are the farthest north (downgradient) of all of the STEP area capture wells. Capture at these wells began in April 2004. Water quality graphs for each of these wells is included in Figure 3-44C. None of these capture wells have boron concentrations that are elevated significantly above BSLs or are necessarily indicative of process water impacts; but levels of SC, sulfate, and chloride are elevated. SC and sulfate concentrations have declined at well 945A in response to pumping. SC and sulfate levels have not exhibited the same response in wells 944A and 943A. Chloride concentrations have been variable in all three capture wells. These wells are located near a strongly losing reach of East Fork Armells Creek that causes fluctuations in groundwater quality. Surface water from East Fork Armells Creek pools directly downstream of the wells. This water shows higher concentrations of dissolved constituents during times of the year due to pooling and evaporation.

942A-P is completed to a depth of 29 feet bgs in alluvium. This well is directly downgradient of capture wells 943A, 944A, and 945A, about 100 feet north of Pine Butte Road. SC and sulfate levels at 942A-P increased slightly in the year following startup of the

nearby capture wells; but steady decreases in these parameters have been observed at 942A-P since 2006 (Figure 3-44C). Similar to boron concentrations at the nearby capture wells, boron at well 942A-P is not indicative of process water impacts. Chloride concentrations at these wells are above the BSL except at well 944A. Chloride concentrations at this location are a function of the many upgradient sources resulting from urbanization and road maintenance.

Stiff Diagrams of current water quality observations at wells in Area 6 are presented in Figure 3-45. Stiff Patterns in the downgradient area are either contrary to the magnesium-sulfate hydrochemical type and/or represent minute concentrations of dissolved constituents compared to STEP process water. Changes in abundance and species of dissolved ions in groundwater at well 910A are plotted in a series of Stiff Diagrams in Figure 3-46. A reduction in TDS is illustrated by the narrower width of the Stiff Diagrams that occurs between 2004 and 2013. Most of the reduction is caused by a decrease in the amount of sodium, magnesium, and sulfate. Patterns on the Stiff Diagrams are similar after 2013 indicated little change in the type of water in the well.

A review of groundwater monitoring results indicates a significant improvement in water quality has occurred throughout the downgradient areas. Continued mitigation efforts and implementation of additional management practices will continue to result in an improved quality of water. Groundwater capture systems will be evaluated for groundwater quality and water level trends. Capture systems showing levels of process water indicator parameters that have dropped below BSLs will be evaluated for possible shutdown.

3.5.3 North 1AD Drain Pond (Area 7)

Piezometers SPN, SPS, SP3, SP4 and SP5 were installed to investigate the extent of a spill that occurred in June 2002 at the North 1AD Drain Pond (Figure 1-1). Initial samples from piezometer SPN showed SC near 7,000 µmhos/cm, sulfate concentrations near 5,700 mg/L, chloride concentrations near 90 mg/L, boron concentrations exceeding 17 mg/L, and low calcium to magnesium ratios. PPLM contained and removed the process water that was outside of the drain pond, and lowered the water within the pond to safe levels within the

structure. Based on the finding of the investigation, a shallow rectangular pit was excavated to capture the near surface water in the area that was potentially impacted by the release. A solar powered pump was installed and water that accumulated within the pit was pumped to the drain. Concentrations of dissolved constituents in the pit dropped; and in 2012 the SC was near 4,000 µmhos/cm, sulfate concentrations were near 2,500 mg/L, chloride concentrations were near 250 mg/L, boron concentrations were 1.5 mg/L, and calcium to magnesium ratios were near one. Chloride concentrations were actually higher than immediately following the spill. This area is prone to salt accumulation due to the shallow groundwater, potential sources from nearby access roads, railroad, and highway. Shallow water tables tend to concentrate salts due to the capillary action that then migrate salts upward towards the surface. The reduction of other indicator parameters in the absence of a reduction in chloride concentrations is likely a function of local sources and site conditions and only marginally from effects of the spill, if at all. Capture of the shallow groundwater in this area was stopped due to the improved quality. Water quality graphs for shallow sand points in the North 1AD Drain Pond area and for monitoring well 917A, downgradient of the Drain Pond, are included in Figure 3-47.

Stiff Diagrams for sand points and monitoring wells are included in Figure 3-48. Water quality data from the STEP D Cell was used for the Stiff diagram representing process water. Water that overflowed at the drain pit is most likely represented by this chemical signature. As can be seen, the water is strongly magnesium-sulfate type water. Stiff Diagrams for the shallow well points around the spill area demonstrate greatly reduced cation/anion amounts, especially indicators magnesium and sulfate. The vastly lower meq/L levels and slightly different patterns (most Stiff Diagrams have nonsymmetrical patterns for magnesium and sulfate when compared to D Cell) demonstrate that process water is likely not affecting the shallow groundwater at this location.. The differences in the Stiff Patterns demonstrate that influences from the spill, if any persist, are very minimal.

4.0 GROUNDWATER MODEL RESULTS AND INTERPRETATION

PPLM initiated groundwater modeling in the area in 2004. The original model was developed by Maxim Technologies (2004) and included the Plant Site and the Units 1 & 2 Stage I and II Evaporation Ponds. In 2005, the initial numerical model in the STEP area was developed by Maxim. The model is based on United States Geological Survey (USGS) MODFLOW code (Harbaugh et al., 2000).

Geomatrix updated the model in 2007 (Geomatrix, 2007). Revisions included updated interpretations of aquifer characteristics, the groundwater flow system and chemistry and integration of new hydrogeologic information obtained through installation of additional monitoring wells, well testing, and water quality sampling. The groundwater model was further refined by again updating hydrogeologic information, revising model boundaries to include a larger portion of the SOEP in addition to the STEP area, revising model layers, and including more calibration with respect to groundwater pumping system data (NewFields, 2014). A more robust code, USGS MODFLOW-SURFACT Version 3 (HydroGeoLogic, 1998) was used in the updated model to allow for variable saturation. Further refinement of the model was recently conducted by updating available data, expanding the boundaries of the model and refining model layer geometry. The updated groundwater model is included in this report as Appendix A.

Information contained in the 2017 revision includes a description of the current model input parameters and any changes since the last version. A description of the revised model design including model limits, boundary conditions, layers, and hydraulic parameters can be found in Appendix A. Calibration methods and results are presented. A sensitivity analysis was performed to identify which areas in the model were most subject to change through variations in individual parameters. Model limitations are discussed.

An updated capture zone analysis was conducted using steady-state and transient simulations. Particle tracking methods were employed to evaluate the effectiveness of the current

groundwater capture systems. Particles were simulated in multiple layers in areas with groundwater exceeding one of the updated BSLs. Note that particles do not represent constituent concentrations or BSLs but only indicate groundwater flow pathways. Additionally, placement of particles in areas with groundwater exceeding BSLs may overestimate the amount of impacted water related to process ponds that is not being captured. For example, particles were placed in areas with chloride concentrations that exceed BSLs but other indicator parameter concentrations don't. Several other sources of chloride exist in the area (de-icing, salt from domestic sources, etc.).

The capture analysis suggests that the most of the particles placed in the model are being intercepted by the existing capture system network. Areas that may not have complete capture of groundwater exceeding BSLs include; groundwater beneath the SOEP and possibly in the sub-McKay along the southeast portion of the SOEP; directly north and northwest of the SOEP; groundwater along the western and northwest edge of STEP Cell A; beneath the west half of Cell B; north and northwest of the SOEP; and near East Fork Armells Creek near wells 938A and 939A, where the BSL for chloride only is exceeded (NewFields 2017, Appendix A). Note that particle tracking focuses only on the movement of groundwater through the subsurface system and does not provide an indication of the fate of the materials. Reverse particle tracking is conducted to try to identify source areas by placing particles in areas that are considered impacted and then running the simulation backwards. Reverse particle tracks started southeast of the SOEP move to the south and west suggesting a source different from the SOEP (Appendix A).

Conclusions of the model simulations are presented in the report in Appendix A. Recommendations to address data gaps and to provide additional data for model adjustments include the following.

- Develop a more accurate method of measuring capture well pumping rates to increase model accuracy.
- Monitoring well(s) should be installed in bedrock between wells 2022D and 2023D and 2009D to evaluate the downgradient extent of process pond-affected groundwater and the feasibility of additional capture on this area based on well yield.

- Monitoring well(s) should be installed in bedrock north of well 2032D to evaluate the downgradient extent of process pond-affected groundwater and the feasibility of additional capture on this area based on well yield.
- It is recommended the feasibility of converting 903D to a capture well be evaluated. It this is not feasible, installation of an additional well in this area should be considered to evaluate feasibility of additional capture based on well yield.

5.0 IDENTIFICATION OF DATA GAPS

Bulleted items listed below are data gaps identified through review of existing data, past reports, and current water quality data. Many of these gaps in data are the basis of recommended additional work described in Section 6. Areas of the SOEP/STEP where additional work is planned are shown on Figure 5-1.

- Groundwater model simulations (NewFields 2017, Appendix A) suggest groundwater capture systems are intercepting the majority of groundwater impacted by process pond water. There were four recommendations in the most recent version of the report. These included:
    - Develop a more accurate method of measuring capture well pumping rates to increase model accuracy.
    - Monitoring well(s) should be installed in bedrock between wells 2022D and 2023D and 2009D to evaluate the downgradient extent of process pond-affected groundwater and the feasibility of additional capture on this area based on well yield.
    - Monitoring well(s) should be installed in bedrock north of well 2032D to evaluate the downgradient extent of process pond-affected groundwater and the feasibility of additional capture on this area based on well yield.
    - It is recommended the feasibility of converting 903D to a capture well be evaluated. If conversion is not feasible, installation of an additional well in this area should be considered to evaluate feasibility of additional capture based on well yield.

- Installation of multiple monitoring wells between well 903D and 355D, two wells at different depths between wells 902D and 903D, and one well northwest of wells 970D (capture) and 971D.
- Currently, flow rates at capture wells are measured from the majority of wells at the well heads. This method results in an overestimation of actual amount of water captured since pumping pressures tend to reduce pump performance. Unfortunately, many of the wells exhibit scaling problems, making use of inline flow meters

impractical. More accurate measurement of flow is necessary to better evaluate system performance. This recommendation aligns with model derived recommendations previously stated.

- Additional data are needed from the area north of the SOEP and STEP. It is recommended that additional wells be installed north of well 2032D and between well 367D and capture well 369D.
- Additional wells are needed north of the former Moose Lodge. It is recommended that paired alluvial and bedrock wells be installed at three locations, two north of the former Moose Lodge along the access road to the Colstrip SES property, and one pair along the county road between the former Moose Lodge and the State Highway Department.

6.0 RECOMMENDATIONS FOR ADDITIONAL SITE CHARACTERIZATION

- Conduct the necessary tasks to address the data gaps identified in Section 5.
- Continue groundwater capture efforts. Evaluate data 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, but monitoring would be continued. 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.
- 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 on-going site characterization.
- Continue operational groundwater and surface water quality monitoring of capture systems. Maintain capture wells as part of the sampling and analysis program.
- Make necessary repairs to groundwater capture systems as they are identified.
- Continue to implement best management practices - BMP's – see Section 3.4.
    - Continue to further educate employees regarding the importance of process water management.
- Continue to manage paste, force evaporation and conduct water management practices to reduce process water volumes.
- Continue conducting annual synoptic runs on East Fork Armells Creek. Parameters for this evaluation should be refined. Groundwater levels adjacent to the Creek should be gathered periodically so flow conditions near the Creek can be evaluated. Every other year should be a sufficient frequency for groundwater level measurements during the synoptic run. Water levels should be measured at other wells during the synoptic run so levels near the Creek can be mapped along with

those further away from the Creek. This will allow construction of a more detailed water table map.

- 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. Mitigation measures should be taken, if necessary.
- Abandon private wells east of the STEP that do not have well logs available to verify construction details or those with well logs that indicate wells are not sufficiently sealed to inhibit movement of groundwater between hydrostratigraphic intervals. Continue monitoring remaining private wells with suitable access and completion information.
- Conduct long-term pumping tests at SOEP wells 2001A and 2002A to further evaluate the effect of pumping from the alluvium on water levels in the flyash.
- Evaluate seal at well EAP-413 and replace the well if a faulty seal is identified. This shallow bedrock well shows water levels that seem to be anomalously high, similar to alluvial water levels. The high water levels are believed to be from either a poor annular seal or the result of lateral communication with alluvial sediments to the south.
- Install one or two sentinel wells along the fence line north of well 912D and east of well EAP-411. These wells would provide additional monitoring coverage near the property boundary and would provide additional model calibration information.
- Further evaluate the area around well 368D. Water quality at this well has declined recently. Water quality had improved after the initiation of pumping at well 976D. Both the interburden and deeper units should be examined.
- Update the groundwater model on a periodic basis using data obtained since the previous update. Particle tracking in future updates should focus on areas interpreted to be impacted by process waters. Introduction of particles into all areas that exceed BSLs is misleading since all of these areas may not be impacted by process waters.

- Fate and transport modeling should be considered in future models. These models simulate the movement and chemical variations as groundwater moves through the hydrogeologic system. These models are simulate the movement of chemical constituents through the system by advection, diffusion and dispersion and may provide a better understanding of the ultimate fate of any impacted groundwater.

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