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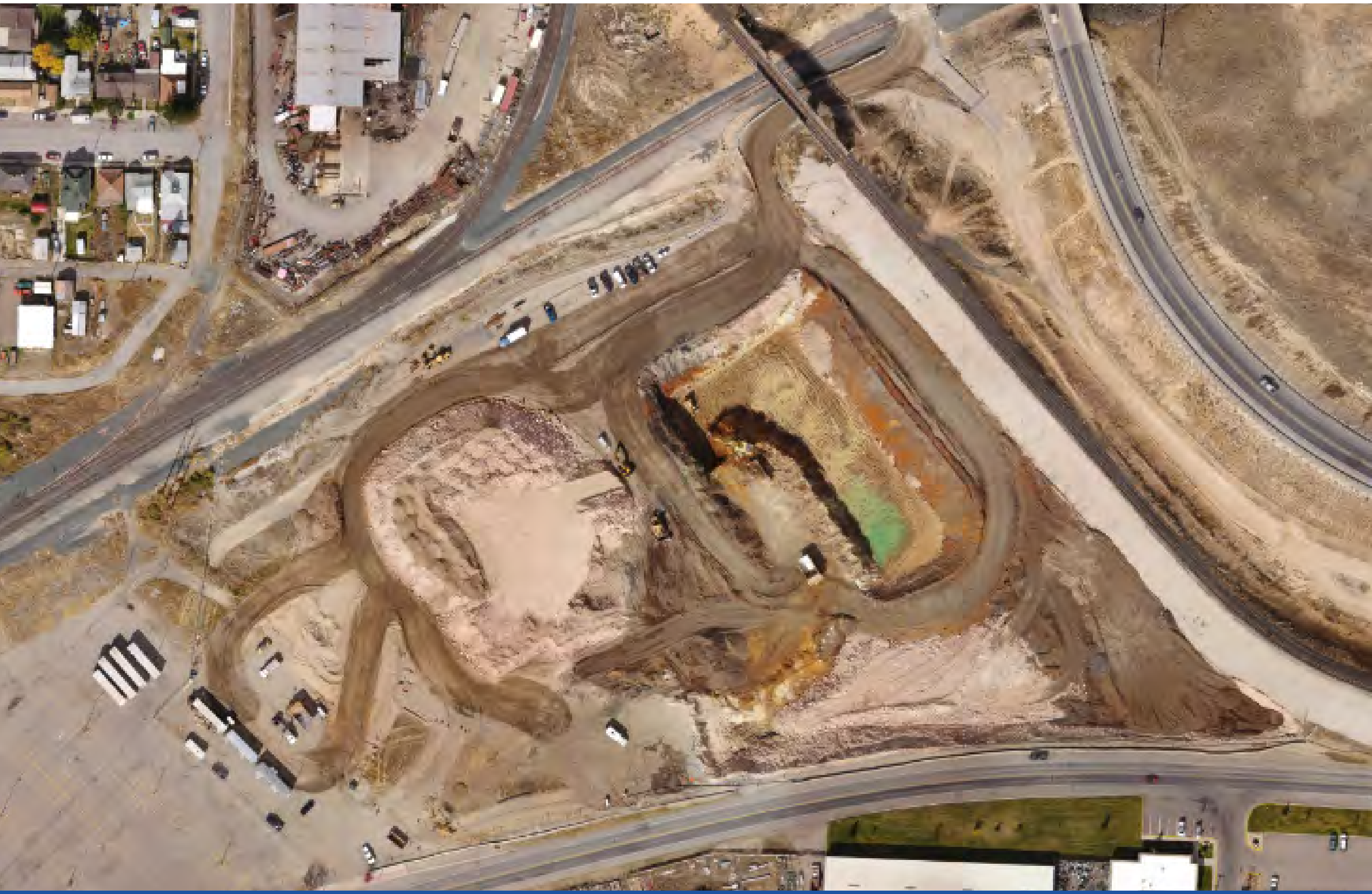

DRAFT FINAL - Butte Area One Parrot Performance Monitoring Program Conceptual Site Model Report

Butte, Montana

Prepared for:

Montana Department of Justice
Natural Resource Damage Program
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ACRONYMS

AMC	Anaconda Mining Company
BP-AR	British Petroleum - Atlantic Richfield Company
ARAR	Applicable or Relevant and Appropriate Requirements
BABCGA	Butte Alluvial and Bedrock Controlled Groundwater Area
BAO	Butte Area One
bgs	below ground surface
BMFOU	Butte Mine Flooding Operable Unit
BNRC	Butte Natural Resource Damage Restoration Council
BPSOU	Butte Priority Soils Operable Unit
BQM	Butte Quartz Monzonite
BTC	Blacktail Creek
BTL	Butte Treatment Lagoons
CCR	Construction Completion Report
CERCLA	Comprehensive Environmental Response, Compensation and Liability Act
CFRSSI	Clark Fork River Superfund Site Investigation
COC	Constituent of Concern
CSM	Conceptual Site Model
CY	Cubic yards
DEQ	Montana Department of Environmental Quality
DNRC	Department of Natural Resources and Conservation
DSR	Data Summary Report
EPA	Environmental Protection Agency
ESD	Explanation of Significant Differences
EVS	Earth Volumetric Studio
FS	Feasibility Study
HHRA	Human Health Risk Assessments
LAU	Lower Alluvial Unit

MAU	Middle Alluvial Unit
MBMG	Montana Bureau of Mines and Geology
NCP	National Contingency Plan
NPL	National Priorities List
NRDP	Natural Resources Damage Program
O&M	Operations and Maintenance
OU	Operable Unit
PMP	Performance Monitoring Program
ppb	parts per billion
QAPP	Quality Assurance Project Plan
RI	Remedial Investigation
ROD	Record of Decision
SBC	Silver Bow Creek
TI	Technical Impracticability
UAO	Unilateral Administrative Order
UAU	Upper Alluvial Unit
UCFRB	Upper Clark Fork River Basin
USFWS	U.S. Fish & Wildlife Service
USGS	United States Geological Survey
WET	Water and Environmental Technologies
WRCC	Western Regional Climate Center
XRF	X-ray fluorescence

EXECUTIVE SUMMARY

This Conceptual Site Model (CSM) report for the Butte alluvial aquifer adjacent to and downgradient of the Parrot Tailings Waste Removal Project (Parrot Tailings Project) was developed on behalf of the Montana Natural Resources Damage Program (NRDP). It presents recent data (2017 through 2019), along with supporting historical data and information that quantify groundwater conditions in a portion of the Butte Priority Soils Operable Unit (BPSOU) in Butte, Montana. This CSM is intended to inform decision makers and planners on conditions in the Upper Silver Bow Creek corridor prior to and following the implementation of the Parrot Tailings Project and other projects that may impact groundwater flow or chemistry in the area.

<u>Site History</u>

The Parrot Tailings Waste Removal Area (Figure 1) is the location of the former Parrot Smelter, which processed ore from 1881 to 1899. At its peak the smelter processed 350 tons/day of ore (Quivik 1998) and operated a concentrating plant that treated second class ore. From 1899 to 1904, the Anaconda Mining Company operated an acid precipitation plant at the site and copper processing took place there again during World War II. Wastes from these facilities were slurried into nearby Silver Bow Creek or deposited on the ground. These near stream wastes (approximately 350,000 cubic yards at the Parrot) resulted in the release of contaminated sediment into Silver Bow Creek and the alluvial aquifer, prior to their being covered. Because a significant portion of these tailings are saturated by groundwater and are susceptible to infiltration of precipitation, the wastes continue to be a primary source of groundwater contamination. The highly concentrated contaminants present in the waste materials, coupled with past practices of acid-washing and effluent discharges from the active mine have created a widespread area of mobile contaminants that have impacted groundwater originating at and downgradient of the Parrot Tailings Site.

Due to its proximity to the Butte mining district, Silver Bow Creek was used extensively for early mining and smelting operations. Tailings and other wastes from these operations were deposited directly into the creek or into tailings impoundments located very near the creek. Periodic flooding distributed the wastes downstream in the Silver Bow Creek/Clark Fork River floodplain. This has resulted in extensive contamination of the alluvium in the drainage. In the early 1930s, the upper portion of the historic Silver Bow Creek drainage was reworked into an open channel under the Work Progress Administration. This channel is surrounded by milling and smelting wastes from decades of mining.

To facilitate underground mining activities, the groundwater level in the interconnected mine workings on the Butte Hill was lowered approximately 4,200 feet from pre-mining levels via pumping. This acidic, contaminant-laden, mine dewatering effluent was released into the channel near the Parrot Complex. The effluent contaminated both surface and groundwater by flowing directly into Silver Bow Creek and infiltrating into the alluvial aquifer and migrating south towards Clark’s Park.

In 2005, the Subdrain, a buried slotted 10-inch PVC drainpipe, was installed by BP-AR directly beneath the existing Silver Bow Creek channel to capture contaminated groundwater before it discharged into Silver Bow Creek above the confluence. Historically, this highly contaminated groundwater discharge caused severe surface water quality problems in Silver Bow Creek for many miles downstream.

Parrot Tailings Project

In 2015, the Governor of Montana, as trustee for natural resources, determined it was appropriate to implement the Parrot Tailings Project, which includes substantial mine waste removal and mine waste capping where appropriate. This decision was preceded by years of investigation of this site and Butte groundwater by the State NRDP Program. To support the development of the project, NRDP completed a data gap investigation and detailed design for the project. The data gap investigation was completed in 2015, and removal design activities were completed from 2016-2018. Final design and contractor selection were finalized in early 2018, and the first phase of waste removal was finished in December 2018. The second phase of waste removal and the construction of an evapotranspiration cover system is scheduled for completion in 2021-2022. Completion of the Parrot Tailings Project will eliminate the largest localized source of mine waste-derived contaminants to alluvial groundwater within BAO.

A Parrot Tailings Performance Monitoring Program (PMP) was developed and implemented by NRDP in 2017 to establish baseline groundwater conditions adjacent to and downgradient of the Parrot Tailings Project and monitor post-project groundwater conditions over time. The PMP monitoring network consists of 25 new monitoring wells and 52 existing wells that are part of the BPSOU and/or BMFOU groundwater monitoring programs. New wells were located and designed to fill long-existing data gaps and provide additional critical insight into the hydraulic flow system and lithology of the alluvial aquifer, directly adjacent to the existing Subdrain, at the bedrock interface, and at groundwater discharge areas near the confluence of Blacktail and Silver Bow Creeks. Existing monitoring wells provide historic data for comparison to recent monitoring data trends. Continuous water levels are collected from 28 monitoring wells, monthly static water levels are collected from 77 wells, and analytical data is collected quarterly from 77 wells and 8 surface water locations on Blacktail Creek, Silver Bow Creek, and the Subdrain. This CSM report evaluates Parrot PMP data from the fourth quarter of 2017 through the first quarter of 2019; however, the PMP is ongoing.

PMP Conceptual Site Model

Utilizing data from the PMP, a Conceptual Site Model (CSM) was developed to detail the geologic framework, groundwater flow regime and mine waste contaminants impacting groundwater and surface water in the study area. It illustrates the pathways in which contaminants are being mobilized and released into the environment and provides a summary of the nature and extent of contamination within a portion of BPSOU, down to the confluence of Silver Bow and Blacktail Creeks.

Several Earth Volumetric Studio (EVS) visualizations have been developed using the PMP dataset, coupled with overlapping BPSOU groundwater data for the Upper Silver Bow Creek corridor from the Parrot Tailings Waste Removal Area to the confluence of Blacktail and Silver Bow Creeks. These data combine environmental, lithologic, and groundwater elevation data to provide a three-dimensional view of contaminant distribution within the alluvial aquifer.

Contaminants of Concern

With respect to regulatory standards for soil/solid media, surface water, and groundwater, the contaminants of concern are those identified as presenting unacceptable risks to human health or the environment in the baseline human health risk assessment and ecological risk assessment. These contaminants are memorialized in Table 7-1 of the Record of Decision for BPSOU (EPA 2006) and are provided below in Table ES-1.

Table ES-1. Contaminants by Media - Butte Priority Soils Operable Unit

Contaminant:	Solid Media	Groundwater	Surface Water
Aluminum			✓
Arsenic	✓	✓	✓
Cadmium		✓	✓
Copper		✓	✓
Iron			✓
Lead	✓	✓	✓
Mercury	✓	✓	✓
Silver			✓
Zinc		✓	✓

Groundwater Characterization

Acidic conditions have mobilized the mine waste contaminants from the tailings, by first overwhelming the natural buffering capacity of the tailings (e.g. carbonate), and subsequently dissolving contaminants at increased concentrations. The extreme acidic conditions have resulted in super-saturated groundwater conditions for contaminants such as copper and zinc which are mobilized in the environment, particularly zinc which is highly pH dependent. As groundwater migrates through the alluvial zones and contacts less impacted water, dilution occurs. The unimpacted alluvial groundwater provides a more oxidized, higher pH environment. When the impacted groundwater encounters this environment, super-saturated contaminants in the groundwater precipitate out in the alluvial pores or adhere to fine grained materials in the alluvial aquifer. These contaminants can be re-released over time to groundwater or surface water during periods of recharge (wet conditions), high flow, or other changing hydrogeologic conditions.

The PMP data defines a contaminated groundwater plume that extends from the Parrot Tailings Site west/southwest and intersects with Silver Bow Creek and Blacktail Creek. PMP and BPSOU data were used to create EVS visualizations that illustrate this plume emanating from the Parrot Tailings Site and migrating southwesterly down valley.

Although the Subdrain is effective at collecting shallow contaminated groundwater from the upper alluvial aquifer (UAU), deeper groundwater flow in the middle alluvial aquifer (MAU) appears to bypass the Subdrain. This bypass occurs in two ways: first, the Subdrain does not capture all groundwater flow from the MAU and portions of the UAU and secondly, the Subdrain fouls over time due to precipitation of contaminants in/near the slotted pipe and surrounding gravel pack, resulting in reduced efficiency in groundwater contaminant capture. This is evidenced by groundwater elevation increases as the Subdrain undergoes fouling, followed by significant groundwater elevation reductions after jetting activities are completed. The fouling plugs the gravel pack, restricting groundwater capture. As the capture efficiency of the Subdrain is reduced, contaminated groundwater bypasses the subdrain, resulting in discharge of contaminants to creek surface water and preferentially partitioning to in-stream sediments.

Zinc and Copper Mass Balance Summary

A quantitative assessment of contaminant transport through a cross-section immediately downgradient of the Parrot Tailings Site was performed to determine the total mass of zinc and copper moving from the Parrot Tailings Site in the alluvial aquifer. This analysis was completed by calculating the groundwater flux and concentration across the cross-section using aquifer parameter data from the 2010 MBMG aquifer test evaluation (MBMG 2010a) and potentiometric surface elevations and zinc and copper concentrations acquired as part of PMP monitoring. A summary of the groundwater flow and loading calculations are included in Table ES-2 below. A full description of the mass balance approach is included in Appendix F of the report.

Table ES-2. Mass Balance Load Summary – PMP Cross Section B-B'

Aquifer	Flow (GPM)	Contaminant	Mass (lbs./day)
Middle Alluvial	272	Copper	59.1
Upper Alluvial	14	Copper	7.2
		Total:	**66.3**
Middle Alluvial	268	Zinc	196
Upper Alluvial	27	Zinc	11.4
		Total:	**207.4**

These load calculations were compared to loads calculated by BP-AR in its Groundwater Management Report. BP-AR reported capture of 97% of contaminated groundwater in the upper corridor with the Subdrain but only calculated a load of 16 pounds per day of copper and 59 pounds per day of zinc (AR 2015). Loads calculated by BP-AR were based on samples collected in the Subdrain. PMP loads were calculated using actual water chemistry data from July 2018 for wells along the B-B' transect. Differences in the time and spatial location of this comparison should be noted; however, the comparison shows collection efficiencies of 24% for copper and 28% for zinc when compared to PMP loads (Table ES-2).

Table ES-3. Load Capture Efficiency Comparison

Contaminant	PMP Measured Load (lb/day) (1)	BP-AR Calculated Load (lb/day)(2)	Capture Efficiency (%)
Copper	66	16	24%
Zinc	207	59	28%

(1) Load calculations at cross-section B-B' just below the Parrot Tailings Site.
(2) BP-AR calculated the subdrain mass in the GWMR at the vault (AR 2015).

Conclusions

Based on an evaluation of data collected as part of the Parrot PMP, the following conclusions can be drawn:

- The Parrot Tailings are the most significant source of contamination in BAO alluvial groundwater.
- Groundwater contamination plumes emanating from the Parrot Tailings Site have migrated downgradient and intersect with and discharge to Blacktail Creek and Silver Bow Creek.
- This study concludes that a majority (72-76%) of contaminated groundwater leaving the Parrot Tailings Site is not being captured by the Subdrain; as a result, contaminated groundwater is partitioning to the aquifer matrix and/or discharging to Blacktail Creek and the Blacktail/Silver Bow Creek confluence area which is the only other discharge point for groundwater. British Petroleum-Atlantic Richfield (BP-AR) has reported capture of 94-97% of all contaminated groundwater in the alluvial aquifer with the Subdrain, depending on the document (AR, 2015).
- Other investigations by NRDP and the Montana Bureau of Mines and Geology within Blacktail Creek and Silver Bow Creek show clear evidence of contaminant loading from groundwater partitioning to instream sediments and instream sediment porewater.
- Precipitation of contaminants and associated fouling plugs the exterior and interior of the Subdrain, reducing its ability to capture groundwater and therefore affecting groundwater flow conditions near the Subdrain, reducing collection system efficiency of the Subdrain, and augmenting groundwater contaminant plume migration.

- Lithologic, hydraulic and geochemical data indicates a groundwater flow path from the Parrot Tailings Project area towards Blacktail Creek, bypassing the Subdrain.

- Additional monitoring wells east of Lexington Avenue and north of Majors Street would provide more detailed lithologic and hydrogeologic information with regard to bypass of the Subdrain in this area.

1.0 INTRODUCTION

This conceptual site model (CSM) report for the Butte Area One / Parrot Tailings Site was developed on behalf of the Montana Department of Justice Natural Resources Damage Program (NRDP). It presents recent data (2017-2019) along with supporting historical information that define conditions within Butte Area One (BAO) west of Montana Street, a subarea located within the Butte Priority Soils Operable Unit (BPSOU) in Butte, Montana (Figure 1).

The CSM will inform decision makers and planners on conditions in the Upper Silver Bow Creek Corridor, prior to and following completion of the Parrot Tailings Waste Removal Project. To meet these objectives, a groundwater performance monitoring program (PMP) was implemented by NRDP in 2017 both to establish baseline groundwater conditions at and around the Parrot Tailings Waste Removal footprint and to monitor post-removal groundwater quality over time. The PMP monitoring network consists of 25 new monitoring wells installed in 2017 by NRDP, as well as 52 existing wells that are part of the existing BPSOU and/or BMFOU groundwater monitoring programs. New well construction was designed to provide additional insight into groundwater behavior and composition within the upper BAO corridor (west of Montana Street), within the various layers of the local alluvial aquifer, at the bedrock interface, and in and around groundwater discharge areas near the confluence of Blacktail and Silver Bow Creeks.

Work was completed according to the *Parrot Tailings Waste Removal Performance Monitoring Work Plan* (NRDP 2017). PMP data has been acquired in accordance with the workplan starting in December of 2017. Soil lithology, water levels, and environmental data have subsequently been acquired, validated, and submitted to NRDP in a Construction Completion Report (CCR) and two data summary reports (DSRs). The following list summarizes project-specific plans and deliverables completed as part of the Parrot Performance Monitoring Plan (PMP). Relevant data from these documents used in the development of this CSM are included in Appendix A.

- *Parrot Tailings Waste Removal, Performance Monitoring Work Plan*, WET, 2017.
- *Butte Area One, Parrot Tailings Performance Monitoring Program, Construction Completion Report, Groundwater Monitoring Well Installation*, WET, 2018.
- *Butte Area One, Parrot Tailings Performance Monitoring Program, Data Summary Report, 4th Quarter 2017 and 1st Quarter 2018,* WET 2018.
- *Butte Area One, Parrot Tailings Performance Monitoring Program, Data Summary Report, 2nd – 4th Quarters 2018, 1st Quarter 2019,* WET 2019.

This report provides a summation of historic and recent data for Butte Area One and is organized as follows:

- Site Setting
- Site History
- Previous Investigations

- Parrot Tailings Removal Project
- Relevant Data
- Conceptual Site Model

Using the PMP dataset through the first quarter of 2019, coupled with overlapping BPSOU groundwater data, a site-specific Earth Volumetric Studio (EVS) visualization has been developed for the Upper Silver Bow Creek corridor from the Parrot Tailings Waste Removal Area (site of the former Parrot Smelter), to the confluence of Blacktail and Silver Bow Creeks. These data combine environmental, lithologic, and groundwater elevation data to provide a three-dimensional view of contaminant distribution within the alluvial aquifer. The EVS program is a useful tool to support the CSM analysis and illustrate the extent of groundwater impacts through the upper BAO corridor.

2.0 SITE SETTING

The following sections summarize the physical and environmental setting in the Upper Silver Bow Creek Corridor, the former Parrot Smelter Site, and adjoining impacted areas.

2.1 Land Ownership

Butte Area One is located within the northeast portion of BPSOU in the central portion of the industrial/urban area of Butte, Montana. At the northwest edge of the BAO boundary, Montana Resources, Inc. (MR) owns and operates an active copper mine. Burlington Northern Santa Fe Railway (BNSF), Patriot Railroad, and NorthWestern Energy (NWE) each have utility rights-of-way adjoining the former smelter site for rail access that services the mine site.

The City and County of Butte Silver Bow (BSB) owns the majority of property in the area of the former Parrot Smelter site, from the southern edge of the MR mine permit boundary extending to Harrison Avenue. The BSB Maintenance Center (i.e. County Shops) and the Butte Civic center, a BSB-owned public events center and its parking lots, north and south of Civic Center Road, occupy the bulk of remaining property west to Harrison Avenue.

Properties immediately west of Harrison Avenue are commercial and occupied by private businesses. Interspersed private homes and businesses are located along Casey Street and west to Kaw Avenue. The Union Pacific Railroad owns the majority of the property north of Casey Street to Front Street. BP-AR owns multiple parcels west of Kaw Avenue and extending to the Interstate-90 bridges, where they operate the Butte Treatment Lagoons (BTL) settling ponds that serve as a portion of the remedy for BPSOU. A privately owned KOA campground and the Butte Chamber of Commerce occupy property near the confluence of Silver Bow and Blacktail Creeks. Major transportation routes in the corridor include Civic Center Road, Harrison Avenue, Casey Street, George Street, and Kaw Avenue. Land ownership and major site features are shown on Figure 2.

2.2 Ecological Setting

Butte and the Summit Valley comprise the headwaters of the Clark Fork River watershed, with Silver Bow Creek, Blacktail Creek, and Basin Creek serving as the primary tributaries. Situated in a high mountain valley, the local elevation is 5,540 feet above mean sea level. The valley is characterized by its semi-arid high mountain climate. Native vegetation includes mixed conifer forests incorporating Lodgepole pine, Douglas fir, and some juniper in the foothills and mountains surrounding the valley, with Bluebunch wheatgrass, Idaho fescue, Rough fescue, Prairie junegrass and sage brush predominant in undisturbed landscapes. Willow, aspen, and cottonwoods are widespread throughout the valley along stream banks and in wetter areas (Montana Tech, 2012).

Butte and the surrounding valley is fully developed in the lowlands and up to and including many of the foothills. Most wildlife species that once inhabited the valley are no longer regular occupants. Some species have adapted to the urban setting and are found year-round, including fox, mule deer, and some rabbit species. Other large species such as elk, moose, and black bear are found throughout western Montana, inhabit the neighboring conifer forests and are occasionally found in the valley, primarily in the spring, late fall and winter during heavy snows. Many bird species are found in and around the valley seasonally, with the majority migrating to warmer climates during the winter months.

The Parrot Tailings Site and the wider BPSOU are within an urban ecological setting with limited natural terrestrial habitat. Aquatic habitat occurs along Silver Bow Creek, Blacktail Creek, in adjacent wetland areas, and in surface water ponds used to control sediments. These aquatic environments are habitat for invertebrates, fish, waterfowl, and other biota. Because of limitations on terrestrial habitat, ecological assessments have focused on the aquatic habitat of Silver Bow Creek and surface water ponds that might represent habitat for waterfowl (EPA 2006). The U.S. Fish & Wildlife Service (USFWS) has listed five species as candidates, proposed, or listed threatened in Silver Bow County. These include:

- Bull Trout (threatened)
- Grizzly Bear (threatened)
- Canadian Lynx (threatened)
- Wolverine (proposed)
- White Bark Pine (candidate)

Silver Bow Creek was once home to thriving trout populations, including Bull trout. As noted, Bull trout are listed as threatened species under the Endangered Species Act. The State and the U.S. Fish and Wildlife Service maintain a strong interest in adequate protection of aquatic receptors, which are at risk under current conditions. Restored portions of Silver Bow Creek have seen the return of limited macroinvertebrate, fish, and other species in the aquatic ecosystem. Populations should continue to increase over time as the remainder of the Silver Bow Creek Corridor and Butte Hill remedy is completed.

2.3 Climate

The Butte area primarily experiences a continental climate characterized by seasonal temperature extremes, with warm to hot days during the summer months, and extreme winters. From 1994 to 2013, July was the warmest month with average high temperature of 80ºF and an average low temperature of 47ºF. January was the coldest month with an average high temperature of 30ºF and an average low of 7ºF. Annual precipitation ranges from 6 to 20 inches. For the period of record through 2013, the average annual precipitation was 12.9 inches (WRCC 2013).

2.4 Physiography

The site is located immediately west of the Continental Divide in southwestern Montana. It occupies the northern portion of Summit Valley and is within the Butte mining district in the upper Silver Bow Creek drainage (Figures 1 and 2). Surface elevation ranges from over 10,000 feet in the surrounding mountains and approximately 5400 to 6400 feet above mean sea level along the valley bottom. The site is located at the geographic top of its drainage basin and thus the mountains and hills surrounding the valley are drainage divides. The terrain is characterized by a steep ridge along the eastern (East Ridge), northern and southern valley margins and lower rolling hills to the west. Blacktail and Basin Creeks drain the southern portion of the valley, while Silver Bow Creek drains the valley from the north, although much of its recharge area was cut off by the Berkeley Pit. Blacktail Creek and Silver Bow Creek combine within the boundary of the BPSOU near Montana Street and flow west, exiting the valley through a low notch in the western hills.

2.5 Geology

The Summit Valley is an intermontane, graben valley underlain by a composite intrusive igneous body, the Cretaceous Boulder Batholith, in which the dominant rock type is Butte Quartz Monzonite (BQM). The intrusive mass is cut by numerous younger rhyolitic and porphyritic dikes and plugs and in some places overlain by extrusive Lowland Creek volcanics. Hydrothermally enriched, the bedrock contains high grade disseminated and vein ore deposits of copper and other metals, primarily in sulfide form. The area has been and continues to be of economic value to the mining industry and has been mined for over 100 years. Extensive underground and open pit mining activities have been prevalent throughout the area since gold was first discovered along Silver Bow Creek in 1864. Underground mining began in the 1880s and by 1964 several thousand miles of underground workings had been driven into the bedrock. Estimates of the extent of mine workings range from 3,000 miles (for major shafts, levels, and drifts) to 10,000 miles for total workings on the Butte Hill.

The area exhibits complex and extensive faulting. The Continental fault, which trends north-south subparallel to the East Ridge forms the eastern edge of the graben and is estimated to have at least 1500’ of vertical displacement (Botz 1969). The alluvium is thinner along the western margin of the basin, possibly due to a smaller fault with less vertical displacement along this edge of the graben (MBMG 1990). Numerous other smaller faults exist within the basin, particularly within the vicinity of the mining district. Exposed granitic rocks show extensive fracturing, which may enhance weathering in place of the bedrock with spalling and disintegration of rock surfaces.

The graben valley is filled with alluvium derived from the weathering of the surrounding bedrock. The steep fault dropped margins of the graben formation induce rapid transport of sediment into the basin, which slows as the basin fills. The alluvium is principally composed of unconsolidated, discontinuous lenses of sand, silt, clay and gravel, throughout the valley bottom. The alluvial deposits include valley fill, debris flows, landslides, and alluvial fans (Botz 1969), but no glacial deposits have been identified within the basin. Some of the alluvium, particularly in deeper parts of the basin, may be correlated with Tertiary intermontane basin deposits.

The thickness of the alluvium valley-wide is not well known, but from early geophysical work completed in the basin (Botz 1969) is estimated to range from 600 to 800 feet deep on the western side of the valley to 1500 feet deep east of the Bert Mooney Airport (Ahrens, 1976). Early geologic mapping of the basin (Meinzer 1914), reports bedrock at depths of 90 to 640' from mine shafts indicating a very irregular bedrock interface. From well log information in upper BAO, depths are not well known in the area of the Parrot Tailings and range from greater than 100 feet near well AMW-01C to 65' at AMC-6, to greater than 200' at GS-08R and BPS11-11C and 86'at AMW-13C. Some deeper alluvial deposits may be Tertiary intermontane basin deposits (DNRC 2008).

2.6 Hydrogeology

Historically, the confluence of Silver Bow Creek and Blacktail Creek was a lowland/wetland area in the northern portion of the Summit Valley. It received groundwater/surface water inflow from the east, north, and south and was a groundwater discharge area for the northern portion of the valley. Because it was both a source of water and a low-lying area within the valley, early mining and smelting operations were placed along the creek. These early operations infilled the drainage but didn't change its overall character as a topographic low in the valley. Thus, the area still receives inflow from the north-northwest and south; recharge from the north-northeast is intercepted by the Berkeley Pit.

The excavation of the Berkeley Pit constitutes the biggest change in the Upper Silver Bow Creek flow regime since the early mining era. The Berkeley Pit effectively became a groundwater sink (or sump) for recharge entering the drainage from the north-northeast, creating a groundwater divide in the alluvial aquifer. Groundwater north and east of this divide enters the pit, while groundwater northwest, south and west continues to flow down the drainage. The location of the divide roughly parallels Shields Avenue, but can be affected by precipitation, groundwater withdrawals and/or changes in mining practices upgradient of the divide.

To facilitate mining activities, the naturally occurring bedrock aquifer groundwater level was lowered approximately 4,200 feet from pre-mining levels via pumping. Two distinct hydrologic systems are present within the bedrock, the East and West Camp Mine systems. The West Camp system is located in the west-central portion of the city of Butte and includes the Travona, Ophir, and Emma shafts and associated underground mine workings. The East Camp system is located in the east-northeast portion of the Butte mining district and consists of the Berkeley Pit and related underground mine workings. The two hydrologic systems are separated by bulkheads installed in the mine shaft workings during the late 1950s. With the cessation of active mining in the Berkeley Pit in 1982, pumping of the system was no longer necessary and the underground mines and the Berkeley Pit began to flood.

Early testing of the hydraulic properties of the alluvial aquifer in the valley was completed by Meinzer (1914) and Botz (1969). Their testing indicated wells completed the valley alluvium should yield 100 gallons per minute (gpm) and may yield as much as 200 gpm. Large irrigation wells have been completed in the valley alluvium with discharge rates in excess of 200 gpm.

Previous work by Metesh and Madison in 2004 (MBMG 2004) described three alluvial units in the upper basin. These units were referred to as the shallow alluvial, middle alluvial and deep alluvial units. Similar nomenclature which builds on this classification is used in this analysis. The uppermost (shallow) alluvial unit is referred to as the UAU (upper alluvial unit), the middle unit is referred to as the MAU (middle alluvial unit), while the deep unit is referred to as the LAU (lower alluvial unit). This identification system is useful in the upper part of the corridor, but becomes less definitive further down the corridor, as thicker alluvial packages were deposited in the basin in response to lower energy, wetland-type deposition.

In February of 2010, aquifer testing was conducted in monitoring well AMW-01B. This monitoring well is located hydraulically downgradient from the Parrot Tailings site, in the parking lot of the Butte Civic Center west of Harrison Ave. The monitoring well is completed in the middle alluvial unit and is part of a nested well set with AMW-01A completed in the upper alluvial unit and AMW-01C completed in the lower alluvial unit. The aquifer test was conducted for 72 hours at a pumping rate of between 88 and 95 gallons per minute (gpm). Pressure transducers were installed in 47 wells surrounding AMW-01 and multi-parameter water quality logging units were installed in 3 wells. Water level responses were noted in wells as far as 2,222 feet from the pumping well, indicating the middle alluvial aquifer in this area is well connected. Data from the testing was used to determine the hydraulic parameters of the aquifer. Testing results indicated that in this area the middle alluvial aquifer hydraulic conductivity is approximately 600 ft/day. Using an aquifer thickness of 15 feet, as observed in the AMW-01B lithologic log, a transmissivity of 9000 ft^2/day can be estimated for this aquifer. (MBMG 2010a)

2.7 Surface Water

The two primary streams in the Summit Valley are Blacktail Creek, which originates in the Highland Mountains to the south, and Silver Bow Creek, which originates from the north/northeast. Silver Bow Creek flows west along the base of the Butte Hill and, prior to mining, originated in the mountains northeast of the current Berkeley Pit. With 8 different smelters located along Silver Bow Creek at one time, its banks were rerouted many times by historic mining activity. Wastes from these operations were deposited directly into Silver Bow Creek or in tailings impoundments located very near the creek. Periodic flooding, most notably the historic flood of 1908, distributed the wastes downstream. This has resulted in extensive contamination of the alluvium in the drainage. The original channel and floodplain upstream of the Parrot Tailings Site was removed by the development of the Berkeley Pit and the Yankee Doodle Tailings Pond. The floodplain remains downstream and west of Harrison Avenue, particularly at the confluence of Blacktail and Silver Bow Creeks. Monitoring well lithologic logs indicate alluvial deposits reflective of historic floodplain deposition.

In the 1930's, the existing Silver Bow Creek channel was filled and realigned. The channel is generally dry, except during storm events and snow melt where runoff from the Butte Hill and other areas to the east are discharged in the channel that runs from approximately Shields Avenue and west to the confluence of Silver Bow and Blacktail Creeks near Montana Street, where this runoff mixes with Blacktail Creek flows. Blacktail Creek serves as the primary source of flow in Silver Bow Creek in the upper corridor and provides year-round recharge to the system.

To address groundwater impacted by historic mining practices, the channel above the confluence was reconstructed in 2005 and fitted with a gravel-bedded subdrain pipeline (referred to hereafter as the Subdrain) designed to capture contaminated groundwater that previously discharged directly into Silver Bow Creek. The system was designed to lower the groundwater table to an elevation below the base of the reconstructed surface channel. The Subdrain acts as a sump, drawing water into the pipeline, and the captured water is treated before being discharged downstream. The subdrain is located directly beneath the channel and traverses the Silver Bow Creek Corridor above the confluence originating near the BSB County Shops south of Civic Center Road west to a pumping vault near Montana Street (EPA 2008).

A Technical Impracticability (TI) waiver was proposed by EPA in 2019, through a proposed plan to amend the 2006/2011 record of decision for BPSOU. The waiver would change the attainment/compliance criteria for surface water discharge into Silver Bow Creek by waiving the Montana DEQ-7 stream water quality standards and replacing them with federal water quality standards under certain conditions.

3.0 SITE HISTORY

Butte has been a center of mining since 1864, following the discovery of placer gold along Silver Bow Creek. In 1876, the population was recorded at 1,000 people. As word spread of the polymetallic mineral deposits on the Butte Hill, Butte grew quickly due to an influx of miners. By August 1880, construction of the Parrot Smelter began, and it was brought on-line in July 1881.

Originally, the Parrot Smelter processed silver ore. However, after the discovery of the first copper vein, the smelter was retrofitted to process copper ore. The Parrot Smelter operated from 1881 to 1899, and was outfitted with reverberatory roasters, and matting reverberatory furnaces for roasting ore. In 1884, the smelter became the first in the U.S. to effectively employ the Bessemer Process, using six converters to transform copper matte into blister copper (NRDP 2015).

At its peak, the Parrot Smelter processed approximately 350 tons/day. This resulted in the production of approximately 12.5 tons/day of copper and 110 tons/day of tailings (Quivik 1998). The Parrot Smelter also operated a concentrating plant that treated second-class ore. The concentrator produced significant quantities of tailings as well. The Anaconda Mining Company (AMC) purchased and closed the Parrot Smelter in 1899. From 1899 to 1904, AMC subsequently developed and operated an acid precipitation plant at the site that leached copper from tailings and waste rock. As improvements in copper processing progressed and World War II began, the tailings were once again reprocessed in an attempt to recover copper for the war effort. The precipitation plant operated throughout the World War II timeframe before its eventual closure (MBMG, 2010). The tailings and other wastes, including slag produced by the smelter, were released into Silver Bow Creek and the surrounding floodplain causing significant contamination to area surface and groundwater. Concentrations of copper in area groundwater can exceed 1,000,000 ug/L (ppb) based on seasonal groundwater elevation. Similarly, zinc and cadmium concentrations can exceed 500,000 ppb and 2,000 ppb, respectively.

In 2007, NRDP staff developed conceptual restoration projects for Butte Area One, a subarea of BPSOU, and summarized them in a report issued under title, *Butte Area One Conceptual Restoration Plan*. In 2010, the Butte Natural Resource Damage Restoration Council (BNRC) was formed and began development of a targeted local *Butte Area One Restoration Plan*. The BNRC plan was completed in 2012. Among other projects, the BNRC plan identified the restoration of the Upper Silver Bow corridor as one of its priorities. The BNRC plan was amended in 2016 to include provisions "*describing the primary work necessary to address contamination associated with the Parrot Tailings*". The stated goals of both restoration plans are to:

- Eliminate known sources of heavy metal contamination to alluvial groundwater and surface water;
- Restore the area to a beneficial end use;
- Enhance the area riparian corridors; and
- Improve the quality of the fishery in Blacktail and Upper Silver Bow Creeks.

After years of investigations, in 2015 the Governor of Montana determined that it was appropriate to remove the Parrot Tailings using natural resource damage authorities. NRDP identified a series of data gaps associated with the Parrot Site and commissioned a data gap investigation in and around the former Parrot Smelter in late 2015. Based on the findings of this investigation, NRDP initiated a design to support the removal of the Parrot Tailings and associated wastes. Design activities were completed from 2016-2018.

Final design and contractor selection were completed in early 2018, and the first phase of waste removal was completed from June through December 2018. Due to the need to relocate the BSB County Shops, the Parrot Tailings Waste Removal Project was split into two phases. The second phase of waste removal is scheduled to be completed in 2021-2022. The Parrot Tailings Site is shown on Figure 3.

4.0 PREVIOUS INVESTIGATIONS

The following sections summarize relevant previous investigations completed in Butte Area One and the larger BPSOU, as well as investigations used to inform the design and removal of the Parrot Tailings and this CSM report. Data from many of these investigations have been used to inform and support remedial decision-making related to the Parrot Tailings Site.

4.1 Butte Priority Soils Operable Unit

As part of characterization efforts for BPSOU, a remedial investigation (RI) / feasibility study (FS) and a number of supplemental studies were completed to delineate the nature and extent of contamination within the BPSOU footprint. These efforts included the collection and analysis of hundreds of soil, sediment, groundwater, and air samples over a wide area within Butte. The results of these investigations, identified contaminated media and specified a number of source areas including:

- Upland Soils/Mine Waste
- Granite Mountain Memorial
- Railroad Beds
- Floodplain Wastes
- Lower Area One
- Parrot Tailings

4.1.1 Record of Decision

Based on the findings of the RI/FS and related studies, EPA issued a record of decision (ROD) for BPSOU in September 2006. As it relates to the Parrot Tailings, the ROD notes the following.

"*Mining wastes and contaminated soils in the Metro Storm Drain[1] area are largely buried below the surface. For example, the Parrott Tailings are under as much as 30 feet of mining overburden in some areas. An estimated 2 million cubic yards of mining-related waste and intermixed fill material are present within Metro Storm Drain. In some places, tailings/fill material extends to depths of over 25 feet below ground surface (Parrott Tailings). A portion of these wastes is in*

[1] In prior Superfund removal and remedial documents and publications, including the 2006 Butte Priority Soils Operable Unit Record of Decision (2006 BPSOU ROD) and 2011 BPSOU Explanation of Significant Differences (ESD), EPA has called this surface area the "Metro Storm Drain." Subsequently, a State of Montana court decision known as *Silver Bow Creek Headwaters Coalition v. State of Montana*, DV-10-431 (August 17, 2015) declared that the surface area between Texas Avenue in Butte and the confluence of Blacktail and Silver Bow Creeks was named "Silver Bow Creek." NRDP uses the term "MSD" or "Metro Storm Drain" solely where it is a direct quotation from a previously published document. Where reference to a specific section of Silver Bow Creek is necessary, a further geographic description, such as Silver Bow Creek "above the confluence with Blacktail Creek" is used.

direct contact with groundwater and serves as a primary source of contaminants to alluvial groundwater. Tailings deposits in the middle and lower reaches of the Metro Storm Drain have also been found to be significant sources of contaminants to groundwater.

Alluvial groundwater and its interaction with mine wastes, contaminated soil, and surface water was the focus of the groundwater investigation for the BPSOU. Unconsolidated deposits that comprise the alluvial aquifer within the upper Silver Bow Creek drainage are found along all the larger streams and throughout the central portion of the basin. Groundwater quality in the alluvial corridor south of the [groundwater] divide [created by the Berkeley Pit cone of depression is severely degraded. Elevated levels of groundwater COCs are concentrated in this corridor of the alluvial aquifer. Contaminant concentrations are highest in the upper Metro Storm Drain and in Lower Area One.

Groundwater in the Metro Storm Drain area is severely impacted by buried and fluvially deposited mining wastes throughout the Metro Storm Drain, including the historic Silver Bow Creek floodplain. Impacts are most apparent beneath and down gradient of the Parrott Tailings, North Side Tailings, and Diggings East Tailings. Contaminant concentrations in these areas exceed applicable water quality standards, in some cases by several orders of magnitude. Impacts to groundwater quality are apparent in the lower Metro Storm Drain area, but they are not as widespread or concentrated as in the middle and upper reaches of the Metro Storm Drain. Beneath the Parrott Tailings, groundwater quality is impacted to a depth of at least 150 feet. "

4.1.2 Explanation of Significant Differences

In 2011, EPA issued an explanation of significant differences (ESD) to the 2006 ROD detailing deviations from the initial ROD that were planned or had already been employed as part of remedy implementation. The following are excerpts from the ESD relating to the Parrot Tailings and related environmental impacts.

"Following the signing of the ROD in September 2006, information generated during remedial design prompted reassessment of portions of the [BPSOU] selected remedy for solid media (mine waste, soil, and residential soil and dust) and alluvial groundwater…. In this case, the changes identified below are significant differences that do not change the fundamental overall cleanup approach. Some of the changes may be considered minor modifications to the BPSOU ROD, but EPA has included them in this document to provide full public disclosure…"

The groundwater component of the Selected remedy requires the continued use of the hydraulic control channel and the MSD capture and interception system to capture and pump contaminated groundwater (and some surface water) into the Butte Treatment Lagoon facility for treatment prior to discharge. Both the control channel and the MSD are to be thoroughly evaluated and improved as needed. Waste left in place will not be excavated. Additional groundwater control measures, such as infiltration barriers, groundwater diversion, or other measures, may also be needed and are to be evaluated. The groundwater aquifer must be further evaluated and characterized to *ensure the effectiveness of the interception and pumping systems. Groundwater monitoring and data reporting is required.*

The wetlands demonstration area near Kaw Avenue and George Street will be used for the construction of an emergency overflow pond (this is a minor modification to the 2006 ROD which listed the area as a possible catch basin area). A five-year shakedown period for operation of the MSD interception and pumping facility is required. Institutional controls to prevent domestic use of the alluvial aquifer are required.

The selected remedy requires the capture and treatment of contaminated groundwater. The 2006 BPSOU ROD contained a waiver of ARAR standards for the alluvial groundwater within the defined TI Waiver Area described in the 2006 BPSOU ROD. The Selected remedy will not and is not intended to clean up groundwater to meet groundwater performance standards within the boundary of the waived standards. Therefore, there are no performance standards for groundwater in the area of the BPSOU alluvial aquifer that is covered by the TI waiver boundary. The TI boundary is shown in Figure 12-6 of the 2006 BPSOU ROD. Based on the data collected during the groundwater monitoring program, additional points of compliance may be determined necessary by EPA in consultation with DEQ in future remedial design (e.g., southern edge of the MSD).

Since the Selected remedy requires that contaminated plumes be prevented from migrating outside the established TI zone, the boundary for the TI zone represents the point of compliance boundary for groundwater, and groundwater performance standards must be met at these points of compliance and beyond, as further defined in the Revised Interim Groundwater Monitoring Plan (EPA 2011). Groundwater quality standards (Appendix B, Table 2) will apply to groundwater at and beyond the edge of this boundary.

Design of a groundwater treatment system at the Butte Treatment Lagoons facility and a sludge disposal plan must be approved by EPA, in consultation with DEQ, and the construction, operation, and maintenance of the facility will be monitored by EPA and DEQ in accordance with approved plans. The facility will be designed so that any discharge from the facility must meet water quality ARARs described in Appendix B and in the ARARs established in the 2006 BPSOU ROD."

The primary change listed in the ESD relating to the Parrot Site and contaminated groundwater, is elimination of the need for tracer dye monitoring of the Subdrain system and replacement with augmented flow monitoring.

4.1.3 Draft Proposed Plan – ROD Amendment

In April 2019, EPA released the draft proposed plan to amend the BPSOU ROD. The focus of the proposed ROD amendment is to waive DEQ-7 in-stream surface water standards for certain contaminants under wetter than normal or high-flow conditions. The following excerpts summarize.

Why Modification is Needed. *Since the 2006/2011 ROD, the responsible parties have implemented significant portions of the remedy, but more work remains. The responsible parties, EPA, and DEQ have been analyzing remaining technical issues and evaluations, primarily focused on the current remedy's surface water component while other remedial work continues. Additional detailed studies have also been conducted to help finalize conceptual aspects for the remedy. Most have centered around how to best protect surface water quality in Blacktail, and Silver Bow Creeks given the physical limitations of the BPSOU. As a result, EPA is proposing changes to the 2006/2011 ROD, which provide for more extensive and more detailed remediation than what was originally specified. Even with this enhanced remediation, surface water data and current modeling evaluations indicate there is uncertainty as to whether remedial goals and ARAR standards for surface water (State of Montana DEQ-7 standards) could be met.*

Uncertainty over whether standards could be met prompted EPA to conduct a surface water Technical Impracticability evaluation in consultation with DEQ to determine the likelihood of meeting remedial goals and ARAR standards for surface water (2006/2011 ROD). A variety of surface water and storm water remedial components were evaluated quantitatively in the TI report. The TI evaluation made the following conclusions for the different surface water flow regimes at the BPSOU:

Up front TI waiver for wet weather flow conditions. *Total recoverable copper and zinc water quality measurements are unlikely to meet Montana DEQ-7 acute water quality standards during most wet weather flow conditions, regardless of measures used to control COCs. Thus, these standards should be waived as technically impracticable and replaced. The replacements are called "waived-to performance standards." They use the same numerical standards, but the analysis is for dissolved metals, a dissolved conversion factor is applied, and there is no minimum or maximum value for hardness. These upfront waivers are predicated on Atlantic Richfield's agreement to implement a robust stormwater remedy, which implements technically practicable BMPs.*

Potential post-construction waivers. *Under base flow and normal high flow conditions, total recoverable copper and lead Montana DEQ-7 standards would likely be met after additional near stream waste removals and groundwater capture are completed. Under wet weather conditions, total recoverable cadmium, lead, and silver DEQ-7 standards would likely be met after the storm water control system is expanded and other remediation actions are taken. However, because the TI evaluation demonstrated that there is uncertainty associated with these contaminant standards, these performance standards could be waived and replaced, but only if necessary. Post-remediation monitoring would have to show exceedances occurred more than once in three years and were not due to a malfunction of the remedy or could not be corrected by remedial actions within the scope of the remedy.*

4.2 EPA Groundwater / Surface Water Interaction – BPSOU

In 2017, EPA completed a study to determine what sources may be contributing to contaminant loading in surface water upstream of Lower Area One. Remedial actions conducted between 2010 and 2011 were completed in an effort to address contaminant loading in surface water from the confluence of Blacktail Creek through the Slag Canyon. Following these actions, EPA and DEQ completed another evaluation of monitoring data collected between 2008 through 2013. The report indicated a significant reduction in loading in Silver Bow Creek overall, but these actions did not eliminate contaminant loading to surface water. Potential sources of loading not related to downstream sources were identified as part of the investigation scoping process and included groundwater inflow and/or sediment mobilization (EPA 2017).

The 2017 EPA surface water characterization report identified few exceedances of water quality standards in surface water during base flow conditions. However, increases in concentrations and loading were identified for total recoverable arsenic, cadmium, copper, lead, and zinc generally in reaches upstream and downstream of the confluence of Silver Bow and Blacktail Creeks, suggesting groundwater may be the secondary source of upstream loading. This is further supported by contaminants exceeding surface water standards during base flow conditions, when sediment mobilization is not occurring.

The groundwater–surface water interaction report includes significant discussion examining where groundwater gains can be attributed within the Silver Bow and Blacktail Creek Corridors, with particular emphasis on evaluating how and where spikes in zinc concentrations originate, particularly during the winter months. A number of hypotheses are put forth, but none are conclusive or fully supported. Overall, the report concludes, zinc concentrations show an increase from upstream to downstream for the five winter spikes observed. Copper and zinc showed relatively flat trends in the available surface water stations. The report confirms the findings of prior USGS studies, that noted zinc mobilization is strongly pH dependent.

4.3 Metro Storm Drain Groundwater Management Report

BP-AR prepared a *Metro Storm Drain Groundwater Management Report* that evaluates the effectiveness of the Subdrain in capturing and treating contaminated groundwater from the upper BAO site (AR, 2015). This report presents a conceptual site model (CSM), identifies sources of groundwater contamination, evaluates the protectiveness of the Subdrain, and evaluates optimization strategies to improve its efficiency.

The primary conclusions of the GWMR are that localized sources of tailings (Parrot Tailings, Diggings East, Northside Tailings, Blacktail Berm, lower Tailings above the confluence with Silver Bow Creek) account for approximately 10.5% of the metal load to groundwater, and approximately 89.5% of the metal load comes from a "dispersed source" caused by over 100-years of mining effluent being discharged down the Silver Bow Creek channel. In the 2006 Record of Decision (ROD), EPA determined that cleanup of the aquifer to human health standards was technically impracticable. The GWMR also concludes that the Subdrain is protective of Blacktail and Silver Bow Creeks by capturing 97% of the contaminant loading. The GWMR also recommends an alternate discharge line for treatment redundancy, and continued jetting/pigging of the Subdrain to remove scale and reduce plugging issues.

4.4 Parrot Tailings Geochemical Investigation

On behalf of the NRDP, the Montana Bureau of Mines and Geology (MBMG) developed a comprehensive site history for the former Parrot Smelter and completed a subsurface investigation at and around the former smelter footprint. The objective of the project was to combine all existing data and acquire new data to fill existing data gaps for soil, waste, and groundwater. The investigation included the installation of soil borings, monitoring wells, and the collection of soil/waste and groundwater samples for chemical analysis. Using the project data, an initial site-specific lithologic profile was developed, as well as chemical iso-concentration and groundwater elevation / contour maps. (MBMG 2010).

4.5 Upper Silver Bow Creek Corridor Geochemical and Hydrogeologic Investigation

The MBMG in cooperation with all BPSOU stakeholders, conducted surface and groundwater sampling in the Upper Silver Bow Creek Corridor. The project emphasis was to acquire data that would improve the understanding of groundwater at varying depths within the alluvial aquifer in the Silver Bow Creek Corridor, above its confluence with Blacktail Creek. Data acquired included soil lithology and environmental data in attempt to identify geochemical signatures (fingerprints), chemical concentration and distribution trends, attenuation mechanisms, and hydrogeology (MBMG 2012).

Contaminant loading to Silver Bow Creek and Blacktail Creek were evaluated throughout the potential discharge area. Although unique chemical signatures were not documented that could distinguish groundwater impacted by specific source areas, the data did provide additional insight into individual groundwater plumes. Specifically, the study expanded the known extent of the Parrot Tailings plume by approximately 0.5 miles, which more than doubled estimates of the plume size developed in 2004 (MBMG 2004). The study also provided a conceptual discussion of chemical fate and transport describing how contaminants in deeper portions of the alluvial aquifer may be transported along the Upper Silver Bow Creek Corridor, potentially bypassing collection in the Subdrain.

4.6 Sediment Investigation - Confluence of Silver Bow & Blacktail Creeks

The MBMG conducted an investigation at and around the confluence of Silver Bow and Blacktail Creeks. The investigation focused on examining the thickness and chemical composition of mine waste in three waste areas along the Silver Bow Creek Corridor, above its confluence with Blacktail Creek:

- Blacktail Creek (BTC) Berm,
- Diggings East, and
- Northside Tailings.

To complete the investigation, test pits and trenches, along with soil borings were advanced into mine waste. Lithologic logs were developed for each location and soil/waste samples were collected for chemical analyses. A total of 44 test pits, one trench, and five boreholes were installed throughout the study area to quantify the aerial extent and depth of tailings and impacted sediments. The results helped to better define the vertical and lateral distribution of mine wastes near the confluence area, supporting the development of more accurate volume estimates. Updated estimates were developed to aid planners with the State of Montana when developing cost estimates for the design and removal of impacted material (MBMG 2014).

4.7 NRDP Data Gap Investigations

To fill identified data gaps, NRDP commissioned a study of the Parrot Tailings Site, which was completed in the fall of 2015. The study included the installation of numerous soil borings across the impacted area, both north and south of Civic Center Road. The investigation sought to complete the lithologic profile of the Parrot Site, by logging all of the soil borings during their installation. The soil lithology coupled with a site survey, enabled NRDP to refine waste volume estimates in support of waste removal and disposal. Coupled with the lithology profiles, soil samples underwent field X-Ray Fluorescence (XRF) and laboratory analysis to aid in determining which layers represented contaminated media, and which could be reused as fill following excavation (Tetra Tech 2016). Supplemental test-pitting / potholing was also completed in areas where slag resulted in refusal during drilling and to verify the location of critical infrastructure. The results of these investigations, coupled with prior MBMG efforts, provided a road map enabling accurate engineering design for the excavation, removal, and placement of slag and overburden during the waste removal phase.

In addition to the Parrot Tailings Site, NRDP also completed a data gap study on Silver Bow and Blacktail Creeks. The purpose of this study was to evaluate surface water, instream and pond sediment, and floodplain soils on Blacktail and Silver Bow Creeks, upstream of their confluence. Field work was completed in March and April of 2016. Floodplain soil and mine waste investigation activities included 17 test pits that were excavated, screened and sampled, along with three soil borings in the Blacktail Creek berm and nearby wetland pond. Multiple samples were collected from each test pit and boring based on visual identification of waste materials and field screening with a portable XRF. In addition, 14 streambank soil and opportunistic samples were collected and analyzed. Instream and pond sediments were sampled at 18 stream and four pond locations and 53 in-stream sediment pore samples were collected from within the active stream, along with 4 pond sediment pore water samples from 3 wetland ponds. In coordination with this effort, groundwater sampling was completed in 32 existing monitoring wells and 3 newly installed piezometers. Samples were analyzed for site COC's including arsenic, cadmium, copper, lead and zinc, plus mercury, iron and manganese in select samples.

This investigation resulted in the following findings:

- Elevated contaminants in streambank and floodplain soil samples;
- Elevated contaminants in in-stream and pond sediments;
- Elevated contaminants in some pond water samples;
- Contaminants in creek sediment pore water were highest in stream sections or wetland ponds with elevated sediment contaminant concentrations; and
- Groundwater contaminant concentrations were highest in areas of known mine waste.

Two, limited duration, single well aquifer tests were conducted on Blacktail Creek berm monitoring well AMW-11. The aquifer pumping rate was approximately 2.5 gpm and the screened interval in the well was 10 feet. The hydraulic conductivity calculated from the tests was approximately 60 ft/day with a transmissivity of 600 ft^2/day.

5.0 PARROT TAILINGS WASTE REMOVAL PROJECT

The Parrot Tailings Waste Removal Project is being completed to remove contaminated source media from the alluvial aquifer in the Silver Bow Creek Corridor, above its confluence with Blacktail Creek. Source removal is an important first step in reducing contaminant loading to the alluvial aquifer, which will aid in reducing contaminant loading to downgradient groundwater and surface water. As stated, the typical lithological profile for the Parrot Site consists of a mix of native soil and imported BQM placed as cover material over smelter slag and/or tailings. The slag and tailings resulted from historical smelting activity. They were deposited over time throughout the site footprint atop the native organic clay/sediment layer, thought to be the original depositional soil horizon of the Silver Bow Creek floodplain. To support waste removal activities, a number of major engineering design components were completed or are planned, including:

- Haul road design and construction;
- Waste removal excavation, transport, and disposal;
- Clean backfill placement and compaction;
- Evapotranspiration (ET) covers;
- Construction Dewatering;
- Facility demolition/utility abandonment;
- Utility/transportation replacement;
- Post-removal grading plan; and
- Post-removal land use plan.

In order to complete the project, the following work sequence was developed by NRDP in coordination with other site stakeholders:

Phase I	Haul Road Construction and Site Security
Phase IIA	Waste Removal North of Civic Center Road
Phase IIB	Demolition of the BSB County Shops
Phase IIC	Waste Removal South of Civic Center Road/ET Cover Construction
Phase III	Final Site Reclamation and End Land Use

Phase I and IIA were completed in 2018. The BSB County Shops are in the process of being rebuilt at a new location. Phase IIB, IIC, and III are planned for 2021 and 2022.

5.1 Phase I and IIA - Haul Road Construction, Waste Removal

Phase I consisted of the construction of the haul road from the Parrot Site to the Stockpile Area on MR property to the east. The road traverses the onsite railroad right-of-way, passing under the Shields Avenue bridge. Once under the bridge, the haul road connects to active MR mining operations connecting the Parrot Tailings Site to a tailings stockpile area. Phase IIA was completed for the portion of the Parrot Tailings Site north of Civic Center Road. The work scope included excavation and stockpiling of native soil and BQM overburden and performing field XRF screening and laboratory confirmation analysis to clear clean material as fill. Once overburden was stripped, exposed slag, tailings, black clay, and alluvium were excavated to the water table or until the limits of contamination were reached in accordance with the design and the provisions defined in the quality assurance project plan (QAPP). Field XRF screening and supporting laboratory analyses were performed daily to aid the general contractor with material routing and disposal.

Contaminated media was transported via the haul road to the stockpile area, where MR moved the material with their haul trucks for final disposal. During construction, XRF and laboratory data was utilized routinely to monitor excavation progress and determine when the limits of contamination were reached. These analyses revealed that alluvium below the organic clay layer was more contaminated than previously anticipated. As a result, additional excavation was completed in these areas to remove contaminated alluvium down to the groundwater interface. This increased waste volumes removed during Phase IIA from approximately 76,000 CY to 170,000 CY, an increase of approximately 94,000 CY. Additional waste volume was also generated due to some overburden material failing backfill specifications, and the mixing of slag and waste material that was hauled as waste. Despite the large increase in waste volumes, the total Phase IIA volume only increased by 6%, from 360,000 CY to 382,000 CY. The increase in waste volume was offset by the lower volume of clean overburden and slag material. Table 1 summarizes the final volume of materials removed, by media type.

Table 5-1. Final Excavation Volumes – Parrot Tailings Removal Phase IIA

Excavation Area	Lithologic Unit:	Lithologic Layer Volumes (CY)
Phase IIA	BQM/Fill (Clean Overburden)	112,421
	Slag	99,390
	Waste (Tailings/Clay/Contaminated Overburden)	170,281
Total Volume:		**382,092**

In accordance with the design, slag was placed on both the east and west sides of the existing Patriot Railroad grade adjacent to the site. An evapotranspiration (ET) cover will be placed over the slag as part of site restoration (Phase IIC). Additional tasks completed as part of Phase I and IIA included:

- Monitoring well abandonment;
- Removal and disposal of existing structures, utilities, and features;
- Stakeholder / property owner coordination;
- Warren Avenue storm sewer relocation; and
- Gravel parking lot construction.

Phase I and Phase IIA were substantially completed in December 2018, with final project punch items completed by September 2019.

5.2 Phase IIB Activities – Demolition of the BSB County Shops

Phase IIB will consist of demolition of the BSB County Shop Complex and all associated utilities and improvements for the portion of the site south of Civic Center Road. These improvements must be removed in order to access waste materials that currently lie beneath the buildings and utilities. Phase IIB is contingent on the relocation and construction of a new BSB Shop complex. The current schedule estimates Phase IIB will be completed in the winter of 2020-2021.

5.3 Phase IIC Activities – Waste Removal Activities and ET Cover Construction

Phase IIC will include the development of an engineering design and removal of waste south of Civic Center Road. Waste excavation, field and laboratory screening, waste segregation, hauling, and disposal will follow the same model as Phase IIA. The haul road constructed to support Phase IIA remains in place and will be utilized for Phase IIC. Following completion of waste removal, an ET cover system will be placed over unsaturated waste areas, including waste removal areas within the Parrot footprint and the adjoining railroad grade where slag has been placed. The design for Phase IIC is in progress. Construction is anticipated to be completed in 2021-2022.

5.4 Phase III Activities - Parrot Project End Land Use

Phase III will consist of final site reclamation and preparation of the site for its designated end land use. The work scope for Phase III will include:

- Application of soil amendments;
- Seeding;
- Parking lot construction;
- Site access planning; and
- Placement of institutional/land use controls to protect ET Covers and other Superfund remedy infrastructure.

The end land use will be identified by the City and County of Butte-Silver Bow. Phase III tasks are anticipated to begin in 2022-2023.

6.0 RELEVANT DATA

The following summarizes data collected as part of the Parrot Performance Monitoring Program (PMP) and other data used to supplement the CSM and the Upper Silver Bow Creek EVS visualization.

6.1 Parrot Performance Monitoring

The Parrot PMP was implemented to establish pre-removal baseline conditions in and around the Parrot Tailings Site, and to provide performance monitoring along the Silver Bow Creek Corridor following waste removal. The PMP incorporates 52 groundwater monitoring wells from BPSOU, 7 surface water locations, and the 25 new wells installed as part of the PMP to better characterize alluvial lithology, groundwater quality and water level fluctuations throughout the corridor (Figure 4). The monitoring network employs five transects that are generally aligned perpendicular to both groundwater flow and the known or anticipated extent of groundwater impacts (Figure 5). The transect approach was implemented to provide data from monitoring locations:

- Upgradient of the Parrot Tailings.
- Immediately downgradient of the Parrot Tailings.
- Additional transects downgradient of the Parrot Tailings.

The placement of new wells, coupled with existing BPSOU wells and surface water sites, support an evaluation to address the specific objectives of the monitoring program:

- Establish current/baseline conditions for the corridor prior to and following Parrot Tailings removal efforts.
- Assess groundwater, hydraulic gradients and water quality through the Parrot Tailings.
- Develop accurate groundwater potentiometric surface maps.
- Evaluate hydraulic properties for three hydrologic features:
  - Blacktail Creek
  - Silver Bow Creek
  - Subdrain Groundwater Collection System

Continuous water levels were acquired using dedicated transducers in 28 monitoring wells, combining both PMP and BPSOU wells. Manual water levels were also acquired monthly, and low-flow sampling, laboratory analysis, and data validation are completed quarterly. Through six quarterly sampling events, a total of 527 groundwater samples have been collected representing 32,880 data points.

6.2 Data Quality and Usability

Results from the first six quarterly PMP monitoring events have undergone data validation in accordance with the *EPA National Functional Guidelines for Inorganic Superfund Methods Data Review* (EPA, 2017) and the project-specific provisions outlined in the Clark Fork River Superfund Site, Data Management and Data Validation Plan, May 1992, as amended February 2000 (AR 1992). As noted, results from these efforts have been compiled in two DSRs and submitted to NRDP.

The findings detailed in the DSRs, reveal no sample results were rejected during validation. All the sample results (32,880) from during the six quarterly events are of sufficient quality to support decision-making as part of the PMP. A total of 1,194 (3.6%) results were qualified due to quality control results outside of control limits. The remaining 31,686 data points (96.4%) are unqualified. The noted qualifications do not limit the use of the results for purposes of decision-making in terms of risk assessment or remediation.

6.3 EVS Visualization

To aid decision makers in their understanding of contaminant fate and transport along the Silver Bow Creek Corridor above the confluence, particularly as it relates to groundwater impacts originating at the Parrot Tailings Site, an EVS visualization has been developed using the PMP dataset and overlapping BPSOU data. The visualization provides a three-dimensional illustration of subsurface lithology, water levels, and analytical chemistry. The visualizations were animated in short video clips for ease of presentation. The video clips include a visualization of the lithology, multiple groundwater elevation surfaces over time (from November of 2017 to April 2019), and visualizations of copper and zinc concentrations for the October 2018 monitoring period and over time from April 2010 through January 2019.

Ground surface elevations were input in the software from the detailed LiDAR survey completed by NRDP in July of 2013. In support of this effort, LiDAR data was collected for 1640 acres in the basin, with data resolution at less than one foot. Monitoring well top of casing (TOC) or ground elevation data accuracy has been a perennial problem within the basin, because of the use of multiple datums. Before developing the visualization, all well elevation data and ground surface elevations were converted to the NAVD 88 datum for consistency throughout the visualization. In addition, the Subdrain as-built data elevations were converted and used in the visualizations.

Monitoring wells drilled using a Rotosonic method were preferentially used as the primary data source when developing the lithologic framework for the visualization, because of their more detailed, higher resolution, continuous lithologic data. Rotosonic wells were infilled with other monitoring wells with detailed lithology where necessary, especially in areas where bedrock interface depths were available.

EVS software allows groundwater chemistry data to be positioned in depth at the well screen of the monitoring well. This enables the visualization to accurately illustrate plume characteristics in three dimensions. One set of visualizations was animated to illustrate the plume core from highest to lowest concentrations, which enables the viewer to understand the geometry of the plume.

Groundwater surface elevation data were also visualized for the three separate alluvial units for the PMP quarterly monitoring events. This allowed the animations to illustrate groundwater fluctuations over several seasons and show the differences in recharge at the Parrot Tailings site versus at the confluence of Blacktail and Silver Bow Creeks.

6.4 EVS Visualization Data Set

The data set used to support the EVS visualizations combines seven quarterly monitoring events completed in support of the Parrot PMP, and overlapping data acquired from BPSOU groundwater monitoring. The PMP dataset incorporates results from the following sampling events (Appendix D):

- October 2017 (water levels only)
- December 2017
- February 2018
- April 2018
- July 2018
- October 2019
- January 2019

Each PMP monthly water level event was collected in a 1 to 2-day window, and each PMP sampling event was completed during a one to two-week window, in order to minimize variation in results due to seasonal influences. A single date (month/year) was assigned for each event, to accommodate EVS software input requirements. Sample results reported below the laboratory detection limit appear with a “<” preceding the value. The EVS software recognizes these values as non-detects and assigns them a value of 1/10th the detection limit. The ‘NM’ designation appearing in a number of cells, indicates no measurement was available. The entry ‘NA’ indicates the information was not available.

BPSOU groundwater monitoring data were also incorporated into the model, to enhance spatial coverage throughout the corridor. Three BPSOU semi-annual sampling events were incorporated into the dataset:

- Fall 2017
- Spring 2018
- Fall 2018

The PMP and BPSOU data sets do not fully overlap, as several parameters are collected at varying frequencies for the BPSOU program. To illustrate, under the BPSOU program, arsenic, copper, specific conductance, and zinc are sampled on a semi-annual basis and sulfate and chloride are sampled once every five years. BPSOU sampling events have generally occurred over a two to three-month period. In order to incorporate these values into the EVS data set, the median date for the event was assigned and corresponding data incorporated into the date set corresponding to the nearest Parrot PMP event. In addition, no reporting limits or data qualifiers were included in the BPSOU database. As a result, it is not clear if non-detects occurred. For purposes of the model, reported values were utilized as provided.

BPSOU data from 2010 to 2017 were also incorporated into an additional data set to examine long term trends in the corridor. Data were acquired for the historical portion of the model concurrently with the 2017/2018 data and utilized the same well set. Historic data were collected and reported in the same manner as the 2017/2018 data and incorporated in the EVS model.

Additional wells installed by the MBMG to support examination of water quality for the Butte Mine Flooding Operable Unit (BMFOU), were also incorporated to enhance geologic / soil lithology coverage along the northwest corner of Butte Area One. There are limited monitoring wells / lithologic logs for this portion of the corridor supporting BPSOU or PMP monitoring efforts. These data utilized in the model were acquired from the GWIC database.

7.0 CONCEPTUAL SITE MODEL

The Conceptual Site Model (CSM) details the contaminants impacting groundwater and surface water in the study area. It also describes the pathways in which these contaminants are being mobilized and released into the environment, and it provides a summary of the nature and extent of known contamination within the study area, down to the confluence of Silver Bow and Blacktail Creeks. The data evaluation is supported by site-specific groundwater elevation contours, isoconcentration maps, and EVS animations that provide three-dimensional illustrations of historic chemical concentrations in and around the Parrot Tailings groundwater plumes down to the confluence area. The EVS program also ties the plume to specific geologic units within the local alluvial aquifer.

7.1 Geology

Butte is located within the Boulder Batholith, a Cretaceous-aged intrusive igneous pluton with an extent of about 40 square miles in southwestern MT and Idaho. Butte is the type area for Butte Quartz Monzonite (BQM), one of the granitic varieties common in this region. The intrusive mass is cut by numerous younger rhyolitic and porphyritic dikes and plugs and in some places overlain by extrusive Lowland Creek volcanics. Hydrothermally enriched, the bedrock contains high grade disseminated and vein ore deposits of copper and other metals, primarily in sulfide form.

The ridges surrounding Butte are composed of exposed igneous bedrock, but in the valley, the bedrock is overlain by alluvial deposits derived from erosion and weathering of the batholith and fluvial deposition and reworking by area streams. Two principal hydraulic units are described within the area, the bedrock and alluvial aquifers.

The alluvial aquifer near the Parrot Tailings is further subdivided as described in previous work by Metesh and Madison in 2004. They describe three alluvial units in the upper basin, referred to as the shallow alluvial, middle alluvial and deep alluvial units. Similar nomenclature which builds on this classification is used in this analysis. The uppermost (shallow) alluvial unit is referred to as the UAU (upper alluvial unit), the middle unit is referred to as the MAU (middle alluvial unit), while the deep unit is referred to as the LAU (lower alluvial unit). This identification system is useful in the upper part of the corridor, but becomes less definitive further down the corridor, as thicker alluvial packages were deposited in the basin in response to lower energy, valley bottom-type deposition. The alluvial aquifer is composed of gravels, sands, silts, and clays, and various mixes of these grain sizes derived from the surrounding igneous rocks.

In upper BAO, granitic bedrock forms the Butte Hill and is overlain by progressively more alluvial material as the hill flattens into the valley. The upper bedrock interface is interpreted to be irregular and fractured, as evidenced by the exposed bedrock around the valley margins. A series of lithologic cross sections (Figures 6 - 12) were developed from the site monitoring wells that describe the specific units encountered during drilling.

The cross sections principally rely on recent wells drilled using a rotary vibratory drilling method (rotosonic). This method reduces friction on the drill string and bit, thereby allowing the collection of long continuous core samples with less compaction, allowing visibility of even small lithologic changes in the core. Because this method requires no drilling mud or air, the cores are not significantly altered, and the ability to describe the lithologic detail is increased.

Monitoring wells using other drilling methods were also used to infill where additional data was necessary. Knowledge of the depth to bedrock is critical to understanding the flow regime and contaminant transport pathways; fifty-seven wells were used to develop the bedrock interface map used in the cross sections. Each cross section is described in detail in Section 7.5.1, along with a geochemical diagram illustrating groundwater quality along the cross section.

Figure 7-1. Screenshot from Bedrock Surface EVS Animation.

7.2 Contaminants

With respect to regulatory standards for soil/solid media, surface and groundwater, the contaminants are those identified as presenting unacceptable risks to human health or the environment in the baseline human health and ecological risk assessments. These contaminants are memorialized in Table 7-1 of the Record of Decision for BPSOU (EPA 2006) and are provided below in Table 6.

Table 7-1. Contaminants by Media – BPSOU

Chemical:	Solid Media:	Groundwater:	Surface Water
Aluminum			✓
Arsenic	✓	✓	✓
Cadmium		✓	✓
Copper		✓	✓
Iron			✓
Lead	✓	✓	✓
Mercury	✓	✓	✓
Silver			✓
Zinc		✓	✓

These contaminants generally represent the same contamination fingerprint originating at the Parrot Tailings Site by media type, although source concentrations at the Parrot are somewhat distinct, given the discrete sources of contamination found there. For example, copper concentrations in groundwater measured during the Phase IIA removal action are in the range of 3% copper. This represents a different source population/contaminant profile than the source media identified in the ROD throughout the remainder of BPSOU (sediments and groundwater), due primarily to extended interaction between groundwater and contaminated tailings/clay in the soil column at the Parrot.

7.3 Sources of Contamination

The primary and secondary sources of contamination along the Upper Silver Bow Creek Corridor are described in this section.

7.3.1 Primary Sources

Historically, sources of contamination in the study area have included uncontrolled mine dumps which released contaminant-laden sediments to area creeks during high flow or storm events. Major stormwater outfalls from Texas Avenue to Lower Area One have historically and continue to contribute contaminant loading to Blacktail and Silver Bow Creeks during snowmelt and rain events via sediment carried during periods of high flow. The sediment enters surface water and is entrained in the flow, with some of the contaminants dissolving during transport. Depending on water pH and other factors relating to surface water and sediment chemistry, contaminants may be mobilized at different rates in the surface water. The Parrot Tailings, Northside Tailings, Diggings East, Blacktail Creek/confluence area, and Butte Reduction Works Smelter Site also serve as principal sources of contaminant loading in the study area corridor.

As described previously, widespread dewatering activities in the interconnected mine workings on the Butte Hill lowered groundwater levels approximately 4,200 feet from pre-mining levels in the bedrock aquifer. This contaminated mine dewatering effluent was discharged directly into Silver Bow Creek near the current intersection of Shields Avenue and Texas Avenue. This highly contaminated effluent impacted both surface water downstream and groundwater by flowing directly into the creek, as well as infiltrating into the alluvial aquifer. Discharge of mine dewatering effluent was discontinued when mining activities were suspended in early 1980's.

Groundwater at the Parrot Tailings Site has been contaminated by more than 100 years of acidic groundwater contacting contaminated tailings and other related smelter wastes. Acid sources entered the system as part of past metals recovery efforts, which included acid washing of tailings to recover copper during the 1940s. Groundwater has been in contact with the tailings throughout this period. Acidic conditions have mobilized the contaminants from the tailings, by first overwhelming the natural buffering capacity of the tailings (e.g. carbonate) and surrounding bedding materials and subsequently dissolving contaminants at heightened concentrations. The extreme acidic conditions have resulted in very high concentrations of dissolved contaminants such as copper and zinc in groundwater, resulting in a highly mobile contaminant plume within the aquifer system at this location.

As groundwater migrates through the alluvial layers and contacts less impacted water, dilution and oxidation occur. As it contacts this environment, some of the super-saturated contaminants in the groundwater precipitate out into the pore water, or adhere to fine-grained materials in the alluvial aquifer. These contaminants can then be remobilized back into groundwater or surface water during periods of high recharge (wet conditions) or high flow. Contaminated groundwater is a primary source of contamination to surface water and in-stream sediments in groundwater discharge areas near the confluence of Blacktail and Silver Bow Creeks.

7.3.2 Secondary Sources

Secondary sources of contamination in surface water consist of resuspension and mobilization of contaminated sediment during periods of spring recharge and during stormwater runoff events. These sources could include any of those identified as primary sources. Secondary sources of contamination in groundwater consist primarily of resuspension of previously precipitated contaminants in the alluvial aquifer under the optimal geochemical conditions.

7.4 Surface Water Characterization

7.4.1 Streamflow Monitoring

Five surface water locations were sampled during the PMP sampling period, as shown on Figure 5. MSDSG-02 and MSDSG-03 are two wetland seeps that discharge to Blacktail Creek. MSDSG-05 is located along Blacktail Creek near Lexington Avenue, and SS-04 is a USGS monitoring station located on Blacktail Creek upgradient of its confluence with Silver Bow Creek. PMP-12 is located on Silver Bow Creek above its confluence of Blacktail Creek.[2]

When surface water elevation data are compared with groundwater elevation data, contours of equal head elevations strongly indicate a gaining reach upstream of SS-04. Stream gaging is conducted monthly at eight mainstem stations using an electronic current meter. An overall increase in discharge is noted between gauging stations SS-01 and SS-06 without additional input from area tributaries, which indicates a groundwater gain in this area (EPA 2018).

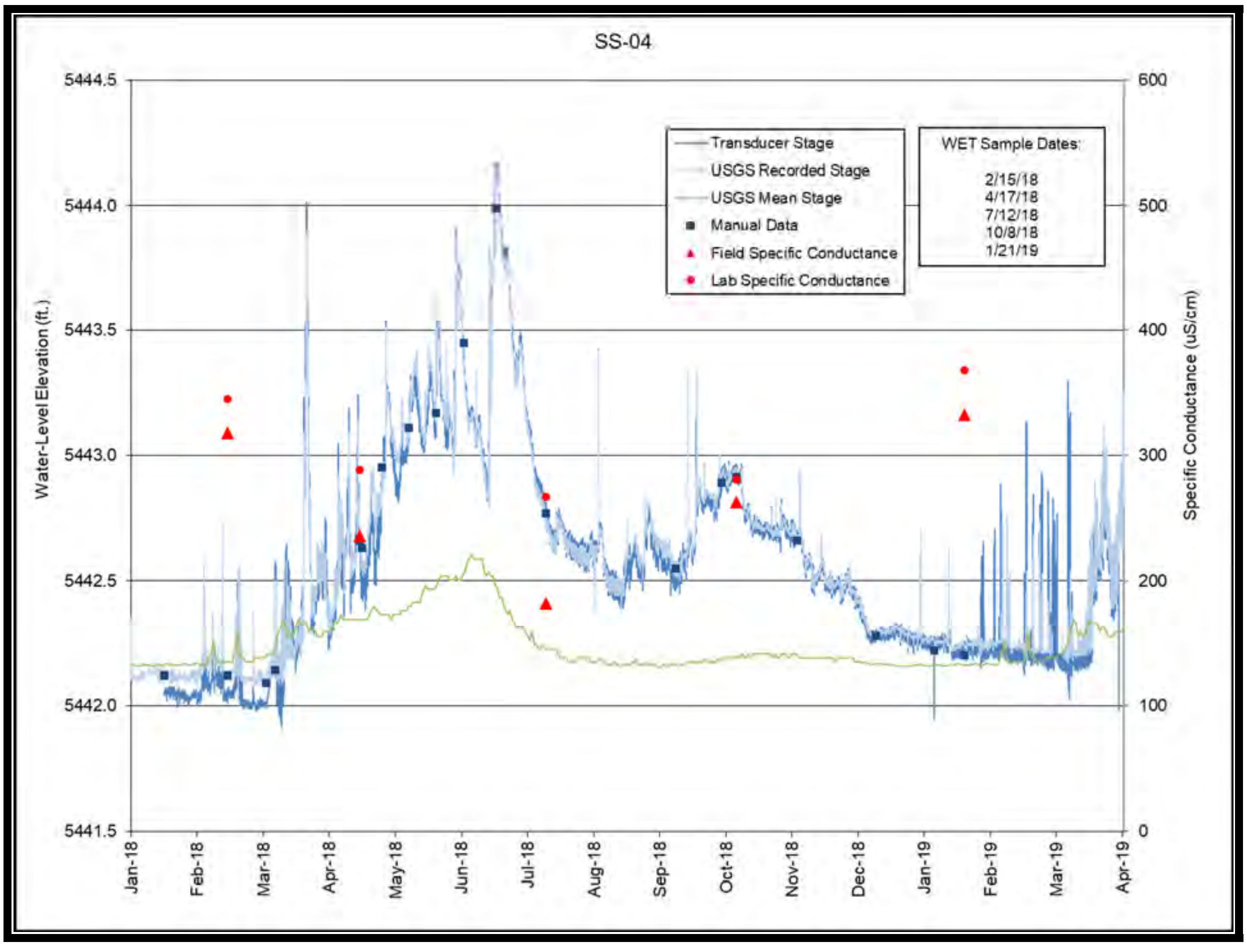

Figure 7-2. SS-04 Hydrograph

A number of PMP wells installed along the corridor of Blacktail Creek respond to changes in surface water stage. Paired wells PMP-11A/B indicate an upward gradient on the north side of Blacktail Creek upstream from gauging station SS-04, and groundwater elevations display a marked response to changes in surface water stage (Appendix B). These wells also show a

[2] Due to freezing issues in the streams, not all sample locations could be sampled every quarter.

response following maintenance of the Subdrain, which is jetted twice a year in April and October. Additional wells along the Subdrain corridor also show a response in groundwater elevation following jetting, including wells PMP-02A, PMP-03A, PMP-05A/BR, PMP-06A/B, PMP-08A/A2/B, BPS07-07B, and MF-07B. These results indicate a strong hydraulic connection between the Subdrain and the aquifer. Wells adjacent to Blacktail Creek commonly exhibit two high water periods annually: one corresponding with spring runoff, and a smaller period in the fall corresponding with increased precipitation at this time of the year. Monitoring wells near the Parrot Tailings area typically show only the fall increase in water levels (wells not hydraulically connected to surface water).

Streamflow on Blacktail Creek is monitored at a real-time USGS gauging station (12323240) at station SS-04 (Figure 7-2). This station has a period of record from 1989 to present. Streamflow on Blacktail Creek during the PMP sampling period was near mean values from November 2017 to mid-March 2018; however, from mid-March 2018 to January 2019 stream flow was substantially higher than the daily mean. Streamflow on Blacktail Creek typically peaks from mid-February to late March in response to snowmelt, and from late May to early June due to spring precipitation. Stream flows during the PMP sampling period showed a similar response, with elevated discharge occurring in late March and late June 2018. The annual mean discharge for water year 2018 on Blacktail Creek was the second highest on record, however, peak flow values during the PMP sampling period were lower than historical peaks. The highest peak flow recorded in 2018 was 125 CFS on June 18, which ranked 15th out of 30 years on record.

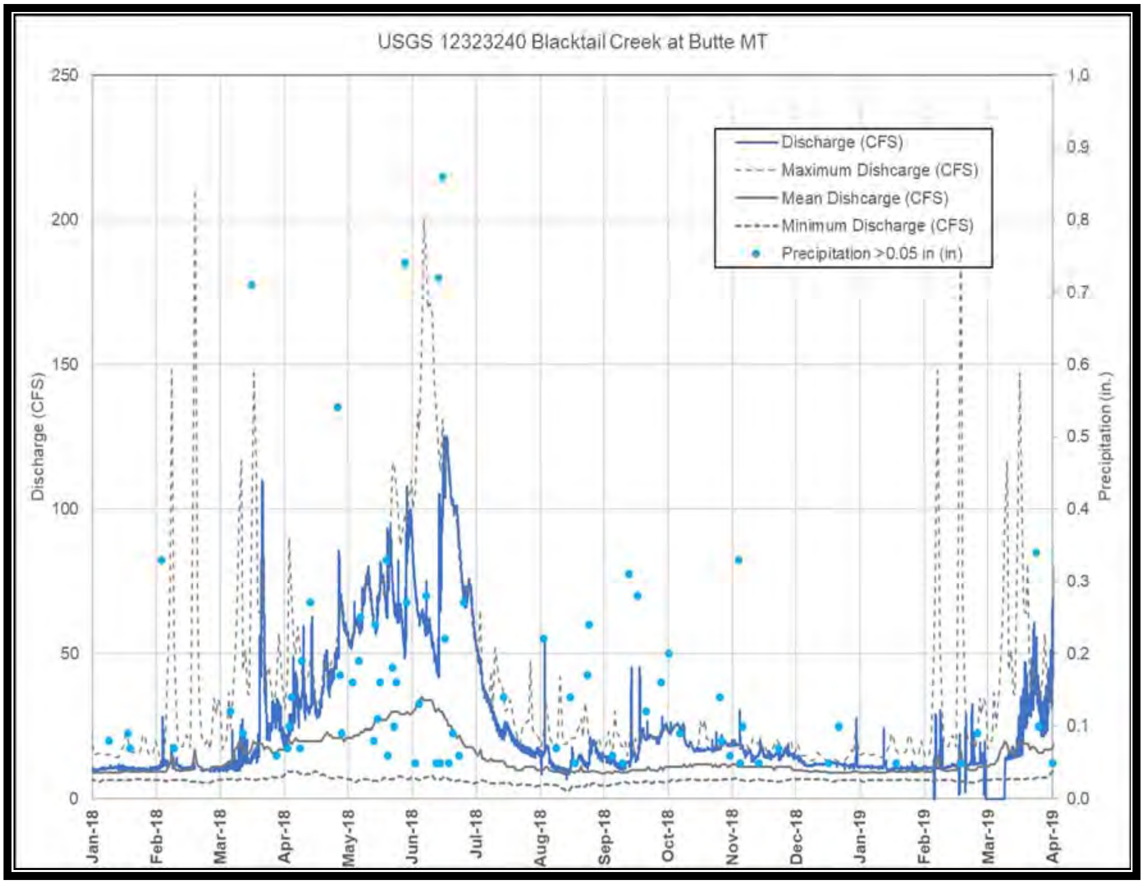

Figure 7-3. Streamflow and Precipitation on Blacktail Creek

Stream flows on Blacktail Creek routinely increase following significant precipitation events. Figure 7-3 displays streamflow on Blacktail Creek and precipitation events >0.05" recorded at the Butte airport during the PMP sampling period. Peak streamflow during the PMP sampling period occurred in mid-June 2018 following a number of precipitation events in late spring. A period of elevated streamflow also occurred in mid-September to early October 2018 in response to fall precipitation.

7.4.2 Surface Water Quality

Surface water chemistry data were plotted on a tri-linear Piper diagram to look at the differences in water chemistry between sample points. Piper diagrams illustrate the water chemistry for each sample site by plotting the relative abundance of major cations and anions in separate triangles on either side of a diamond, where each analysis is plotted as a circle and illustrates relative abundance as a percentage of the milliequivalents per liter. Generally, the circles are plotted with the diameter of the circle proportional to the TDS. To simplify the diagrams (because of large TDS variation), the circle diameter for each analysis was not varied by TDS. Water type and chemical changes along groundwater flow paths are illustrated using these diagrams. Piper diagrams are located in Appendix C.

A seasonal comparison of the Piper Diagrams with surface water sample points can be made from Figures C-1, C-4, C-7, C-8, and C-10 (Appendix C). PMP-12 (SBC sample point) plots slightly above the rest of the surface water samples (from Blacktail Creek), indicating the higher sulfate and chloride percentage in surface water from Silver Bow Creek at this location. SS-04 and MSDSG-05 plot on top of each other indicating the similarity of the chemistry at these two locations which are approximately 2000 feet apart. MSDSG-02, MSDSG-03 plot between SS-04 and MSDSG-05 and have a slightly different chemical signature. The surface water sample geochemistry varies over the selected monitoring period both within and between sample locations.

7.5 Groundwater Characterization

The following sections define the characteristics of the aquifer, and the findings of combined PMP and BPSOU groundwater monitoring data beginning in 2017.

7.5.1 Physical Description of Aquifer

The bedrock aquifer is composed of granitic material that can be fractured and/or weathered in place. Because the permeability of the bedrock is significantly lower than that of the alluvium and the Berkeley Pit acts as a groundwater sink for flow in the bedrock aquifer, most of the data collected for the PMP was collected from the alluvial aquifer. The alluvial aquifer is primarily composed of sands, silts, clays, and gravels derived from the weathering of the surrounding bedrock. Lithology is complex in the alluvial aquifer with highly variable interlayering of the sedimentary sequences, which makes correlation from even nearby wells challenging. Additionally, many of the older existing wells do not have detailed lithologic descriptions, further complicating interpretation.

In order to interpret these discrete lithologic units, monitoring wells were drilled using a rotosonic drilling method for all new wells. The soil borings were continuously cored and logged throughout drilling operations. Soil cores were used to identify the subsurface soil lithology in higher resolution and more accurately select well screen intervals. Additionally, interpretation of existing wells and generation of geologic cross-sections prioritized those wells installed using the rotosonic drilling method.

7.5.2 Lithologic Cross-Sections

A series of cross sections were developed across the upper stream corridor from monitoring well lithology logs (Figures 6 - 12). Because of increased recovery and detailed lithologic descriptions from the rotosonic wells, they were prioritized for use in the cross sections and in the lithology developed for the EVS visualizations. Topographic information was incorporated from LIDAR data collected by NRDP in the corridor in 2013, and the bedrock interface was developed from available wells in the basin which intercepted the bedrock interface. Because of the limited wells completed to bedrock, deep alluvial wells that did not intercept bedrock, were used to interpret the depth to bedrock as greater than the total depth of the alluvial well in discrete areas of the basin.

Cross section A-A' (Figure 6) is located northeast and upgradient of the Parrot Tailings Waste Removal Area and indicates the interfingering of alluvial deposits and the steeply dipping bedrock interface which is exposed at the ground surface to the north. The expansive areas of fill labeled on the drawing coincide with a set of elevated railroad tracks that service the Montana Resources (MR) mining operation to the northeast. Overburden from the excavation of the Berkeley Pit was placed over the surface exposure of the Parrot Tailings in the 1950's. Fill between GS-09-03 and BPS11-20 represents this overburden. Stiff Diagrams, a graphical representation of the major ion concentrations in a water sample in milli-equivalents/liter (meq/L), were developed from PMP monitoring event water chemistry data in the wells depicted on the cross section. These Stiff Diagrams indicate the characteristic shape of groundwater geochemistry beneath the Parrot Tailings. Parrot groundwater exhibits enhanced sulfate and calcium peaks with a relative deficit of bicarbonate, sodium, chloride and magnesium, but without the magnitude of sulfate exhibited by the wells in cross B-B', which is directly downgradient of the Parrot Tailings Site. In cross section A-A', the groundwater contaminant composition, as represented graphically in the Stiff Diagrams, is very similar in the upper and middle alluvial units.

Moving hydraulically downgradient, cross section B-B' (Figure 7) again indicates the shallowing bedrock interface to the north and the interlayering of alluvial packages in the topographic low in the center of the cross section. This cross section is located directly downgradient of the Parrot Tailings Waste Removal Area. The notch in the fill material in the center of the cross section represents the current location of the Silver Bow Creek channel and the upper portion of the underlying Subdrain. Stiff diagrams for wells in this cross section show more variability in relation to each other both laterally and with depth and exhibit the largest sulfate shift of any monitoring wells in the corridor. Of the wells depicted on this cross section, the PMP-02 nested well pair has the largest sulfate peak in both the upper and middle alluvial units. Monitoring wells on either side of the middle wells (AMW-01A,B and PMP-02A,B and PMP-03A) have smaller calcium/sulfate shifts, as does the deeper well (AMW-01C), indicating that these wells are further from the plume core. The Stiff diagrams also indicate that the plume is more concentrated and wider in extent in the MAU near wells BPS07-11A/B than in the UAU.

Cross section C-C' (Figure 8) is located near the Columbus Plaza in the center of the corridor and the notch in the fill near wells PMP-05 and PMP-06 marks the location of the current Silver Bow Creek channel, now occupied by the Subdrain. The lithology in this area is similar to the other cross sections with complex alluvial package mixtures of sand, silts, clays and gravel and a shallowing bedrock interface to the north. Stiff diagrams for PMP-05A, PMP-05BR, PMP-06A, PMP-06B, and PMP-07B show the characteristic calcium/sulfate shift of the Parrot Tailings plume. The Stiff diagram for PMP-07A has a very different shape from PMP-07B with no calcium/sulfate shift, indicating most of the contamination at this location is moving in the MAU and indicates migration of plume to the south/southwest as corroborated by the groundwater elevation and contaminant concentration mapping. BPS11-17C shows the muted calcium/sulfate shift characteristic of the deeper alluvial aquifer.

Paralleling Kaw Avenue, cross section D-D' (Figure 9) indicates the sloping bedrock interface to the north with a thicker sedimentary package that varies from gravels to clays. The cross section also shows the thicker organic clay/silt layer just beneath the fill in this area as compared to the much thinner organic layer in the upgradient cross sections. Again, the variability of the lithology is apparent. Stiff diagrams for monitoring wells in this cross section have a much smaller sulfate peak indicating improving water quality moving downgradient away from the Parrot Tailings. Except for in PMP-08A, the wells completed in the MAU have a higher percentage of contaminants than either the UAU or LAU. The contaminant signature in the monitoring wells also appears to decrease with distance from the Subdrain. PMP-08A is completed in a perched aquifer near the historic location of what may have been the Fool's Concentrator. The higher meq/L at this location appears to be due to a secondary source, possibly from the former concentrator operations.

Cross section E-E' (Figure 10) is sub-parallel to Blacktail Creek near the KOA. The lithology in this area contains more coarse material with more sand and gravel than clay and silt as compared with upgradient cross sections. The organic layer at this location is thicker than further upgradient and may indicate ponding of water or more of a wetlands-type regime in the past. Stiff diagrams for this cross-section indicate lower meq/L percentages of the major minerals with the exception of BPS07-23 and AMW-13A, which have relatively higher percentages. BPS07-23 is located several hundred feet downgradient of the end of the Subdrain and may indicate bypass groundwater that does not get collected. AMW-13A may represent a preferential flow path of contaminated groundwater near Blacktail Creek.

At the lower end of the PMP study area (near Montana Street), cross section F-F' (Figure 11) illustrates the deepening of the bedrock interface to the south. Lithologies in this area indicate more coarse sand and gravel material but still contain the organic silt/clay layer that is continuous throughout this portion of the basin. Stiff diagrams for monitoring wells in this area show no calcium sulfate shift, in contrast to the wells nearer the Parrot Tailings area.

Figure 12 illustrates the lithologic transect G-G. This cross section is perpendicular to the transects. It begins upgradient of the Parrot Tailings and runs down the corridor to its intersection with U.S. Interstate-90. This transect illustrates the deepening of the alluvium/bedrock interface mid-transect and the Stiff Diagrams clearly show the most impacted groundwater beneath the Parrot Tailings, with improving quality both upgradient and downgradient of the Parrot. The Stiff diagrams also indicate that among alluvial aquifers, generally, water quality is poorer in the middle alluvial unit and (with limited data) indicate improvement of water quality with depth.

7.5.3 Groundwater Elevation

As part of PMP monitoring efforts, transducers were placed at 29 sampling locations (Appendix A, Table 2) in order to monitor water level fluctuations throughout the study area. The transducers are programmed to record water level and temperature at 15-min intervals. Five transducers also have the capability of recording specific conductance, and one of the three surface water transducers also records specific conductance. The majority of transducers have been recording data since January 16, 2018, although several transducers were installed later in the Spring of 2018 due to freezing conditions (PMP-12 and PMP-10B). A barometric pressure logger has been installed near the center of the study area at PMP-05A in order to correct transducer data for fluctuations in atmospheric pressure.

The hydrographs compiled from both manual and in situ water level measurements, indicate several trends in groundwater elevation over the PMP monitoring period. Most hydrographs for monitoring wells in the upper study area (near the Parrot Tailings) have only one seasonal high (Figure 7-4) in the fall (September/October) while monitoring well hydrographs in the lower study area (near the confluence of Silver Bow and Blacktail Creeks) have two seasonal highs (Figure 7-5); one in the spring (May/June) and one in the fall (October/November) with the fall high being the smaller of the two. Generally, monitoring wells near Blacktail Creek show less magnitude in their seasonal variation than wells completed nearer the Parrot Tailings (GS-28B shows less than one foot of fluctuation, while PMP-02B varies approximately 2 ft over the period). Monitoring wells near the Subdrain in the upper basin have a downward vertical gradient, while those further from the Subdrain have an upward to neutral vertical gradient. Nested monitoring wells near the confluence area have a strong upward gradient. Monitoring wells near the Columbus Plaza clearly show the cycling of an irrigation well in that area (Figure 7-7).

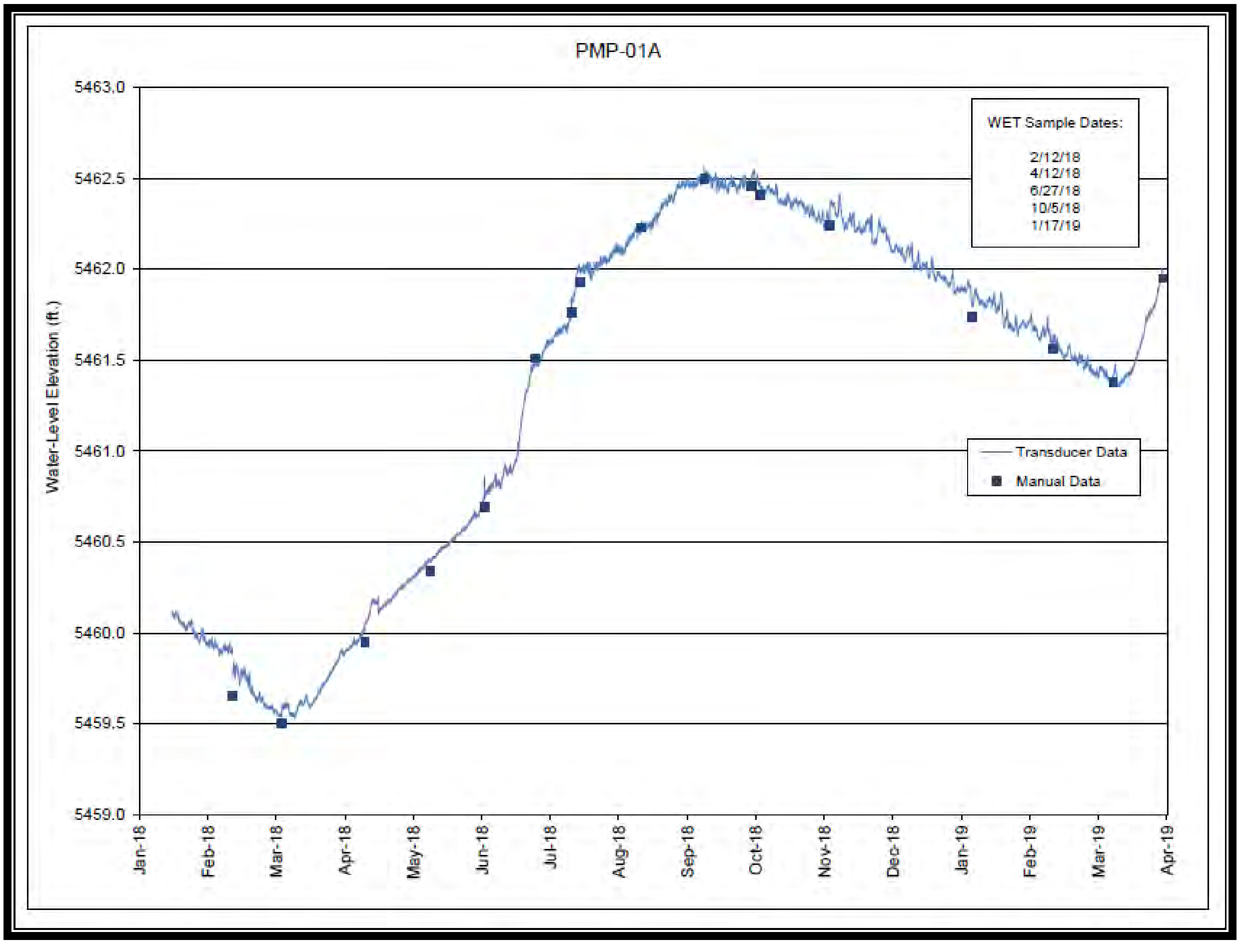

Figure 7-4. PMP-01A Hydrograph – Fall Peak

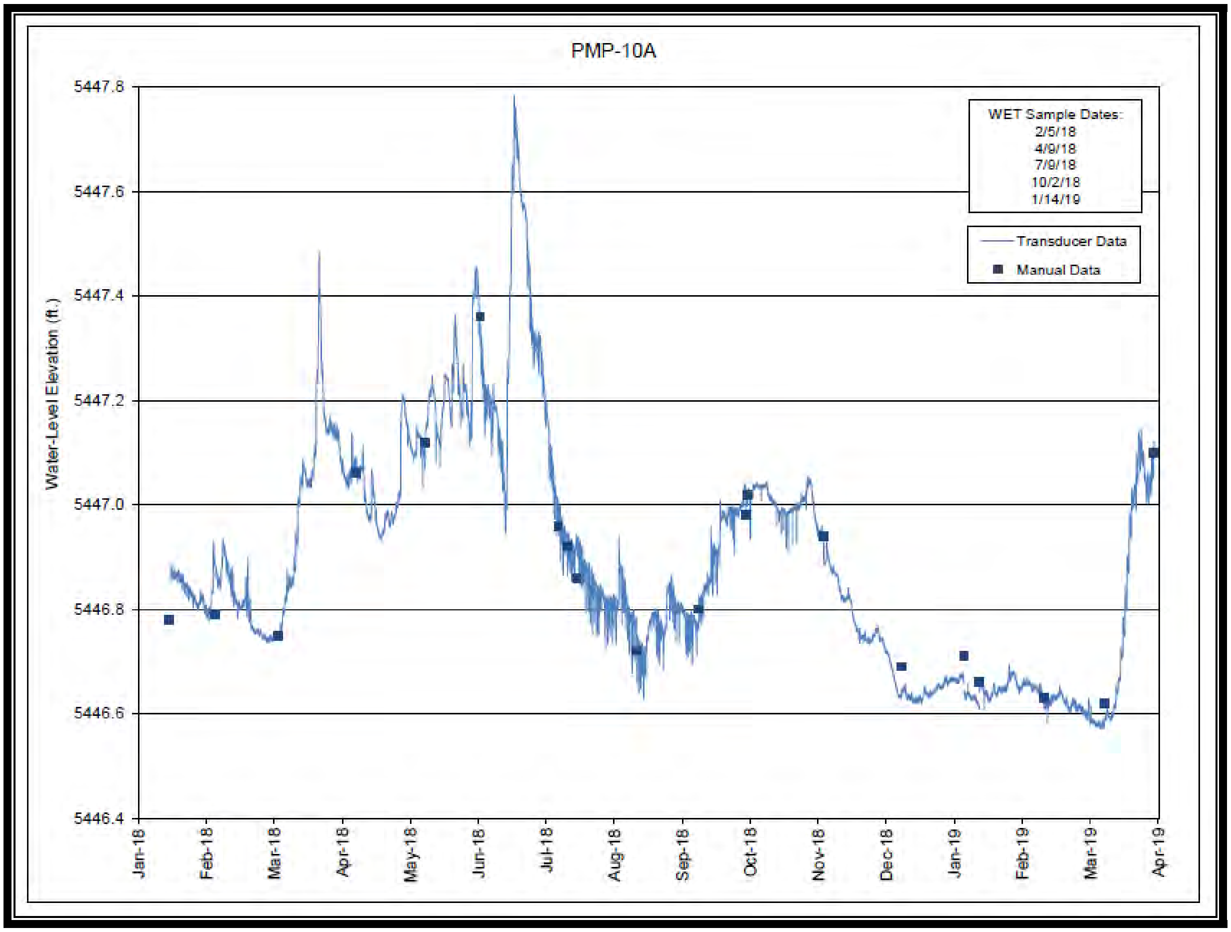

Figure 7-5. PMP-10A Hydrograph – Spring and Fall Peaks

In general, water level fluctuations displayed in hydrographs are a result of natural influences such as precipitation or snow melt. However, water level fluctuations shown in the hydrographs may also be influenced by activities such as well sampling, interference from nearby irrigation wells, or jetting and pigging of the Subdrain. Quarterly sampling events were performed in December 2017, February, April, July, and October 2018, and January 2019. These sampling events are often identified with a marked decrease in water level on the hydrographs.

Jetting is performed on the Subdrain in April and October in order to remove scale and improve connectivity between the Subdrain and aquifer. Scaling and screen fouling affect the ability for groundwater to enter the Subdrain and therefore its capture effectiveness. As a result, mounding conditions often occur prior to jetting (Figure 7-6), which produces elevated groundwater elevations in wells adjacent to the Subdrain. When this occurs, contaminated groundwater is not being effectively captured. Immediately after jetting, a marked decrease in water levels is commonly exhibited in wells adjacent to the Subdrain for a variable period of time.

This is especially evident in the following wells:

PMP-2A	PMP-08A
PMP-06A	MF-07B
PMP-06B	PMP-03A
BPS07-07B	PMP-08A2
PMP-05A	PMP-08B
PMP-05BR	

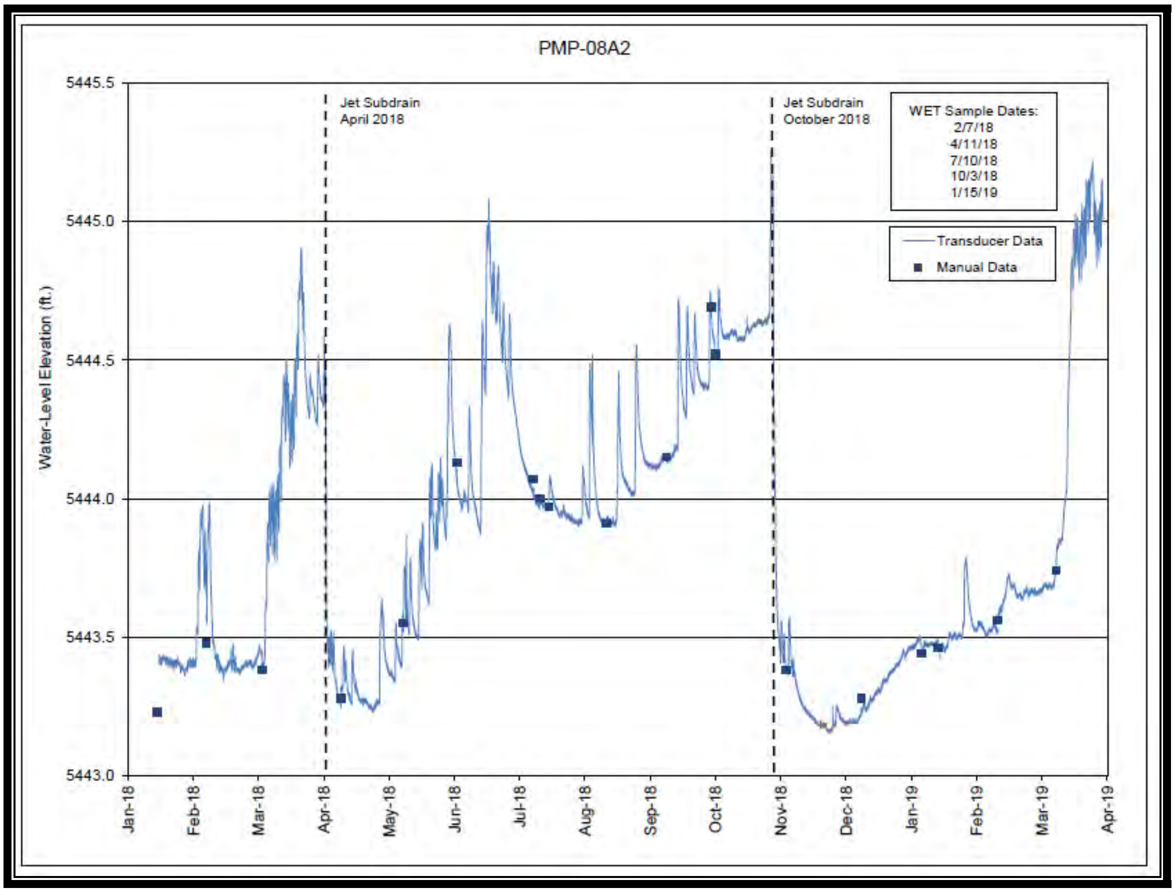

Figure 7-6. PMP-8A2 Hydrograph – Response to Subdrain Jetting/Pigging

Several wells within transect C-C' are also affected by withdrawals from the irrigation well at Columbus Plaza. Hydrographs (Figure 7-7) for these wells show periodic drops in water elevation which recover during the same day during summer months. The irrigation withdrawals begin in late June and terminate in mid-September. The frequency of withdrawals is 2 to 5 days from late June to mid-July, increasing to daily withdrawals from mid-July to mid-August, and decrease back to 2 to 5 days from mid-August to mid-September. Wells affected by the Columbus Plaza irrigation well include: MF-07B, PMP-05A, PMP-05B, and MF-11.

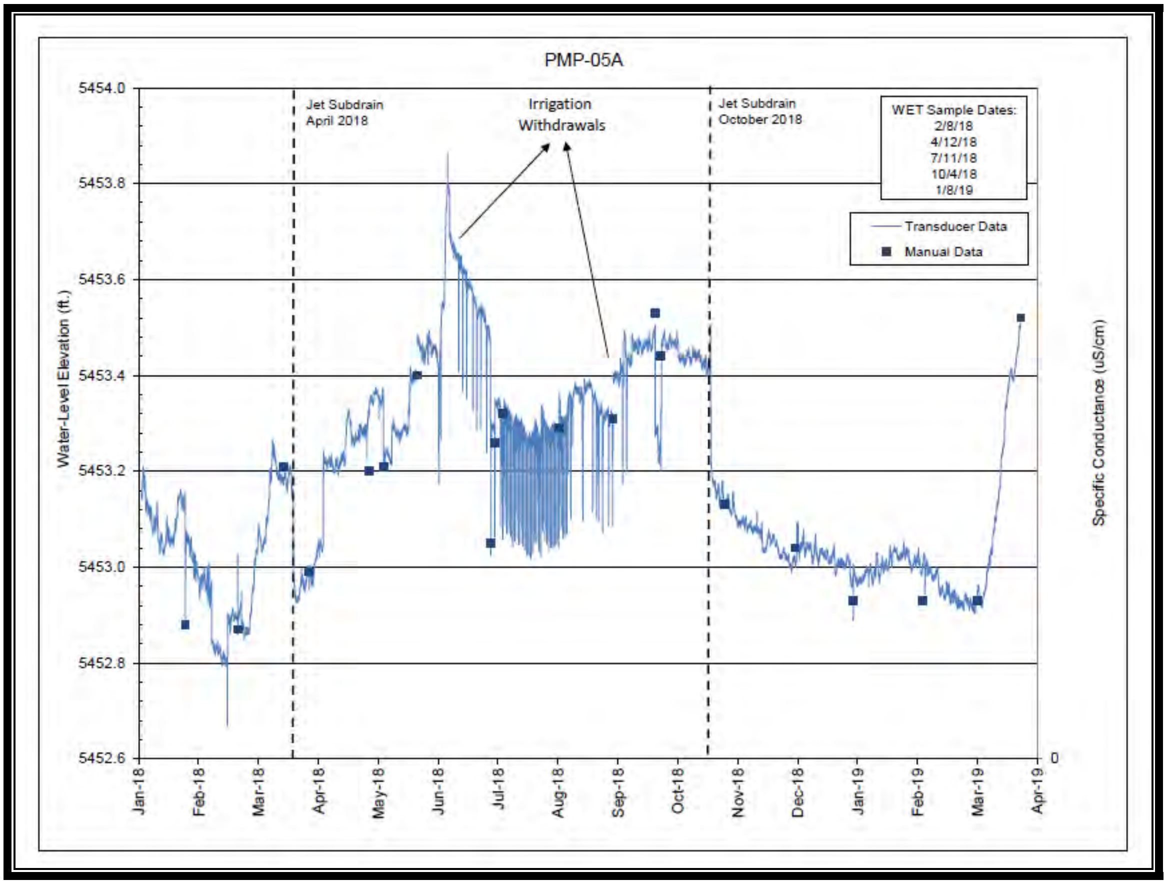

Figure 7-7. Well PMP-05A Hydrograph – Irrigation Effects

Several sampling locations are subject to freezing during winter months, including the surface water location PMP-12 and well PMP-10B, which has artesian conditions. Transducers are removed from these locations in November and reinstalled following the spring thaw. Well PMP-10B also has a well packer installed during winter months to maintain a groundwater elevation below the ground surface in order to prevent freezing.

April, July, and October of 2018 groundwater potentiometric contour maps were developed for the PMP dataset for the UAU, MAU and LAU (Figures 13 through 15). BPSOU data collected within a month of the PMP data was also used. Multiple monitoring wells near the Parrot tailings Site in the UAU and MAU were removed as part of Phase I of the Parrot Tailings Project before the October monitoring event. Because chemical data in these monitoring wells is relatively consistent from event to event, the July 2018 monitoring data was exhibited for comparison purposes on the October 2018 iso-concentration maps. These data are shown with an asterisk on the monitoring well identification labels.

The UAU maps (Figures 13A, 14A and 15A) indicate the Subdrain's effect on water levels in its proximity and the effect dissipates with distance from the Subdrain and depth in the aquifer, i.e., much less definitive on the MAU potentiometric maps (Figures 13B, 14B and 15B). Groundwater flow parallel to the Subdrain, that may not be captured by the Subdrain, is indicated on MAU maps and to a limited extent on the UAU maps. The bypass is particularly noticeable on both sides of Lexington Avenue, north of the interstate in the MAU. The LAU (Figures 13C, 14C and 15C) groundwater maps indicate the low number of deeper wells in the study area; however, even with the limited well control, groundwater is moving in a similar direction as the upper aquifers. Horizontal hydraulic gradients in the UAU vary from 0.003 to 0.006 ft/ft with the highest gradient in July 2018 and October 2018, in the MAU they vary from 0.002 to 0.009 ft/ft with the highest gradients in October 2018 and in the LAU they vary from 0.003 to 0.005 with the highest gradient in October 2018. The highest gradients are for wells completed along the Subdrain and flattens with distance from the Subdrain.

7.5.4 Groundwater Quality

Groundwater chemistry iso-concentration contour maps were developed for pH and field specific conductivity (SC) (Figures 16 and 17) for the October 2018 PMP monitoring event for all three aquifer units[3]. Before the October monitoring event, multiple monitoring wells near the Parrot tailings Site in the UAU and MAU were removed as part of Phase I of the Parrot Tailings Project. Because chemical data in these monitoring wells is relatively consistent from event to event, the July 2018 monitoring data was exhibited for comparison purposes on the October 2018 iso-concentration maps. These data are shown with an asterisk on the monitoring well identification labels.

pH

Figures 16a - 16c indicate pH measurements within the alluvial units. Figure 16a, illustrates several areas of depressed pH in the UAU, with the lowest values of less than 4 at the Parrot Tailings Site. One area of depressed pH is shown to the south from the Parrot Tailings Site towards Clark's Park, while another follows the Subdrain, southwest of the Parrot Tailings Site and moves out into the aquifer east of Lexington Avenue, possibly defining another contaminant flow path in this area. The MAU shows similar areas of low pH, but with less definition in the areas east of Lexington, most likely due to less well control in the MAU in this area. The MAU also has lower pH along the Subdrain, west of Lexington Avenue. The LAU exhibits depressed pH below the Parrot Tailings Site, but not as low as in the UAU and MAU. The available data also indicates higher pH downgradient of the Parrot as compared to the UAU and MAU.

Field Specific Conductivity

Field specific conductivity (SC) values for October 2018 are shown on Figures 17a - 17c. Generally, SC values indicate an area of higher specific conductivity beneath the Parrot and downgradient along the Subdrain. Figure 17b indicates that the highest specific conductivity values are in the MAU. This map also shows an area of high conductivity south of the Subdrain along Lexington Avenue. Neither the UAU nor MAU maps indicate the area from the Subdrain

[3] BPSOU data collected within a month of the PMP data was also used.

south to Clark's Park as having SC values above 1000 mg/L. Similar to the shallower SC maps, LAU SC values are higher beneath the Subdrain, but not to the magnitude or extent of the upper alluvial units.

Contaminants
Groundwater iso-concentration contour maps were developed for major contaminants from Table 6, including dissolved arsenic, copper, cadmium, lead, and zinc for each aquifer unit for the October 2018 PMP monitoring event (Figures 18 - 22). BPSOU data results were used for events where sampling overlapped within a month of the PMP monitoring event.

Copper
Figures 18a - 18c indicate dissolved copper concentrations for the UAU, MAU and LAU. The highest concentrations are beneath the Parrot Tailings Site in the UAU. The area from the Parrot south to Clark's Park shows elevated copper in both the UAU and MAU and the UAU map indicates other source areas near the Northside Tailings and Diggings East areas. The MAU copper iso-concentration map also indicates an area of elevated copper south of the Subdrain, along Lexington Avenue. With limited well control, the copper concentrations in the LAU are again much lower and confined to the area below the Parrot Tailings Site.

Zinc
Zinc concentrations for the October 2018 monitoring event were contoured on Figures 19a - 19c. The highest zinc concentrations are below the Parrot Tailings Site in the MAU. Both the UAU and the MAU maps exhibit elevated zinc along the Subdrain, south of the Parrot Tailings Site towards Clark's Park and in the area south of the Subdrain and east of Lexington Avenue. Zinc concentrations in UAU and MAU are elevated to Blacktail Creek east of Lexington and south of the KOA. LAU zinc concentrations are elevated beneath the Subdrain, but as with the other contaminants, Figure 19c, the LAU exhibits lower concentrations and less widespread distribution than in the shallower alluvial units.

Cadmium
The iso-concentration contour maps for cadmium are shown on Figures 20a - 20c. Again, the highest concentrations are measured below the Parrot Tailings Site in the MAU. Concentrations decrease in the downgradient direction both towards Clark's Park and along the Subdrain. Elevated concentrations in the UAU and MAU are evident east of Lexington Avenue, south of the Subdrain. The LAU cadmium data indicate elevated cadmium below the Subdrain to Blacktail Creek south of the KOA, but concentrations in the LAU are reduced when compared to the shallower alluvial units.

Lead
As expected because of its low solubility, lead concentrations (Figures 21a - 21c) are highest in the UAU and decrease quickly with depth and distance from the Parrot Tailings Site. The highest LAU concentration reported for the October dataset was 0.00056 mg/L and thus no iso-concentration contours were developed for the LAU for this contaminant.

Arsenic

The arsenic distribution for October 2018 is shown in Figures 22a - 22c. These iso-concentration maps exhibit similar spatial distributions as noted in the other contaminant iso-concentrations maps, specifically that the concentrations are highest beneath the Parrot Tailings Site, elevated concentrations are noted to the south towards Clark's Park, downgradient along the Subdrain and near Blacktail Creek south of the KOA and east of Lexington Avenue.

As discussed in Section 6.3, an EVS visualization using the PMP dataset and overlapping BPSOU data was developed to provide a three-dimensional illustration of subsurface lithology, water levels, and analytical chemistry data.

As shown by potentiometric surface maps and chemistry data, highly contaminated groundwater originating from the Parrot Tailings Site has migrated southwest in a multi-contaminant plume that have traveled to and intersect with Silver Bow Creek and Blacktail Creek. EVS model animations depict highly contaminated groundwater originating at the Parrot Tailings Site and traveling along the Subdrain. The Subdrain appears to be somewhat effective in capturing the contaminants along the northern portion of the plume. However, near the southwest bend in the Subdrain, elevated contaminant concentrations are observed as the plumes continue migrating to the south and west to the Blacktail/Silver Bow Creek confluence, perpendicular to the Subdrain. This is particularly true of zinc, which is highly mobile in groundwater under the low pH conditions found in groundwater impacted by the Parrot Tailings.

7.5.5 Groundwater Geochemistry

Water chemistry data were plotted on a tri-linear Piper diagram to show the differences in water chemistry between sample points. Piper diagrams illustrate the water chemistry for each well by plotting the relative abundance of major cations and anions in separate triangles on either side of a diamond, where each analysis is plotted as a circle and illustrates relative abundance as a percentage of the milliequivalents per liter. Generally, the circles are plotted with the diameter of the circle proportional to the TDS. To simplify the diagrams (because of large TDS variation), the circle diameter for each analysis was not varied by TDS. Water type and chemical changes along groundwater flow paths are illustrated using these diagrams. Piper diagrams are located in Appendix C.

Appendix C contains Piper diagrams for each PMP monitoring event from the fourth quarter of 2017 to the first quarter of 2019. Each quarterly PMP dataset from 2017 to 2019 is plotted together on one Piper diagram and separated out by alluvial unit, with the yellow dots representing the UAU, orange the MAU and red the LAU. Lettered identifiers are labelled in the legend to identify individual wells. The Pipers provide a unique perspective to the geochemistry in this area.

The most noticeable characteristic of the diagrams (Figure C-1 - C-12) is that the wells in and around the Parrot Tailings Site plot in the uppermost diamond along the calcium axis, indicating the relatively high calcium and sulfate percentages in these wells. Because the chemistry is similar in these wells in the UAU and MAU, they tend to plot on top of each and leaders are provided to identify individual wells.

Moving from the area of the Parrot Tailings Site wells, vertically down the large diamond, parallel but separate alignments (flow paths) can be discerned for each alluvial aquifer unit (Figure C-7, C-8, C-12). For the UAU (yellow dots), the alignment is further to the left than the other alluvial units and the yellow dots spread further down the diagram. The blue dots on the graph are the surface water points on Blacktail Creek and PMP-12 (Silver Bow Creek surface water above the confluence). The vertical alignment of the UAU points (yellow) ends near the surface water sample points (in blue) with these monitoring wells (GS-28, BPS11-11A2, AMW-13A) completed near the creek, indicating surface water/ groundwater interaction in this area. The diagram indicates that groundwater at the Parrot Tailings Site in the UAU has the same chemistry as that in the MAU and progressively decreases in sulfate and calcium and increases in carbonate/bicarbonate as it moves down the corridor until it has chemistry very similar to that in Blacktail Creek.

The chemistry in the MAU exhibits a different pattern than in the UAU. Wells around the Parrot Tailings have the same characteristic high calcium/sulfate percentages as the UAU wells, but the chemistry doesn't change as consistently or completely down the corridor as the UAU monitoring wells. Several of the wells near Columbus Plaza still plot with the wells near the Parrot, including PMP-05BR, PMP-07B, indicating little change (oxidation or dilution) in MAU water chemistry from the Parrot to the Columbus Plaza area. The MAU sulfate percentages do not decrease as quickly, nor bicarbonate percentages increase as quickly moving down the corridor. Instead of a consistent alignment down the graph characteristic of UAU wells, the MAU wells progress down the diagram to well BPS07-07B (near the western end of the Subdrain) and then there is a large gap to the four MAU wells completed on Blacktail Creek (GS-28B, PMP-11B, AMW-13B, AMW-13B2). This indicates less mixing of the MAU groundwater with cleaner groundwater and precipitation as it moves down the corridor, as compared to the UAU. This may confirm the interpretation of a discontinuous clay layer and/or conductivity contrast between the UAU and MAU, somewhat isolating the MAU from surficial recharge and Subdrain capture.

The LAU groundwater chemistry also shows a similar mixing/dilution flow path as it moves down the corridor, but most of the change in chemistry in these wells is in calcium and not sulfate or bicarbonate. Again, the wells near the Parrot (BPS11-17C BPS11-18C and AMW-01C) plot in the upper diamond but not at the 100% sulfate axis and progressively move along the calcium axis as the well locations move down the corridor. The monitoring well farthest along the alignment is BPS11-11C, which is located near Blacktail Creek at Lexington Avenue. Although the farthest downgradient LAU wells plot near the middle of the diagram, the LAU wells have higher sulfate percentages and lower bicarbonate percentages than the surface water sample points. Comparison of the LAU wells between monitoring periods shows very little variation of individual well chemistry, indicating less seasonal change in these wells as compared to the shallower aquifer, as would be expected (Figures C-3, C-6 and C-11).

Stiff Diagrams were also developed for the site monitoring wells over the PMP quarterly monitoring period. They are shown along the top of Figures 6 - 12. The Stiff Diagram for each monitoring period is shown in a different color and superimposed over each other to illustrate changes in groundwater chemistry over the period. A description of the diagrams is included with the geologic cross sections in Section 7.5.2 of this report. To summarize, the Stiff Diagrams for monitoring wells near the Parrot Tailings show a characteristic calcium/sulfate shift. The "shift" dissipates with distant both laterally and in depth below the Parrot Tailings, indicating the Parrot as the source of the plume.

7.5.6 Mass Balance Summary

A quantitative assessment of contaminant transport through cross-section B-B' was performed in order to determine the total mass of zinc and copper moving through the aquifer immediately downgradient of the Parrot Tailings Site and to evaluate the percent of contaminants emanating from the Parrot Tailings captured by the existing Subdrain. This analysis was completed by utilizing the groundwater elevation and concentration data collected at cross-section B-B', combined with site specific hydraulic parameters from the 2010 MBMG aquifer test evaluation (MBMG, 2010a) to develop an estimate of the mass of copper and zinc moving with groundwater in this area. Due to geochemical conditions (anoxic condition and low pH values) in the MAU and UAU within the Parrot Tailings and downstream to cross-section B-B', copper and zinc are assumed to be conservative solutes, i.e. are transported at the approximate rate of groundwater flow, since a majority of available sorption sites have already been filled due to contaminant transport in this area for over 100 years. This assumption is supported by data in Figures 6 and 10 and Table 5 of MBMG's 2012 geochemical and hydrologic investigation report (MBMG 2012), showing similar copper and zinc concentrations along the groundwater flow-path towards cross-section B-B'.

A description of the mass balance methodology is included in Appendix F. A summary of the groundwater flow and loading calculations are include in Table 6.

Table 7-2. Mass Balance Load Summary – PMP Cross Section B-B’

Aquifer	Flow (GPM)	Analyte	Mass (lb/day) PMP
Middle Alluvial	272	Copper	59.1
Upper Alluvial	14	Copper	7.2
		Total:	**66.3**
Middle Alluvial	268	Zinc	196
Upper Alluvial	27	Zinc	11.4
		Total:	**207.4**

8.0 CONCLUSIONS

Multiple lines of evidence (groundwater contaminant fate and transport data, aquifer hydraulic parameters, discrete alluvial unit chemical and geochemical analysis, and recent high resolution lithologic data) support the conclusion that the most significant source of alluvial groundwater contamination in the study area is the Parrot Tailings. The lines of evidence are outlined throughout this report and include the following. Section 7.4.1 highlights the substantial hydraulic connection between groundwater and surface water in the creeks. In Section 7.5.4, groundwater chemistry data define the contaminant impacts to groundwater from the Parrot Tailings and show less contaminated groundwater both upgradient and downgradient of the Parrot Tailings and with depth in the aquifer, indicating the Parrot Tailings as the source. Multiple contaminant plume maps for discrete monitoring periods trace the plume migration down basin. Section 7.5.5 illustrates that the monitoring wells near the Parrot Tailings show a characteristic calcium/sulfate “shift,” which dissipates with distant both laterally and in depth below the Parrot Tailings, again indicating the Parrot Tailings as the source of the plume. Additionally, groundwater potentiometric maps in the UAU and MAU indicate flow paths that bypass the Subdrain, and Piper diagrams further identify a flow path in the MAU from the Parrot Tailings that bypasses the Subdrain.

Based on an evaluation of data collected as part of the Parrot PMP, supported by data collected by multiple other parties, the following conclusions are made:

- The Parrot Tailings are the most significant source of contamination in the BAO alluvial aquifer. Groundwater chemistry data supports the conclusion that a multi-contaminant plume is emanating from the Parrot Tailings Site and migrating downgradient towards and to Blacktail and Silver Bow Creeks. The zinc plume currently intersects with Blacktail Creek and the confluence area.

- Contaminant loading calculations completed along the B-B’ transect immediately below the Parrot Tailings Site indicate 66.3 lbs/day of copper and 207.4 lbs/day of zinc are present in the aquifer, with the majority of groundwater flow occurring in the middle alluvial aquifer. These values are significantly higher than those reported by BP-AR as captured from the Subdrain at its lower end. Therefore, these data support the conclusion that zinc and copper-contaminated groundwater flowing from the Parrot Tailings Site is not being captured by the Subdrain; as a result, contaminated groundwater is discharging to Blacktail Creek and the Blacktail/Silver Bow Creek confluence area and/or being bound up in the alluvial aquifer. The latter is caused by geochemical conditions downstream from cross-section B-B' changing from anoxic to oxic with pH increasing by up to two standard units, thus allowing adsorption of zinc and copper within the aquifer material to occur.

- Multiple other investigations by NRDP, Montana Tech, and the Montana Bureau of Mines and Geology within Blacktail Creek and Silver Bow Creek show clear evidence of contaminant loading from groundwater partitioning to instream sediments, instream sediment porewater, and surface water.

- Precipitation of contaminants and associated fouling from other water quality constituents plugs the Subdrain, affecting groundwater flow conditions near the Subdrain and negatively affecting collection system efficiency, while increasing groundwater plume migration.

- Lithologic, hydraulic, and geochemical data indicates a groundwater flow path from the Parrot Tailings Project towards Blacktail Creek, bypassing the Subdrain.

- A limitation in the PMP Conceptual Site Model is the lack of adequate well density in specific areas of the corridor. Additional monitoring wells east of Lexington Avenue and north of Majors Street would provide additional lithologic and hydraulic control on bypass of the Subdrain in this area.

- Contaminated groundwater near transect C-C' is being captured by an irrigation well at the Columbus Plaza, potentially creating a potential exposure pathway for residents and visitors of the facility. This well should be evaluated for replacement with a municipal water source.

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