BUTTE'S METRO STORM DRAIN RECLAMATION: ADDRESSING STORMWATER, GROUNDWATER AND LAND USE CHALLENGES[1]

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Abstract. Butte's Metro Storm Drain (MSD) is a channel that was constructed in the 1930's to manage storm flows from Butte, Montana's midtown area. It was in disrepair and contained large amounts of sediments, impacted by local industrial and urban activity. In addition, it collected base flow groundwater impacted with elevated levels of metals. These metal-impacted waters drained from the MSD to the local stream, Silver Bow Creek.

To address these issues, a reclamation design was implemented in order to accomplish these major goals: 1. clean the channel of sediments to reduce sediment loads to Silver Bow Creek; 2. separate groundwater flows for routing to a treatment system and to reduce dissolved metals loads to Silver Bow Creek; and 3. provide a recreational corridor with enhancements to be more natural and aesthetically pleasing and functional for public use.

Construction began in 2003. The channel was reconstructed with a sub-drain beneath the surface channel. The sub-drain collects groundwater that previously entered the surface channel, and the collected groundwater is routed to a nearby treatment system. The reconstructed surface channel was first lined with a low-permeability liner to prevent storm flows from infiltrating into the sub-drain. Then, the surface channel was re-constructed using several features which allowed the channel to continue to drain storm flows, but also be more natural-looking. These features included a small meandering pilot channel incised into the base of the channel, which was constructed and revegetated for a natural appearance. Also, in several areas, the channel was widened with more gentle side slopes to reduce its original "engineered ditch" look. Finally, off-channel vegetation was planted, including large native trees and shrubs, and a walking trail was constructed along the channel's entire length to make the corridor more useable as a recreational corridor. The construction was completed in 2004, and initial water quality monitoring results suggest there have been substantial reductions in metals loading to Silver Bow Creek from the MSD. Based on the successful construction completion and the water quality results, the major goals of the project have been achieved.

Additional Key Words: Butte Priority Soils Operable Unit, BPSOU, Mine Flooding Operable Unit, MFOU, sub-drain; design; loading; metals; Montana.

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Introduction

During the reclamation of the MSD channel, located along a constricted urban corridor in Butte, MT, the Atlantic Richfield Company (Atlantic Richfield) and the local government, Butte-Silver Bow County, strove to complete a fully functional reclamation project while enhancing the aesthetics and land use of the channel's corridor. The reclamation goals were to remove large quantities of impacted sediments from the surface channel and separate metals-impacted groundwater entering the channel from surface water, then route the groundwater to a treatment system. Urban aesthetic goals were to enhance the appearance of the MSD by naturalizing the structure of the channel (where possible) by utilizing vegetation to resist erosion from storm events, designing the pilot channel to look like a small freestone brook, and making the corridor more useable as a recreational corridor by installing a walking trail along the channel's entire length.

Reclamation completed under this project also supported the remedial activities associated with the Butte Priority Soils Operable Unit (BPSOU) and Mine Flooding Operable Unit (MFOU) of the Silver Bow Creek/Butte Area National Priorities List (NPL) site.

Background

The MSD passes through and drains storm water from Butte's midtown area and, prior to the MSD reclamation in 2003, collected base flow groundwater and urban runoff. Nearly 2,500 meters (8,000 feet) in length, the MSD originates in the east side of Butte. As the MSD flows to the southwest, it skirts both public and private property, crosses underneath three roadways and ends at Silver Bow Creek (Fig. 1).

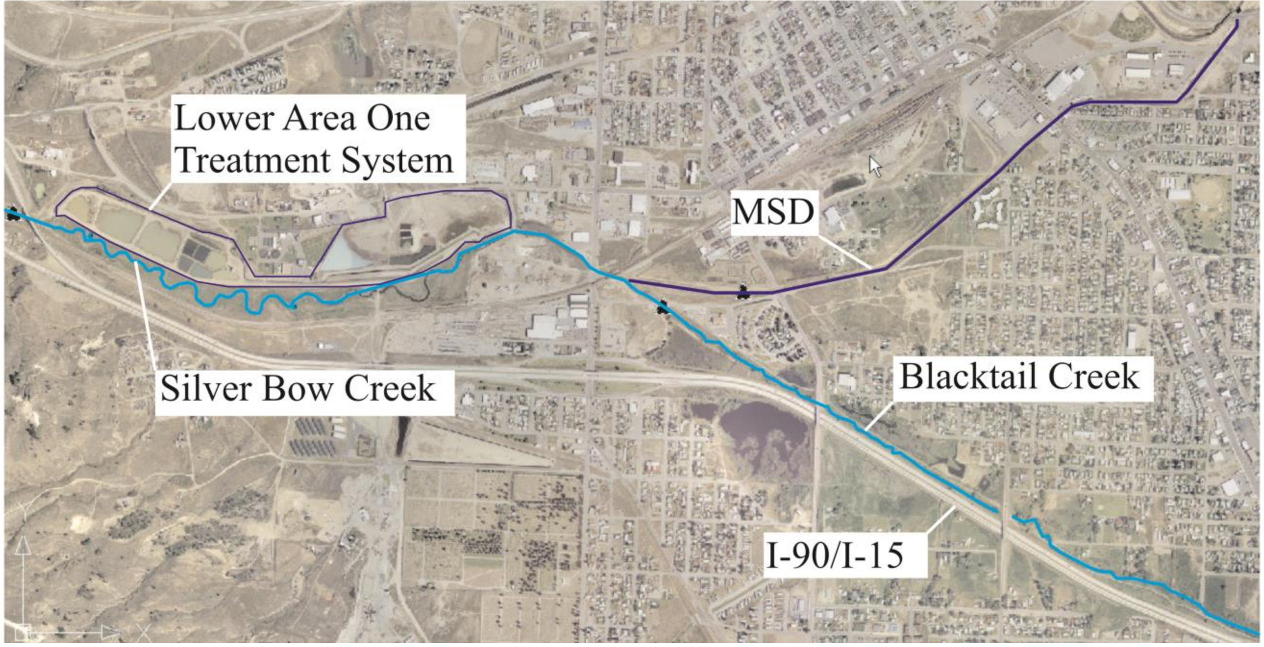

Figure 1. Configuration of the Metro Storm Drain.

Construction of the original MSD was completed in the 1930's by the Works Progress Administration (WPA) to convey storm flows and domestic sewage from Butte's midtown area (Fig. 2). Over the next 70 years, sewage was managed separately, but the MSD was impacted by large quantities of sediments and debris from local industrial and urban activities. In addition to these impacts, the MSD channel collected metals-impacted groundwater and surface water that flowed downgradient to Silver Bow Creek.

Groundwater

Prior to the MSD reclamation in early 2003, metals-impacted groundwater provided a consistent base flow in the MSD, with the groundwater primarily entering the MSD within the lower 1.6 kilometers (1 mile) of the channel (Figure 1). This groundwater drained into Silver Bow Creek via the MSD.

The source of this groundwater is primarily from the surrounding alluvial aquifer. Depth to groundwater ranges from less than 2 feet along the lower MSD channel to more than 40 feet along the upper MSD channel (near Continental Drive) (EPA, 2004a). Shallow groundwater flow directions mimic the slope of topography and generally run parallel to the MSD channel. Aquifer thickness ranges from less than 20 feet to greater than 200 feet (EPA, 2004a). The hydraulic conductivity ranges from 2.5 to 45 feet per day (PRP Group, 2002). Important physical characteristics of the alluvial aquifer located in the upstream portion of the MSD include a relatively thick aquifer and lower hydraulic conductivity. In the downstream portion, the aquifer becomes significantly thinner and has a higher hydraulic conductivity. This unique feature is important because, as the aquifer pinches out, the majority of the groundwater is forced to the surface, to be expressed as surficial base flow in the MSD.


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Figure 2. Metro Storm Drain Channel (Pre-reclamation).

Characterization of the metals emanating from the aquifer into the MSD has been conducted from 1984 to present, and has been summarized in Attachment A of the BPSOU Feasibility Study (Atlantic Richfield Company, 2004a). Groundwater surfacing into the MSD has elevated concentrations of As, Cd, Cu, Pb, and Zn (Table 1).

Storm Water

The MSD manages storm water from Butte's midtown area, including both snowmelt and precipitation events (Fig. 3). Water and sediment from these events is collected within a drainage basin with an area of approximately 1.7 square kilometers (0.65 square miles), and carry elevated concentrations of certain metals into the MSD.

Measurable wet weather events within the MSD channel occur 10 to 12 times per year with recorded peak flows measuring up to 0.6 cubic meters per second (20 cubic feet per second [cfs]). Typical storm flow hydrographs within the MSD channel include a sudden increase in flow rate that is short in duration. Because of the steepness of the Butte Hill drainages, much of the sediment and solids carried within the steep runoff water from the Butte Hill drainages is contained within the MSD channel, which has a much flatter slope in comparison. Over time this has led to large areas of sediment deposits within the MSD. In some areas sediment depths ranged from one to four feet in the channel.

Storm water volume and sediment deposition within the MSD has decreased substantially over the past 10 years, due to remediation activities conducted under the scope of the BPSOU projects within the eastern drainages of the Butte Hill. These activities have successfully diverted runoff in some of the unreclaimed areas to the Berkeley Pit, or diverted storm water to sediment basins. In other areas, substantial soil reclamation, stabilization and vegetation have occurred. The net result is a smaller volume of water containing less quantities of sediment.

Table 1. Water Quality Summary: Metro Storm Drain Base Flow Conditions, Pre-Reclamation Project (2001 - 2003).

	Concentration (µg/L)*		
Constituent	**Average**	**Minimum**	**Maximum**
Arsenic	17.8	6.8	39.7
Cadmium	26.1	15.5	40.8
Copper	212	105	363
Lead	4.6	0.6	13.3
Iron	6,764	2,130	19,700
Zinc	9,516	5,540	12,700

*: Total Recoverable Concentration

Figure 3. Storm Event within Metro Storm Drain (March 13, 2004).

Nonetheless, storm event sampling prior to reclamation within the MSD showed runoff from this area contained resuspended sediment during larger runoff events, as well as groundwater with elevated metals concentrations in comparison to the receiving stream. Concentrations of major COCs within the base flow (Table 1) that has been captured by the project are ten to one hundred times the applicable water quality standards.

Comparison of Metals Loading from Groundwater and Storm Events

Based on monitoring during wet weather and base flow conditions, two things became apparent.

- The MSD waters were major metal loading sources to Silver Bow Creek within the BPSOU during base flow and wet weather runoff events; and
- The water quality of the base flow was usually worse than the water quality measured during wet weather runoff events.

The flow gain from the MSD to Silver Bow Creek (5.6 E-03 to 2.0 E-02 cubic meters per second [0.2 to 0.7 cfs]) is slightly discernable during base flow. However, the metals loading from the MSD to Silver Bow Creek is very noticeable. Within the BPSOU, concentrations of metal constituents in Silver Bow Creek were the highest just below the outlet of the MSD. This was evident in both base flow and wet weather flow conditions.

When COC concentrations in base flow and wet weather events were compared, it was observed that wet weather event COCs were usually at lower concentrations than the same COCs during base flow conditions. This indicated that the wet weather runoff was generally of a better water quality than the base flow, since wet weather runoff measurements included the base flow and any re-suspended sediment in the MSD. From these two main conclusions, it was determined that addressing the base flow from the MSD, and the sediments it contained, was a major priority in improving the surface water quality in Silver Bow Creek.

Priority was then placed on mitigating metals loading of the base flow from MSD. To collect and treat base flow groundwater (estimated during design at 5.6 E-03 to 2.0 E-02 cubic meters per second [0.2 to 0.7 cfs]) was determined to be practicable with existing treatment and storage facilities at the nearby water treatment facility (Lower Area One Treatment Lagoon System [LAO]). With storm water quality expected to continue improving as remediation is completed on Butte Hill, removal of the historic sediments from MSD would further reduce loads being re-suspended and washed into Silver Bow Creek during storm events. Therefore, managers decided to collect groundwater from MSD and treat it at LAO (and subsequently discharge it back to Silver Bow Creek), and to reclaim the MSD surface channel to mitigate metals loading during surface runoff events. EPA's Proposed Plan (U.S. Environmental Protection Agency, 2004b) for the BPSOU, released in 2005, also concluded that this was appropriate.

Design

Based on the BPSOU Feasibility Study, the collection and treatment of groundwater and the reclamation of the MSD surface channel were determined to be practicable and became major goals of the reclamation design. Additional major goals of the reclamation design included the following:

- Safely convey the 25-year, 24-hour storm event;
- Naturalize the channel's appearance; and
- Allow the channel corridor to be transformed into a recreational corridor by adding an adjacent walking trail.

Additionally, the preferred treatment for the collected base flow groundwater is routing it to an existing water treatment facility, which is currently treating metals-impacted groundwater.

Design Considerations

To accomplish the major goals of the design, consideration was given to reclamation goals, including sub-drain design, groundwater transport and routing, and the channel corridor's function and aesthetics. Reclamation goals within the MSD channel included removing impacted sediments from the channel and mine waste from within the footprint of the sub-drain channel.

Considerations for the design of the sub-drain included the following:

- Mechanisms for separating base flow groundwater and surface water;
- Estimating the quantity of groundwater that would be intercepted;

- Accessing the sub-drain for sampling and potential cleaning after it has been placed below the lined and reclaimed MSD;
- Preventing iron precipitates from clogging the sub-drain;
- Collecting groundwater at the end of the sub-drain in a centralized collection facility (sump);
- Evaluating how far the sub-drain should extend up the drainage to intercept impacted groundwater;
- Determining how close the sub-drain could approach Blacktail Creek without drawing water from the creek itself; and
- Routing of the sub-drain underneath Harrison Avenue, Casey Street, and Kaw Street.

Finally, channel aesthetics considerations included creating a more natural appearance, though the MSD is severely constrained laterally by commercial and residential infrastructure. A more natural-looking channel appearance was achieved by widening the channel and decreasing channel side slopes that were not constrained laterally. In the base of the channel, a meandering pilot channel was designed to create an appearance of a meandering freestone brook. Also, local grass and forb vegetation types were utilized within the channel to resist erosional forces therein. Finally, along the channel's entire length, a walking trail was planned to make the corridor more useable as a recreational corridor.

Design Concept

Incorporating both the major goals and design considerations, the concept of the design was separated into three major functions:

- Capture groundwater in a 1.6 kilometer (1 mile)-long French-drain type system (MSD sub-drain);
- Separate groundwater from surface water utilizing a geosynthetic clay liner (GCL); and
- Create a natural appearing storm water channel.

Components

Four major components of the design were required to support the above design concept while considering the following site-specific requirements: a sub-drain; a storm conveyance channel; a pilot channel; and vegetation (Figure 4).

<u>Sub-drain</u>. A French-drain style sub-drain was designed to intercept base flow groundwater. Land use restrictions (i.e., MSD alignment is abutted by urban infrastructure throughout most of its length) required the sub-drain to be located immediately beneath the reconstructed MSD channel. Advantages of this location include the full concealment of the sub-drain and optimal capture of base flow groundwater. The subdrain consists of a 10-inch diameter, perforated polyvinyl chloride (PVC) pipe that is surrounded by a washed gravel envelope. The sub-drain was designed to collect and convey groundwater to a collection sump at the downgradient end of the sub-drain. Water collected in the collection sump would be conveyed to a nearby treatment system (LAO) via a pump and separate pipeline. Sub-drain access, for purposes of sampling or cleaning, was provided with cleanouts spaced on a 150-meter (500-foot) interval.

<u>Storm Conveyance Channel</u>. To separate storm flows within the channel from groundwater in the sub-drain, the MSD channel was lined with a low-permeability GCL. This liner forms the base of the channel and was extended up the sidewalls of the channel approximately 0.3 meters

(one foot) above the 25-year, 24-hour storm event level. To reduce the "engineered ditch" look and provide more gentle sideslopes, the sidewalls of the storm conveyance channel were widened in several areas.

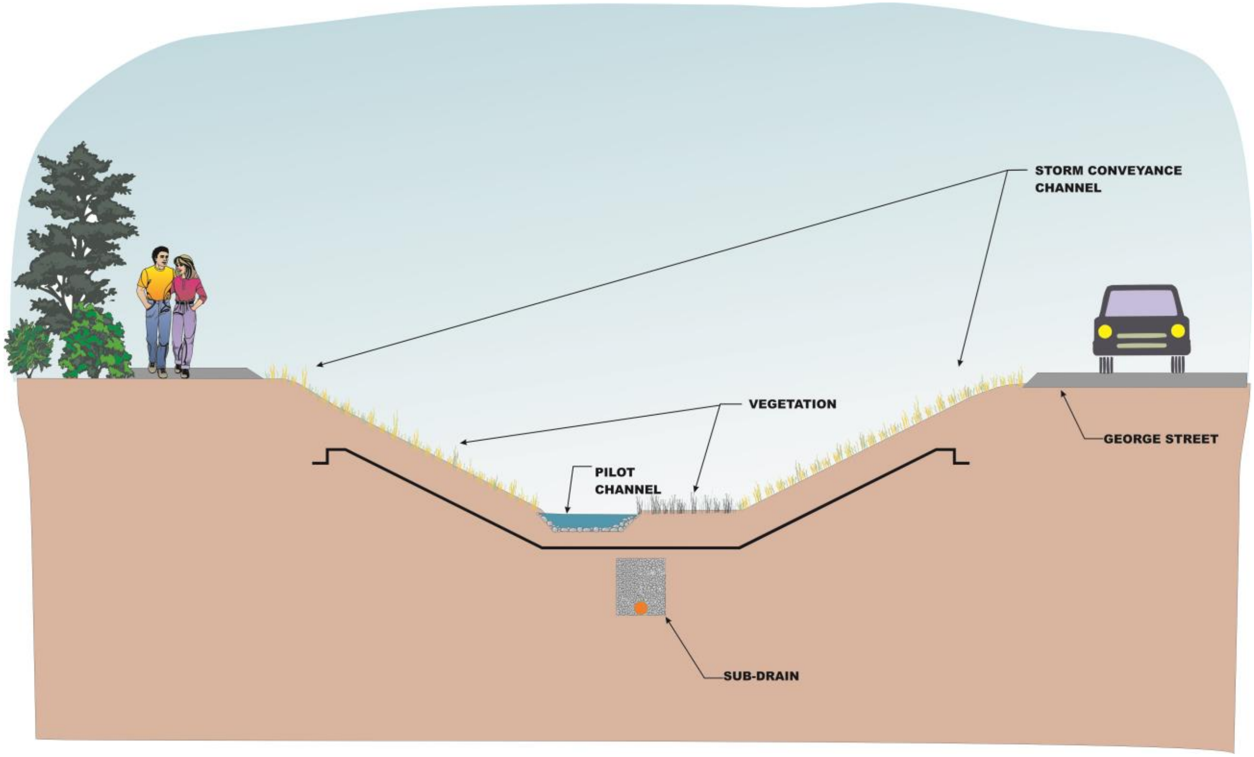

Figure 4. Typical Cross Section of MSD Channel.

Placed at the channel bottom, a channel bed aggregate was utilized to both resist erosion and provide a more natural, freestone brook appearance. Hydraulic and hydrologic calculations indicated that erosional forces generated on the sides of the storm conveyance channel could be resisted by natural vegetation, except at high stress locations such as bends and around inlets from culverts and storm water pipes. The GCL prevented the use of woody vegetation at these locations, so rock was utilized to prevent erosion. The use of rock was minimized as much as possible, and where feasible, inter-plantings were used to mask the rock.

Pilot Channel. Incised into the bottom of the storm conveyance channel, the pilot channel was designed to accommodate small flows and look like a small single-thread meandering freestone brook. This appearance was achieved by constructing the bed of the pilot channel on top of the coarse channel bed aggregate (i.e. river rock) and the banks out of growth media that was stabilized by riparian vegetation (i.e., grasses and sedges). To resist erosion for the short-term, an erosion control fabric was installed on top of the growth media until the riparian vegetation was fully established.

Vegetation. As mentioned previously, hydrologic and hydraulic calculations indicated that riparian grass species would withstand the majority of erosional forces generated by the 25-year, 24-hour storm event. Riparian grass species withstood the erosional forces through their rooting into the soil, slowing of near soil flows by the dense, above-ground biomass, as well as the biomass layering down in higher flows to further protect the soil from erosion. Riparian near-channel vegetation was utilized to protect the integrity of the GCL, as the GCL could be penetrated by deeper-rooting woody species.

To ensure that the in-channel vegetation would be of sufficient density, designers considered the bank stability before the vegetation would be fully established the growing conditions along the banks of the storm conveyance channel and along the pilot channel, and the native vegetation types in southwestern Montana.

To provide the foundation for vegetation on the sides of the storm conveyance channel and pilot channel, growth media was placed and anchored with an erosion control fabric constructed of coconut fiber and black polypropylene netting.

Types of vegetation were selected according to growing conditions or hydrologic zone. For the MSD, three hydrologic zones were identified (wetland, transitional, and upland) and separate seed mixes were specified for each zone (Table 2). Within the wetland hydrologic zone, vegetation included both a wetland seed mix and a wetlands sod.

Additional off-channel vegetation was established to enhance aesthetics of the channel corridor. Off-channel vegetation consisted of larger native trees and shrubs including aspen, chokecherry, cottonwood, juniper, poplar, spruce, and willow trees, as well as shrubs including buffaloberry, current, nootka rose, serviceberry, silverberry, and snowberry (Table 3). Because the off-channel location would not allow their roots to compromise the GCL, deeper-rooting vegetation types were specified to take advantage of the shallow water table as a continual water source.

Land Use Challenges

To prepare for the reconstruction of the MSD, the project had to address several land use challenges along the MSD, in addition to managing the groundwater and storm water flows separately. These land use challenges are creating a more visually aesthetic channel, making the channel corridor more useable to the community, and accomplishing these goals without negatively impacting adjacent commercial and residential landowners.

Because the MSD is located in an urban setting, some properties located within and immediately adjacent to the MSD were under private ownership. Furthermore, the urban infrastructure such as sewage and water pipelines, roads, and bridges physically constrained the corridor. Therefore, the channel corridor could not be expanded laterally, leaving a straight and narrow corridor to work with through the majority of the site.

As noted in previous sections, the channel appearance was naturalized in the following ways: 1. widened the channel laterally, where allowed, to lessen the “ditch-like” appearance; 2. incised a meandering pilot channel in the bottom of the channel; 3. utilized riparian vegetation throughout its extent; and 4. planted larger trees and shrubs in locations adjacent to the channel. Prior to the MSD reclamation, the channel corridor was largely an unmaintained drainage ditch, and not in a condition conducive to public use. Located adjacent to the channel was a large buried water pipeline which was to remain in place. The pipeline’s location and even grade made it suitable to place a walking trail on top of it. Therefore, a 3-meter (10-foot) wide walking trail, with public access points at major street crossings, was constructed as part of this project. With cooperation and coordination with the local government, this new trail provided a critical new link for recreational, non-vehicular users between Butte’s midtown and its western end.

Table 2. Revegetation Mixes for Upland, Channel Bottom, and Channel Sides.

Revegetation Mix 1: Upland Seeded Herbaceous Species
(basic seed mix for Disturbed, Flat areas)

Scientific Name	Common Name	Variety	Percent of Mix
Grasses			
Poa canbyi	Canby bluegrass	Canbar	10
Festuca ovina	Sheep fescue	Covar	10
Agropyron dasystachyum	Thickspike wheatgrass	Critana	15
Agropyron spicatum	Bluebunch wheatgrass	Goldar	15
Elymus cinereus	Great Basin wildrye	Magnar	15
Poa ampla	Big bluegrass	Sherman	10
Agropyron riparium	Streambank wheatgrass	Sodar	15
Oryzopsis hymenoides	Indian ricegrass	Nezpar	10
Forbs/Subshrubs			
Artemisia frigida	Fringed sagebrush	NA	2.5
Achillea lanulosa	Western yarrow	NA	1.5
Linum lewisii	Common blue flax	Appar	1.0

Revegetation Mix 2: Channel Bottom, Wetland Herbaceous Seeded Species

Scientific Name	Common Name	Variety	Percent of Mix
Grasses			
Agropyron smithii	Western wheatgrass (FAC)	Rosanna	15
Deschampsia caespitosa	Tufted hairgrass (FACW)	Nortran	10
Agropyron trachycaulum	Slender wheatgrass (FAC)	Revenue	15
Hordeum brachyantherum	Meadow barley (FACW)	NA	20
Poa palustris	Fowl bluegrass (FAC)	Reubens	15
Calamagrostis canadensis	Bluejoint reedgrass (FACW)	Sourdough	15
Puccinellia airoides	Alkaligrass (FACW)	Fults	5
Grass-like			
Scirpus bulrush	Alkali bulrush	NA	5

Table 2. Continued.

Revegetation Mix 3: Channel Side Slopes Herbaceous Seeded Species

Scientific Name	Common Name	Variety	Percent of Mix
Grasses			
Agropyron smithii	Western wheatgrass	Rosanna	15
Agropyron riparium	Streambank wheatgrass	Sodar	20
Agropyron trachycaulum	Slender wheatgrass	Revenue	15
Oryzopsis hymenoides	Indian ricegrass	Nezpar	10
Elymus cinereus	Great basin wildrye	Magnar	15
Leymus triticoides	Creeping wildrye	Shoshone	15
Poa canbyi	Canby bluegrass	Canbar	5
Forbs			
Linum lewisii	Common blue flax	Appar	5

Table 3. Off-Channel Vegetation.

Trees
Black cottonwood
Canada red chokecherry
Chokecherry
Colorado spruce
Native willow
Pacific willow
Quaking aspen
Rocky Mountain ash
Rocky Mountain juniper
Silver buffaloberry
Siouxland poplar
Shrubs
Golden current
Silverberry
Common snowberry
Serviceberry

Construction

Initiated in 2003 and completed in 2004, the reclamation construction of the MSD accomplished the major goals of the reclamation design. Four main components were completed as part of the construction, these components include the following:

- Removal of visible mine waste (Fig. 5);

- Installation of the MSD sub-drain (Fig. 6);
- Reconstruction of the MSD channel by installing the GCL, growth media, and erosion control fabric to complete the channel (Fig. 7); and
- Establishment of vegetation (Fig. 8).

Figure 5: Removal of Visible Mine Waste.

Figure 6. Metro Storm Drain Sub-Drain.

Figure 7. Construction of the Metro Storm Drain Channel.

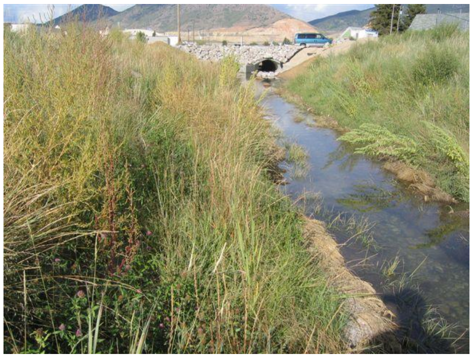

Figure 8. Established vegetation on the reclaimed Metro Storm Drain, along with the meandering pilot channel to “renaturalize” the MSD.

Modifications

During the construction, groundwater conditions required one significant modification. Base flow groundwater was present in a portion of the MSD channel located upgradient of Harrison Avenue. Before construction, the upper end of the sub-drain was to end just downgradient (west) of Harrison Avenue. Because base flow groundwater was encountered above Harrison Avenue, the sub-drain was extended underneath, and approximately 180 meters (600 feet) upgradient (east) of Harrison Avenue. To accommodate the sub-drain, the surface water channel underneath Harrison Avenue was removed and reconstructed. Taking advantage of the reconstruction, a pedestrian tunnel was placed underneath Harrison Avenue and adjacent to the storm water channel (Fig. 9).

Figure 9. Pedestrian tunnel passing underneath Harrison Avenue, linking the MSD trail between east and west Butte.

Post-Construction Monitoring

To verify that arsenic and metals loading has been reduced to Silver Bow Creek from the MSD, post-construction monitoring (Atlantic Richfield Company, 2004b) is being utilized. This monitoring included an initial measuring of groundwater elevations within the MSD drainage basin to demonstrate groundwater was draining to the sub-drain and not toward Silver Bow Creek. Also, water quality and flow monitoring in Silver Bow Creek above and below where MSD enters the creek is performed quarterly to determine post-construction arsenic and metals loading that enters the creek from the MSD. This monitoring is performed during base flow conditions and during storm events.

Initial results from the post-construction monitoring have demonstrated that a substantial reduction in arsenic and metals loading from the MSD to Silver Bow Creek has been achieved. By comparing the arsenic and metals load removed by the sub-drain and sent to LAO for treatment to the remaining surface water load downgradient of the sub-drain, these reductions in loading range from a 93 percent for arsenic to 99.9 percent for copper, thus meeting the final major goal of reducing arsenic and metals loading to Silver Bow Creek from the MSD (Table 4).

In addition to monitoring the direct reduction in arsenic and metals loading to Silver Bow Creek, the reduction of metals concentrations in the downstream Silver Bow Creek was monitored at Station SS-05 and SS-05A (Table 5). From this monitoring vantage point, the reduction of metals concentrations from pre-reclamation to post-reclamation ranges from 14 percent for arsenic to 79 percent for zinc (Table 5). The reduction was greatest for the two COCs, cadmium and zinc, which originally had significant pre-construction loads from MSD.

Table 4. Post-Construction Reduction of Loading from MSD Baseflow.

Constituent	Loading (pounds per day) Removed Baseflow from MSD via Sub-Drain	Loading (pounds per day) Remaining Baseflow in MSD	Percent Reduction
Arsenic	0.015	0.0011	93%
Cadmium	0.14	0.0012	99%
Copper	8.1	0.0062	99.9%
Lead	0.00091	0.00002	98%
Zinc	32	0.22	99%

Table 5. Comparison of Base Flow Water Quality: Pre- and Post-Reclamation at Silver Bow Creek Stations Located Downgradient from MSD.

	Average Constituent Concentrations (µg/L) Pre-Reclamation (2001 – 2003)	Average Constituent Concentrations (µg/L) Post – Reclamation (May 2005 - Dec 2005)	Percent Reduction in Stream Concentration
SS-05			
Arsenic	7.1	5.5	23%
Cadmium	0.79	0.19	76%
Copper	20.4	15.1	26%
Zinc	240	50	79%
SS-05A			
Arsenic	7.6	6.5	14%
Cadmium	0.82	0.28	66%
Copper	25.4	21.4	16%
Zinc	233	67	71%

Utilizing the arsenic and metals loading from Table 4 and the concentrations from Table 5, a loading comparison for arsenic and metals from both the MSD baseflow and downstream Silver Bow Creek is provided in Table 6. This comparison demonstrates that the downstream Silver Bow Creek received significant cadmium and zinc loads from the pre-construction MSD baseflow. Compared to the amount of loading observed in the downstream Silver Bow Creek, the pre-construction MSD baseflow contributed 3 percent of the arsenic, 48 percent of the cadmium, 14 percent of the copper, and 59 percent of the zinc. This comparison demonstrates the reason for the larger reductions in cadmium and zinc concentrations observed in the downstream Silver Bow Creek (Table 5). Furthermore, this comparison supports the conclusion that the final major goal, to reduce arsenic and metals loading to the downstream Silver Bow Creek from the MSD, has been achieved.

Table 6. Comparison of Base Flow Arsenic and Metals Loading: Pre- and Post-Reclamation at Silver Bow Creek Stations Located Downgradient from MSD.

	Average Constituent Loading (lbs/day)	
	Pre-Reclamation (2001 - 2003)	**Post - Reclamation (May 2005 - Dec 2005)**
MSD	**SS-03**	**Remaining baseflow in MSD (Table 4)**
Arsenic	0.01	0.0012
Cadmium	0.018	0.0062
Copper	0.15	0.00002
Zinc	6.52	0.22
SS-05		
Arsenic	0.36	0.54
Cadmium	0.035	0.013
Copper	0.89	1.37
Zinc	10.86	3.54
SS-05A		
Arsenic	0.4	0.59
Cadmium	0.04	0.02
Copper	1.26	1.93
Zinc	11.42	4.9

Conclusions

The MSD reclamation project had three major goals, as follows:

- Clean the channel of impacted sediments to reduce sediment loads to Silver Bow Creek;
- Separate groundwater flows from surface water and route the groundwater to a nearby treatment system to reduce dissolved metal loads to Silver Bow Creek; and
- Enhance the channel corridor’s aesthetics to appear more natural and reduce the “engineered ditch” look, and improve its land use for the public.

To achieve the goals of the project, a groundwater sub-drain more than 1.6 kilometers (one mile) in length was constructed. During the construction, the MSD was cleaned of metals-impacted sediments and the groundwater flowing to MSD was separated from surface water via a sub-drain. Channel aesthetics were enhanced during the construction by widening and varying the channel’s form where allowed, utilizing natural vegetation to resist erosion, and creating a meandering pilot channel in MSD to give the appearance of a small brook. A walking trail was constructed along the channel’s entire length to make the corridor more useable as a recreational corridor. Based on the final review of the construction activities, and the results from the post-construction monitoring that show a significant reduction in arsenic and metals loading and concentrations, it has been demonstrated that these three major goals have been achieved.

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