

## RECLAMATION OF A TAILINGS IMPACTED STREAM CORRIDOR<sup>1</sup>

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**Abstract:** A history of environmentally insensitive tailings disposal practices across the U.S. has resulted in large-scale ecological disruptions caused by acid mine drainage, surface and groundwater contamination, nutrient-poor soil with little or no vegetation, and prevalent erosion. Reclamation of stream corridors impacted by tailings must consider the transport mechanisms inherent to fluvial systems, and the geomorphic processes that occur at the interface between the stream and its boundary material. Case histories of two stream reclamation projects located along Silver Bow Creek are presented. Contamination in the basin is the result of more than 125 years of copper, silver and associated base metal mining and processing in Butte and Anaconda, Montana. In 1992, the U.S. Environmental Protection Agency (EPA) and the Atlantic Richfield Company began reclamation activities within the Lower Area One Operable Unit, through an Expedited Response Action under the EPA's Superfund program. Major work elements included removal of mine waste material and reconstruction of the creek using an elevated gradient. The elevated channel, in conjunction with ground water hydraulic controls, minimized the potential for stream flows to collect potentially contaminated ground water. The second project involved remediation of a 1.25-mile reach of Silver Bow Creek within the Streamside Tailings Operable Unit, located immediately downstream of the Lower Area One Operable Unit. The Montana Department of Environmental Quality, in conjunction with EPA, managed this project. Design work for this project began in 1997, and construction was completed during 1999-2000. Major work elements included tailings/impacted soils removal, placement of the tailings/impacted soils in an adjacent mine waste repository, reconstruction of a natural stream channel with deformable banks, floodplain reconstruction and associated groundwater dewatering, a flow regulation control structure and high-flow diversion channel, and one county road crossing. Due to the presence of geologic controls at the boundary between the two projects, the potential for contaminated groundwater to contact stream flows was minimal in the Streamside Tailings Operable Unit. Therefore, the stream was reconstructed at a new gradient that was dictated by the post-tailings removal surface, and general channel stability and sediment transport competence criteria.

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<sup>1</sup>Paper was presented at the 2004 National Meeting of the American Society of Mining and Reclamation and The 25<sup>th</sup> West Virginia Surface Mine Drainage Task Force, April 18-24, 2004. Published by ASMR, 3134 Montavesta Rd., Lexington, KY 40502.

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Proceedings America Society of Mining and Reclamation, 2004 pp 1532-1562

DOI: 10.21000/JASMR04011532

<https://doi.org/10.21000/JASMR04011532>

### **Site History**

The Upper Clark Fork River basin consists of four contiguous Superfund sites which, taken together, makes up one of the largest areas in the nation to be cleaned up as part of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) program. Contamination in the basin is the result of more than 125 years of copper, silver and associated base metal mining and processing in Butte and Anaconda, Montana. The processes associated with the concentration and smelting of the metal ores produced mill tailings and slag with elevated levels of heavy metals such as copper, cadmium, lead, mercury and zinc, as well as the metalloid arsenic. In high enough concentrations, any one of these metals can cause fish mortality. The contamination of Silver Bow Creek is the result of the deposition of mill tailings and slag by direct discharge, and the failure of waste impoundments from historic milling and smelting operations. Mean values of contaminants in the floodplain of Silver Bow Creek range from 8.9 mg/kg for cadmium to 2,300 mg/kg for zinc (MDEQ and EPA, 1995).

In Silver Bow Creek, all aspects of the aquatic environment are contaminated with toxic metals. This includes the substrates that form the bed and banks of the creek, aquatic insects that are the primary food source for fish, and the water that must pass over the fish's gills and into its system to provide it with oxygen and carry on bodily functions. Metals affect fish in various ways. Trout population densities in Silver Bow Creek are about one-sixth what they should be based on the numbers found in matched, uncontaminated reference streams. Several trout species are absent from the population even though there are no physical barriers preventing them from migrating upstream. These species include rainbow trout, westslope cutthroat trout, bull trout and eastern brook trout. Trout in Silver Bow Creek do not grow as well as they should and survival of young trout is poor. Decreased growth can adversely affect reproduction that could help account for lower population densities.

The four Superfund sites have been broken into 26 discrete units, known as operable units, for more efficient management. The two projects described in this paper are located at the headwaters of Silver Bow Creek; the first project is located in the Lower Area One (LAO) Operable Unit, and the second project is located in the Streamside Tailings (SST) Operable Unit, both of which are part of the Silver Bow Creek/Butte Area National Priorities List Site (Fig. 1).

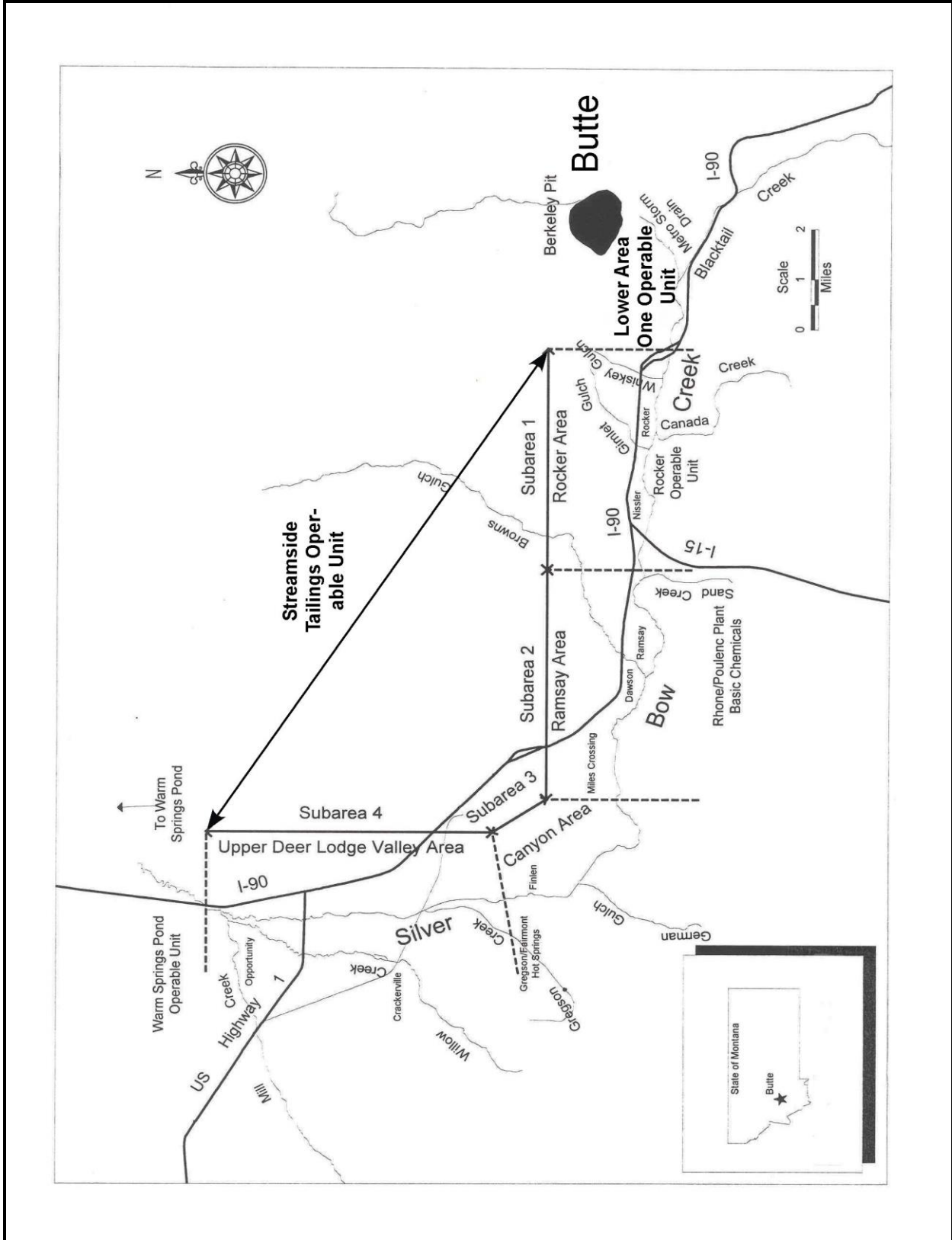


Figure 1. Location map of LAO and SST Operable Units, and designation of SST Subareas.

### Lower Area One (LAO)

LAO lies in the valley bottom and is the upstream-most reach of Silver Bow Creek. The site incorporates approximately 80 acres, and it is about one mile in length. Virtually all surface and ground water flows gathered within the surrounding 90-square mile Summit Valley basin flow into LAO. LAO is roughly divided in half by the Butte Metro Sewage Treatment Plant.

West of the sewage treatment plant is the area known as Colorado Tailings. The Colorado Tailings consist of smelter/mill wastes, which were hydraulically deposited, in a tailings impoundment from the historic Colorado Smelter, previously located to the south. To the east of the sewage treatment plant is the area known as Butte Reduction Works. This area is characterized by a combination of deposits, which include copper tailings, manganese, ore stockpiles, slag, and other remnants of manganese processing conducted on the site between 1928 and 1959.

Within the site boundary there are four hydro-stratigraphic units of interest. These are the tailings, peat, alluvium, and weathered bedrock. The primary hydro-stratigraphic unit is considered to be the alluvium. Within LAO the alluvial deposits are on the order of 20 to 30 feet thick, thinning to only a few feet at the western end of the site, as the bedrock rises in this area at the end of the valley.

The weathered bedrock underlies the alluvium and is characterized by variable degrees of weathering, fracturing, and faulting. Peat deposits overlie some areas of alluvium. The peat is intermittent and ranges in thickness from only a few inches to several feet, resulting from an extensive wetland system existing prior to human development of the area. Although not an actual peat deposit, this layer is characterized by organic, finer grained soils. The tailings and other waste deposits overlie the peat and/or alluvium. Although discontinuous across the LAO site, the peat layer impedes vertical flow between the tailings and alluvium where it is present.

The primary contaminants of concern within LAO are metals, particularly copper, zinc, arsenic, cadmium, and lead. An additional concern for Expedited Response Action (ERA) activities is the location of the Montana Pole and Treating Plant (MPTP) Superfund site adjoining LAO to the south. The MPTP site contains organic contaminants, including petroleum hydrocarbons and pentachlorophenol. The potential for exacerbating migration of organic contaminants from MPTP was of considerable concern in planning dewatering activities for removal of materials below the ground water table within LAO.

### Streamside Tailings (SST)

The SST Operable Unit extends for 26 miles, beginning at the downstream end of LAO, and terminating at the Warm Springs Ponds. SST is subdivided into four subareas (Fig. 1) based upon geologic and topographic features that control the soil, hydrogeologic, geomorphic, surface water, ecologic, demographic, and land use characteristics of the operable unit. Additionally, each subarea was further subdivided into stream reaches for further detailed evaluation and characterization. Twelve stream reaches were defined, with one or more reaches located in each subarea. The first phase of remediation within SST, Reach A – Subarea 1, is the second project discussed in this paper.

### **Lower Area One – Case Study**

On December 31, 1991, EPA approved a non-time-critical removal action for LAO as part of an Enforcement Action Memorandum. The work plan provided that completion of the ERA occur in three phases (ESA, 1992). Phase I of the ERA is the primary focus of this case study.

Phase I included excavation and disposal of tailings and contaminated soils within LAO. These materials were expected to be a major contributor to metals loading in Silver Bow Creek through and downstream of the site (Photo 1). To avoid exacerbating the migration of organic contaminants from the adjacent MPTP site, Phase I was subdivided into two segments. Segment 1 consisted of the removal of tailings and contaminated soils that were accessible above the water table and did not require dewatering for excavation purposes. Segment 1 was completed in 1996. Segment 2 included removal of the remaining accessible tailings and contaminated soils, most of which were below the ground water table, and required construction dewatering to accommodate excavation and backfilling. Segment 2 also included some backfilling of excavated areas and reconstruction of the Silver Bow Creek channel and floodplain. Segment 2 removal had to be performed following removal of organic contaminants and attainment of hydraulic control at the adjacent MPTP site.

Phase II provided an interim period to allow monitoring of the ground water and surface water system for both hydraulic balance and water quality, following the removal of tailings and contaminated soils. This monitoring was necessary to provide water quality and quantity information to facilitate final design of the Phase III reclamation, and to determine the effect of Phase I removal and hydraulic controls.



Photo 1. View of Silver Bow Creek within LAO prior to reclamation work.

Phase III includes the design and implementation of final site reclamation, including a suitable system for collection and treatment of contaminated ground water, and appropriate land use features.

#### Objectives and Design of Phase I - LAO

Phase I of the ERA had the following three primary design objectives:

1. Removal of the accessible tailings and contaminated soils;
2. Reconstruction of Silver Bow Creek to a stable, yet natural-appearing setting; and
3. Hydraulic separation of clean waters from metals-impacted ground water flows.

Objective 1: Removal of Tailings. Phase I of the LAO ERA included removal of most of the tailings and contaminated soils within the LAO site. However, some of these materials were considered inaccessible and remained in place. Tailings and contaminated soils were left in

place below the Butte Metro Sewage Treatment Plant and below slag walls and tunnels to be preserved intact for their historic value. Since some quantity of tailings and contaminated soils remained in place, it was anticipated that some metals-contaminated ground water remains present within the site.

Silver Bow Creek, which drains a basin of approximately 90 square miles, runs directly through the LAO site. Much of the tailings and contaminated soils to be removed during the LAO ERA were located directly beneath Silver Bow Creek or below the ground water table within its floodplain. The LAO ERA required that Silver Bow Creek be reconstructed through the site to accommodate the 100-year flood flow of 2,330 cubic feet per second (cfs) (CH2M Hill, 1989). However, as part of site reconstruction, ARCO proposed to reconstruct the creek to closely resemble a natural stream environment.

Objective 2: Reconstruction of Silver Bow Creek. Based on gradients established by the ground water studies, the reconstructed Silver Bow Creek channel was designed to pass the 100-year flood through the site. A low flow channel with natural characteristics was designed to meander within the 100-year floodplain (Fig. 2). Because the native channel bed material was removed during excavation activities, coarse sand and gravel material was imported and placed in the floodplain to provide a competent streambed. Grade control sections of coarser material were

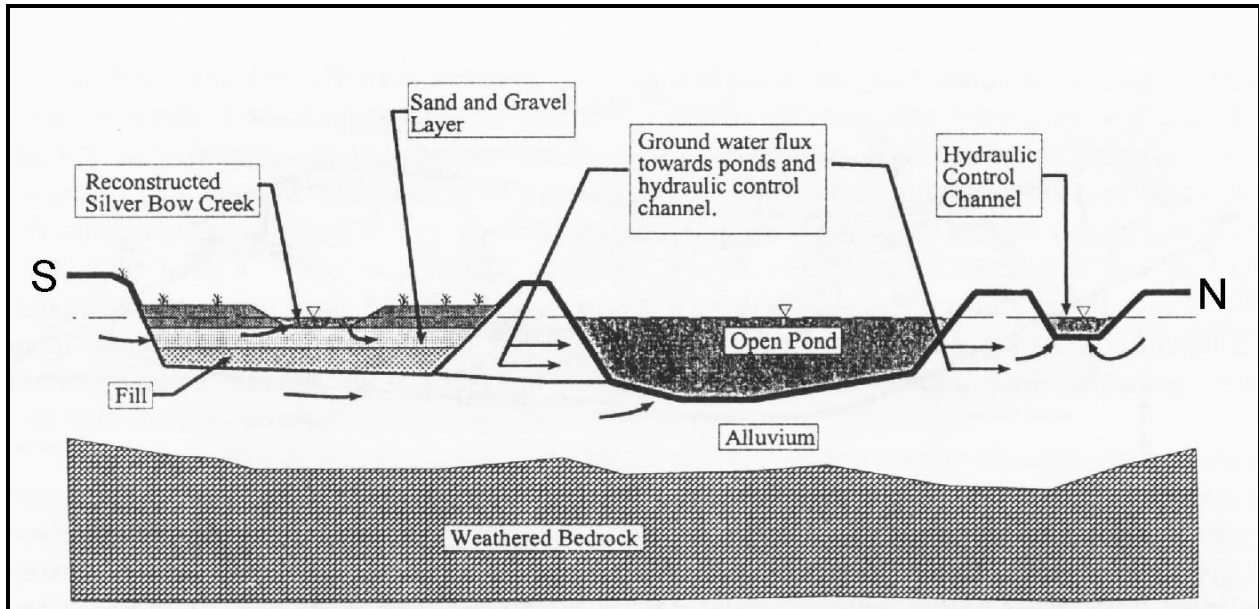


Figure 2. LAO Hydraulic Control System.

placed at period intervals to limit streambed degradation and erosion. The streambed material was overlain with fill capable of supporting a floodplain vegetation community.

A flood dike was constructed to bound the 100-year flood on the north. The floodplain dimensions and capacity were designed using HEC-2 hydraulic modeling. This control dike essentially divides the site into north and south portions. Terraces and depressions were constructed within the floodplain to add diversity of landform. These terraces and depressions, along with the vegetation plan and a naturally meandering channel design, soften the appearance of the flood dike and channel geometry, and result in a more aesthetically pleasing floodplain.

Objective 3: Hydraulic Controls. Currently, Silver Bow Creek through LAO carries the combined flows of the Metro Storm Drain, which captures runoff from the Butte Hill area, Blacktail Creek, which carries uncontaminated flows from less developed portions of the basin, and other storm drainages within the Butte area. Blacktail Creek merges with the Metro Storm Drain just upstream of the site to form Silver Bow Creek. Blacktail Creek has a base flow of approximately 10 cfs and accounts for the major portion of flow in Silver Bow Creek through LAO. Prior to Phase I activities, the base flow of Silver Bow Creek gained approximately 2 cfs of ground water flow as it passed through the site. A key concern in the reconstruction of Silver Bow Creek was the separation of uncontaminated Blacktail Creek/Silver Bow Creek flows from potentially contaminated ground water within the site.

Several alternatives for the separation of surface flows in Silver Bow Creek from the ground water within LAO were discussed in the early stages of the project. Options utilizing physical barriers such as an impermeable liner below the creek channel were discarded as being costly, potentially low in reliability, difficult to maintain, and impractical for developing a natural stream channel environment. The selected remedy included controlling the hydraulic gradients to minimize the potential for Silver Bow Creek to collect ground water as it runs through LAO. A hydraulically balanced system was proposed, in which hydraulic features incorporated into site reconstruction allowed the control of interaction between ground water and surface water.

The hydraulically balanced system incorporated several components. An elevated Silver Bow Creek channel, along with a hydraulic control channel (drains), were the primary components of the system. The design for reconstruction of Silver Bow Creek placed the creek higher than the historic condition. The hydraulic control channel (HCC) functions as a sink that



intercepts ground water flow. Together the elevated channel and the HCC minimized ground water flow into the reconstructed Silver Bow Creek.

Design gradients for the reconstructed Silver Bow Creek channel and the HCC were based upon numerical ground water modeling studies. A three-dimensional ground water flow model was developed using the MODFLOW computer software to aid in the design process. Four layers (tailings, peat, alluvium and weathered bedrock) were used to represent the ground water flow system. The ground water model was calibrated to March 1990 site conditions. The MODFLOW stream package was used to incorporate the reconstructed Silver Bow Creek into the model. Different design options were simulated to examine the site responses, and optimal stream channel gradients were estimated by iteratively adjusting channel invert elevations until the channel gains/losses were close to zero.

North of the flood channel, the design minimized backfilling of excavated areas. In Colorado Tailings, open areas below the ground water table were bounded by dikes, allowing ponds to form. Adjustable outlet structures in the dikes control the water surface elevations in the ponds. These ponds serve as additional hydraulic controls and help minimize steep hydraulic gradients between the reconstructed Silver Bow Creek channel and the HCC (Fig. 3).

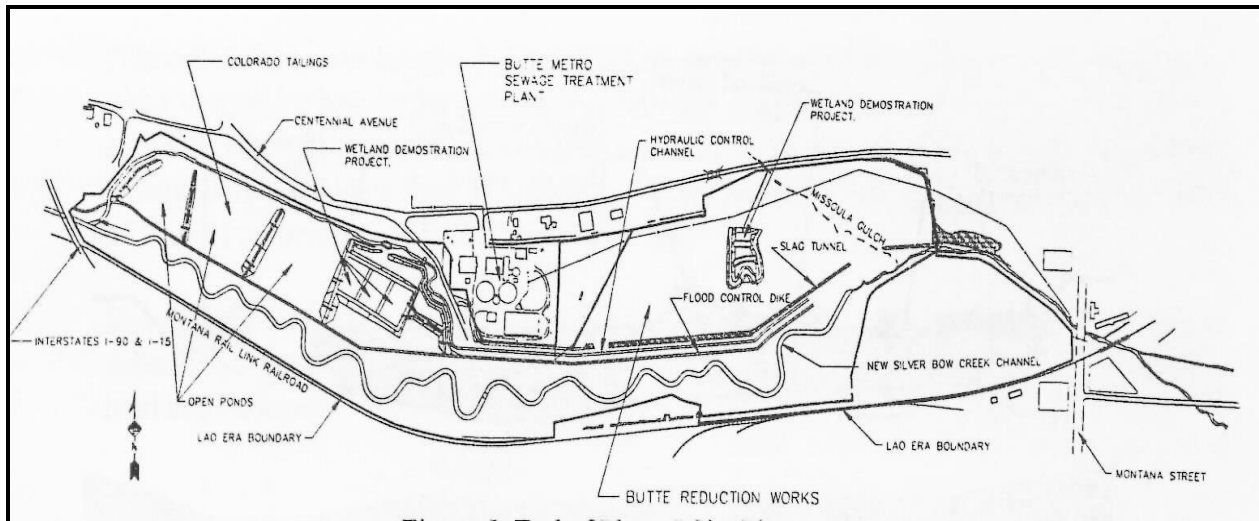


Figure 3. LAO Site Plan at end of Phase I construction.

In Butte Reduction Works, the excavated area north of the flood channel will be left open. It is anticipated that this area will be used in the future as a storm water detention basin. In 1996, two treatment wetland demonstration projects were constructed on site. A treatment wetland design, utilizing new technology intended to combine subsurface and surface treatment

components, was pilot-tested using impacted ground water from the site. These demonstration wetlands combine physical, biological and chemical technologies to treat metals-laden, low pH water. Data is being collected over several years to evaluate the performance of this wetland treatment system. Should this technology prove to be viable, the open area in Colorado Tailings and a portion of Butte Reduction Works could be used to construct additional treatment wetlands.

#### Phase I - LAO Construction

Full-scale construction activities for Phase I of the LAO ERA began in July 1996. Approximately 1.2 million cubic yards (CY) of tailings and contaminated soils were removed from the site; approximately 250,000 CY were removed in Segment 1, and 920,000 CY were removed in Segment 2. Photo 2 shows the reconstructed Silver Bow Creek channel and floodplain.



Photo 2. Reconstructed Silver Bow Creek channel and floodplain within LAO.

In 1995 a pilot excavation of approximately 50,000 CY was completed to evaluate and optimize different dewatering methodologies and excavation techniques. Well points and trench/sump systems were examined. It was determined that a trench and sump system would best meet the dewatering requirements. Several sediment ponds were constructed prior to dewatering activities. As required by EPA, dewatering discharge was routed to the sediment ponds before discharging to Silver Bow Creek. The construction staging was based on a system of backfilling following the excavation through the site. This minimized the duration and extent of areas requiring concurrent dewatering.

To facilitate the efficient removal of the contaminated material, an elevation-based performance standard was negotiated with the EPA. Excavation contours were generated based on existing borehole data to define the excavation surface. In general, the excavation surface follows the base of the peat layer above the alluvium. A grid system on 50-foot intervals was used in the field to verify compliance with the ERA excavation performance standard. This system avoided problems associated with using a visual-identification or chemically-based performance standard, and provided an efficient means of insuring that excavation performance standards were met prior to backfilling each area. This method of excavation control was highly critical to achieving the environmental goal of effectively removing the vast majority of the potential source materials, while allowing a cost-effective and verifiable removable process.

The excavated material was loaded into trucks and moved to a nearby repository site allowing for excavation rates of approximately 5,000 CY per day. During the excavation process, the peat material was separated from other materials and stockpiled for use as an infiltration barrier at the repository. Because of the depositional nature of the peat, (generally horizontally underlying the tailings), the peat was separated based on visual observation and selectively loaded into trucks by the equipment operators.

In the fall of 1996, a diversion channel capable of conveying the 10-year, 24-hour runoff was constructed in the east half of the site to divert Silver Bow Creek. The diversion channel functions as a storm water routing. The diversion channel will allow the volume of flows entering the newly reconstructed channel to be limited, thereby allowing stream bank vegetation to become established before being subjected to full storm flows.

**Streamside Tailings, Subarea One / Reach A – Case Study**

In 1995, the Record of Decision (ROD) was issued for the SST Operable Unit. The ROD is the document that presents the outline of the remedial investigation/feasibility study, the actual and potential risks to human health and the environment, and the selected remedy. The selected remedy includes:

1. Removal of contaminated tailings/impacted soils within the 100-year floodplain, with the provision that Streambank Tailings and Revegetation Study (STARS) treatment can be used in certain areas;
2. Excavated tailings/impacted soils relocated to safe, local repositories clearly outside the present 100-year floodplain, treated with lime and revegetated, with the provision that a centralized dry repository could be used;
3. Replacement fill imported into the excavated floodplain, with fill being of suitable growth media to establish mature vegetation; replacement fill placement will be appropriately sloped toward the stream channel to create geomorphic stability;
4. Removal of fine-grained instream sediments currently located in depositional areas, with material placed in repositories;
5. Channel bed and streambank reconstructed to an appropriate slope with material of appropriate size, shape and composition;
6. A reconfigured streambed containing suitable bedform morphology (riffles, bars, and pools) for aquatic habitat; and,
7. Adequate growth media placed along streambanks to allow for immediate establishment of a healthy riparian vegetative system to protect the remedy from high flows.

**Remedial Action (RA) Construction Summary**

Implementation of the selected remedy included the following components, briefly described below:

**Tailings/Impacted Soils Removal.** Tailings/impacted soils were removed from the floodplain after being sufficiently dewatered to keep clean and contaminated materials from mixing during excavation and to permit transport of tailings to the waste repository with minimal spillage. The

total volume of tailings/impacted soils removed in Reach A was 174,000 CY, at an average depth of 2.8 feet and covering approximately 36.8 acres.

Mine Waste Relocation Repository. A repository site was located in a near-stream location identified as MWRR-2. MWRR-2 was designed so that mine wastes can be placed to a total height of about 25 feet in a seven-acre area.

In-stream Sediment Removal. For the uppermost portion of Reach A, between the interstate highway bridges, the stream channel was not be relocated, but the channel bed and banks were rebuilt with clean material. 800 CY of in-stream sediments were removed from this reach of stream and hauled to the mine-waste relocation repository (MWRR). In the remainder of Reach A, in-stream sediments, located in areas where the new channel overlays the existing stream channel, we removed and clean channel bed material placed during channel reconstruction. An estimated 1,200 CY of in-stream sediments were excavated and hauled to the MWRR. Portions of the existing channel that remained in the reconstructed floodplain were abandoned and backfilled according to the floodplain reconstruction staking plan.

Floodplain Reconstruction. Complete reconstruction of the floodplain was required within the boundaries defined by the horizontal extent of tailings/impacted soils removal. Floodplain design generally consisted of a one percent slope towards the channel from the approximate extent of tailings/impacted soils excavation. The margin of the reconstructed floodplain was tied into the existing topography.

Stream Diversion and Dewatering. Dewatering of Silver Bow Creek was selected as the preferred method for removal of contaminated in-stream sediments and for reconstruction of the channel and banks. The creek was diverted into a rock lined diversion channel constructed downstream of the interstate highway bridges. Stream diversion and dewatering also served to reduce sediments generated during construction of the channel and enabled construction to occur in an environment relatively free of water. The latter condition is essential for proper installation of material during channel and bank reconstruction.

Channel and Streambank Reconstruction. The streambanks that contained tailings and impacted soils required removal. To effectively remove tailings and impacted soils from the channel bed and banks, complete reconstruction of the channel was necessary.

Bridges and Stream Crossings. A new culvert was installed at an existing county road crossing located just west of the I-90/15 eastbound bridge. A second culvert was also installed where this county road crossed the diversion channel.

Haul Road Construction. Primary haul routes were developed to facilitate movement of mine waste and borrow materials. Secondary haul roads were constructed at the Contractor's discretion to access the tailings/impacted soils.

Lime Resources. The tailings/impacted soils removed to MWRR-2 were amended with lime to neutralize the active and potential acidity of the materials and reduce the solubility of metals.

Groundwater Dewatering. A significant portion of the tailings/impacted soils was saturated with groundwater. To mitigate problems associated with excavation, transport, and disposal of saturated materials, the groundwater level in the floodplain was lowered by installing groundwater dewatering trenches. Important facets of trench dewatering are excavation, pumping of water to sediment basins, and sediment detention.

Borrow Area. Fill material for the floodplain and the MWRR-2 cap required about 70,000 CY of clean borrow material. The required borrow material was purchased and hauled to the site as necessary.

Revegetation. Revegetation completed as part of this project included the streambanks, the mine waste repository, and the floodplain area between the interstate highway bridges. All other revegetation was completed under a separate contract beginning in 2000.

The following design elements are presented in greater detail: tailings and impacted soils removal and groundwater dewatering; mine waste relocation repository and lime resources;

floodplain reconstruction and borrow area; stream diversion and dewatering; and channel and streambank reconstruction.

#### Tailings/Impacted Soils Removal and Groundwater Dewatering

Tailings/impacted soils were the largest source of contamination. In order to address this problem the tailings in Reach A were removed from the floodplain and placed in a repository located outside the floodplain. Approximately 65 percent of the area of tailings/impacted soils is saturated or potentially saturated by groundwater during some part of the year. Therefore, ground water dewatering is an integral part of the tailings removal.

Definition of the tailings/impacted soils was accomplished through an extensive test pit investigation. The horizontal and vertical extent of contamination was found through application of “order-of-magnitude break” criteria to the soils metal data collected from these test pits (ARCO, 1997). Because of the variability in the elevation of the base of tailings, an over-excavation factor of 0.5 feet was applied to provide 95% confidence that 90% of contaminated materials will be removed (Maxim and Research Reclamation Unit, 1998). The total volume of tailings/impacted soil removed for Reach A was 174,000 CY. The average depth of removal was about 2.8 feet. Tailings excavation cuts were staked on a 50-foot grid. Tolerances for tailings removal were to within 0.2 foot of the staked elevation and grade evenly between stakes. Over 600 grid points were staked within Reach A.

To mitigate problems associated with excavation, transport, and disposal of saturated materials, the groundwater level in the floodplain was lowered with groundwater dewatering trenches. Dewatering saturated tailings/impacted materials prior to excavation was selected as the preferred method of preparing these materials for excavation because of the difficulties involved with keeping clean and contaminated materials from mixing in a saturated environment when the materials are excavated. In addition, wet tailings would otherwise have to be stockpiled and allowed to drain prior to hauling, which would require double handling during construction.

Based on construction experience gained from the *Remedial Design Pilot Test* (Maxim and Inter-Fluve, 1998), the following design criteria served as guidelines for locating the groundwater dewatering trenches:

1. Locate the centerline of outer trenches within 40 feet of the outer extent of the impacted soils saturated by groundwater.
2. Locate the trenches no further than 150 feet apart centerline to centerline.
3. To provide for optimum groundwater removal, the base elevation of trenches shall be greater than three feet below the base elevation of tailings/impacted soils saturated by groundwater.
4. Dewatering trenches must be in operation a minimum of 2 weeks prior to excavating tailings.
5. Groundwater must be detained for a sufficient amount of time to reduce turbidity prior to release to Silver Bow Creek. Sediment detention ponds shall be sized based on the projected flow in the trenches and guidelines outlined in Montana Sediment and Erosion Control Manual (MDEQ, 1996).

#### Mine Waste Relocation Repository and Lime Resources

Mine waste relocation repositories (MWRR) were a central component of the remedial action. These repositories were intended to provide permanent locations for mine waste that are protective of human health and the environment. One repository, identified as MWRR-2, was located in Reach A outside of the 100-year floodplain. This location was the repository for all tailings/impacted soils, in-stream sediments, and railroad materials generated by removal activities in Reach A.

An *Alternatives Analysis for Mine Waste Relocation Repositories* (Maxim, 1998) was prepared for DEQ and EPA to investigate the effectiveness and cost of alternative MWRR locations and designs. Particular emphasis was placed on protectability of groundwater in this investigation. As a result of this analysis, the resource agencies selected an alternative that included near-stream repositories with an appropriate soil cover design. MWRR-2 was selected and designed in accordance with this decision. MWRR-2 was designed to accommodate mine waste material to a total height of about 25 feet in a seven-acre area. All mine wastes placed in the repository were amended with lime. The cover design incorporates local, stripped topsoil and imported soil from the borrow area to provide a vegetative growth medium. The soil cover and vegetation are planned to reduce the infiltration of water into the repository to less than 0.6



inches of moisture in an average year. This low infiltration rate will reduce the likelihood of leachate generation in the repository.

Lime sources for the MWRR2 include cement kiln dust from the Holnam cement plant in Trident, Montana, and lime kiln dust from the Continental Lime plant in Townsend, Montana and the Montana Limestone Company plant near Warner, Montana. Acid-base accounting was performed on 44 test pits in Reach A, with the results being used to determine the appropriate lime requirements for tailings/impacted soils. Using a conservative approach, a master lime rate was selected that accounted for acid generation in approximately 86 percent of the removed tailings/impacted soil material. For the remaining 14 percent of the tailings, specific lime rates will be applied to six individual areas of tailings that require higher lime rates. Application of a master lime rate for a majority of the material reduced the need to track specific floodplain materials and amend them at varying rates, thereby simplifying construction management. The total lime requirement for Reach A tailings/impacted soils and in-stream sediments was 9,400 tons of effective calcium carbonate equivalent.

The design of MWRR-2 called for the uppermost three feet (exclusive of the 18-inch soil cap) and the lowest four feet to be fully amended, which required both the appropriate quantity and quality of lime addition and complete mixing of lime in these intervals. The repository material between these two layers will have a minimum of 80 percent of the material properly amended. The repository amendment design was selected to insure that the uppermost portion was sufficiently amended so as not to be detrimental for use by vegetation. Similarly, full amendment of the lowest four feet will prevent direct percolation of potential acid leachate from this material.

#### Floodplain Reconstruction and Borrow Area

Reconstruction of the floodplain after removal of the tailings/impacted soils was necessary to restore a properly functioning stream ecosystem. The resulting surface following contaminant removal was regraded to create a floodplain with appropriate slopes and topography consistent with the goal of providing geomorphic stability. In some areas this required additional excavation beyond the vertical extent of contaminated materials. Borrow material was imported and placed in areas that required fill to satisfy the grading plan. Photo 3 shows placement of borrow material over floodplain after removal of contaminated soils and tailings.



Photo 3. Borrow material being placed over floodplain within SST Operable Unit.

In general, the reconstructed floodplain surface was graded with a minimum slope of one percent (1%) towards the channel. The floodplain surface is higher than the top of bank elevation at all locations except in areas where standing water wetlands were incorporated. As a preventive measure against potential channel avulsion, several terraces were integrated into the new floodplain grading to provide more restrictive limits on the lateral extent of overbank flows.

Tailings/impacted soils were removed from the entire floodplain, as delineated by the lateral extent of the 100-year flow for the existing channel. At the horizontal limits, a 4:1 transition slope connects the new floodplain surface with the existing ground surface, except in areas where the new grade coincides with existing grade.

The backfill material for floodplain reconstruction consisted of non-impacted soils from the floodplain and new stream channel excavation, and soils from a designated borrow area located approximately 3 miles from Reach A. In most areas, the top 12 inches of backfill consisted of

borrow area material which meets the criteria listed in Table 1. The non-impacted floodplain excavation material comes from areas where the reconstructed floodplain grades are lower than the base of tailings excavation grade. The non-impacted stream channel excavation material is material generated from the new channel corridor excavation after in-stream sediments and tailings/impacted soils have been removed.

The reconfigured floodplain resulted in a substantial reduction in required backfill as compared to reestablishment of the existing floodplain topography. Reconstruction of the floodplain required 94,000 CY of backfill, whereas 174,000 CY of tailings/impacted soils were removed. However, 46,000 CY of the required backfill was obtained from the non-impacted materials excavated from the new floodplain grading and from the new channel excavation materials, resulting in a net quantity of imported borrow material of 48,000 CY.

Table 1. Suitability Criteria For Floodplain Backfill Materials.

Parameter	Suitability Criteria
Soil Textural Classes (2 millimeters)	Cannot be sand, clay, or loamy sand (U.S. Dept. of Agriculture textural triangle classification)
Rock Fragments	< 35% on volume basis for root zone (0-18 inches) < 60% on a volume basis for general fill
Saturation Percentage	> 25% and < 85%
pH	> 5.5 and < 8.5 standard units
Electrical Conductivity	< 4000 $\mu$ mhos/cm for root zone materials < 6000 $\mu$ mhos/cm for general fill
Sodium Adsorption Ratio	< 12 for root zone materials < 20 for general materials
<u>Element</u>	<u>Total Concentration (milligrams per kilogram)</u>
Arsenic	< 30
Cadmium	< 4
Copper	< 100
Lead	< 100
Mercury	< 5
Zinc	< 250

### Stream Diversion and Dewatering

Providing a work area that is relatively free of water is considered essential for proper installation of channel and bank reconstruction components. Surface diversion of the existing creek was selected as the preferred method to achieve such an environment. The diversion allows for more efficient removal of tailings/impacted soils located near the existing channel, and results in reduced sediment loading related to channel reconstruction activities.

To provide a reconstructed channel and floodplain system that functions properly at minimum cost, the design required that flood flows from Silver Bow Creek be diverted around the reconstructed channel for some period of time (i.e., several years) while the newly constructed streambanks revegetate. After the vegetation matures and can withstand flood flows, the diversion channel will be reclaimed and the entire range of flows in Silver Bow Creek will be available to the new channel.

Channel and floodplain reconstruction also required localized dewatering efforts to remove incidental water from the work zone during construction. Seepage flow from groundwater and through the existing or former Silver Bow Creek channel bed was collected in trenches and sumps and pumped to sediment detention ponds or dewatering trenches constructed for groundwater dewatering.

Two separate and significantly different diversion systems were constructed as part of the Remedial Action for Reach A. Each type of reconstructed channel – *deformable* and *non-deformable* – utilized a different means for stream diversion.

Non-Deformable Diversion Channel. The upper 1,200 feet of Silver Bow Creek in Reach A is confined by a variety of infrastructure including two interstate highway bridges, two overhead water lines and a railroad embankment (Fig. 4). Because of this infrastructure, it was necessary to reconstruct the channel in its present alignment using methods and materials that would prevent future planform migration (see Non-Deformable Stream Channel section). The design for dewatering this portion of Reach A had originally contemplated using a cofferdam system to confine flows to one side of the channel while removal of contaminated materials and channel/bank reconstruction is conducted on the other side.

The Reach A contractor proposed an alternative strategy that involved construction of a diversion channel to the south of, and running parallel to, the existing stream channel. The only

feasible location for the diversion channel was atop a high embankment located between Silver Bow Creek and the Montana Western rail line. The top of this embankment is located 10 to 15 feet above the streambed elevation, therefore providing a substantial challenge for pumping stream flows up to the diversion channel. Stream flows were blocked from the existing stream by constructing a low-head, earthen dam across the channel. The diversion channel extended from the upstream end of the non-deformable channel reconstruction to a point several hundred feet downstream of the non-deformable channel, where it discharged back into Silver Bow Creek (Photo 4).



Photo 4. Non-deformable channel excavation with flow in diversion channel at right.

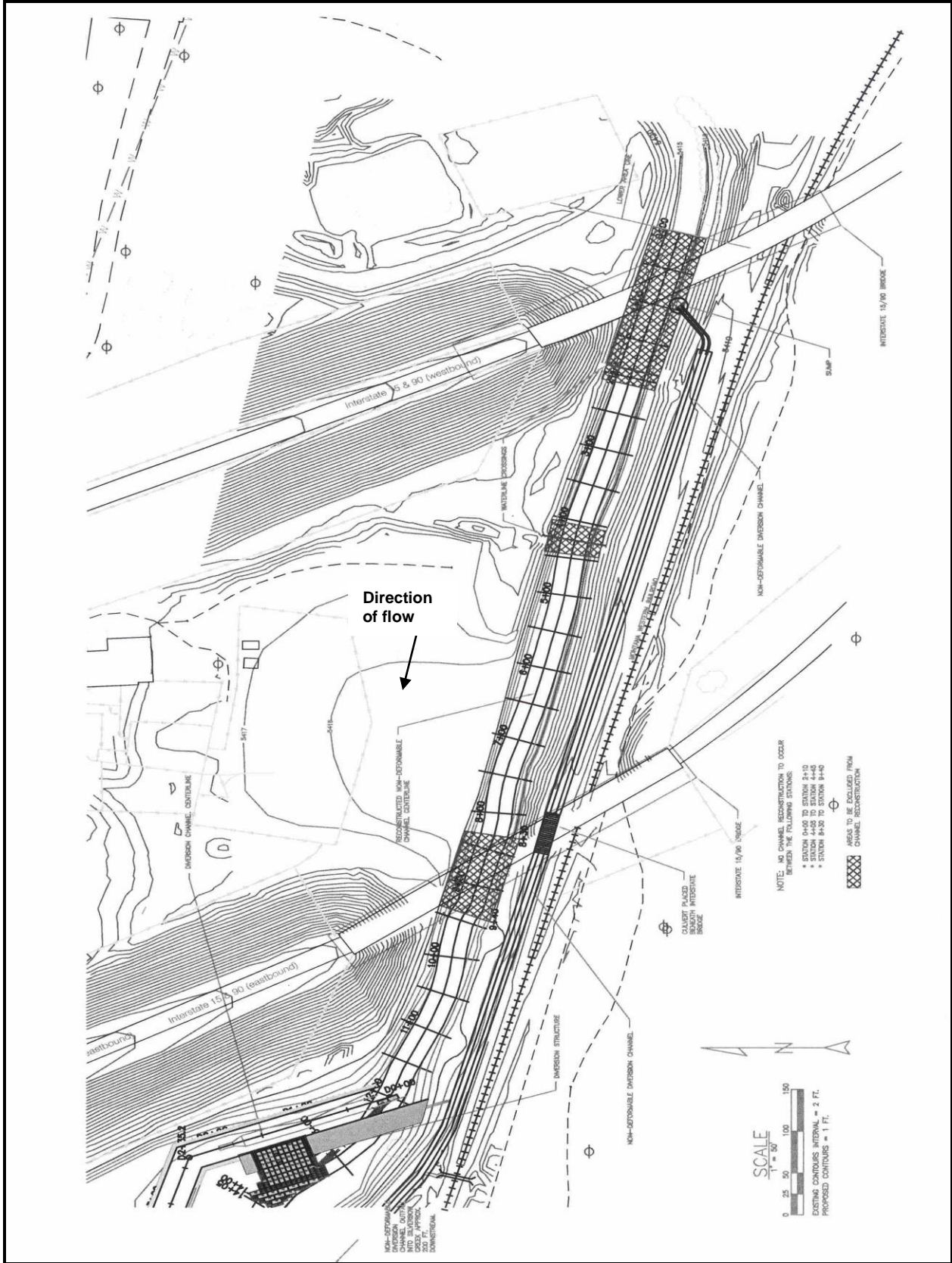


Figure 4. Plan view of non-deformable stream channel and diversion channel.

Flow Regulation Diversion System (Deformable Channel)

Regulation of flows in the deformable portion of the reconstructed channel was accomplished with a diversion structure and rock-lined diversion channel. The diversion structure, located several hundred feet west of the Interstate highway bridges, also provided dewatering of surface flows in Silver Bow Creek during deformable channel and floodplain reconstruction. Construction of the diversion structure and channel was completed during the fall of 1999.

The diversion structure consists of a large, earthen embankment that was constructed across Silver Bow Creek, nearly perpendicular to the direction of flow. Two 30-inch diameter culverts were placed within the embankment, and headgates on these culverts will be used to regulate flow within the deformable channel. The culverts are designed to allow up to 50 cfs into the reconstructed channel under most flow conditions. When the headgates are closed, or when greater than 50 cfs is flowing in Silver Bow Creek, water will be diverted into the diversion channel. The diversion channel is approximately 5,800 feet long, and is located roughly parallel to the existing channel near the northern floodplain boundary. The channel consists of a trapezoidal cross section with 2:1 side slopes and has a capacity of 610 cfs, which is the 10-year flow. The average diversion channel depth (from top of bank to channel bottom) is eight feet, and the channel is lined with a one-foot thick layer of riprap. A spillway is incorporated into the diversion structure to allow flows exceeding 610 cfs to spill back into the reconstructed channel.

Construction of the diversion channel included excavation of both tailings/impacted soils and uncontaminated fill material. Tailings/impacted soils were removed to the mine waste repository. The range of design slopes for the diversion channel (0.12 percent – 0.49 percent) dictated that some segments would require the upper portion of the channel side slopes to be built-up using levees. It was originally intended that clean material resulting from diversion channel excavation would be used for levee construction. However, a significant amount of this material was saturated and unsuitable for meeting compaction requirements in the levees. Therefore, fill material from a local borrow source was used to construct part of the levees.

At the present time, it is anticipated that the diversion channel will remain in place to provide flow regulation for at least several years. Vegetation growth and bank stability in the deformable channel will be monitored closely to determine when flow regulation is no longer necessary. At that time, the diversion channel will be removed and floodplain within its

alignment reclaimed. Photo 5 shows the deformable stream channel and the flow regulation diversion channel.



Photo 5. Flow regulation diversion channel (at right), and deformable stream channel (at center).

#### Channel and Streambanks Reconstruction

The primary objective of channel and streambank reconstruction was to first allow for removal of contaminated materials from the existing channel and streambanks, and then to provide a stable and functioning reconstructed channel. Remedial design objectives specified that the reconstructed channel should insure long-term geomorphic stability, and use “soft” engineering practices for bank reconstruction where vegetation is relied upon for ultimate streambank stability. Where not constrained by infrastructure such as railroads, bridges, etc., the reconstructed channel should be designed to emulate a natural stream system that is allowed to meander. Remedial action within Reach A required the application of two design strategies:



1. The upper portion of Reach A (1,200 feet) is confined by project boundaries and existing infrastructure, therefore requiring that channel reconstruction occur within the existing alignment. A *non-deformable* channel design was used to prevent lateral channel migration and insure long-term stability of the present planform.
2. The lower section of Reach A extends from just west of the Interstate 15/90 bridges downstream for a reconstructed channel distance of 5,800 feet. This section utilized a *deformable* channel design that allows meandering. Flows are being regulated in the deformable channel for several years until vegetation is established. Flows up to 50 cfs are available to the reconstructed channel. Flows in excess of 50 cfs are diverted into a diversion channel (refer to Deformable Channel Reconstruction section).

Non-Deformable Channel Reconstruction. The existing Silver Bow Creek channel between Lower Area One and the eastbound Interstate 15/90 bridge embankment is artificially straight and armored with large riprap. Two overhead water lines and a railroad on the south side further confine this section. It was necessary to reconstruct this portion of the channel in-place, due to this infrastructure. Several segments of the existing channel were excluded from reconstruction to reduce potential risks associated with construction activities in close proximity to highway bridge piers and water lines.

Construction work was conducted under dewatered conditions made possible by use of a diversion system. Prior to channel reconstruction, contaminated streambed and streambank materials were removed. Additional excavation of clean materials was then undertaken to create a channel corridor for subsequent placement of new bed and bank materials. Reconstruction began with placement of bank toe materials consisting of a layer of filter gravel overlain by 15-inch minus rock. The toe rock was placed along the bank to a depth of four feet (the maximum calculated scour depth), and was designed to withstand the anticipated shear stresses for the 100-year flow event. Streambed gravel ( $d_{50}=1.5$  inches) was then placed in the channel bed covering all but the upper six inches of the toe rock. A fabric wrapped soil lift (1.5-feet thick) was then constructed on top of the toe rock. Construction of the lift included placement of a subsoil that was capped with a 4-inch layer of cover soil, which was amended with organic material (compost) to promote vegetative growth. The soil profile was lightly compacted and then wrapped in coir erosion control fabric (Fig. 5).

Deformable Channel Reconstruction. The reconstructed channel reach downstream from the diversion structure was designed to be deformable over time such that it closely mimics a natural, meandering channel. Following construction of the remedial channel and banks, flows were regulated such that all base flow (approximately 20 cfs) is available to the new channel. Flows in excess of base flow, up to approximately 50 cfs, are also directed into the new channel under normal operating conditions. At discharges greater than 50 cfs, the majority of flow (above 50 cfs) is diverted into the diversion channel. Regulation of flow limits erosive forces in the reconstructed channel while stabilizing bank vegetation becomes established.

Channel and streambank design was based on the assumption that flows will be regulated, therefore requiring a reduced level of protection from bank toe materials and the upper bank structure. A pool-riffle sequence was determined relative to planform layout and channel geometry (width/depth). Upon completion of channel corridor excavation, new streambanks were constructed according to specific bedform types (pool or riffle) (Fig. 5). A one-foot thick sill of gravel (streambed material) was placed as a foundation layer for streambank construction, extending from the bank toe to a point 10 feet behind the toe. This gravel also serves as channel bed material as the banks deform and the channel begins to migrate. Unlike the non-deformable channel, no toe rock is incorporated into the bank design. Compacted subsoil overlain by organically amended cover soil and coir erosion control fabric completes the reconstructed bank profile. Gravel was then placed over the channel bed, between the toes of the reconstructed banks, as the final component of channel reconstruction. The gravel is placed to a thickness of 1.5 feet based on the anticipated depth of scour, and accounts for the predicted winnowing of fine-grained material following construction.

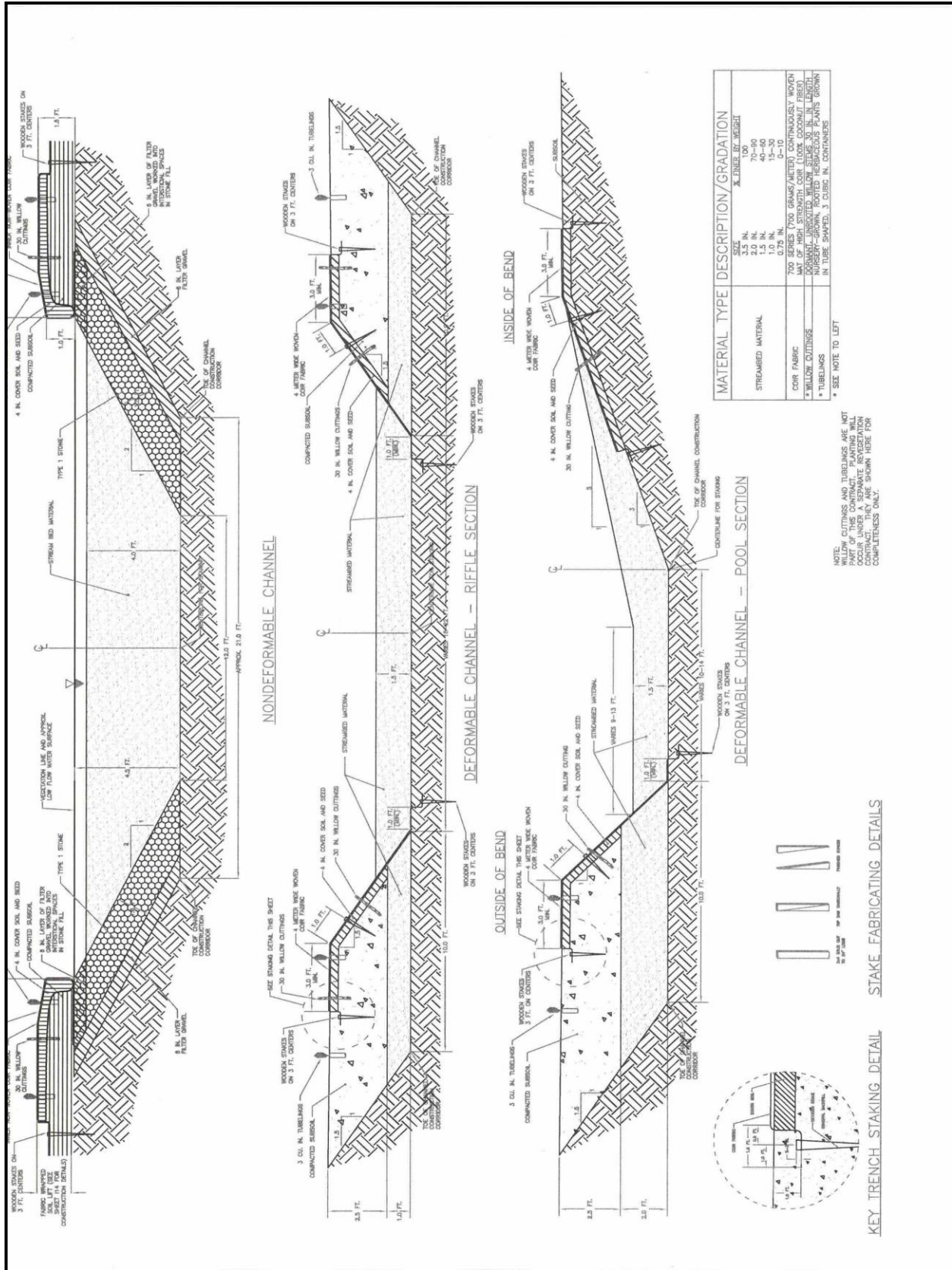


Figure 5. Cross-section drawings of deformable and non-deformable stream channel.

Photos 6 and 7 show the deformable channel during construction and immediately following the introduction of flows to the channel, respectively.



Photo 6. Deformable channel during construction.



Photo 7. Deformable channel immediately following introduction of flows.

### **Discussion**

The two case studies presented in this paper illustrate methodologies for reconstructing stream channels and floodplains within tailings impacted environments. Both projects involved the removal of contaminated soils and replacement of these soils with non-contaminated fill material, followed by construction of a new stream channel. These projects were located at the upstream end of Silver Bow Creek and, together, comprised a stream length of approximately 1.75 miles.

To date, reclamation efforts within the basin include reconstruction of an additional four miles of stream channel within the SST Operable Unit, located immediately downstream from Reach A of Subarea One. Nearly 1,000,000 CY of tailings have been removed from the floodplain, which comprises approximately one quarter of the estimated total volume of tailings within the SST Operable Unit. MDEQ estimates that the remaining 17 miles of stream channel and floodplain within the SST Operable Unit will be reclaimed by the year 2010.

A significant difference in tailings disposal strategy is being applied with current reclamation activities along Silver Bow Creek. Tailings and impacted soils were placed within mine waste repositories located adjacent to the work sites for the LAO and SST – Subarea One, Reach A projects. Current reclamation efforts located downstream have included the removal and transport of tailings by rail to large tailings ponds located approximately 20 miles downvalley. This approach insures that contaminated materials (tailings) will never have the possibility, although remote, of re-contaminating the floodplain area from which they were removed.

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