The Lake Fork of the Arkansas River Watershed Plan

2010

The Lake Fork Watershed Working Group
Acknowledgments

The creation of this document was a team effort completed through the Colorado Mountain College Natural Resource Management Internship Program for the Lake Fork Watershed Working Group.

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Thanks to CMC NRM Interns for their project support and assistance: Jake Franklin, Shana O’Rear, Chris Norwood, Rich Silkey, Torrance Parker, Deb Deimer, and Benner Harttnet.

This project was only possible with the financial and in-kind support from the Bureau of Land Management, Colorado NPS 319 Program, Colorado Division of Reclamation Mining and Safety, Trout Unlimited, Lake Fork Watershed Working Group, and Colorado Mountain College.
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Executive Summary

The Lake Fork Watershed is located in central Colorado, approximately four miles west of the city of Leadville in Lake County. The Sugarloaf Mining District, in the north eastern quadrant of the watershed, was heavily mined and logged from the 1880’s through the 1920’s. The remnants of historical mining are still present via abandoned mine shafts, flowing adits and tunnels, and numerous mine waste piles, in addition to producing degraded water quality conditions.

The Lake Fork Watershed Working Group (LFWWG) is a community stakeholder group that was formed in 2000 by cooperation between various federal and state agencies and environmental entities. The objective of the group’s formation was to focus on the improvement of the water quality in the Lake Fork of the Arkansas River (the Lake Fork). The group is largely comprised of environmental professionals whose employment tasks correlate with the group’s mission and who continually seek to involve the community in the informational open discussions based on the health of the Lake Fork Watershed. The goal of the LFWWG is to reduce metals concentrations in the Lake Fork to water quality table value standards (TVS) for stream segment 5 of the Arkansas River Basin, contained within the Classification and Numeric Standards for Arkansas River Basin, Regulation No. 32 (CDPHE, 2010).

This watershed plan was created to identify corrective actions to aid in the remediation of impacted aquatic and terrestrial ecosystems, compile existing information to provide a strategy to address the problems, identify data needs, and increase information availability among the community. This document indicates water quality TVS for pollutants identified in the Lake Fork watershed, details geographic areas of concern, presents best management practice (BMP) options for site remediation, and outlines a monitoring plan and evaluation framework to thoroughly assess the water quality of the Lake Fork and the results of applied BMPs.

The pollutants of concern stem from acid mine drainage (AMD) produced from historic mine sites within the watershed. These processes result in acidified waters that in turn lead to elevated metal concentrations in water and sediment. The Sugarloaf Mining District, which has been greatly impacted by historical mining, contributes AMD waters and sediment to the Lake Fork. An initial investigation of Lake Fork data by CDPHE has determined that acute water quality TVS are exceeded for Cd, Cu, Zn, Mn, and temperature, while chronic water quality TVS are exceeded for Cd, Cu, Zn, minimum pH, and dissolved oxygen (R. Anthony, personal communication, June 22, 2010). These findings will be verified through further analysis and may lead to the potential listing of the Lake Fork as a 303(d) impaired segment in 2012. It has also been noted in biological surveys of the benthic macro-invertebrates (BMI) and fish that the aquatic life within the Lake Fork watershed has been adversely affected (Barrack, 2001).

The prioritization of geographic areas within the watershed has been determined by the selection of sites with the highest contributing metals load into the Lake Fork. Remediation of pollution sources within a given area has typically began up gradient and proceeded down to the Lake Fork. Historically, Sugarloaf Gulch had been identified by the LFWWG as the area of primary concern and successful remediation has occurred within that gulch on the Nelson and Dinero Mine Complexes. Future prioritization of remedial work in Sugarloaf Gulch will likely depend on the effectiveness of metal concentration reduction as a result of the remediation management plans and the implemented BMPs at the Dinero and Nelson Mine Complexes. Currently, mine
waste piles in Upper Sugarloaf Gulch and its impact on water quality is seen as a low priority until other higher priority remedial activities are completed in Colorado Gulch.

Colorado Gulch was the second prioritized gulch identified by the LFWWG in 2001 (Barrack). Within this gulch, the Tiger Mine Complex was recognized as the site of main concern. Therefore, completion of the relocation, capping, and revegetation of the Tiger Mine Waste Piles were completed in October of 2010. The Little Frying Pan Water Quality Improvement Project is a Non-Point Source 319 grant that is also focused on remediation and monitoring at the Tiger Mine Complex, with placement of hydrologic controls around mine waste piles above the Tiger Tunnel and water quality monitoring through 2013. The Venture Mine Complex has been identified as the next priority site within Colorado Gulch due to exceedances of water quality TVS. An Engineering Evaluation and Cost Analysis (EE/CA) for identifying the best alternative action was completed and put out for public in April 2011.

In the interim, re-evaluation of site specific high flow metal loading values for Al, As, Cd, Cu, Mn, Pb, and Zn will be assessed shortly after data collection on an annual basis. To account for the improvement over the watershed as a whole, the LFWWG will monitor LF-11 as the watershed plan conformance site at peak flow. The goal of the LFWWG is to reduce metals concentrations in the Lake Fork to water quality TVS for stream segment 5 of the Arkansas River Basin (CDPHE, 2010). In addition to the interim measurable milestones that will be developed through the load reduction estimates of future project’s remediation management plans, the evaluation framework in combination with the monitoring program defined within this document will help guide the future reclamation of the Lake Fork Watershed.
1. Introduction

1.1. Overview of the Watershed Plan

The Lake Fork Watershed Working Group’s (LFWWG) primary goal was to create a watershed plan that will address mining related contamination and prioritization of the related reclamation efforts within the Lake Fork of the Arkansas River (the Lake Fork). Although road erosion, sedimentation, land status, forestry, soils, recreation, and water uses are issues within the Lake Fork Watershed, they are not currently being addressed by the LFWWG, as they are ancillary to historic mining contamination. These concerns will only be dealt with where the improvement of degraded conditions can be incorporated into current remediation efforts.

The main impetus for the Lake Fork Watershed Plan is the poor water quality caused by input from Sugarloaf Mining District, which includes Bartlett Gulch, Sugarloaf Gulch, Strawberry Gulch, and Colorado Gulch. A baseline study completed in 2001 by the LFWWG prioritized the input from various gulches into the Lake Fork and concluded that Sugarloaf and Colorado Gulch are the largest contributors of metals (Barrack, 2001). The following document provides background information on the Lake Fork Watershed area, pollutants of concern, previous and future reclamation efforts, and water quality goals. This document will be utilized to address the water quality degradation in the Lake Fork caused by acid mine drainage and metal laden sediments from historic mining in the Sugarloaf Mining District. The goals of this watershed plan are to:

1. Synthesize the existing data collected by the LFWWG and other entities
2. Provide a cohesive plan to address the water quality problems
3. Identify current data gaps within the watershed
4. Identify the appropriate remediation management plan utilizing Best Management Practices (BMPs) to address the sources of contamination
5. Ultimately reduce metals loading into the Lake Fork to meet water quality table value standards (TVS) set by the State of Colorado for stream segment 5 of the Arkansas River Basin in Regulation 32 (CDPHE, 2010)

1.2. Overview of the Watershed

1.2.1. Geography and Ecology

The Lake Fork Watershed lies in central Colorado, incorporating 86 square miles, in Lake County, Colorado. The watershed ranges in elevation from over 14,443 feet at the summit of Mount Elbert to 9,400 feet at the confluence with the Arkansas River. It is east of the Continental Divide in the Upper Arkansas River Valley. Major physical features within this watershed include the Sawatch Range (Mt. Elbert at 14,443 feet and Mt. Massive at 14,421 feet peaks are the highest features of the watershed) with key drainage basins of the Lake Fork, Halfmoon Creek and Rock Creek. The lower reach of the watershed is a high mountain valley located between the Sawatch and Mosquito Ranges bordered on the northern end by the Tennessee Park Basin and the southern Homestake Range. Turquoise Lake Reservoir, held by Sugarloaf Dam, is the largest
water body located in the watershed (Figure 1). For a 3D overview of the watershed see Map A1 in Appendix A.

There are no communities located within the Lake Fork Watershed boundary. Leadville, located four miles to the east of the watershed, is the nearest municipality. The 2010 census lists the total population, by census block, of the Lake Fork Watershed as 89 (US Census Bureau, 2010). This appears to be incorrect as the census block surveyed a portion that lies outside of the watershed. The most populated area of the watershed is the southern portion of the Lake Fork Valley. There are residents in seasonal dwellings at Outward Bound, United States Fish and Wildlife Service National Fish Hatchery as well as year round residents at High Mountain Institute and in ranches and private homes throughout the watershed. A map of the watershed's population per census blocks is contained in Map A2 in Appendix A.

The watershed is predominantly coniferous forest dominated by Pinus contorta (lodgepole pine). Stands of Populus tremuloides (quaking aspen) and Alnus tenuifolia (alder) can also be found throughout the watershed. Pseudotsuga menziesii (Douglas-fir) is interspersed, typically on north facing slopes. Slopes within the watershed tend to be steep with minimal undergrowth and scattered with pine needle litter (BLM, 2000). The southern end of the watershed is an open, high mountain valley dominated by riverine, riparian and wetland habitats. The valley basin transitions with increased elevation, into a montane and sub-alpine ecosystem. The beginning of the alpine zone (mountain tundra) may vary, but is generally considered to be between 11,200 feet and 11,700 feet in elevation. Map A3 in Appendix A contains a detailed map of vegetation within the watershed.

The tributary system within this watershed contains lacustrine, riverine, stream, riparian, and wetland ecosystems. A total of approximately 900 acres of swamp-marsh-wetland area exists within the watershed, varying in size from one quarter acre to one hundred and thirteen acres. See Map A6 in Appendix A for a map depicting swamp-marsh-wetland areas.

Due to wide variances of elevation, aspect, and climate, the flora and fauna habitat zones in the watershed tend to vary from the lower to the upper reaches. A general reflection of temperature change is a three degree Fahrenheit decrease per one-thousand feet of elevation gain. The climate along the Lake Fork has an average mean temperature of 36°F. The frost free season ranges from 10 to 75 days. The mean annual precipitation for the watershed ranges from 20 inches in the lower reaches to over 35 inches in the higher reaches. Approximately 10 inches of precipitation falls in the watershed between April and September. Monthly maximum precipitation usually occurs in March and April, with secondary peaks in July and August reflecting the influence of summer monsoon flow. Average annual snowfall averages around 150 inches in the lower reaches to over 300 inches near the headwaters. However, significantly more snow accumulates along the continental divide. Snowmelt runoff from the higher elevations markedly augments the flow of Lake Fork and its tributaries. During July low temperatures average 40°F to 50°F, while the high temperatures average 75°F to 82°F. January mean low temperatures are 10°F to 15°F, while mean high temperatures are 25°F
to 35°F. Depictions of average annual precipitation and the minimum and maximum temperatures for the watershed can be found in Maps A4 and A5, respectively in Appendix A.

Figure 1. Overview of the Lake Fork Watershed
1.2.1.1. **Spatial Data Inventory**

A substantial amount of spatial data has been collected, created, or modified through the creation of this watershed plan. An online geographic information system (GIS) data server is currently in the design phase and will ultimately make this data available to the public free of charge. Currently, data requests may be sent to Colorado Mountain College Natural Resource Management (CMC NRM) program where data are housed on a local GIS server. Data includes all information presented on the maps in Appendix A as well as other miscellaneous files.

1.2.2. **Geology**

The Lake Fork Watershed is predominantly composed of Pre-Cambrian metamorphic and igneous rocks that were uplifted during the Laramide Orogeny, 80-35 million years ago. The Laramide Orogeny, caused by shallow subduction of the Farallon Plate below the North American Plate, is responsible for the uplift of the Rocky Mountains, including the Sawatch Range. The Arkansas Valley Graben, and bounding valley faults, is the northern most extent of the Rio Grande Rift, which formed after the Laramide Orogeny approximately 27 million years ago.

The Sugarloaf Mining District is part of the Colorado Mineral Belt, a northeast trending belt of highly mineralized ore deposits, stretching from the San Juan Mountains near Durango to the Front Range near Boulder. Precambrian porphyry and pegmatite deposits within the Sugarloaf Mining District, and surrounding Arkansas River Valley, were uplifted with the Sawatch Mountain Range. This uplift exposed pegmatites, which eventually became the source of gold placer deposits found in the area initiating the gold rush to the Arkansas Valley. During the Laramide Orogeny, much of the Colorado Mineral Belt was mineralized by enriched hydrothermal fluids. Mineralization of this belt occurred in a weakened northeast and northwest trending Proterozoic shear zone. Ore veins in the Sugarloaf Mining District consisted mainly of quartz, pyrite, sphalerite, chalcopyrite and tetrahedrite. The ore within these veins was predominantly silver, in the form of galena and argentite, unlike the rest of the Leadville Mining District, Sugarloaf Mountain did not have lead, zinc or copper ores that were of economic volumes (Twitty, 2003).

The Pleistocene geology of the Lake Fork watershed is controlled by three distinct periods of glaciation. The first being Pre-Bull Lake 300,000-700,000 years ago and the second is the Bull Lake 130,000-300,000 years ago. The most recent glaciation is the Pinedale, which occurred 10-30,000 years ago and is responsible for most of the present day topography in the watershed, including significant glacial outwash and moraine deposits (Richmond, 1986). The Lake Fork watershed is defined by glacial valleys and deposits with smaller tributaries that originate from tarn lakes. The Lake Fork and the majority of its tributaries originate in glacial valley terrain with distinct U-shape valley walls and steep floor gradients in their upper reaches. Upon reaching the Arkansas River Valley, glacial deposits of medial and lateral moraines control the channels of the Lake Fork where stream gradient drops. The Sugarloaf Mountain Mining District contains a
combination of glacial moraines and exposed bedrock as a result of glacial activity and hydrologic erosion.

Soils in the watershed are fairly thin above the Arkansas River Valley although some areas contain substantial deposition of glacial till. On slopes between 5-35 percent soils are typically gravelly to loamy-sands, while the valley floor, with slopes of less than five percent, consists of sandy and loamy soils. There are a few areas of riparian marsh soils near the Lake Fork as well as at inlets of tributaries. The major pedologic and geologic features of the watershed are displayed in Maps A6 and A7 in Appendix A.

### 1.2.3. Fluvial Morphology

The Lake Fork, from Sugarloaf Dam to the confluence with Strawberry Gulch, a downstream tributary from Sugarloaf Gulch, displays morphological features typical of a controlled river. The sinuosity is low to moderate with a ratio of 1:2 and a width to depth ratio of 18.75. The channel material is largely defined by non-angular cobbles with a small integration of boulder and gravel particles. This reach has established a quasi equilibrium defined by interspersed cut bank erosion and an absence of defined point bar regeneration. The best fit Rosgen (1994) stream classification is a B3 with a Pfankuch (1975) stability index of 88. The Lake Fork is a 5th order stream, whereas Sugarloaf Gulch is a 2nd order stream. Sugarloaf Gulch varies greatly from headwaters to its confluence with the Lake Fork, for example the Pfankuch stability index ranges from 99 to 130 in the upper reaches of the gulch whereas near the confluence all flow is encompassed by wetland. The Rosgen stream classification for Upper Sugarloaf Gulch would be best described as A5 with a low sinuosity of 1.1 and upper and lower banks sparse with vegetative cover. Sediment from eroded granite outcrops and transported waste tailings from historic mining operations dominate the sediment load of the channel. It is likely that the mine waste tailings contribute metal laden sand to silt sized particles throughout the reach and into the Lake Fork, increasing the inhabitability of the Gulch, and diminishing water quality downstream.

### 1.2.4. Hydrology

The Lake Fork is a tributary of the Arkansas Headwater Basin which has a hydrologic unit code (HUC) of 11020001. The Lake Fork Watershed includes all or part of the following 12-digit HUCs: 110200010103 (Turquoise Lake); 110200010104 (Willow Creek); 110200010105 (Halfmoon Creek); and 110200010106 (Leadville City). The LFWWG is not aware of a specific 12-digit HUC for the Lake Fork itself. Within the Arkansas River Basin the Lake Fork is part of Segment 5 of the Arkansas River Basin (CDPHE, 2010).

Discharge of the lower Lake Fork is controlled in large part by the releases generated by the United States Bureau of Reclamation (BOR) Sugarloaf Dam facility. However, the Lake Fork and its tributaries demonstrate annual, seasonal, and flow regimes that are controlled by snowpack melt and summer storm runoff. Peak flow of the Lake Fork generally occurs from Mid-May to Mid-June as a result of snow melt. Total Lake Fork base flow discharge near its confluence with the Arkansas River is approximately 14,000
acre/ft for the months of September through March; total flow discharge for the months of April through August is approximately 22,000 acre/ft. (The Sugarloaf Dam releases in cubic feet per second (cfs) are displayed in Figure 13 in Section 5.2.4.)

Discharge from fractured rock aquifers above the Arkansas River Valley and alluvial aquifers in the Arkansas River Valley are the primary sources of groundwater in the watershed. Although minimal, but important from an environmental degradation standpoint, groundwater discharge from mine tunnels are also considered sources of water for streams in the watershed. Two studies have identified a connection between Turquoise Lake and the fracture system of Sugarloaf Mountain, including a flowing mine adit (Engblom et al., 2004 and Walton-Day and Poeter, 2009). A gas tracer study by Engblom and others (2004) identified a groundwater connection between Turquoise Lake and the Bartlett Tunnel but not the Dinero Tunnel. A study by Walton-Day and Poeter (2009) found similar results in that the Dinero Tunnel was influenced by less than 10% of recharge from Turquoise Lake or seasonal snowmelt. When compared to nearby Bartlett Tunnel, the discharge patterns mimic levels in Turquoise Lake. Although not all are connected to Turquoise Lake, groundwater on Sugarloaf Mountain is largely controlled by fractured aquifers, which are fed by deep groundwater aquifers and annual snowmelt. Alluvial aquifers in the Lake Fork Watershed dominate the valley and glacial deposits.

The State of Colorado’s Division of Water Resources reports 105 well permits with the status of issues, extended, or constructed (2010). Of these wells, the permitted uses are noted in Table 1. The location of these wells can be viewed on the Lake Fork Watershed Pedologic and Hydrologic map found in Map A6 of Appendix A.

<table>
<thead>
<tr>
<th>Well use</th>
<th>Number of wells</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commercial</td>
<td>1</td>
</tr>
<tr>
<td>Domestic</td>
<td>33</td>
</tr>
<tr>
<td>Household Use Only</td>
<td>31</td>
</tr>
<tr>
<td>Irrigation</td>
<td>1</td>
</tr>
<tr>
<td>Monitoring Well</td>
<td>35</td>
</tr>
<tr>
<td>Other</td>
<td>4</td>
</tr>
<tr>
<td>Total Wells</td>
<td>105</td>
</tr>
</tbody>
</table>

Table 1. List of Wells and Use within the Lake Fork Watershed

1.2.5. Historical & Present Land Use

Before initiation of mining on Sugarloaf Mountain, the area was heavily logged for timber to support the mining boom in Leadville which began in the 1860’s. Mining on Sugarloaf Mountain was first prospected in the 1880’s and was active from the 1890’s through the 1920’s. The Dinero Mine was the largest and most productive in the mining district, producing 25,000 tons of ore worth a minimum of $800,000 in its history (Twitty, 2003). Other major mines in the district include the Bartlett, the Nelson, the Tiger-Shields and the Venture, which left shafts and tunnels in their wake. Smaller mining and prospecting efforts can also be seen throughout the mining district with small mine waste piles, prospecting pits, and mining relics (Figure 2).
Land use in the watershed has not been delineated, but it can be assumed from analyzing land cover, land ownership, access information, and local knowledge. Primary uses presently include: recreation, irrigation water, dispersed recreation (primarily motorized), wildlife habitat, and aquatic habitat. The National Land Cover Dataset was obtained from the USDA/NRCS - National Cartography & Geospatial Center (updated 2001) and analyzed using a geographic information system to determine Lake Fork Watershed land covers (see Table 2). See Map A8 in Appendix A for land cover information.

Ownership of the land in the watershed is a combination of U. S. Forest Service (USFS) (70%), U.S. Bureau of Land Management (BLM) (15%), private owners (10%), unknown (5%), and the state (less than 1%). The watershed is sparsely populated with scattered residences predominantly in the lower elevations of the watershed. See the Map A9 in Appendix A for land ownership and infrastructure information.

Businesses located within the watershed include:

- BOR, Operations at Sugarloaf Dam
- Outward Bound
- High Mountain Institute
- Mount Massive Golf Course
- Sugar Loaf Campground
- Leadville National Fish Hatchery
- Various working and non-working ranches

<table>
<thead>
<tr>
<th>Land Cover/Use</th>
<th>% of watershed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Open Water</td>
<td>3.28</td>
</tr>
<tr>
<td>Perennial Ice/Snow</td>
<td>3.15</td>
</tr>
<tr>
<td>Barren Land (Rock/Sand/Clay)</td>
<td>15.86</td>
</tr>
<tr>
<td>Deciduous Forest</td>
<td>1.55</td>
</tr>
<tr>
<td>Evergreen Forest</td>
<td>46.86</td>
</tr>
<tr>
<td>Mixed Forest</td>
<td>0.03</td>
</tr>
<tr>
<td>Shrub/Scrub</td>
<td>0.02</td>
</tr>
<tr>
<td>Grassland/Herbaceous</td>
<td>24.37</td>
</tr>
<tr>
<td>Pasture/Hay</td>
<td>0.06</td>
</tr>
<tr>
<td>Woody Wetlands</td>
<td>3.67</td>
</tr>
<tr>
<td>Emergent Herbaceous Wetlands</td>
<td>1.15</td>
</tr>
</tbody>
</table>

Table 2. Land Cover Percentage within the Watershed Boundary

There is only one permitted discharger located in the Watershed- the Leadville National Fish Hatchery (USFWS) NPDES Permit # 0000582 (non-municipal permit). There are no oil and gas wells, permits, or facilities currently located within the watershed (Colorado Oil and Gas Conservation Commission, 2010). A small southeastern section of the Lake Fork watershed, at the confluence of the Lake Fork with the Arkansas River, is located within Operable Unit 11 of the California Gulch, CERCLA NPL.
Figure 2. Sugarloaf Mining District
2. Watershed Partnerships and Efforts

2.1. Watershed Group Overview

The mission of the LFWWG is to represent community and stakeholder interests through watershed activities, facilitate communication, acquire data, recommend remediation, and complete restoration activities in areas of environmental degradation within the watershed boundary. The focus of the LFWWG has been on improving the water quality of the Lake Fork watershed through mine remediation projects that work to reduce heavy metal concentrations. These projects are the result of collaborative efforts initiated by those concerned about water quality within the Lake Fork Watershed. The group formed in October, 2000 as a response to investigations on the impacts of mine related activities on water quality and aquatic habitat. Membership and active involvement is dynamic, and has fluctuated over the years based on the needs of the project(s) at hand. Interested parties include private landowners, and representatives from county and city governments, state agencies, and federal agencies and non-governmental organizations.

2.2. Stakeholders

The LFWWG was established in order to coordinate the efforts of agencies such as:

- Bureau of Land Management (BLM)
- U.S. Geological Survey (USGS)
- Environmental Protection Agency (EPA)
- Colorado Department of Public Health and Environment (CDPHE)
- Bureau of Reclamation (BOR)
- Colorado Division of Wildlife (CDOW)
- U.S. Fish and Wildlife Service (USFWS)
- U.S. Forest Service (USFS)
- Colorado Division of Reclamation and Mining Safety (CDRMS)
- Colorado Mountain College Natural Resource Management (CMC NRM) Dept.
- Lake County Commissioners
- Local private landowners
- Trout Unlimited (TU)

Additional stakeholders are continuously sought through the outreach and education endeavors discussed in Section 2.3. Appendix E contains a detailed list of current LFWWG members.

2.3. Outreach and Education

Quarterly meetings held by the LFWWG are open to the public, and provide the opportunity for updates and discussion regarding past, current, and future projects. Seasonally permitted site visits occur in conjunction with the quarterly meeting, thus offering the opportunity to see project work first-hand as it progresses. These meetings help keep the stakeholders and public informed, as well as address any concerns or project priorities. Meetings are scheduled on a quarterly basis to allow for planning and publicizing on the website, newsletter, and other informational media.
The LFWWG website (www.coloradomtn.edu/LakeForkWatershedWorkingGroup) has been developed and is continually updated as needed. The website provides comprehensive and up-to-date project information, photos, resource links for teachers and the general public, and relevant documents, including meeting minutes. A newly developed quarterly newsletter is sent to the interested stakeholders and made available on the website. This newsletter highlights project progress, new projects, and relevant water and watershed related information. A Facebook profile, and email distribution list provide additional avenues for stakeholders and the public to stay updated and informed.

Additionally, in 2009, informational materials that include a general information brochure, and fact sheets pertaining to current projects, and watershed-related issues of acid mine drainage, pine beetle, and zebra mussels were developed. Throughout the summer and early fall these materials were distributed to the public at local farmers markets, the annual Leadville Boom Days weekend, and the Sustaining Colorado Watersheds Conference in Vail. Outreach through public events will continue in the future as the opportunities are available. In order to identify new stakeholders, a sign-up sheet was available at all events for those interested in receiving information on meetings and project updates.

As a member of the LFWWG, CMC NRM utilizes many of the group’s projects as educational examples for students within the NRM Department and other related programs. Further, employed interns within the NRM Internship Program gain invaluable field experience and refine their skills by applying classroom knowledge and techniques to actual field projects. Students have the rare opportunity to directly interact with environmental professionals from private companies, as well as state and federal agencies, providing additional educational opportunities and networking. These projects enable students to develop a wide variety of hands-on skills by performing characterization essential in reclamation, wetland delineation, environmental remediation and site monitoring. Students are gaining background information on Geographical Information Systems (GIS), wetland science, environmental chemistry, geology, aquatic ecology, remedial design, and hydrology during their work on projects within the Lake Fork Watershed.

3. Environmental Impairments

3.1 Water Quality Table Values Standards

The LFWWG is using water quality table value standards (TVS) for stream segment 5 of the Arkansas River Basin, contained within the Classification and Numeric Standards for Arkansas River Basin, Regulation No. 32 (CDPHE, 2010), which includes all tributaries to the Arkansas River from its source to Browns Creek. The chronic water quality TVS for listed metals in Table 3 are based on average hardness values in the Lake Fork of 25 mg/L and are displayed for example purposes only, as all graphs throughout this document contain TVS that have been calculated using site-specific hardness for the data displayed in the figure or table. Al and Fe do not have water quality standards set for stream segment 5 and the values noted as standards throughout the tables and graphs of this report are based on the chronic levels for aquatic life (acute values for Al are used for sample site where hardness is equal to or greater than 50 mg/L CaCO3 and pH is equal to or greater than 7.0).
Water Quality TVS for Aquatic Life (hardness of 25 mg/L CaCO₃)

<table>
<thead>
<tr>
<th>Metals of Concern</th>
<th>Chronic (µg/L)</th>
<th>Acute (µg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cadmium</td>
<td>0.15</td>
<td>0.51</td>
</tr>
<tr>
<td>Copper</td>
<td>2.74</td>
<td>3.64</td>
</tr>
<tr>
<td>Lead</td>
<td>0.62</td>
<td>13.88</td>
</tr>
<tr>
<td>Manganese</td>
<td>1040</td>
<td>1881</td>
</tr>
<tr>
<td>Zinc</td>
<td>38.13</td>
<td>43.97</td>
</tr>
</tbody>
</table>

Table 3. Water quality TVS based on a general hardness of 25 mg/L (CaCO₃)

### 3.2. Pollutants of Concern

Within the Lake Fork Watershed the main contributor of heavy metal loading into the Lake Fork is caused by historic mining activity, predominantly located in the Sugarloaf Mining District. Metal loading occurs from two main sources within the watershed. The first being mine waste piles that generate acid rock drainage (ARD) which can influence surface and groundwater systems. Secondly, mine shafts and adits that actively drain degrades surface and ground water through input of acid mine drainage (AMD). In Figure 2, all mine waste piles and tunnels within the mining district are denoted. Of the mine waste piles, the Dinero, Tiger, and Venture Mine Complexes are of concern to the LFWWG based on a mine waste pile analysis completed in 2007 (CMC NRM, 2007). Of the draining tunnels within the mining district Bartlett, Dinero, Nelson, Tiger, and Siwatch, prioritization of decreasing metal loading from the tunnels has focused on the Nelson, Dinero and Tiger Tunnels. Thus, a significant goal of the LFWWG and this document is to prioritize the aforementioned mine sites which contribute metal loading into the Lake Fork.

Both AMD and ARD are caused by the oxidation of sulfide minerals, particularly pyrite. As pyrite is exposed to water and oxygen a hydrolysis reaction takes place producing sulfuric acid (H₂SO₄), which dissociates into hydrogen (H⁺) and sulfate (SO₄²⁻) ions (see below for unbalanced equation).

\[
\text{FeS}_2(s) + O_2 + H_2O \rightarrow \text{Fe}^{2+}(aq) + \text{SO}_4^{2-}(aq) + H^+(aq)
\]

Due to the nature of mining, metals such as aluminum (Al), cadmium (Cd), copper (Cu), iron (Fe), manganese (Mn), lead (Pb) and zinc (Zn) are concentrated in the subsequent mines and waste piles. These oxidation reactions can occur underground within the extensive mine workings, causing metal laden water to exit the mine workings through adits or tunnels. Similarly, these reactions can occur as water infiltrates into mine waste piles, which are often located near flowing gulches. The effect of AMD can have a negative influence in three ways: primarily, acidification of the water; secondly, mobilization of trace metals in the acidified water; and finally precipitation of metals on the stream bed (Gaikwad and Gupta, 2008).

Because of input from AMD into the Lake Fork, increasing the pH and reducing the metal load in the watershed is critical to restoring a healthy aquatic habitat. Waters with a pH less than 6.5 will impact most aquatic organisms through the resulting imbalance of sodium ions.
leading to osmoregulatory or respiratory failure (Earle and Callaghan, 1998). In addition, low pH waters interrupt the lowest ends of the food chain by inhibiting bacteria and algae growth, Rosemond and others (1992) have determined that the direct effects of low pH on aquatic species have a greater impact on survival. Nonlethal pH values have been demonstrated by Kimmel (1983) to adversely affect fish growth rates and reproduction.

Metals of concern in the Lake Fork, and its tributaries, include those previously mentioned: Al, Cd, Cu, Fe, Mn, Pb, and Zn. Metals can exist in waters in a variety of forms, for example as dissolved ions, organic complexes, metal complexes, hydroxides. These various forms will ultimately influence their bioavailability. Depending upon the chemical state, i.e. bioavailability, and concentration of metals the influence could be either acute (short term exposure at high concentrations) or chronic (long term exposure at lower concentrations). Toxicological interactions of multiple metals can produce a variety of affects, including additive, synergistic, or potentiation effect, all of which increase the toxicity due to the presence of multiple metals, or reversely an antagonistic effect reducing the toxicity of the metals (Rand et al., 2003). The presence of metals, particularly in ionic form, is detrimental to aquatic life as it can interfere with osmoregulatory and ionic regulation in fish (Heath, 1995) as well as a decrease in abundance and diversity of macroinvertebrate communities.

While metal concentrations often reach toxic levels in AMD laden waters, their precipitate is also damaging to aquatic habitats. Metal precipitants commonly found within AMD waters greatly hinder algae growth and reduce the traction available on substrate surfaces, inhibiting fish and macroinvertebrate reproduction and stability of insect species within the water column (Earle and Callaghan, 1998). In addition, metal precipitation can increase turbidity and suspend solids and decrease oxygen availability by the formation of hydroxides (Earle and Callaghan, 1998).

The contamination from historic mining on the waters of the Lake Fork is far reaching, as the Lake Fork supplies water to the Arkansas River Valley for municipal and industrial purposes. The Arkansas River from the Lake Fork to Lake Creek (Segment 2c) was listed on the Colorado Department of Public Health and Environment (CDPHE) 2008 303(d) list of impaired waters for Zn and Cd, and a TMDL was adopted in July 2009. Segment 5, which includes all tributaries to the Arkansas River from the source to Browns Creek, specifically lists Halfmoon Creek as impaired for dissolved Pb and Cd. Adopted beneficial uses for Segment 5 include aquatic-life cold-water class 1, recreation, water supply, and agricultural uses (CDPHE, 2008). In addition, the Lake Fork itself was identified as a contributory source of concern (due to elevated levels of Zn, Cd and other associated metals) for the Lake County Assessment under Section 208 of the Clean Water Act completed by SourceWater Consulting in cooperation with the Upper Area Arkansas River Restoration Project Corps Team (Upper Arkansas Area Council of Governments-UACOG, 2002).

A baseline study conducted on the Lake Fork in 2001, measured water quality and benthic macroinvertebrates (BMI), at sites along the Lake Fork, including all flowing tributaries (Barrack, 2001). This study was conducted during low flow and concluded that the Lake Fork received metals input from two main sources, Sugarloaf and Colorado Gulch. The highest levels of metals input came from Sugarloaf Gulch, due to input from the Dinero and Nelson Mine Complexes with considerable increases of Al, Fe, Mn and Zn. The next
significant input occurred at Colorado Gulch, where no BMI were present during the study, and levels of Al, Cd, Cu, Fe, Mn and Zn were elevated relative to chronic and acute water quality TVS. Final observations of this study note considerable amounts of manganese precipitant downstream in the Lake Fork at levels detrimental to aquatic life (Barrack, 2001).

In a mass loading study conducted by Walton-Day and others (2005), it was noted that the Lake Fork was the major contributor of Al (68%), Cu (65%), and Fe (87%) loads into the Arkansas River below its confluence with the Lake Fork. In the same study, it was noted that the levels of Zn in the Lake Fork did not decrease below levels of the hardness based on chronic and acute toxicity levels until its confluence with Fish Hatchery inlet at Hunt Gulch. Thus, Zn concentrations are above chronic and acute toxicity levels from Sugarloaf Gulch, just below Sugarloaf Dam, approximately two miles downstream (Walton-Day et al., 2005).

Until recently, CDPHE had not received data regarding the Lake Fork and therefore it has not been identified on Colorado’s 303(d) list as an impaired water body. A recent estimation of degradation in the Lake Fork, utilizing CDPHE water quality TVS for stream segment 5, determined that Cd, Cu, Zn, D.O. and pH do not meet chronic water quality TVS, while Cd, Cu, Mn, Zn, and temperature do not meet the acute water quality TVS (See Appendix B). Along with the Lake Fork Watershed Plan, CDPHE recently acquired the Lake Fork Watershed Database, a database containing all water and soil data collected within the watershed through 2009, there is potential that the Lake Fork will be listed as impaired in the next 303(d) list in 2012.

### 3.2.1. Impacted Ecosystems

The upper Arkansas River basin is a high priority riparian corridor and the lower Lake Fork riparian corridor is a segment of concern (UACOG, 2002). Heavy metals leached from mine waste piles degrade several tributaries in the watershed, as a result negatively impacting fish and BMI populations, and wetland habitats. LFWWG stakeholders are most concerned about improving the water quality so that the watershed may again support a healthy fishery. Recreation and tourism are major funding sources for the local economy and improving the water quality will help support the promotion of the areas spectacular resources. Returning the areas of negatively impacted wetlands to a healthy habitat will promote biodiversity of both wildlife and vegetation. Finally, the general health of the Lake Fork, including stream bank stability, sedimentation, and discharge are of concern.

Table 4, below, provides a brief estimation of the proper functioning condition (PFC) of gulches within the Lake Fork Watershed. The riparian area assessment methodology (Prichard, 1998) takes into account hydrology, vegetation and erosion/deposition to determine if the segment is at PFC, functional-at risk, nonfunctional, and unknown. Due to the historic mining within a portion of the watershed, it is evident that many of the streams within the mining district are at-risk or nonfunctional. In contrast, those gulches that originate in the Mount Massive Wilderness area (Rock and Willow Creek) are in PFC until they reach agricultural land.
<table>
<thead>
<tr>
<th>Stream/Gulch/Reach</th>
<th>Estimated Condition</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lake Fork from outlet of Dam to midpoint at County Road 5</td>
<td>Proper Functioning Condition</td>
<td>Bank erosion high due to BOR releases</td>
</tr>
<tr>
<td>Lake Fork from midpoint to confluence with Arkansas</td>
<td>Proper Functioning Condition</td>
<td></td>
</tr>
<tr>
<td>Bartlett Gulch</td>
<td>Functional – At Risk</td>
<td></td>
</tr>
<tr>
<td>Sugarloaf Gulch</td>
<td>Functional – At Risk</td>
<td>Historic Mining</td>
</tr>
<tr>
<td>Strawberry Gulch</td>
<td>Proper Functioning Condition</td>
<td>No Historic Mining</td>
</tr>
<tr>
<td>Little Frying Pan East</td>
<td>Not Functional</td>
<td>Erosion concerns and Fe and Al precipitation on gulch</td>
</tr>
<tr>
<td>Little Frying Pan West</td>
<td>Not Functional</td>
<td>Erosion Concerns</td>
</tr>
<tr>
<td>Colorado Gulch above LFP</td>
<td>Functional - At Risk</td>
<td>Improving</td>
</tr>
<tr>
<td>Colorado Gulch below LFP</td>
<td>Functional - At Risk</td>
<td>Near confluence with Lake Fork Colorado Gulch has been channelized and there is extreme Fe precipitation</td>
</tr>
<tr>
<td>Hunt Gulch</td>
<td>Not Assessed</td>
<td>Assume low PFC</td>
</tr>
<tr>
<td>Rock Creek</td>
<td>Not Assessed</td>
<td>Assume low PFC to FAR</td>
</tr>
<tr>
<td>Willow Creek</td>
<td>Not Assessed</td>
<td>Assume PFC originates within wilderness area</td>
</tr>
<tr>
<td>Halfmoon Creek</td>
<td>Not Assessed</td>
<td>Assume PFC originates within wilderness area</td>
</tr>
<tr>
<td>Tributaries above Turquoise Lake</td>
<td>Not Assessed</td>
<td>Assume PFC within wilderness and forest service area</td>
</tr>
</tbody>
</table>

Table 4. Riparian Functional Assessment and Site Characterization

3.2.2. Species of Concern

There is a wide diversity of wildlife in the Upper Arkansas Valley associated with the variety of habitat zones. Due to the wide reaching contamination of AMD, within the Sugarloaf Mining District in particular, many species may be impacted by metals laden water and reduced forage due to contaminated soils. A complete listing of wildlife within Lake County can be found in Appendix D. The USFS has identified sensitive species in the San Isabel National Forest, which makes up the majority of land within the watershed. This information can be found in Appendix D. The threatened, endangered, and candidate species for Lake County are provided in Table 5 (USFWS, 2010) and detailed information can be found in Appendix D.

<table>
<thead>
<tr>
<th>Threatened, endangered, or candidate species for Lake County</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boreal Toad, bufo boreas boreas</td>
<td>Endangered</td>
</tr>
<tr>
<td>Canada lynx, Lynx canadensis</td>
<td>Threatened</td>
</tr>
<tr>
<td>Greenback cutthroat, trout Oncorhynchus clarki stomias</td>
<td>Threatened</td>
</tr>
<tr>
<td>Gunnison’s prairie dog, Cynomys gunnisoni</td>
<td>Candidate</td>
</tr>
<tr>
<td>Penland alpine fen mustard, Eutrema penlandii</td>
<td>Threatened</td>
</tr>
<tr>
<td>Uncompahgre fritillary butterfly, Boloria acrocnema</td>
<td>Endangered</td>
</tr>
</tbody>
</table>

Table 5. List of Threatened, Endangered and Candidate Species in Lake County.
4. Remediation Management Plans

The following section describes the BMPs as key components of remediation management plans that are appropriate for the treatment of abandoned or inactive mines. Figure 3 presents a flow diagram to facilitate the creation of remediation management plans and determine which BMPs should be considered for all future priority sites within the Lake Fork Watershed. All information in Section 4 is based on the booklet *Best Practices in Abandoned Mine Land Reclamation: The Remediation of Past Mining Activities*, published by the State of Colorado Department of Natural Resources, Division of Minerals and Geology (2002). *Best Practices in Abandoned Mine Land Reclamation* may be consulted for more information regarding each BMP, including guidelines, considerations, maintenance, and estimated cost.

4.1. Overview

The BMPs have potential to reduce the environmental impacts related to mining activities. Under certain scenarios, one BMP may address a particular problem. Often times, however, several BMPs must be incorporated, as part of a remediation management plan, in order to minimize the environmental impacts at a given site. Site hydrology, geology, composition, and safety issues all need to be addressed, frequently necessitating the use of several BMPs, either simultaneously or consecutively. BMP costs can vary greatly by site. A table provided by CDRMS for a rough estimation of BMP costs can be found in Appendix K.

The effectiveness of any particular BMP is highly site-specific. While Figure 3 helps direct the LFWWG’s investigation for potential remediation options for priority sites, adequate background research on the site should be conducted in order to properly select and implement BMPs and is the primary purpose for the development of an Engineering Evaluation and Cost Analysis (EE/CA) for any given site. This should include, but is not limited to, the site hydrology, constituents of concerns, pollutant fate and transport, and environmental risk assessment. Control measures presented below are grouped into hydrologic controls and passive treatment.

1) **Hydrologic Controls**: These are practices which prevent or inhibit the contact of water with mine waste piles, thereby reducing acidification and the mobilization of pollutants. Practices include water diversions, the removal of wastes, site regrading, the capping of wastes, and revegetation.

2) **Passive Treatment**: Passive treatment options are utilized to treat drainage of a site. Options include aeration and settling ponds, sulfate-reducing wetlands, oxidation wetlands, aqueous injection of limestone, and other acid neutralizing options.
Mine Waste Remediation Management Flow Diagram

Figure 3. Mine Waste Remediation Flow Diagram
(Figure modified from CDMG, 2002)
4.1.1. Hydrologic Controls

4.1.1.1. Diversion Ditches (BMP #1)

Diversion ditches are an appropriate technique when surface runoff, snowmelt, or precipitation contains pollutants from flowing through mine wastes, tailings, or workings. Diversion ditches are used to intercept and redirect the flow of water that may come in contact with any mine wastes, reducing potential loading of pollutants caused by direct contact.

Diversion ditches should be placed upstream from mine waste and should be deep enough to adequately intercept surface runoff and shallow groundwater interflow. The slope of the diversion ditch should be steep enough to prevent the ponding of water, and should not be so steep as to encourage erosion. Revegetation may also be utilized to slow the movement of water as an erosion control measure. For especially steep slopes, riprap may also be used, so long as it is ensured that the source material has not been impacted by surrounding mine wastes.

The cost of implementing diversion ditches varies greatly, depending on the length, depth, and slope of the ditch. Cost may also be impacted by revegetation or riprap placement. Maintenance should be periodically performed to ensure that excessive debris has not collected, and that no erosion is occurring.

4.1.1.2. Tailings Removal and Consolidation (BMP #2)

Tailings removal and consolidation is used to completely remove mine wastes away from water sources, reducing the risk of water quality degradation resulting from direct contact. Removal and consolidation is an effective technique when the size of mine waste piles are small or when water is flowing directly into larger mine waste piles.

A suitable repository for mine wastes must be located, such that mine wastes no longer pose a risk to surface or shallow groundwater flow. Once a suitable area has been identified, the site must be cleared of all topsoil and organic matter, and regraded to contain the mine wastes. Contours or berms may be required if the material is partially to fully saturated or if the grade is steep enough to promote flow. Capping and revegetation may also be used on top of the deposit, discussed further in Sections 4.1.1.5 and 4.1.1.6.

Costs for tailings removal and consolidation vary widely, depending on the toxicity of the material, the size of the mine waste piles, the distance material needs to be moved, and preparation necessary for the repository site. For an estimate of costs of previous mine pile remediation projects within the Sugarloaf Mining District, see Table 6.
<table>
<thead>
<tr>
<th>Project</th>
<th>Year</th>
<th>Repository</th>
<th>Liner Type</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nelson</td>
<td>2004</td>
<td>On-site</td>
<td>Top only</td>
<td>$250,000</td>
</tr>
<tr>
<td>Dinero Pile</td>
<td>2005</td>
<td>On-site</td>
<td>Top only</td>
<td>$300,000</td>
</tr>
<tr>
<td>Tiger Pile</td>
<td>2009-2010</td>
<td>On-site</td>
<td>Top only</td>
<td>$340,000</td>
</tr>
</tbody>
</table>

Table 6. Cost of pile relocation of completed projects within the Sugarloaf Mining District

4.1.1.3. **Stream Diversions (BMP #3)**

Stream diversions are used when a stream is flowing directly into, or adjacent to, a mine waste site. The stream is diverted such that flow is no longer coming in direct contact with mine waste piles, decreasing the potential for degradation of surface water.

The overall site topology must be suitable for a stream diversion, with adequate space to relocate the stream channel away from mine wastes at an acceptable distance. As with diversion ditches discussed in BMP #1 above, care must be taken to ensure adequate flow without excessive pooling and to prevent erosion. Stream diversion banks should be adequately reinforced to ensure overflow does not occur, and the stream channel should be sufficiently deep to account for high-flow runoff conditions.

Costs for stream diversions will vary depending on the site, due to consideration of the distance of mine waste piles from the new stream channel, and the overall distance of the new diversion. Periodic inspections should also be performed, to ensure stream flow is staying in the new channel, and large amounts of debris are not collecting. It should also be noted that the Army Corps of Engineers must also be contacted at the beginning of the planning process to determine if a 404 permit is required.

4.1.1.4. **Erosion Control and Regrading (BMP #4)**

Mine waste areas are often highly disturbed sites, with little to no vegetation present, and are often located on-slope. The potential for erosion via surface runoff, wind, or frost action is high, and regrading may be used to improve the situation. The surface should be regraded to provide a more uniform and gentle slope, reducing the impacts of erosion.

All debris must be removed from the area prior to regrading, including tree trunks and stumps, and any manmade debris. Commonly following grading is revegetation (as discussed in BMP #6) if the area is suitable. Revegetation helps to prevent further erosion of the site and limit the effects of surface water ponding on the site.

Regrading most often involves the use of heavy equipment, impacting overall costs. The size of the site and overall contour may also greatly influence overall costs, especially if large amounts of material will need to be relocated. Saturated soils
could also increase cost by slowing regrading efforts. Periodic inspections should be performed to ensure erosion is not reoccurring on the site.

4.1.1.5. Capping (BMP #5)

Runoff on the surfaces of mine wastes may be reduced by employing capping. Capping is the placement of a protective layer over mine wastes, be it a simple layer of soil or more expensive liners followed by soil. Capping encourages runoff from mine wastes and reduces overall infiltration of precipitation into mine wastes.

The type of capping used is determined by materials that are available near the site, the overall reactivity level with water of the mine wastes, and cost. Optimally, capping should be followed by revegetation (as discussed in BMP #6) to prevent cap erosion and to decrease the force of precipitation on the cap.

Costs vary depending on the topology of the pile and the type of cap used. The use of liners on highly reactive mine wastes can greatly increase costs, but is generally not necessary for the majority of sites. The distance of capping material relative to the pile can also impact cost. Inspections should regularly be performed to identify areas of erosion or disturbance, and corrective action should be taken if necessary.

4.1.1.6. Revegetation (BMP #6)

Revegetation at mine waste sites reduces infiltration into waste areas and helps prevent erosion from occurring. Revegetation is most commonly used in conjunction with several other BMPs, especially in regrading and capping. Other BMPs can be made more effective by integrating a revegetation component.

Preferably, revegetation should be placed on top of unimpacted soils. The surface should also be moderately rough to allow seeds to stay in place and moisture to collect for germination. The surface should not be roughened too much, however, as excessive pooling could form, resulting in water infiltrating into waste piles. Care should be taken in selecting the proper seed mix for the site, making sure to plan in adequate diversity in case any individual species should fail to propagate.

Cost varies depending on the area requiring revegetation, the seed mix utilized, and any soil amendments required prior to seeding. The site should be periodically checked for signs of erosion and any areas where vegetation has failed to develop. Reseeding may be required in certain areas.

4.1.2. Passive Treatment

4.1.2.1. Aeration and Settling Ponds (BMP #7)

Aeration and settling ponds are an appropriate technique for dealing with drainage from a mine opening. Drainage is aerated, or made turbulent, using steep slopes, riprap or rocks on the drainage bed, or waterfalls. The drainage is then channeled
into a settling pond, allowing heavy metals to precipitate out. This technique is most effective in drainage containing high levels of total suspended solids.

The settling pond should be located below any aeration channels that are installed. A dam at the bottom of the settling pond should be constructed such that water can flow back into the stream, without eroding the dam itself. The settling pond should be designed to allow for a minimum of 24 hours residence time of the drainage. Several smaller ponds can also be utilized to achieve a combined residence time of 24 hours.

Cost is highly dependent on site topology and the material that must be excavated to construct the settling pond. Rocky sites may be more expensive during initial construction. Overall site slope must be adequate. Extremely steep sites present little opportunity for the placement of settling ponds, and flatter sites make aeration channels difficult. The aeration channels should be periodically inspected to ensure adequate aeration, and sediment levels in settling ponds should also be monitored. Metals that have settled out as sediment can be transported to a hazardous waste site or placed in a lined and capped repository on site.

4.1.2.2. **Sulfate Reducing Wetlands (BMP #8)**

Sulfate-reducing wetlands may be used to treat drainage from mine waste piles, tailings, and mine openings. The wetlands function by utilizing sulfate-reducing bacteria (SRBs), which combine oxygen with sulfates for respiration, producing sulfides. Heavy metals from the drainage combine with these sulfides, forming insoluble metal sulfides. These heavy metal sulfides then precipitate out. The bacteria need a carbon energy source, usually from manure or compost.

Sulfate-reducing wetlands are constructed down-stream from drainage areas. They are created by constructing a small dam or berm, allowing water to collect. If the site soil is fine-grained, a liner is generally not needed. For other areas, a liner may be necessary, made of PVC or HDPE. A layer of gravel, approximately 3-6 inches, is placed on top of the bottom of the wetlands. This layer should contain perforated pipes to allow filtered water to exit the wetlands. The entire gravel layer should be covered with a highly permeable fabric.

SRBs prefer an environment with a pH above 4.5. If the pH of entering flow is below 4.5, liming may be necessary to raise the pH. Sulfate-reducing wetlands should not be constructed near populated areas, as hydrogen sulfide is often produced in excess, creating foul odors.

Costs to install a sulfate-reducing wetland vary depending on the size of the wetland needed to handle the drainage, whether additional bedding material must be obtained from off-site, and if additional amendments such as liming are necessary. Sulfate-reducing wetlands generally have an anticipated lifetime of 20 to 30 years. After this amount of time, effectiveness of the wetlands begins to deteriorate as flow decreases, necessitating the removal of sediment and hydrous metal oxide precipitants.
4.1.2.3. Oxidation Wetlands (BMP #9)

Oxidation wetlands are most commonly used when the pH of the water is around 6.5 or higher and where metal concentrations are considerably higher during high-flow conditions. Oxidation wetlands primarily use plants and algae to oxidize heavy metals, which then precipitate out. Plant material provides aeration, sites for algal growth, and absorption surfaces for the heavy metals.

Oxidation wetlands look more like “wetlands” then do sulfate-reducing wetlands discussed in BMP #8. The wetland should be constructed to allow drainage through uneven grading, such that drainage flows through shallow and deep areas. High flow rates should be prevented for optimal performance, both to allow adequate time for oxidation and to reduce channeling at the bottom of the wetland. Wetlands should generally be sized to allow for 200-900 ft\(^2\) per one gallon per minute of drainage. The base layer of the wetland site should be filled with gravel and organic matter. The site should then be planted with cattails, rushes, and sedges. These can be transplanted from another wetland site in clumps. Hay and grass clippings can also be added to promote algal growth. Areas surrounding the site should be revegetated if necessary to prevent sediment loading of the newly-constructed wetland, as outlined in BMP #6.

Costs for oxidation wetlands vary depending on the size of the wetland necessary, the source of bedding materials, and the availability of transplants to seed the wetland. Periodic inspections are necessary to ensure even, low-velocity flow across the wetland, and to ensure that channelization does not occur. As with sulfate-reducing wetlands, the anticipated lifetime is 20 to 30 years due to decreasing flow conditions. The level of the wetland water surface may be raised to extend the lifetime of this BMP. As this BMP relies heavily on plant production, a drop in efficiency should be expected during winter months.

4.1.2.4. Other BMPs to treat AMD (BMP #10)

No BMP outlined above deals specifically with high levels of acid mine drainage from mine openings. The purpose of this BMP is to briefly outline a few options for dealing with such a situation. Generally, the options that follow are more expensive to implement and require ongoing maintenance. These options also involve a high level of understanding of the volume of water at hand, the water chemistry, and the mine configuration present.

Dilution may be used by injecting clean water into the acid mine drainage and then funneled to a settling pond. Heavier metals may precipitate out under these higher pH conditions. If adequate supplies of clean water are available, this method can be cost-effective, though it is considered to be much less effective than BMPs outlined above.

Land application may be used, which involves natural processes in soils to combine with and remove metals. This can include evapotranspiration, soil exchange capacity,
and plant uptake. Large areas of land are needed so that drainage can be spread across the site relatively thinly. Drainage entering the site must have a near neutral pH so the plants are not killed. Within a mine, bulkhead seals may be used to isolate drainage. This prevents discharge and the subsequent development of acid mine drainage. Bulkhead seals can be expensive and require significant amounts of engineering to design.

Anoxic limestone drains (ALDs) can be used to treat acidic drainage from a mine opening. Drainage is channeled through a trench containing limestone. The acid mine drainage dissolves the limestone, which is naturally alkaline. This raises the pH of the drainage. Settling ponds are then used downstream to precipitate out heavy metals. Aqueous lime injection functions much like dilution, except that aqueous lime is injected instead of clean water. The solution is mixed with the acid mine drainage, raising the pH. As with ALDs, the water is then channeled into a settling pond where metals can precipitate out. If alkaline industrial byproducts such as fly ash can be obtained at little to no cost, this can be a cost-effective method.

A hybrid of a mechanical and passive treatment system can also be employed to treat AMD water, such as the Aquafix Unit. This system utilizes calcium oxide pellets and a dispenser to neutralize acidic waters. A portion of the total water is sent through a water wheel, which governs the amount of calcium oxide/neutralizing agent dispensed. This water heavily neutralizes the pH of the water, which allows metals to precipitate out of the water into a settling pond located below the dispensary. The final effluent and water quality is controlled by the amount of neutralizing agent released and residence time in the settling pond, which is controlled by its size. This is a cost effective treatment requiring a start up cost of approximately $50,000 along with a yearly maintenance cost.

5. Watershed Management Areas

5.1. Overview of the Areas of Concern

The primary sampling efforts by the LFWWG, as well as previous research, are concentrated within the Sugarloaf Mining District, focusing on Sugarloaf and Colorado (and its tributaries) Gulches. A sampling effort in 2001 by the LFWWG (Barrack, 2001) determined that Sugarloaf and Colorado Gulches were the largest contributors of metal loading into the Lake Fork, with the greatest loading originating from Sugarloaf Gulch. Due to previous prioritization, tributaries entering the Lake Fork that are not sites of historic mining have not been sampled as thoroughly. Tributaries outside the mining district include Hunt Gulch, Rock Creek and Willow Creek. Similarly, within the mining district, Bartlett Gulch and Strawberry Gulch have not been sampled as rigorously due to the lack of evidence of water quality impairment originating from those gulches. Halfmoon Creek is also a site of historic mining, particularly at the Champion Mine and Iron Mike Mine, but has not been sampled consistently by the LFWWG (for further information on Halfmoon Creek see Section 5.4.11).
Previous and current prioritization of source remediation within the Lake Fork Watershed focused on Sugarloaf Gulch first, which contains the Dinero Mine Complex. The second geographic priority area is Colorado Gulch and its tributary, Little Frying Pan Gulch. Little Frying Pan Gulch is home to the Tiger and Venture Mine Complexes.

In general, once the LFWWG has identified an area for remediation, projects have been completed systematically beginning upstream and moving downstream toward the Lake Fork. For example, in Sugarloaf Gulch, the first project to proceed was removal and capping of the Nelson Mine pile (2002), followed by removal and capping of the two Dinero Mine Piles (2004), and finally emplacement of the Dinero Bulkhead (2009). (See Figure 2 for location of these three sites.) Current remediation efforts by the LFWWG have been in the upper reaches of Little Frying Pan East, a tributary of Colorado Gulch, at the Tiger Mine Complex. Future work is planned for the Venture Mine Complex, downstream near the confluence with Colorado Gulch.

Site specific characterizations in Section 5 are grouped first geographically and then prioritized within the geographic context, by known pollutant loading, concentration exceedances relative to aquatic habitat, and funding opportunities. In the proceeding site specific sections, both concentration and loading data from 2008 (when available) are displayed. Concentration results from both high and low flow are also displayed to determine any seasonal variation. Sites lacking 2008 high flow data depict the most recent high flow event available. Loading figures for dissolved metals compare the loading for a given reach with the chronic water quality TVS, converted to loading using the site’s discharge, and based on a calculated hardness.

Figure 2 provides an overview of the Sugarloaf Mining District and Figure 4 provides a visual display of pH within the watershed. Figure 4 also provides an overview of current data gaps in water quality information within the watershed, as tributaries without pH values are typically also missing water quality data. Map A11 in Appendix A provides a map of sampling locations presented in the forthcoming loading charts and Maps A12-14 provide exceedances percent of the water quality TVS for Cd, Mn, and Zn (for available sample sites). Erosion has also been noted as an area of concern within the watershed, but it has not been addressed as a priority by the LFWWG, other than avoiding excessive erosion into the Lake Fork during reclamation projects.
Figure 4. pH of the Lake Fork Watershed and Existing Data Gap

pH contains a compilation of data from CMC, EPA, and the USGS 2002-2009. Data gaps are present for the areas not displaying a pH value. Created by CMC NRM for visual reference only.
5.2. Lake Fork

5.2.1. Previous Research

An initial study conducted by the LFWWG in 2001 attempted to prioritize problem areas in the Lake Fork Watershed below Sugarloaf Dam (Barrack, 2001). A similar study was completed along the Lake Fork in 2001 by the USGS (Walton-Day et al., 2005). More detail on these studies is provided in Section 3.1. Moving forward from these baseline studies, continued research, sampling, and remediation efforts have occurred within the watershed. More specific research on individual gulches and mine sites is provided in subsequent sections.

Biotic impacts due to metal toxicity in the Lake Fork can be seen in BMI studies conducted by both CMC NRM (Barrack, 2001) and the BLM/CDOW (2007, 2008). From these data, it is evident that BMI abundance and diversity decreases within the Lake Fork as you move downstream from the confluences of Sugarloaf Gulch and Colorado Gulch toward the confluence of the Arkansas River. For example, BMI sampling in 2001 described a total BMI abundance at LF-3, just below the confluence of Sugarloaf Gulch, at 14 with three species, while site LF-9, near the confluence with Hunt Gulch on Outward Bound property, had a total BMI of 294 with eight species (Barrack, 2001). Thus input from Sugarloaf Gulch causes a decrease in both number and diversity of aquatic life. Similar results can be seen from data collected in 2007 and 2008 by the BLM (Figure 5a and 5b). From these data both abundance and diversity of BMI increase from sampling conducted below the confluence with Sugarloaf Gulch to sampling conducted on Outward Bound property, two miles down-stream.

![Figure 5. BMI (a) Species Diversity and (b) Species Abundance in the Lake Fork](image)

The CDOW extensively sampled the fish population in the Lake Fork below Turquoise Reservoir in 1994. From this sampling event brown trout were determined to dominate the fish community from the confluence of the Arkansas to the confluence with Halfmoon Creek. In contrast, brook trout were consistently more prevalent upstream of Rock Creek. Fish populations decreased drastically below the outlet of both Colorado
Gulch and Sugarloaf Gulch. An increased number of fish were found above the inlet of Colorado Gulch below the confluence with the Dunn Ditch, but no young of the year were found. This fish community consisted of larger individuals that probably migrated in from downstream reaches. In a study conducted in 2006, the fish population characteristics were similar to those seen in 1994 except that brown trout were now successfully reproducing and recruiting from below the inlet of Colorado Gulch downstream to the Arkansas River. Fish populations remain similar above Colorado Gulch and below County Road 11 to the Arkansas River but increases in brown trout up to the confluence of Colorado Gulch may be attributed to remediation efforts upstream in the Lake Fork (Policky, 2006).

5.2.2. Previous Remediation Efforts

Previous remediation projects that have taken place within the Lake Fork Watershed are described in the “Previous Remediation Efforts” sections contained within the remainder of Section 5.

5.2.3. Pollutant Loads and Data Analysis

A yearly high flow and low flow Lake Fork sampling event has occurred since 2001. In recent years, sampling has occurred at sites of concern from outflow of Sugarloaf Dam (LF-01 Figure 6a), below the confluence with Sugarloaf Gulch (LF-03), below the confluence with Strawberry Gulch (LF-06), below the confluence with Colorado Gulch (LF-08), below the confluence with Hunt Gulch (LF-09), and above the confluence with the Arkansas River (LF-11 Figure 6b) to quantify loading in the Lake Fork. It is evident from the 2008 loading data, as seen in Figures 7-12, that initial loading into the Lake Fork occurs below Sugarloaf Gulch and Colorado Gulch. Below Sugarloaf Gulch water quality in the Lake Fork exceeds water quality TVS for dissolved Cu, Cd, Mn and Zn (compare Table 7 and 8). Below the confluence with Colorado Gulch water quality in the Lake Fork exceeds water quality TVS for Al, Cd, Cu and Zn, while Fe levels increase and Mn levels stay elevated (Table 9). Further down the Lake Fork, prior to its confluence with the Arkansas River only Cd, Al and Zn are still elevated above chronic loading water quality TVS (Table 10). After its confluence with the Arkansas only Cd and Zn are elevated above TVS (Table 12), which were elevated to similar levels before its confluence (Table 11). Interestingly, levels within the Lake Fork before the confluence are very similar to values after its confluence (compare Table 10 Zn and Cd to Table 12 values). After the confluence with the Arkansas River, Cu values are diluted below TVS.

The amount of metals loading attributed from the Lake Fork in the Arkansas River was documented in the mass loading study by Walton-Day and others (2005). In this study, it was determined that more than half of the Ca (70%), SO$_4^{2-}$ (82%), Mn (77%), Pb (78%) and Zn (95%) loading in the Arkansas can be attributed to the Arkansas or upstream tributaries. In contrast, loading of Al (68%), Cu (65%), and Fe (87%) into the Arkansas can be attributed to input from the Lake Fork (Walton-Day et al., 2005).
Figure 6. Lake Fork Sample Sites (a) LF-01 and (b) LF-11

* Al and Fe do not have water quality standards set for stream segment 5 (CDPHE, 2010) though values have been referenced for the protection of aquatic life from Table III Metal Parameters (CDPHE, 2009a).

Figure 7. Loading for the Lake Fork below Sugarloaf Dam

Table 7. Concentration Comparison for the Lake Fork below Sugarloaf Dam

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Units</th>
<th>High Flow</th>
<th>Chronic TVS</th>
<th>Low Flow</th>
<th>Chronic TVS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al-Tot</td>
<td>ug/L</td>
<td>93.9</td>
<td>87*</td>
<td>85.8</td>
<td>87*</td>
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<tr>
<td>Cd-Diss</td>
<td>ug/L</td>
<td>0.2</td>
<td>0.08</td>
<td>BDL</td>
<td>0.08</td>
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<tr>
<td>Cu-Diss</td>
<td>ug/L</td>
<td>10</td>
<td>1.45</td>
<td>BDL</td>
<td>1.32</td>
</tr>
<tr>
<td>Fe-Tot</td>
<td>ug/L</td>
<td>450</td>
<td>1000*</td>
<td>417</td>
<td>1000*</td>
</tr>
<tr>
<td>Mn-Diss</td>
<td>ug/L</td>
<td>72.8</td>
<td>810.3</td>
<td>5.23</td>
<td>783.1</td>
</tr>
<tr>
<td>Zn-Diss</td>
<td>ug/L</td>
<td>20</td>
<td>20.15</td>
<td>BDL</td>
<td>18.47</td>
</tr>
</tbody>
</table>

* Al and Fe do not have water quality standards set for stream segment 5 (CDPHE, 2010) though values have been referenced for the protection of aquatic life from Table III Metal Parameters (CDPHE, 2009a).
Lake Fork Watershed Plan

Lake Fork Watershed Working Group

* Al and Fe do not have water quality standards set for stream segment 5 (CDPHE, 2010) though values have been referenced for the protection of aquatic life from Table III Metal Parameters (CDPHE, 2009a).

Figure 8. Loading for the Lake Fork after the Confluence with Sugarloaf Gulch

Table 8. Concentration Comparison for the Lake Fork after the Sugarloaf Gulch Confluence

* Al and Fe do not have water quality standards set for stream segment 5 (CDPHE, 2010) though values have been referenced for the protection of aquatic life from Table III Metal Parameters (CDPHE, 2009a).

Figure 9. Loading for the Lake Fork after the Confluence with Colorado Gulch
Table 9. Concentration Comparison for the Lake Fork after Colorado Gulch Confluence.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Units</th>
<th>High Flow</th>
<th>Chronic TVS</th>
<th>Low Flow</th>
<th>Chronic TVS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al-Tot</td>
<td>ug/L</td>
<td>1130</td>
<td>87*</td>
<td>162</td>
<td>87*</td>
</tr>
<tr>
<td>Cd-Diss</td>
<td>ug/L</td>
<td>7.31</td>
<td>0.13</td>
<td>0.371</td>
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<td>Cu-Diss</td>
<td>ug/L</td>
<td>72.7</td>
<td>2.45</td>
<td>BDL</td>
<td>3.05</td>
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<td>Fe-Tot</td>
<td>ug/L</td>
<td>1450</td>
<td>1000*</td>
<td>931</td>
<td>1000*</td>
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<tr>
<td>Mn-Diss</td>
<td>ug/L</td>
<td>958</td>
<td>994.9</td>
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<td>Zn-Diss</td>
<td>ug/L</td>
<td>852</td>
<td>34.1</td>
<td>155</td>
<td>42.5</td>
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</tbody>
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* Al and Fe do not have water quality standards set for stream segment 5 (CDPHE, 2010) though values have been referenced for the protection of aquatic life from Table III Metal Parameters (CDPHE, 2009a).

Table 10. Concentration Comparison for the Lake Fork before the Confluence with the Arkansas River.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Units</th>
<th>High Flow</th>
<th>Chronic TVS</th>
<th>Low Flow</th>
<th>Chronic TVS</th>
</tr>
</thead>
<tbody>
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<td>165</td>
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<td>Cd-Diss</td>
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<td>0.15</td>
<td>BDL</td>
<td>0.23</td>
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<td>Cu-Diss</td>
<td>ug/L</td>
<td>10.8</td>
<td>2.69</td>
<td>BDL</td>
<td>4.44</td>
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<td>Fe-Tot</td>
<td>ug/L</td>
<td>998</td>
<td>1000*</td>
<td>895</td>
<td>1000*</td>
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<td>Mn-Diss</td>
<td>ug/L</td>
<td>277</td>
<td>1032</td>
<td>52.1</td>
<td>1255</td>
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<tr>
<td>Zn-Diss</td>
<td>ug/L</td>
<td>206</td>
<td>37.40</td>
<td>BDL</td>
<td>61.73</td>
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* Al and Fe do not have water quality standards set for stream segment 5 (CDPHE, 2010) though values have been referenced for the protection of aquatic life from Table III Metal Parameters (CDPHE, 2009a).
Al and Fe do not have water quality standards set for stream segment 5 (CDPHE, 2010) though values have been referenced for the protection of aquatic life from Table III Metal Parameters (CDPHE, 2009a).

**Figure 11. Loading for the Arkansas River before the Lake Fork Confluence**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Units</th>
<th>High Flow</th>
<th>Chronic TVS</th>
<th>Low Flow</th>
<th>Chronic TVS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al-Tot</td>
<td>ug/l</td>
<td>238</td>
<td>87*</td>
<td>799</td>
<td>750 (acute)**</td>
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<tr>
<td>Cd-Diss</td>
<td>ug/l</td>
<td>1.07</td>
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<tr>
<td>Cu-Diss</td>
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<td>5.02</td>
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<tr>
<td>Fe-Tot</td>
<td>ug/l</td>
<td>665</td>
<td>1000*</td>
<td>2620</td>
<td>1000*</td>
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<tr>
<td>Mn-Diss</td>
<td>ug/l</td>
<td>67</td>
<td>1316</td>
<td>70.1</td>
<td>1761</td>
</tr>
<tr>
<td>Zn-Diss</td>
<td>ug/l</td>
<td>296</td>
<td>69.78</td>
<td>148</td>
<td>146.9</td>
</tr>
</tbody>
</table>

* Al and Fe do not have water quality standards set for stream segment 5 (CDPHE, 2010) though values have been referenced for the protection of aquatic life from Table III Metal Parameters (CDPHE, 2009a). ** Due to a hardness of 122 mg/L CaCO3 and a pH of 8.0 during low flow Al acute values for aquatic life are referenced as per footnote 11 of Table III Metal Parameters (CDPHE, 2009).

**Table 11. Concentration Comparison for the Arkansas River before the Lake Fork Confluence**

* Al and Fe do not have water quality standards set for stream segment 5 (CDPHE, 2010) though values have been referenced for the protection of aquatic life from Table III Metal Parameters (CDPHE, 2009a).

**Figure 12. Loading for the Arkansas River after the Lake Fork Confluence**
### Concentration Comparison
Arkansas River after the Lake Fork Confluence - AR-04

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Units</th>
<th>High Flow</th>
<th>Chronic TVS</th>
<th>Low Flow</th>
<th>Chronic TVS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al-Tot</td>
<td>ug/l</td>
<td>266</td>
<td>87*</td>
<td>51.2</td>
<td>750 (acute)**</td>
</tr>
<tr>
<td>Cd-Diss</td>
<td>ug/l</td>
<td>0.94</td>
<td>0.23</td>
<td>BDL</td>
<td>0.35</td>
</tr>
<tr>
<td>Cu-Diss</td>
<td>ug/l</td>
<td>2.7</td>
<td>4.39</td>
<td>BDL</td>
<td>7.24</td>
</tr>
<tr>
<td>Fe-Tot</td>
<td>ug/l</td>
<td>761</td>
<td>1000*</td>
<td>416</td>
<td>1000*</td>
</tr>
<tr>
<td>Mn-Diss</td>
<td>ug/l</td>
<td>80</td>
<td>1249.7</td>
<td>53.9</td>
<td>1518</td>
</tr>
<tr>
<td>Zn-Diss</td>
<td>ug/l</td>
<td>239</td>
<td>61.1</td>
<td>74.9</td>
<td>100.5</td>
</tr>
</tbody>
</table>

* Al and Fe do not have water quality standards set for stream segment 5 (CDPHE, 2010) though values have been referenced for the protection of aquatic life from Table III Metal Parameters (CDPHE, 2009a). ** Due to a hardness of 78 mg/L CaCO3 and a pH of 8.1 during low flow Al acute values for aquatic life are referenced as per footnote 11 of Table III Metal Parameters (CDPHE, 2009)

Table 12. Concentration Comparison for the Arkansas River after the Lake Fork Confluence.

#### 5.2.4. Data Gaps

Erosion on the Lake Fork is a topic of concern to the LFWWG that needs to be assessed and addressed after modified release schedules can be agreed upon for Sugarloaf Dam with the US Bureau of Reclamation (BOR). Current release methods, specifically the minimal release ramping and rates (Figure 13), have greatly concerned local landowners (Figure 14a, 14b) and have made the LFWWG hesitant to tackle erosion remediation under current conditions. Improvement of degraded stream segments of the Lake Fork by systematically addressing the highest priority sites within the watershed may also reduce erosion rates as riparian health increases.

![Figure 13. Lake Fork Discharge from Sugarloaf Dam (BOR, 2010).](image-url)
5.2.5. Current Efforts

Current efforts on the Lake Fork include yearly collection of high (May-June) and low (August-September) flow samples, discharge, and in-situ water quality parameters at the sites designated above in Section 5.2.3. CDOW will sample BMI and fish for the next three years (2010-2012) within the Lake Fork, which will be added to BMI and fish data collected since the mid-1990s. The BOR continuously monitors discharge from Sugarloaf Dam. In addition, other areas of the watershed include current efforts that are discussed further in subsequent sections.

5.2.5.1. Sources of Financial and Technical Assistance

Yearly sampling along the Lake Fork has been sponsored by BLM funding and various projects, which include sampling of Lake Fork sites. Three years of comprehensive hydrological, chemical and biological sampling from 2010-2012 will reproduce the baseline study completed by the USGS in 2006 and will include >70 sites as part of the Sugarloaf BMP Performance Monitoring funded through the Section 319 NPS Council (see Section 5.3.1.5 for more details) and Appendix H for the Sugarloaf Performance Monitoring Scope of Work.

5.2.6. Future Needs, BMPs and Estimated Cost

The current monitoring efforts primarily address the pollutant loading originating from the Sugarloaf Mountain Mining District. Future monitoring will likely encompass other areas of the Lake Fork watershed that includes Halfmoon Creek and the Lake Fork reach above Turquoise Lake.

5.3. Sugarloaf Gulch

5.3.1. Dinero Mine

In 2001, the Dinero Mine was identified as the top source of heavy metals loading into the Lake Fork (Barrack, 2001) and became one of the first projects completed by the LFWWG. The Dinero Mine site included several mine waste piles and the Dinero Tunnel (Figure 15a).
5.3.1.1. Previous Research

Previous research completed on the Sugarloaf Wetland Complex can be found below:

- Sugarloaf Wetland Characterization, CMC NRM, 2010
- Hydrologic Characterization of Sugarloaf and Little Sugarloaf Gulch, CMC NRM 2009
- USGS, CMC NRM 2006 baseline study.
- Functional Assessment Report Sugarloaf Gulch Wetland, SAIC, 2000
• Metal Retention in Sugarloaf Gulch Wetland, Lake County, Colorado. Colorado State University, Department of Earth Science. Rowe, C. M.S. Thesis. 1994

5.3.1.2. Previous Remediation Efforts

Historically, two Dinero Mine waste piles were located within a wetland area at the convergence of Sugarloaf and Little Sugarloaf Gulches. These two piles (Figure 15a) were relocated to on-site engineered repositories (Figure 15b) in 2004 (BLM and The National Science and Technology Center, 2006). One pile, located directly below the mouth of the Dinero Tunnel, was relocated to an area above its original site and capped. The other pile, originally located in the Sugarloaf Wetlands, was relocated to a repository approximately 300 feet up hill out of the gulch. Relocation and capping of both mine waste piles was completed in 2004.

Several limestone lined settling ponds were installed below the Dinero Tunnel in the footprints left by the relocated mine waste piles to assist neutralizing AMD from the Dinero Tunnel and detain the precipitant (Figure 16a). Due to the significant amount of Fe-OOH or “yellowboy” precipitant that collects in the ponds, maintenance is required every two to three years in the form of manually excavating the precipitants. The installation of the ponds was initially a short-term BMP for the Dinero Tunnel AMD until the bulkhead was installed. The ponds will likely remain to assist in neutralizing acidity from Sugarloaf Gulch and any flow from the Dinero Tunnel.

Figure 16. (a) Dinero Detention Ponds and the (b) Dinero Bulkhead
The Dinero bulkhead was installed in September of 2009 (Figure 16b) and has greatly reduced the flow of AMD from the Dinero Tunnel. Due to the recent timeframe of this action, no studies have yet determined the reduction of metals loading to Sugarloaf Gulch and the Lake Fork from the Dinero Tunnel. While the bulkhead has obstructed flow from the lower tunnel workings, currently, faults and fractures located in front of the bulkhead are still contributing minimal amounts of AMD to Sugarloaf Gulch. Flow from the Dinero Tunnel varied from approximately 320 gallon per minute (gpm) to around 30 gpm before the bulkhead installation. Recent measurements, after bulkhead installation, have estimated a flow of approximately 11 gpm during the winter of 2010. With the installation of the bulkhead it is expected that water quality below the confluence of Sugarloaf Gulch in the Lake Fork will improve.

**5.3.1.3. Pollutant Loads and Data Analysis**

Historically the Dinero Tunnel has been a major source of Mn, Zn, Fe, and Cd entering the Sugarloaf Wetlands and eventually the Lake Fork through the Dinero Channel and groundwater seeps. Sampling efforts from 2010 through 2012 will evaluate BMP effectiveness by monitoring the concentration and loading in the receiving waters. High and low flow data from the Dinero Tunnel show significant loading of Cd, Fe, Mn and Zn from its outflow (Table 13) and provide sufficient data for why the LFWWG pursued installation of the Dinero Bulkhead as a BMP. Figures 17-18 depict the loading from the Dinero Tunnel before and after bulkhead installation and a resulting 10 fold decrease in the estimated amount of metals loading into the Sugarloaf Wetlands.

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* Al and Fe do not have water quality standards set for stream segment 5 though values have been referenced for the protection of aquatic life from Table III Metal Parameters (CDPHE, 2009).

**Figure 17. Loading for the Dinero Tunnel Pre-Bulkhead**
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Units</th>
<th>High Flow</th>
<th>Chronic TVS</th>
<th>Low Flow</th>
<th>Chronic TVS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al-Tot</td>
<td>ug/L</td>
<td>285</td>
<td>87*</td>
<td>38</td>
<td>87*</td>
</tr>
<tr>
<td>Cd-Diss</td>
<td>ug/L</td>
<td>10.7</td>
<td>1.07</td>
<td>3.45</td>
<td>0.84</td>
</tr>
<tr>
<td>Cu-Diss</td>
<td>ug/L</td>
<td>1.78</td>
<td>25.47</td>
<td>BDL</td>
<td>19.49</td>
</tr>
<tr>
<td>Fe-Tot</td>
<td>ug/L</td>
<td>27400</td>
<td>1000*</td>
<td>16400</td>
<td>1000*</td>
</tr>
<tr>
<td>Mn-Diss</td>
<td>ug/L</td>
<td>62100</td>
<td>2479</td>
<td>36500</td>
<td>2234</td>
</tr>
<tr>
<td>Zn-Diss</td>
<td>ug/L</td>
<td>20400</td>
<td>352.6</td>
<td>10800</td>
<td>270.1</td>
</tr>
</tbody>
</table>

* Al and Fe do not have water quality standards set for stream segment 5 though values have been referenced for the protection of aquatic life from Table III Metal Parameters (CDPHE, 2009).

Table 13. Concentration Comparison for the Dinero Tunnel Pre-Bulkhead

5.3.1.4. **Data Gaps**

The Dinero Tunnel area has been extensively studied in the past. As new remediation projects are completed monitoring should conclude the effectiveness of the implemented BMPs.

5.3.1.5. **Current Efforts**

A NPS 319 project, Sugarloaf Mountain Mining District BMP Performance Monitoring Project, will monitor the bulkhead for three years to determine its success in reducing metals loading into the Lake Fork. This project began in the summer of 2010.
5.3.1.5.1. Sources of Financial and Technical Assistance

The current Sugarloaf Mountain Mining District BMP Performance Monitoring Project scope of work is attached is Appendix H. For sources of funding and technical assistance of previous research, see the respective project document available upon request.

5.3.1.6. Future Needs, BMPs and Estimated Cost

Due to the recent implementation of the Dinero Bulkhead future monitoring via the Sugarloaf Mountain Mining District BMP Performance Monitoring Project will be necessary to determine the effectiveness of the BMP. Continued maintenance of the Dinero detention ponds is a perpetual need that may be reevaluated in the future. Estimated cost for maintenance on the detention ponds is approximately $7,500 per cleaning (once every 2-3 years).

5.3.2. Nelson Mine

The Nelson Mine site contains a partially collapsed, seasonally flowing adit that enters Sugarloaf Gulch after flowing through a detention pond (Figure 19a). A waste rock pile has been combined into an on-site capped repository in 2002 (Figure 19b).

![Figure 19a: Nelson Detention Pond (2004)](image1)

![Figure 19b: Repository (2008)](image2)

Figure 19. (a) Nelson Detention Pond (2004) and (b) Repository (2008)

5.3.2.1. Previous Research


5.3.2.2. Previous Remediation Efforts

Restoration at the Nelson Mine was a similar project to the Dinero Mine Complex Restoration without the passive treatment systems. The Nelson Mine waste piles were removed to an on-site repository in 2001. This project was completed in 2002.
5.3.2.3. **Pollutant Loads and Data Analysis**

As depicted in the chart below (Figure 20), the Nelson adit drainage contributes Mn, Cu, and Cd. This drainage combines with Sugarloaf Gulch before entering a marsh area and eventually the Sugarloaf Wetlands. Table 14 shows that Mn is the only metal above TVS for both high and low flow data collected in 2006 by the USGS.

*Al and Fe do not have water quality standards set for stream segment 5 though values have been referenced for the protection of aquatic life from Table III Metal Parameters (CDPHE, 2009).

**Figure 20. Nelson Tunnel Loading based on data from 2006 high flow data**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Units</th>
<th>High Flow</th>
<th>Chronic TVS</th>
<th>Low Flow</th>
<th>Chronic TVS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al-Tot</td>
<td>ug/L</td>
<td>60</td>
<td>87</td>
<td>11</td>
<td>87*</td>
</tr>
<tr>
<td>Cd-Diss</td>
<td>ug/L</td>
<td>0.02</td>
<td>0.24</td>
<td>0.01</td>
<td>0.31</td>
</tr>
<tr>
<td>Cu-Diss</td>
<td>ug/L</td>
<td>0.12</td>
<td>4.79</td>
<td>0.13</td>
<td>6.23</td>
</tr>
<tr>
<td>Fe-Tot</td>
<td>ug/L</td>
<td>1540</td>
<td>1000</td>
<td>3560</td>
<td>1000*</td>
</tr>
<tr>
<td>Mn-Diss</td>
<td>ug/L</td>
<td>4580</td>
<td>1292</td>
<td>4110</td>
<td>1432</td>
</tr>
<tr>
<td>Zn-Diss</td>
<td>ug/L</td>
<td>41</td>
<td>66.5</td>
<td>47</td>
<td>86.5</td>
</tr>
</tbody>
</table>

* Al and Fe do not have water quality standards set for stream segment 5 though values have been referenced for the protection of aquatic life from Table III Metal Parameters (CDPHE, 2009).

**Table 14. Concentration Comparison for the Nelson Tunnel.**

5.3.2.4. **Data Gaps**

Post-BMP monitoring of the Nelson adit has been intermittent before 2010. Continued sampling is planned through the Sugarloaf Mountain Mining District BMP Performance Monitoring project which will monitor the performance of the Dinero Bulkhead. This project will provide data twice a year through 2012.
5.3.2.5. **Current Efforts**

There are no current efforts directly focused on the Nelson site. The Sugarloaf Mountain Mining District BMP Performance Monitoring Project will monitor the Nelson and Sugarloaf Gulch for the next three years to determine the success of the Dinero bulkhead implementation in reducing metal loadings into the Lake Fork.

5.3.2.5.1. **Sources of Financial and Technical Assistance**

The current Sugarloaf Mountain Mining District BMP Performance Monitoring Project scope of work is attached is Appendix H. For sources of funding and technical assistance of previous research, see the respective project document available upon request.

5.3.2.6. **Future Needs, BMPs and Estimated Cost**

Until the loading reduction caused by recent BMPs is quantified and future work determines that the Nelson is a source of metal loading, no future needs have been identified for the Nelson Mine. Currently only Mn is elevated above TVS as seen in Table 14.

5.3.3. **Sugarloaf Wetlands**

The Sugarloaf Wetland complex is located approximately five miles west of the town of Leadville, CO and is 450 feet down drainage from the Dinero Mine Tunnel (Figure 21a). The wetland empties into Lake Fork of the Arkansas through a surface water channel and groundwater seeps. The wetland complex is fed by the intermittent flow of Sugarloaf and Little Sugarloaf Gulches, ephemeral flow from the Dinero Mine Tunnel, and groundwater from numerous springs that exist on the northeast side of the wetland. The Sugarloaf Wetland covers a total of 13 acres, while 3 acres of the northeast section are classified as a fen wetland (SAIC, 2000).

Figure 21. (a) Sugarloaf Wetlands and (b) CMC Students Sampling Wetland Soil (2009)
5.3.3.1. Previous Research

- Sugarloaf Wetland Characterization, CMC NRM, 2010
- Functional Assessment Report Sugarloaf Gulch Wetland, SAIC, 2000
- Metal Retention in Sugarloaf Gulch Wetland, Lake County, Colorado. Colorado State University, Department of Earth Science. Rowe, C. M.S. Thesis. 1994

Previous research on the Sugarloaf Wetlands has been conducted in order to determine the impact of AMD and ARD input into the Lake Fork. An initial study in 1994 (Rowe) looked at the loading of metals into the wetland complex and exiting the wetland, to determine if the heavy metal capacity had been reached. Findings based on surface water analysis concluded that Sugarloaf Wetlands did remove metals (Fe and Mn) from the water flowing into the Lake Fork (Rowe, 1994). The effect of AMD from Sugarloaf Gulch on the Lake Fork was studied in 1997, which investigated the retention of metals, Zn, Cd, Mn, Fe, Cu and Pb, through Sugarloaf Wetlands (Neopane, 1997). This research concluded that 87% of Fe, 32% of Mn, and 20% of Zn were retained in the wetland, while Cd and Cu were not retained in the wetland, and released into the Lake Fork. In 2000, the BLM hired Science Application International Corporation (SAIC) and Johnson and Malhotra, P.C. (CCJM) to delineate the boundary, perform a functional assessment, and a small environmental analysis of the Sugarloaf Wetlands. This report concluded that the Sugarloaf Wetlands had an overall rating of moderate to high functional assessment and was sufficient to aid in removal of heavy metals (SCAIC, 2000). Other research has included a study on the seasonal variability of metals through the wetland (August et al., 2002). August and others (2002) concluded that the wetlands act as a sink for Fe, Mn and Zn in the summer but alternatively as a source of Mn and Zn in the winter.

In 2009, CMC NRM completed a characterization study of the wetlands. During this study 29 soil cores were collected and analyzed for metal concentrations (Figure 21b). Thirteen monitoring wells were installed and two sampling events occurred in September and November. An initial Br- tracer study was conducted on the Sugarloaf Wetlands, in order to characterize the hydrologic regime of the wetland complex, but the results were inconclusive. Results from this characterization determined that metals were concentrated on the southwest side of the wetland, in the upper portion of the wetland soil, which received drainage from the Dinero Tunnel (CMC NRM, 2010).
5.3.3.2. Previous Remediation Efforts

While no previous remediation efforts have been conducted directly in the Sugarloaf Wetlands, major remediation projects have been completed within the watershed that supply the Sugarloaf Wetlands. These projects include relocation and revegetation of three mine waste piles (Nelson and Dinero), installation of detention ponds and installation of a bulkhead in the Dinero Tunnel. These efforts should greatly reduce the amount of AMD and ARD reaching the wetlands. Despite the remediation efforts, the impact of 100 years of inflow water affected by AMD is evident in the hydrologic and soil characterization of Sugarloaf Wetlands. It is evident from the chemical characterization of both the soil and water, that metal input into the wetland is concentrated in the upper humus soil layer, with AMD and ARD water affecting this layer, particularly in the flow direction from the Dinero Tunnel to the Lake Fork. The wetland complex is still able to function at a moderate level despite input from acidic, metal laden waters (SAIC, 2000).

5.3.3.3. Pollutant Loads and Data Analysis

As discussed in Section 5.3.3, the Sugarloaf Wetland enters the Lake Fork through groundwater seeps and one surface water channel, named the Dinero Channel. The chart below (Figure 22) depicts loading from the Dinero Channel prior to the installation of the Dinero Bulkhead (the Dinero adit feeds the Sugarloaf Wetlands). Data from Table 15 shows that the Sugarloaf Wetlands are a source of Cd, Mn, and Zn above TVS into the Lake Fork during high flow, while Cd is retained during low flow, releasing only Mn and Zn. Elevated levels of Al, Fe and Cu are also present from the output of Sugarloaf Wetlands during high flow.

* Al and Fe do not have water quality standards set for stream segment 5 though values have been referenced for the protection of aquatic life from Table III Metal Parameters (CDPHE, 2009).

Figure 22. Loading below Sugarloaf Wetland (Dinero Channel)
### Concentration Comparison

**Dinero Channel - DC**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Units</th>
<th>High Flow</th>
<th>Chronic TVS</th>
<th>Low Flow</th>
<th>Chronic TVS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al-Tot</td>
<td>ug/l</td>
<td>403</td>
<td>87*</td>
<td>361</td>
<td>87*</td>
</tr>
<tr>
<td>Cd-Diss</td>
<td>ug/l</td>
<td>16.06</td>
<td>0.43</td>
<td>2.05</td>
<td>0.83</td>
</tr>
<tr>
<td>Cu-Diss</td>
<td>ug/l</td>
<td>6.361</td>
<td>8.99</td>
<td>BDL</td>
<td>19.14</td>
</tr>
<tr>
<td>Fe-Tot</td>
<td>ug/l</td>
<td>1229</td>
<td>1000*</td>
<td>630</td>
<td>1000*</td>
</tr>
<tr>
<td>Mn-Diss</td>
<td>ug/l</td>
<td>10980</td>
<td>1652</td>
<td>28800</td>
<td>2218</td>
</tr>
<tr>
<td>Zn-Diss</td>
<td>ug/l</td>
<td>4459</td>
<td>124.8</td>
<td>3360</td>
<td>265.2</td>
</tr>
</tbody>
</table>

* Al and Fe do not have water quality standards set for stream segment 5 though values have been referenced for the protection of aquatic life from Table III Metal Parameters (CDPHE, 2009).

Table 15. Concentration Comparison for the Dinero Channel.

#### 5.3.3.4. Data Gaps

Continued monitoring of the Sugarloaf Wetlands would provide useful input to the academic community as to the response of wetlands following the removal of a heavy metal and surface water source. In addition, information as to how metals could be released into the Lake Fork following a large storm event would be beneficial in identifying ways to protect the water quality of the Lake Fork.

#### 5.3.3.5. Current Efforts

Water sampling events associated with the Sugarloaf Mountain Mining District BMP Performance Monitoring Project will continue to monitor groundwater during high flow from spring run-off and during low-flow through 2012. The future needs discussed in Section 5.3.3.6 will be accomplished by CMC students and faculty through various classes in the near future as feasible.

##### 5.3.3.5.1. Sources of Financial and Technical Assistance

The current Sugarloaf Mountain Mining District BMP Performance Monitoring Project scope of work is attached is Appendix H. For sources of funding and technical assistance of previous research, see the respective project document available upon request.

#### 5.3.3.6. Future Needs, BMPs and Estimated Cost

A tracer study was attempted in 2009, but results were inconclusive and therefore new efforts are needed to characterize both the high and low flow hydrologic regime in the wetland complex. Determination of how the high concentrations of metals are stored within the soil by sequential extraction (exchangeable or bound to carbonates, Fe- and Mn-oxides, organics, etc.) will provide valuable information as to how metals will be released into the Lake Fork in a big storm event. Preliminary work on sequential extraction experiments suggest that a large portion of metals are bound up to Fe- and Mn-oxides and organics. Continued monitoring of water quality and soil
chemistry, as funding becomes available, will provide valuable background information as to the response time of a wetland complex and if the functionality of the wetland increases with reduced metal input.

5.3.4. Upper Sugarloaf Gulch

Upper Sugarloaf Gulch contains the headwaters of two tributaries, Sugarloaf and Little Sugarloaf Gulch. Both are intermittent streams that flow primarily from May through early July with snowmelt runoff and major summer storm events. There have been no biological monitoring efforts in the Sugarloaf Gulch or Little Sugarloaf Gulch due to the intermittent nature of the streams.

5.3.4.1. Previous Research

In 2007, CMC NRM, prioritized mine waste piles in Sugarloaf Gulch based on chemical and physical characteristics. The piles of greatest concern in Upper Sugarloaf Gulch include SLD-01 (seen in Figure 23a), SLD-05 and SLD-06 as they contain significant heavy metals in the waste rock. Leachate analysis of these mine waste samples demonstrated the ability for Cd, Cu, Pb, Mn and Zn to mobilize as well as the high acidity of the mine waste piles (Table 16). In 2009, CMC NRMI characterized the hydrologic regime and identified heavy metals loading from the mine dumps in Sugarloaf Gulch and Little Sugarloaf Gulch, in addition to assessing the potential remediation BMPs for the area. The view of the Arkansas River Valley from atop SLD-02 is displayed in figure 23b.

<table>
<thead>
<tr>
<th>Pile</th>
<th>Paste pH</th>
<th>Paste cond. (uS)</th>
<th>Acidity mg/L (CaCO₃)</th>
<th>Leachate analysis (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Cd</td>
</tr>
<tr>
<td>SLD-01</td>
<td>2.8</td>
<td>1188</td>
<td>250</td>
<td>0.46</td>
</tr>
<tr>
<td>SLD-05</td>
<td>2.95</td>
<td>517</td>
<td>400</td>
<td>0.02</td>
</tr>
<tr>
<td>SLD-06</td>
<td>3.94</td>
<td>115.7</td>
<td>460</td>
<td>0.02</td>
</tr>
</tbody>
</table>

Table 16. Paste and leachate analysis on mine waste dumps of concern in Sugarloaf Gulch

Figure 23. (a) Mine Waste pile in Sugarloaf Gulch (SLD-01) and (b) Arkansas River Valley from SLD-02
5.3.4.2. Previous Remediation Efforts

There have been no previous remediation efforts in Upper Sugarloaf Gulch.

5.3.4.3. Pollutant Loads and Data Analysis

Based on leachate analysis performed from mine piles in Upper Sugarloaf Gulch, there exists a potential for snowmelt and precipitation runoff to contribute metal loading, particularly Cd, Cu, Pb, Mn and Zn, into Sugarloaf and possibly Little Sugarloaf Gulch (see Figure 24 for pile location, prioritization, and water quality exceedances). In 2009, high flow metals sample concentrations entering Sugarloaf and Little Sugarloaf Gulches during spring snow-melt exceeded aquatic water quality TVS for the Lake Fork, at all sample sites and in all samples collected, for Zn and Cd (CMC NRMI, 2009). Cu and Al also are of concern as depicted in the charts below (Figures 25 and 26). The metals loading increase by two to three times after the mine waste piles (Figure 24). Little Sugarloaf Gulch contributes elevated levels of Zn, Al, Cu, and Cd to Sugarloaf Wetland, though loading is significantly less in comparison to Sugarloaf Gulch. For example, loading values from a high flow event in 2009 in Sugarloaf Gulch (SL-01C) are 11.16 lbs/day of Zn, while Little Sugarloaf Gulch (SL-01G) is 3.50 lbs/day of Zn. Similarly, for loading of total Al at the same sites, Sugarloaf Gulch has 3.67 lbs/day of Al while Little Sugarloaf has only 1.03 lbs/day of Al. For a graphical representation that compares loading from Sugarloaf and Little Sugarloaf Gulches see Figure 28. From a comparison of Tables 17 and 18 it is evident that metal loading of Cd, Cu, Mn and Zn significantly increases from interaction with mine waste pile SLD-06 (see Figure 24 for location). In Little Sugarloaf Gulch Cd, Cu and Zn are elevated above TVS (Table 19). Interestingly, there is only one mine waste pile in Little Sugarloaf Gulch (SLD-01) at its headwaters, and the metal laden nature of those waters maybe natural or groundwater fed.
Figure 24. Metals of concern in Sugarloaf and Little Sugarloaf Gulch
* Al and Fe do not have water quality standards set for stream segment 5 (CDPHE, 2010) though values have been referenced for the protection of aquatic life from Table III Metal Parameters (CDPHE, 2009a).

Figure 25. Loading in Sugarloaf Gulch below Mine Tailings

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Units</th>
<th>High Flow</th>
<th>Chronic TVS</th>
<th>Low Flow</th>
<th>Chronic TVS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al-Tot</td>
<td>ug/L</td>
<td>193.6</td>
<td>87*</td>
<td>NM</td>
<td>N/A</td>
</tr>
<tr>
<td>Cd-Diss</td>
<td>ug/L</td>
<td>4.072</td>
<td>0.16</td>
<td>NM</td>
<td>N/A</td>
</tr>
<tr>
<td>Cu-Diss</td>
<td>ug/L</td>
<td>4.877</td>
<td>3.04</td>
<td>NM</td>
<td>N/A</td>
</tr>
<tr>
<td>Fe-Tot</td>
<td>ug/L</td>
<td>66.92</td>
<td>1000*</td>
<td>NM</td>
<td>N/A</td>
</tr>
<tr>
<td>Mn-Diss</td>
<td>ug/L</td>
<td>2138</td>
<td>1083</td>
<td>NM</td>
<td>N/A</td>
</tr>
<tr>
<td>Zn-Diss</td>
<td>ug/L</td>
<td>1319</td>
<td>42.33</td>
<td>NM</td>
<td>N/A</td>
</tr>
</tbody>
</table>

* Al and Fe do not have water quality standards set for stream segment 5 (CDPHE, 2010) though values have been referenced for the protection of aquatic life from Table III Metal Parameters (CDPHE, 2009a).

Table 17. Concentration Comparison for Sugarloaf Gulch before Mine Tailings.

* Al and Fe do not have water quality standards set for stream segment 5 (CDPHE, 2010) though values have been referenced for the protection of aquatic life from Table III Metal Parameters (CDPHE, 2009a).

Figure 26. Loading in Sugarloaf Gulch after Mine Tailings
### Table 18. Concentration Comparison for Sugarloaf Gulch after Mine Tailings.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Units</th>
<th>High Flow</th>
<th>Chronic TVS</th>
<th>Low Flow</th>
<th>Chronic TVS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al-Tot</td>
<td>ug/L</td>
<td>552.4</td>
<td>87*</td>
<td>NM</td>
<td>N/A</td>
</tr>
<tr>
<td>Cd-Diss</td>
<td>ug/L</td>
<td>22</td>
<td>0.22</td>
<td>NM</td>
<td>N/A</td>
</tr>
<tr>
<td>Cu-Diss</td>
<td>ug/L</td>
<td>11.6</td>
<td>4.34</td>
<td>NM</td>
<td>N/A</td>
</tr>
<tr>
<td>Fe-Tot</td>
<td>ug/L</td>
<td>114.1</td>
<td>1000*</td>
<td>NM</td>
<td>N/A</td>
</tr>
<tr>
<td>Mn-Diss</td>
<td>ug/L</td>
<td>2876</td>
<td>1244</td>
<td>NM</td>
<td>N/A</td>
</tr>
<tr>
<td>Zn-Diss</td>
<td>ug/L</td>
<td>3152</td>
<td>60.4</td>
<td>NM</td>
<td>N/A</td>
</tr>
</tbody>
</table>

*Al and Fe do not have water quality standards set for stream segment 5 (CDPHE, 2010) though values have been referenced for the protection of aquatic life from Table III Metal Parameters (CDPHE, 2009a).*

### Table 19. Concentration Comparison for Little Sugarloaf Gulch.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Units</th>
<th>High Flow</th>
<th>Chronic TVS</th>
<th>Low Flow</th>
<th>Chronic TVS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al-Tot</td>
<td>ug/L</td>
<td>431.2</td>
<td>87*</td>
<td>NM</td>
<td>N/A</td>
</tr>
<tr>
<td>Cd-Diss</td>
<td>ug/L</td>
<td>17.77</td>
<td>0.20</td>
<td>NM</td>
<td>N/A</td>
</tr>
<tr>
<td>Cu-Diss</td>
<td>ug/L</td>
<td>7.67</td>
<td>3.8</td>
<td>NM</td>
<td>N/A</td>
</tr>
<tr>
<td>Fe-Tot</td>
<td>ug/L</td>
<td>19.88</td>
<td>1000*</td>
<td>NM</td>
<td>N/A</td>
</tr>
<tr>
<td>Mn-Diss</td>
<td>ug/L</td>
<td>772</td>
<td>1177</td>
<td>NM</td>
<td>N/A</td>
</tr>
<tr>
<td>Zn-Diss</td>
<td>ug/L</td>
<td>2690</td>
<td>52.4</td>
<td>NM</td>
<td>N/A</td>
</tr>
</tbody>
</table>

*Al and Fe do not have water quality standards set for stream segment 5 (CDPHE, 2010) though values have been referenced for the protection of aquatic life from Table III Metal Parameters (CDPHE, 2009a).*
5.3.4.4. **Data Gaps**

The BLM and the National Science and Technology Center (2006) reported that the water behind the Dinero Bulkhead could seep out via geologic faults, fractures, or veins and through interconnected mine workings. Due to this uncertainty, as well as this study’s short monitoring period for upper Sugarloaf Gulch, it is recommended that the spring run-off sampling regime be repeated in 2011 along with the proposed sampling of seeps and springs that will be performed by the USGS and CMC NRM. It is also recommended that previously unattainable discharge measures at sample locations SL-01B, SL-01F, and SL-02 be obtained in addition to the Dinero Tunnel. Ideally, a large rain event would also be sampled to quantify the summer storm run-off effect on the watershed.

5.3.4.5. **Current Efforts**

Sugarloaf Gulch is slated to be monitored during high and low flow periods by USGS and CMC NRM through 2012 by the Sugarloaf Mountain Mining District BMP Performance Monitoring Project for which sample sites are identified on the Map A10 in Appendix A.
5.3.4.5.1. Sources of Financial and Technical Assistance

The current Sugarloaf Mountain Mining District BMP Performance Monitoring Project scope of work is attached in Appendix H. For sources of funding and technical assistance of previous research see the respective project document available upon request.

5.3.4.6. Future Needs, BMPs and Estimated Cost

The mine waste piles within Upper Sugarloaf Gulch are sources of ARD and are in yearly contact with snow melt and ephemeral flow in Sugarloaf and Little Sugarloaf Gulches. Reclamation alternatives for this area were presented to a LFWWG in October 2009 and are included in the CMC NRMI 2009 report Hydrologic Characterization of Sugarloaf and Little Sugarloaf Gulch. The reclamation alternatives proposed in that document from low to high cost include: emplacement of a lime-dispensing system, such as an Aquafix unit at the base of the gulches; hydrologic controls around the upper mine waste piles; or moving and/or capping of the mine waste piles within Sugarloaf Gulch. The estimated low-end cost for each of the three remediation projects range from $50,000 for the Aquafix unit, $75,000 for the hydrologic controls, and more than $750,000 for moving of the mine waste piles, due to the large volume (SLD-01 alone is estimated at 140,000 cubic yards of material). Based on previous research and future results from Sugarloaf Mountain Mining District BMP Performance Monitoring Project and availability of funding, remediation would be prioritized in Sugarloaf Gulch and the mine waste piles located therein.

Prioritization of remedial work in Sugarloaf Gulch will likely depend on the effectiveness of metal concentration reduction as a result of the BMPs implemented in the Dinero Mine Complex. Currently, Sugarloaf Gulch is seen as a low priority until other higher priority remedial activities are completed in Colorado Gulch. If there are still exceedances, then these findings will be presented to the LFWWG to determine if a formal EE/CA will need to be developed.

5.4. Colorado and Little Frying Pan Gulches

Colorado Gulch discharges into the Lake Fork of the Arkansas River 1.4 miles downstream of the Turquoise Reservoir Dam outlet and approximately 3 miles above the confluence of the Lake Fork with the Arkansas River (Figure 1). Colorado Gulch was designated as the second priority for metal input into the Lake Fork. It receives input from the Little Frying Pan and consequently is a source of metals including Al, Cd, Cu, Fe, Mn and Zn into the Lake Fork (Barrack, 2001). See Maps A12-14 in Appendix A for water quality of the Little Frying Pan Gulch. The main tributary to Colorado Gulch is Little Frying Pan Gulch which consists of an East and West Fork. These forks as well as the main stem of the Little Frying Pan contain numerous mine features, waste piles and metal leaching source areas. Within the Little Frying Pan system, the Tiger and Venture mining complexes exist, which are large, historically important mine features to the Sugarloaf Mining District, and are depicted in Figure 2.
5.4.1. Previous Research

From 2002 through 2004, CMC NRMI conducted a metals loading analysis and mine waste characterization on Colorado Gulch. Results determined that during low flow Colorado Gulch is not a significant source of metals load to the Lake Fork (CMC NRMI, 2004). For example, it was determined that Cd, Cu, Mn, Pb, Mn and Zn all occur at higher load at COG-06 which is above the Little Frying Pan confluence as compared to load at COG-07. This indicates that these metals are ‘settling out’ or diminishing in load over distance traveled.

At high flow conditions however, Colorado Gulch can contribute upwards of 80% of Zn metals load within the Lake Fork immediately downstream. Of this loading, approximately 91% of the Zn within Colorado Gulch was attributed to the Little Frying Pan (CMC NRMI, 2004). Colorado Gulch, armored with iron oxide, was devoid of any signs of aquatic life in 2001, excluding moss that is able to grow on the iron oxidized gulch. A minimal amount of aquatic life has been identified in Colorado Gulch in later sampling events. The CDRMS also completed a site characterization report on the area in 2005. The CDRMS Ratings and Characterization Data report includes information for 43 different mine waste piles within Colorado Gulch. The mine waste characterizations are based on five categories; 1) erosion severity, 2) salt crust hardness, 3) vegetation, 4) vegetation kill zone, and 5) distance to a stream. The sites were then given a physical rating, by adding the five categories together.

5.4.2. Previous Remediation Efforts

The relocation and capping of the Tiger Mine waste piles began in 2009 and is currently in the final project stages. This will be discussed further in Section 5.4.7. The Little Frying Pan Water Quality Improvement Project is occurring simultaneously with the Tiger Mine waste pile relocation and will be discussed in Section 5.4.8. Other than these two currently ongoing projects, no other remediation has taken place within these Gulches.
5.4.3. Pollutant Loads and Data Analysis

Loading in the upper reaches of Colorado Gulch before the confluence with the Little Frying Pan (LFP) tends to be relatively low with the exception of Al and Cu. After the confluence with LFP, loading values for all depicted analytes are extremely high with Fe loading reaching 793 lbs/day. Colorado Gulch, after the wetland and before the confluence with the Lake Fork, experiences some improvement, though loading for Al, Cd, Cu, Fe, and Zn remain above water quality TVS loading values. Figures 30-34 clearly show Little Frying Pan Gulch and the large amounts of metals loading contributed to Colorado Gulch and the Lake Fork. In comparison of concentration, it is evident that significant loading into Colorado Gulch of Cd, Cu, Mn and Zn is caused by input from Little Frying Pan (compare Tables 20 and 21). The LFWWG is unaware of the source of elevated Zn levels in Colorado Gulch prior to input of Little Frying Pan (Table 20).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Units</th>
<th>High Flow</th>
<th>Chronic TVS</th>
<th>Low Flow</th>
<th>Chronic TVS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al-Tot</td>
<td>ug/L</td>
<td>BDL</td>
<td>87*</td>
<td>BDL</td>
<td>87*</td>
</tr>
<tr>
<td>Cd-Diss</td>
<td>ug/L</td>
<td>BDL</td>
<td>0.02</td>
<td>BDL</td>
<td>0.08</td>
</tr>
<tr>
<td>Cu-Diss</td>
<td>ug/L</td>
<td>BDL</td>
<td>0.27</td>
<td>BDL</td>
<td>1.40</td>
</tr>
<tr>
<td>Fe-Tot</td>
<td>ug/L</td>
<td>390</td>
<td>1000*</td>
<td>40</td>
<td>1000*</td>
</tr>
<tr>
<td>Mn-Diss</td>
<td>ug/L</td>
<td>12.4</td>
<td>420.4</td>
<td>30</td>
<td>799.1</td>
</tr>
<tr>
<td>Zn-Diss</td>
<td>ug/L</td>
<td>20</td>
<td>3.76</td>
<td>70</td>
<td>19.45</td>
</tr>
</tbody>
</table>

* Al and Fe do not have water quality standards set for stream segment 5 (CDPHE, 2010) though values have been referenced for the protection of aquatic life from Table III Metal Parameters (CDPHE, 2009a).

Table 20. Concentration Comparison for Upper Colorado Gulch before the Confluence with Little Sugarloaf Gulch.
* Al and Fe do not have water quality standards set for stream segment 5 (CDPHE, 2010) though values have been referenced for the protection of aquatic life from Table III Metal Parameters (CDPHE, 2009a).

Figure 31. Loading in Colorado Gulch below the confluence with Little Frying Pan

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Units</th>
<th>High Flow</th>
<th>Chronic TVS</th>
<th>Low Flow</th>
<th>Chronic TVS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al-Tot</td>
<td>ug/L</td>
<td>3220</td>
<td>87*</td>
<td>100</td>
<td>87*</td>
</tr>
<tr>
<td>Cd-Diss</td>
<td>ug/L</td>
<td>18.2</td>
<td>0.2</td>
<td>BDL</td>
<td>0.09</td>
</tr>
<tr>
<td>Cu-Diss</td>
<td>ug/L</td>
<td>276</td>
<td>0.27</td>
<td>BDL</td>
<td>1.51</td>
</tr>
<tr>
<td>Fe-Tot</td>
<td>ug/L</td>
<td>8640</td>
<td>1000*</td>
<td>8640</td>
<td>1000*</td>
</tr>
<tr>
<td>Mn-Diss</td>
<td>ug/L</td>
<td>1490</td>
<td>420.4</td>
<td>BDL</td>
<td>824.5</td>
</tr>
<tr>
<td>Zn-Diss</td>
<td>ug/L</td>
<td>1370</td>
<td>3.76</td>
<td>140</td>
<td>21.1</td>
</tr>
</tbody>
</table>

* Al and Fe do not have water quality standards set for stream segment 5 though values have been referenced for the protection of aquatic life from Table III Metal Parameters (CDPHE, 2009).

Table 21. Concentration Comparison for Colorado Gulch after the Little Frying Pan Confluence.

* Al and Fe do not have water quality standards set for stream segment 5 (CDPHE, 2010) though values have been referenced for the protection of aquatic life from Table III Metal Parameters (CDPHE, 2009a).

Figure 32. Loading in Colorado Gulch before confluence with Lake Fork
Table 22. Concentration Comparison Colorado Gulch before the Lake Fork and after the Wetland.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Units</th>
<th>High Flow</th>
<th>Chronic TVS</th>
<th>Low Flow</th>
<th>Chronic TVS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al-Tot</td>
<td>ug/L</td>
<td>2470</td>
<td>87*</td>
<td>130</td>
<td>87*</td>
</tr>
<tr>
<td>Cd-Diss</td>
<td>ug/L</td>
<td>12.9</td>
<td>0.02</td>
<td>BDL</td>
<td>0.12</td>
</tr>
<tr>
<td>Cu-Diss</td>
<td>ug/L</td>
<td>161</td>
<td>0.27</td>
<td>BDL</td>
<td>2.22</td>
</tr>
<tr>
<td>Fe-Tot</td>
<td>ug/L</td>
<td>5830</td>
<td>1000*</td>
<td>840</td>
<td>1000*</td>
</tr>
<tr>
<td>Mn-Diss</td>
<td>ug/L</td>
<td>1030</td>
<td>420.4</td>
<td>200</td>
<td>957.1</td>
</tr>
<tr>
<td>Zn-Diss</td>
<td>ug/L</td>
<td>930</td>
<td>3.76</td>
<td>130</td>
<td>30.9</td>
</tr>
</tbody>
</table>

* Al and Fe do not have water quality standards set for stream segment 5 (CDPHE, 2010) though values have been referenced for the protection of aquatic life from Table III Metal Parameters (CDPHE, 2009a).

Figure 33. Loading in Little Frying Pan East

Table 23. Concentration Comparison for Little Frying Pan East.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Units</th>
<th>High Flow</th>
<th>Chronic TVS</th>
<th>Low Flow</th>
<th>Chronic TVS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al-Tot</td>
<td>ug/L</td>
<td>24300</td>
<td>87*</td>
<td>41630</td>
<td>87*</td>
</tr>
<tr>
<td>Cd-Diss</td>
<td>ug/L</td>
<td>105</td>
<td>0.26</td>
<td>500</td>
<td>0.65</td>
</tr>
<tr>
<td>Cu-Diss</td>
<td>ug/L</td>
<td>2540</td>
<td>5.14</td>
<td>3230</td>
<td>14.61</td>
</tr>
<tr>
<td>Fe-Tot</td>
<td>ug/L</td>
<td>75200</td>
<td>1000*</td>
<td>56400</td>
<td>1000*</td>
</tr>
<tr>
<td>Mn-Diss</td>
<td>ug/L</td>
<td>6850</td>
<td>1328</td>
<td>36440</td>
<td>1996</td>
</tr>
<tr>
<td>Zn-Diss</td>
<td>ug/L</td>
<td>8550</td>
<td>71.41</td>
<td>21310</td>
<td>202.5</td>
</tr>
</tbody>
</table>

* Al and Fe do not have water quality standards set for stream segment 5 (CDPHE, 2010) though values have been referenced for the protection of aquatic life from Table III Metal Parameters (CDPHE, 2009a).
Al and Fe do not have water quality standards set for stream segment 5 (CDPHE, 2010) though values have been referenced for the protection of aquatic life from Table III Metal Parameters (CDPHE, 2009a).

Figure 34. Loading in Little Frying Pan before the confluence with Colorado Gulch

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Units</th>
<th>High Flow</th>
<th>Chronic TVS</th>
<th>Low Flow</th>
<th>Chronic TVS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al-Tot</td>
<td>ug/L</td>
<td>8600</td>
<td>87*</td>
<td>41630</td>
<td>87*</td>
</tr>
<tr>
<td>Cd-Diss</td>
<td>ug/L</td>
<td>48</td>
<td>0.17</td>
<td>500</td>
<td>0.65</td>
</tr>
<tr>
<td>Cu-Diss</td>
<td>ug/L</td>
<td>807</td>
<td>3.15</td>
<td>3230</td>
<td>14.6</td>
</tr>
<tr>
<td>Fe-Tot</td>
<td>ug/L</td>
<td>23500</td>
<td>1000*</td>
<td>56400</td>
<td>1000*</td>
</tr>
<tr>
<td>Mn-Diss</td>
<td>ug/L</td>
<td>4260</td>
<td>1097</td>
<td>36440</td>
<td>1996</td>
</tr>
<tr>
<td>Zn-Diss</td>
<td>ug/L</td>
<td>3960</td>
<td>43.8</td>
<td>21310</td>
<td>202.5</td>
</tr>
</tbody>
</table>

* Al and Fe do not have water quality standards set for stream segment 5 (CDPHE, 2010) though values have been referenced for the protection of aquatic life from Table III Metal Parameters (CDPHE, 2009a).

Table 24. Concentration Comparison for Little Frying Pan before the Colorado Gulch Confluence.

5.4.4. Data Gaps

Data gaps throughout Colorado and Little Frying Pan Gulches will be assessed further through the Little Frying Pan Water Quality Improvement Project discussed further in Section 5.4.8. and may be identified through the completion of the Venture Engineering Evaluation and Cost Analysis (EE/CA). Colorado Gulch is a perennial stream that has decent water quality above its confluence with Little Frying Pan (see Figure 29) and is known to have brook trout. No biological monitoring (fish or BMI) has occurred within Colorado Gulch and may be a necessary component of future monitoring projects to assess improvement of water quality after BMP emplacement.
5.4.5. Current Efforts

Current efforts include the relocation of the Tiger Mine waste piles discussed further in Section 5.4.7 and of the Little Frying Pan Water Quality Improvement Project discussed further in Section 5.4.8.

5.4.5.1. Sources of Financial and Technical Assistance

Current financial and technical assistance endeavors will be discussed further in Section 5.4.7.5.1 and Section 5.4.8.5.1.

5.4.6. Future Needs, BMPs and Estimated Cost

The Venture EE/CA is the current undertaking that may lead to future remediation in the West Fork of the Little Frying Pan Gulch. The prioritization of the mine waste piles in Colorado Gulch by CDRMS in 2005 and the monitoring results after the completion of the Little Frying Pan Water Quality Improvement Project may be evaluated/re-evaluated in the future to assess which, if any, further remediation needs to take place.

5.4.7. Tiger Mine

The Tiger Mine Complex (tunnel, mine waste piles, and adits) is located in the upper reach of the East Fork of Little Frying Pan Gulch, which is an intermittent drainage of Colorado Gulch. The mine complex is located approximately 4/10 of a mile from the intersection with the West Fork of Little Frying Pan Gulch, where the water flows almost continually throughout the year. Due to the acidic and metal laden nature of water coming from the Tiger Mine there is no biologic life within the East Fork of Little Frying Pan Gulch.

![Figure 35. Tiger Mine Complex (a) before remediation and (b) post mine pile removal.](image-url)
5.4.7.1. Previous Research

Colorado Gulch contributes approximately 80% of the Zn load to the Lake Fork of the Arkansas River during high flow periods. Drainage from the Tiger Tunnel Mine Complex contributes approximately 23% of the Zn load to Colorado Gulch during high flow (CMC NRM 2009). The results from the mine waste characterization completed in 2005 (CDRMS) indicated that the piles located within the Tiger Complex are of the highest metals content and lowest paste pH values within the entire Little Frying Pan and Colorado Gulch watershed. These results are in accordance with the stream sampling in that the East Fork of the Little Frying Pan is the major contributor of surface water metals loading to the Little Frying Pan, Colorado Gulch, and Lake Fork during high flow (CMC NRMI, 2004). The Engineering Evaluation and Cost Analysis (EE/CA) for the Tiger Tunnel Waste Rock Dumps and Acid Mine Drainage was completed by the BLM National Science and Technology Center in 2006.

5.4.7.1. Previous Remediation Efforts

Mine pile relocation occurred in the summer of 2009 and revegetation and settling ponds will be completed in the summer of 2010. Remediation efforts at the Tiger Mine complex has included mine pile relocation of TC-07 and TC-08, two mine piles which sat in the headwaters of Little Frying Pan Gulch and received perennial drainage from the Tiger Tunnel (Figure 35-36).

5.4.7.2. Pollutant Loads and Data Analysis

The discharge from the Tiger Tunnel is markedly laden with metal concentrations as depicted in Figure 37 and Table 25. The Tiger Tunnel water becomes more concentrated with low flow, due to the perennial nature of the tunnel and lack of snow melt to dilute metal concentrations. Metal concentrations in water from the Tiger Tunnel have levels well above the TVS for Cd, Cu, Mn and Zn, while Al and Fe values are also extremely high. Tiger Tunnel water typically ranges in pH from 2.4 - 2.8. The percent exceedance of water throughout the Little Frying Pan Gulch and Colorado Gulch is graphically depicted in Figure 38 for Al, Cd, Mn and Zn.
* Al and Fe do not have water quality standards set for stream segment 5 though values have been referenced for the protection of aquatic life from Table III Metal Parameters (CDPHE, 2009).

Figure 37. Loading Below Tiger Tunnel Drainage

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Units</th>
<th>High Flow</th>
<th>Chronic TVS</th>
<th>Low Flow</th>
<th>Chronic TVS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al-Tot</td>
<td>ug/L</td>
<td>20480</td>
<td>87*</td>
<td>35260</td>
<td>87*</td>
</tr>
<tr>
<td>Cd-Diss</td>
<td>ug/L</td>
<td>230</td>
<td>0.32</td>
<td>810</td>
<td>0.69</td>
</tr>
<tr>
<td>Cu-Diss</td>
<td>ug/L</td>
<td>3880</td>
<td>6.44</td>
<td>5430</td>
<td>15.6</td>
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<td>Fe-Tot</td>
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<td>106200</td>
<td>1000*</td>
<td>150500</td>
<td>1000*</td>
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<td>Zn-Diss</td>
<td>ug/L</td>
<td>8930</td>
<td>89.4</td>
<td>15230</td>
<td>215.9</td>
</tr>
</tbody>
</table>

* Al and Fe do not have water quality standards set for stream segment 5 though values have been referenced for the protection of aquatic life from Table III Metal Parameters (CDPHE, 2009).

Table 25. Concentration Comparison for the Tiger Tunnel.

5.4.7.3. Data Gaps

There are no currently identified data gaps for the Tiger Mine remediation area.

5.4.7.4. Current Efforts

Revegetation and settling pond construction will be completed in 2010. Potential inclusion of a sulfate reducing bioreactor (SRB) is dependent upon the long term project liability being assumed by a responsible party or passing of the Good Samaritan Act by the U.S. Congress necessary to provide liability protection. It is anticipated that the implementation of BMPs (both pile removal and hydrologic control implementation Section 5.4.8) within the Tiger Mine Complex will reduce the zinc loading from the Tiger Mine Complex waste piles by approximately 90%, which
in turn will reduce the zinc load from Colorado Gulch into the Lake Fork by at least 20% during high flow periods.

5.4.7.4.1. **Sources of Financial and Technical Assistance**

The repository work was funded and completed by CDRMS for a total cost of approximately $340,000. The proposed SRB is largely funded by the BLM with grant funds being contributed from Trout Unlimited. The SRB technical assistance is collaboration between stakeholders of the LFWWG with outside assistance from Linda Figueroa, a Colorado School of Mines expert on the topic.

5.4.7.5. **Future Needs, BMPs and Estimated Cost**

After successful revegetation, the anticipated future needs for the Tiger Mine Complex includes maintenance on the detention ponds and on the SRB, pending its construction.

5.4.8. **Little Frying Pan Water Quality Improvement Project**

5.4.8.1. **Previous Research**

The Little Frying Pan Water Quality Improvement Project is a result of the combination of preferred alternatives that were identified through the Engineering Evaluation and Cost Analysis (EE/CA) for the Tiger Tunnel Waste Rock Dumps and Acid Mine Drainage (BLM, 2006). In addition to the relocation and capping of the Tiger Mine waste piles TC-07 and TC-08 (discussed in Section 5.4.7.2), the Tiger EE/CA identified that implementation of hydrologic controls above the Tiger Tunnel may help to reduce the amount of AMD emanating from the Tunnel. Further, run-on controls will reduce the amount of waste rock eroded from contact with surface flow (BLM, 2006).

5.4.8.2. **Previous Remediation Efforts**

The only previous remediation that has taken place in the Little Frying Pan Gulch is the Tiger Mine Complex work described in Section 5.4.7.

5.4.8.3. **Pollutant Loads and Data Analysis**

Loading charts for the Little Frying Pan and its cumulative effect on Colorado Gulch can be seen in Section 5.4.3. The hydrologic control portion of the Little Frying Pan Water Quality Improvement Project is located in the east branch of the Little Frying Pan, while water quality monitoring and analysis occurs throughout Little Frying Pan Gulch, Colorado Gulch as well as above and below its confluence with the Lake Fork. It is anticipated that the implementation of BMPs (both pile removal, Section 5.4.7, and hydrologic control implementation) will reduce the zinc loading from the Tiger Mine Complex waste piles by approximately 90%, which in turn will reduce the zinc load from Colorado Gulch into the Lake Fork by at least 20% during high flow
periods (BLM, 2006). Copper loading into the Lake Fork can be correlated to Little Frying Pan East, as loading originates from the Tiger Mine Complex (Table 25) and stays elevated through LFP-05 (Table 23). Data from Little Frying Pan West do not have Cu concentrations nearly as high as the East Fork (West Fork Cu 20 µg/L compared to East Fork Cu 2540 µg/L). Similar to Cu, metal concentrations are highest in Little Frying Pan East (compare Table 23 and Table 24). Metal concentrations within Little Frying Pan are elevated throughout its reach and near the confluence with Colorado Gulch, Little Frying Pan continues to be saturated with Cd, Cu, Mn, Zn, Al and Fe (Table 25).

5.4.8.4. Data Gaps

Post BMP implementation monitoring is part of this project and will cover current data needs and may identify data gaps that are not currently apparent.

5.4.8.5. Current Efforts

The Little Frying Pan Water Quality Monitoring Project, a NPS 319 grant, will complete the installation of hydrologic controls around the mine waste piles upslope from the Tiger Tunnel and Tiger Mine pile relocation project (Section 5.4.7). This project is scheduled to be completed by 2013 and includes continuous monitoring of the Little Frying Pan Gulch to determine the decrease of metals loading from remediation efforts.

5.4.8.5.1. Sources of Financial and Technical Assistance

The budget and schedule for the Little Frying Pan Water Quality Monitoring Project is presented in Appendix G. Technical assistance for this project includes members of the LFWWG including CDRMS, BLM, CMC and TU.

5.4.8.6. Future Needs, BMPs and Estimated Cost

Future tasks for this project, as outlined in the Little Frying Pan Water Quality Monitoring Project Implementation Plan (CMC, 2009), include channel stability of the hydrologic controls and limestone channels, removal of any excess sedimentation in the hydrologic control, replacement of limestone by CMC NRM or LFWWG, and dredging of stilling basins once per year, in addition to other currently unidentified future needs.
Figure 38. Percent Exceedance above Toxicity in Little Frying Pan Gulch
5.4.9. West Fork of Little Frying Pan Gulch

5.4.9.1. Previous Research

The West Fork of Little Frying Pan Gulch flows through multiple mine complexes, including the Cabin Shaft, Golden Curry, Gertrude and Venture Mines. The largest complex is the Gertrude-Venture Mine Complex, which is located downstream of the Tiger Mine Complex, is another contributor of heavy metals into the Little Frying Pan Gulch tributary. The Gertrude-Venture Complex is located near the junction of the East and West Fork of Little Frying Pan Gulch, which is approximately ½ mile upstream from the confluence of Little Frying Pan with Colorado Gulch. Unlike the East Fork, portions of the West Fork of Little Frying Pan Gulch flow continuously during snow free months. In its upper reaches, before contact with the Cabin Shaft Complex, the West Fork of the Little Frying Pan maintains good water quality and is not susceptible to any acid mine drainage (CMC NRMI, 2004). However, 50 feet downstream of this complex the pH levels lower from ~6.50 to ~3.50. Further investigation has determined that the cause is from the Cabin Shaft which is located adjacent to the stream channel. During high flow, the stream flows infiltrate the Cabin Shaft and cause it to overflow. Above the shaft the water quality is good, while quality quickly degrades below the shaft (Figure 40a) and mine waste piles (Figure 40b) (CMC NRMI, 2004).

5.4.9.2. Previous Remediation Efforts

No previous remediation efforts have taken place at the Venture Mine Site.

5.4.9.3. Pollutant Loads and Data Analysis

Loading charts for the Little Frying Pan and its cumulative effect on Colorado Gulch can be seen in Figure 39. Little Frying Pan West contains elevated levels of Cd, Cu, Mn and Zn (Table 26), well above the TVS, but lower than water in Little Frying Pan East (Table 23). The West Fork of Little Frying Pan does not flow after snowmelt and precipitation events cease, beginning in late July or August. The Venture Shaft is located in the West Branch of the LFP as depicted in Figure 2 and seen in Figure 40a.
* Al and Fe do not have water quality standards set for stream segment 5 (CDPHE, 2010) though values have been referenced for the protection of aquatic life from Table III Metal Parameters (CDPHE, 2009a).

Figure 39. Loading in Little Frying Pan West

<table>
<thead>
<tr>
<th>Parameter</th>
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<th>Chronic TVS</th>
<th>Low Flow</th>
<th>Chronic TVS</th>
</tr>
</thead>
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<tr>
<td>Fe-Tot</td>
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<td>1750</td>
<td>33.9</td>
<td>NM</td>
<td>N/A</td>
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</tbody>
</table>

* Al and Fe do not have water quality standards set for stream segment 5 (CDPHE, 2010) though values have been referenced for the protection of aquatic life from Table III Metal Parameters (CDPHE, 2009a).

Table 26. Concentration Comparison for Little Frying Pan West.

5.4.9.4. Data Gaps

Sufficient environmental data has been collected, analyzed, and has shown that the Venture Mine is a source of contamination therefore warranting the completion of an EE/CA. Any additional data needs will be completed with the proposed Venture Mine EE/CA.
5.4.9.1. **Current Efforts**

The Venture Mine Complex is currently being considered by the LFWWG for remedial activities similar to the work performed on the Dinero, Nelson, and Tiger Mine Complexes. An EE/CA is planned to be completed towards the end of 2010 that will be used to determine appropriate BMPs and their associated costs. It is anticipated that the EE/CA will suggest the relocation of the mine waste piles to an adjacent repository (TBD) and likely involve significant stream restoration and hydrologic controls. Currently, this project is under consideration to receive partial funding from the California Gulch Natural Resource Damage Assessment (NRDA) funding settlement from Resurrection Mining and bankruptcy settlement funds from ASARCO LLC. Remedial activities involving the Venture Mine are essential for down-stream, near-future projects such as the Colorado Gulch Wetland remediation project (Section 5.4.10).

5.4.9.1.1. **Sources of Financial and Technical Assistance**

This project has been designated as a Tier II project to receive NRDA funds. See Appendix I for the restoration alternatives funding tiers. The proposed funding for this project consists of the following:

- Estimated Total Costs: $400,000 (Based on Tiger and Dinero Mine costs)
- NRDA Funds: $200,000
- In-Kind (CMC and LFWWG partnership volunteers): $50,000
- Other funding sources $150,000 (To be identified)

5.4.9.2. **Future Needs, BMPs and Estimated Costs**
• Completion of an Engineering Evaluation and Cost Analysis (EE/CA) in summer 2010 that will likely include the following:
  ▪ Identify and design a repository site for the mine waste piles. This will also include resolving any landowner issues, permitting, and historic inventory associated with the site.
  ▪ Preparation of the repository site.
  ▪ Relocation of the mine waste piles to a repository.
  ▪ Reclamation of the Venture Mine Waste site. This will include revegetation and stream restoration activities.
  ▪ Long-term operation and maintenance (O&M) of the site. This will include monitoring of the repository, reclaimed site, and water quality of Little Frying Pan Gulch.

5.4.10. Colorado Gulch (Cecelia McNichols) Wetland

The Colorado Gulch wetland system sits near the confluence of Colorado Gulch and the Lake Fork (see Figure 2). The site is located on the McNichol’s property and is an estimated 3.6 acres in size. Ideally, this project site will be placed under a conservation easement by the landowner, therefore providing protection of the wetlands in perpetuity. A conservation easement is currently in review as an option for NRDA funds made available to the Lake County Open Space Initiative (LCOSI).
5.4.10.1. Previous Research

Classes from CMC investigated the wetland in 2008. The Colorado Gulch wetland has experienced severe sedimentation (Figure 41a and 41b) from upstream sources (weathered outcrops of bedrock, mine waste piles, and unimproved roads) resulting in widespread sediment deposits. Water quality samples have been collected from Colorado Gulch before and after the wetland.

5.4.10.2. Previous Remediation Efforts

No previous remediation has taken place in the Colorado Gulch wetlands.

5.4.10.3. Pollutant Loads and Data Analysis

Loading charts and concentration comparison tables for Colorado Gulch can be seen in section 5.4.3. COG-07 is located above the wetland whereas COG-12 is located below the wetlands and directly before the confluence with the Lake Fork as depicted in Map A11 in Appendix A.

5.4.10.4. Data Gaps

There are currently many data gaps, including wetland delineation, water and soil chemistry, and wetland functioning. Filling of data gaps are funding dependent, but will potentially be filled if it is placed under a conservation easement (see Section 5.4.10.5.1 below) or through class work within the NRM department at CMC.

5.4.10.5. Current Efforts

Currently this project is under consideration to receive partial funding from the NRDA funding settlement. Placing the land under a conservation easement is being investigated by the landowner and the Lake County Open Space Initiative (LCOSI). Once the easement has been approved and implemented, funding for wetland design and permitting will be sought. A professional wetland scientist will be utilized during all planning and implementation phases of this project.
5.4.10.5.1. Sources of Financial and Technical Assistance

This project has been designated as a Tier III project to receive NRDA funds. See Appendix I for the restoration alternatives funding tiers. The proposed funding for this project consists of the following:

- Estimated Total Cost at $100,000/acre is $600,000 (includes long-term O&M)
- NRDA Funds: $300,000
- NFWF Funds: $25,000
- Other wetland restoration funding sources (to be identified): $200,000
- In-kind (CMC and LFWWG partners): $75,000

The technical assistance for this project will chiefly include a wetland consultant/contractor, CMC NRM faculty and staff, and the stakeholders of the LFWWG.

5.4.10.6. Future Needs, BMPs and Estimated Costs

- Work with a professional wetland scientist, for planning and implementation.
- Identify appropriate contractors for wetland restoration design, permitting, and construction via a request for proposal.
- Restoration activities will include dredging and replacement of soil. Dredged soil will be placed in an on-site repository and reclaimed.
- Revegetation and slope stability activities
- Long-term O&M of the site will include vegetation monitoring and necessary revegetation. This will also likely include dredging of any sediment catchment basins constructed to trap any transported sediment originating from above the project site.
- Public Outreach

5.4.11. Halfmoon Creek

5.4.11.1. Previous Research

Halfmoon Creek has been sampled for Pb and Cd four times by CDPHE from 1993-2003. All of the samples contained levels of Cd and Pb that were above the chronic water quality TVS. All but one of the Cd samples were above the acute water quality standard. These results have resulted in Halfmoon Creek being listed as a 303(d) impaired water body for aquatic life cold 1, for acute Cd, and chronic Cd and Pb, and annual ambient standards (CDPHE, 2008) using the Colorado Basic Standards and Methodologies for Surface Water, Regulation 31, applicable to all surface waters statewide (CDPHE, 2009a). Samples were collected in two locations, Halfmoon Creek below North Fork Halfmoon Creek (upper site), and Halfmoon Creek near Leadville (lower site). Monitoring has also been performed by the USGS (1988-1990) and the LFWWG (Barrack, 2001). Two Preliminary Assessment and Site Inspection (PA/SI) reports were completed for the USFS by Summit Technical
Resources in the North Fork of Halfmoon Creek at the Champion Mill Site (USFS, 2006a) and at the Halfmoon Creek Mine Site (USFS, 2006b).

5.4.11.2. Previous Remediation Efforts

As of 2010, the LFWWG has made no remediation efforts within the Halfmoon Creek drainage.

5.4.11.3. Pollutant Loads and Data Analysis

The LFWWG has not focused on the Halfmoon Creek Drainage and therefore, in house data is sparse. The Total Maximum Daily Load (TMDL) Assessment, Arkansas River/Lake Creek/Chalk Creek/Evans Gulch, Lake/Chaffee County, Colorado written by the CDPHE June of 2009 reported that loading, based on median flows and 95th percentile instream metal concentrations, for Cd averages 13 lbs/year at the upper site and 82 lbs/year at the lower site. Pb loading values were 145 lbs/year at the upper site and 268 lbs/year at the lower site. CDPHE (2009) has determined that 80% of the Cd load and 95% of the lead load can be attributed to historic mining in the area. The two PA/SI reports completed for the USFS did not find the mine sites in the North Fork of Halfmoon Creek as significant areas of concern. The Champion Mill PA/SI report detected only Al metal concentrations above the water quality standards in surface water analysis (2006a), while the Halfmoon Creek site did not find any metals of considerable concern in surface water analysis (2006b). At both sites, the greatest concern was elevated levels of As in the mine waste piles, along with Cr in the Halfmoon Creek Mine site, which exceeded both EPA and BLM criteria. Leachate analysis did not detect metal metals of concern (USFS, 2006a and 2006b). Data presented here in that watershed plan in Figure 42 and Table 27 do not show levels above TVS.

* Al and Fe do not have water quality standards set for stream segment 5 (CDPHE, 2010) though values have been referenced for the protection of aquatic life from Table III Metal Parameters (CDPHE, 2009a).

**Figure 42. Loading in Halfmoon Creek**
Table 27. Concentration Comparison for Halfmoon Creek near Malta, CO.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Units</th>
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<th>Chronic TVS</th>
<th>Low Flow</th>
<th>Chronic TVS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al-Tot</td>
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</table>

* Al and Fe do not have water quality standards set for stream segment 5 (CDPHE, 2010) though values have been referenced for the protection of aquatic life from Table III Metal Parameters (CDPHE, 2009a).

5.4.11.4. **Data Gaps**

Identifiable information from the Halfmoon Creek drainage indicates it is impaired in its upper reaches (CDPHE, 2009b). There is also some concern from mining activity in the North Fork of the Halfmoon Creek Drainage as reported in the PA/ST reports produced for the USFS in 2006. Until recent completion of the Watershed Plan, the LFWWG has not prioritized Halfmoon Creek for monitoring because data collected in 2001 near the confluence with the Lake Fork did not show Cd (<0.15 µg/L) or Pb (<2.0 µg/L) at levels of concern (Barrack, 2001). Therefore, a more comprehensive assessment and characterization by the LFWWG is necessary to advance the understanding of the water quality concerns and sources of contamination. Filling these data gaps will help identify potential remediation if warranted. Halfmoon Creek near its confluence with the Lake Fork will be monitored (funding dependent) as part of the comprehensive monitoring program discussed in Section 6.2. The LFWWG is also not aware of any biological monitoring within Halfmoon Creek and therefore both BMI and fish monitoring would be helpful to determine the health and impact of historic mining within the Halfmoon Creek drainage basin. If water quality concerns are verified then sources of pollution can be investigated with additionally sought funds in addition to reassessment of site prioritization and determination of the appropriate remediation management plan and financial and technical assistance required for project completion.

5.4.11.5. **Current Efforts**

Currently, the LFWWG is constructing a comprehensive monitoring plan to assess all segments within the Lake Fork watershed including the Halfmoon Creek drainage (for further details see Section 6.2).

5.4.11.5.1. **Sources of Financial and Technical Assistance**

Funding has not been procured, to date, for any monitoring efforts within the Halfmoon Creek drainage. The LFWWG will address the funding and technical assistance needed to resolve water quality issues in the future. Technical
Assistance for future work will likely come from within the LFWWG, CDPHE, John Neubert, the Abandoned Mine Land coordinator for the San Isabel National Forest, and other entities that have experience within Halfmoon Creek.

5.4.11.6. Future Needs, BMPs and Estimated Costs

Although Halfmoon Creek is not currently considered a top priority for the LFWWG, it is evident that future monitoring is needed to provide the information needed to understand and assess the water quality concerns. From the 303(d) listing assessment completed by CDPHE (2008), there is need to determine the non-point source of Pb and Cd in Halfmoon Creek. Upon further assessment of Halfmoon Creek and identification of the pollutants of concern, the LFWWG will seek funding for identifying its source and potential BMPs to remediate identified problems. Until this has occurred, no potential BMPs or estimated costs can be made.

5.5. Other Tributaries

5.5.1. Bartlett Gulch

The flow from Bartlett Gulch does not directly enter the Lake Fork but has been estimated to feed into the Sugarloaf Wetlands as groundwater. Sampling in September 2001 added metal contributions from Bartlett Gulch into total loading calculations of the wetland, but this may be an overestimation (Walton-Day et al., 2005). Flow from the Bartlett Tunnel collected during that study revealed the Bartlett as a source of slightly elevated concentrations of lead, cadmium, copper and arsenic. Flow is continuously monitored from the Bartlett Tunnel with a USGS gauge station (391517106223801). After completion of the aforementioned restoration and remediation activities, the LFWWG will evaluate if Bartlett Gulch is a significant source of metals into the Lake Fork. Sampling for the Sugarloaf BMP Monitoring 319 project will monitor seeps and flow within Bartlett Gulch and at the Bartlett Tunnel.

5.5.2. Strawberry Gulch

Strawberry Gulch is the receiving drainage of the Siwatch Tunnel. The Siwatch Tunnel is not a significant source of metals loading into the Lake Fork, due to the wetlands that sit below its outflow (Walton-Day, 2005). Flow is continuously monitored from the Siwatch Tunnel at a USGS gauge station (391435106230801). The bi-annual sampling of the Lake Fork during high flow and low flow samples the Lake Fork below its confluence with Strawberry Gulch, and there is no significant increase of metals loading at LF-06 below the confluence. Sampling for the Sugarloaf BMP Monitoring 319 project occurs within Strawberry Gulch and at the Siwatch Tunnel.

5.5.3. Hunt Gulch

Hunt Gulch brings water from the Leadville National Fish Hatchery into the Lake Fork, near County Road 300. Sampling in the Lake Fork below the confluence as well as within Hunt Gulch has not showed any significant metal loading. In fact, water quality in the Lake Fork improves below the confluence with Hunt Gulch due to dilution.
5.5.4. Rock Creek

The inlet of Rock Creek is on Colorado Outward Bound’s property and receives drainage from the northeast side of Mount Massive. Rock Creek is not a significant source of metals loading into the Lake Fork.

5.5.4.1. Willow Creek

The Willow Creek drainage is a secondary tributary system of Rock Creek comprised of three main stems: Willow Creek, North Willow Creek, and South Willow Creek, which originate in the Mount Massive Wilderness area. Water quality for this section of the Lake Fork system is unknown and needs further investigation and monitoring of water quality conditions. Funding dependent, the comprehensive monitoring plan discussed in Section 6.2 will monitor Willow Creek directly above the confluence with the Lake Fork to fill this data gap.

5.5.5. Upper Lake Fork Watershed Tributaries

Several secondary tributaries comprise the upper Lake Fork drainage system:

- North Tributary Drainages:
  - Saint Kevin Lake, Galena Lake, and Bear Lake drainage including Bear Creek.
  - Homestake Tunnel
- West Tributary drainages:
  - Mill Creek drainage.
  - Timberline Lake drainage and Lake Fork headwaters.
  - Virginia Lake(s) drainage.
- South Tributary Drainages:
  - Glacier Creek drainage.
  - Notch Lake, Windsor Lake, and Hagerman Lake drainage including Busk Creek.
  - Charles H. Boustead Tunnel
  - Ivanhoe-Carlton Tunnel

The upper Lake Fork does contain areas of historical mining activities, primarily located on the north side of Sugar Loaf Mountain, Bear Creek Drainage, and the southern aspect of Galena Peak. Water quality research conducted on the upper Lake Fork from the USGS “Colorado Water-Quality Data Repository” web-site, www.rmgsc.cr.usgs.gov/cwqdr/Arkansas did not identify any concerns within the upper Lake Fork above Turquoise Lake. Water quality data within these areas is minimal to none and future monitoring of these historical mining areas may provide important information to assess water quality within the upper Lake Fork reach. Due to minimal concerns with water quality in the upper tributaries only one site, LF-00 on the Lake Fork directly above Turquoise Lake, has been added to the comprehensive monitoring program (funding dependent) discussed further in Section 6.2.
5.6. Schedule of Current and Future Efforts

As seen in Table 28, the LFWWG is currently working on three main projects, the Lake Fork and Sugarloaf BMP 319 projects are entirely monitoring related, while the Little Frying Pan WQ 319 project is a combination of hydrologic controls and monitoring. Projected future work includes the remediation of the Venture Mine and the Colorado Gulch Wetland. The Venture Mine Restoration project will be the next project (funding dependent) tackled by the LFWWG. Other sub-watersheds, particularly Halfmoon Creek, will take precedence once BMPs in the priority sites (currently Colorado Gulch and its tributary Little Frying Pan) have successfully reduced metal loading into the Lake Fork.

Revisions to the Lake Fork Watershed Plan will be completed as important changes occur that affect the status of the current watershed plan. Changes will most likely occur after quarterly LFWWG meetings when project status, new data, funding sources, or significant information is agreed upon within the working group. The Lake Fork Watershed Plan is thought of as a continuously modified document that will track and document the health of the Lake Fork Watershed. Updates to the Lake Fork Watershed will be made available on the LFWWG website (http://www.coloradomtn.edu/communities_friends/lake_fork_of_the_arkansas_watershed_working_group/).

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<td>Strawberry Gulch</td>
<td>Siwatch Tunnel</td>
<td>USGS Gauging Station (391435106230801)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sugarloaf BMP 319</td>
<td>Dinero Tunnel WQ Monitoring/NRDA</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Strawberry Gulch</td>
<td>Sugarloaf BMP 319</td>
<td>Dinero Tunnel WQ Monitoring/NRDA</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Colorado Gulch and Little Frying Pan</td>
<td>Tiger Mine Pile Relocation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Little Frying Pan and Colorado Gulch</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Venture Mine Restoration</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Colorado Gulch Wetland</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hunt Gulch</td>
<td>Hunt Gulch</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rock Creek Drainage</td>
<td>Rock Creek and Hunt Creek</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Halfmoon Creek Drainage</td>
<td>Halfmoon Creek</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| Future funding dependent |

Table 28. Schedule of Current and Future Events
6. Pollutant Reductions

The goal of the LFWWG is to reduce metals loading of the Lake Fork to water quality TVS as determined for section 5 of the Arkansas River Basin Regulation 32 (CDPHE, 2010). The approximate metal concentration reductions necessary to bring values within standards are presented in Tables 29-32. The percent reduction values are calculated from the site specific hardness TVS and the high and low flow concentration data found in each pollutant loading section. The tables are listed from the Lake Fork below Sugarloaf Gulch (LF-01) down toward its confluence with the Arkansas (LF-11). Data from LF-03 and LF-08 are significant as these sites are directly below the confluence with the top two priority gulches within the watershed, LF-03 (Table 30) is on the Lake Fork below confluence with Sugarloaf Gulch, while LF-08 (Table 31) is below the confluence with Colorado Gulch. From these data it is evident that the necessary metal concentration reductions are greatest during high flow, which is expected due to the intermittent nature of many of the gulches. Percent reduction requirements near the Arkansas River (Table 32) are most significant during high flow, particularly for three of the metals (Cd, Cu, and Zn) that are above TVS in the preliminary 303 (d) list assessment (See Appendix B). The purpose of the reclamation BMPs within the Sugarloaf Mining District will aim at directly reducing these metal loads, for example the 20% Zn load reductions predicted by BMPs emplaced at the Tiger Mine complex. To assess the effectiveness of these BMPs, and the resulting load reduction, will require continued monitoring throughout the Lake Fork and its tributaries. The future monitoring and evaluation methods are discussed in Sections 6.1-6.3.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Units</th>
<th>Reduction</th>
<th>% Reduction</th>
<th>Reduction</th>
<th>% Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al-Tot</td>
<td>ug/L</td>
<td>6.90*</td>
<td>7.93*</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Cd-Diss</td>
<td>ug/L</td>
<td>0.12</td>
<td>136.58</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Cu-Diss</td>
<td>ug/L</td>
<td>8.55</td>
<td>591.69</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Fe-Tot</td>
<td>ug/L</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Mn-Diss</td>
<td>ug/L</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Zn-Diss</td>
<td>ug/L</td>
<td>X</td>
<td>X</td>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>

* Al and Fe do not have water quality standards set for stream segment 5 (CDPHE, 2010) though values have been referenced for the protection of aquatic life from Table III Metal Parameters (CDPHE, 2009a). N/A = concentration below detection limit, X = no reduction needed.

Table 29. Target Concentration Reductions Lake Fork below Sugarloaf Dam
### Table 30. Target Concentration Reductions on the Lake Fork after the Sugarloaf Gulch Confluence

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Units</th>
<th>Reduction</th>
<th>% Reduction</th>
<th>Reduction</th>
<th>% Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al-Tot</td>
<td>ug/L</td>
<td>68*</td>
<td>78.2*</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Cd-Diss</td>
<td>ug/L</td>
<td>4.40</td>
<td>2905</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Cu-Diss</td>
<td>ug/L</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Fe-Tot</td>
<td>ug/L</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Mn-Diss</td>
<td>ug/L</td>
<td>522.9</td>
<td>49.9</td>
<td>241.4</td>
<td>26.6</td>
</tr>
<tr>
<td>Zn-Diss</td>
<td>ug/L</td>
<td>1111</td>
<td>2861</td>
<td>54.3</td>
<td>200.9</td>
</tr>
</tbody>
</table>

* Al and Fe do not have water quality standards set for stream segment 5 (CDPHE, 2010) though values have been referenced for the protection of aquatic life from Table III Metal Parameters (CDPHE, 2009a). N/A = concentration below detection limit, X = no reduction needed.

### Table 31. Target Concentration Reductions on the Lake Fork after the Colorado Gulch Confluence

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Units</th>
<th>Reduction</th>
<th>% Reduction</th>
<th>Reduction</th>
<th>% Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al-Tot</td>
<td>ug/L</td>
<td>1043*</td>
<td>11989*</td>
<td>75*</td>
<td>86.2*</td>
</tr>
<tr>
<td>Cd-Diss</td>
<td>ug/L</td>
<td>7.18</td>
<td>5322</td>
<td>0.21</td>
<td>126.4</td>
</tr>
<tr>
<td>Cu-Diss</td>
<td>ug/L</td>
<td>70.25</td>
<td>2870</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Fe-Tot</td>
<td>ug/L</td>
<td>450*</td>
<td>45.0*</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Mn-Diss</td>
<td>ug/L</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Zn-Diss</td>
<td>ug/L</td>
<td>817.9</td>
<td>2400</td>
<td>112.54</td>
<td>265.1</td>
</tr>
</tbody>
</table>

* Al and Fe do not have water quality standards set for stream segment 5 (CDPHE, 2010) though values have been referenced for the protection of aquatic life from Table III Metal Parameters (CDPHE, 2009a). N/A = concentration below detection limit, X = no reduction needed.

### Table 32. Target Concentration Reductions on the Lake Fork before the Arkansas River Confluence

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Units</th>
<th>Reduction</th>
<th>% Reduction</th>
<th>Reduction</th>
<th>% Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al-Tot</td>
<td>ug/L</td>
<td>314*</td>
<td>360.9*</td>
<td>78*</td>
<td>89.7*</td>
</tr>
<tr>
<td>Cd-Diss</td>
<td>ug/L</td>
<td>1.3</td>
<td>869.8</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Cu-Diss</td>
<td>ug/L</td>
<td>8.1</td>
<td>301.9</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Fe-Tot</td>
<td>ug/L</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Mn-Diss</td>
<td>ug/L</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Zn-Diss</td>
<td>ug/L</td>
<td>168.6</td>
<td>450.8</td>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>

* Al and Fe do not have water quality standards set for stream segment 5 (CDPHE, 2010) though values have been referenced for the protection of aquatic life from Table III Metal Parameters (CDPHE, 2009a). N/A = concentration below detection limit, X = no reduction needed.
6.1. Interim Measurable Milestones

Continued monitoring through 2012 (as scheduled with current projects and funding, while subsequent grants may lengthen that time frame) will provide the data to measure the reduction of metals loading within the tributaries of the Lake Fork. These data will be used to evaluate effectiveness of implemented BMPs (bulkhead emplacement, hydrologic controls, sulfate reducing wetland, etc), which will be useful for future BMP implementation projects efforts in tributaries effected by historic mining activities. The goals of the LFWWG for the Lake Fork include:

- Water quality improvements to meet water quality TVS (from CDPHE, 2010) throughout the reach of the Lake Fork
- Improvement of aquatic life in the Lake Fork
  - Increased BMI diversity and abundance
  - Increased biomass and species diversity in fish

Re-evaluation of site specific high flow metal loading values for (Al, Cd, Cu, Fe, Mn, Zn, as well as the evaluation of As, Pb) will be assessed shortly after data collection. Some projects will result in immediate load reductions while others may produce gradual results. Site specific interim measurable milestones will be developed in conjunction with load reduction estimates as remediation management plans (and EE/CAs) are prepared and cannot be determined at this time. To account for the improvement over the watershed as a whole, from previous, current, and future remediation efforts, the LFWWG will monitor LF-11 as our watershed plan conformance site. This site will be monitored during peak high flow which will be assessed by the rising limb of the hydrograph, monitored online by the USGS gauging station of the Arkansas River near Leadville (07081200). The long term water quality goal for this site is meeting the water quality TVS (from CDPHE, 2010) for Cd, Cu, Mn, Pb, and Zn, as seen in Table 3, in addition to aquatic life protection levels of Al, As, and Fe (CDPHE, 2009a)

It is expected that remediation efforts will reduce loading of heavy metals into the Lake Fork, particularly Cd, Cu, Mn and Zn, as the non-point sources of these metals, i.e. mine waste piles, are removed. Elimination of the source of heavy metals will decrease current degradation seen in water quality and bring water quality closer to aquatic life standards. BMI sampling efforts, through the Sugarloaf Mountain Mining District BMP Performance Monitoring Project 319 grant and in future sampling, will be completed in reaches throughout the Lake Fork at high and low flow and will look at density, taxa richness, and EPT taxa richness [Ephemeroptera (mayfly), Plecoptera (stonefly), and Trichoptera (caddisfly)]. Presumably, a sufficient decrease in metal laden waters in the Lake Fork should cause BMI data to mimic that found in the East Fork of the Arkansas (N. Viera, personal communication, April 14, 2010). Monitoring of fish biomass will provide detailed information on the fitness and density of each species. Fish shocking events will be coupled with low flow BMI sampling. Increases in water quality should be reflected in increases in species diversity and biomass (G. Policky, personal communication, April 12, 2010).
6.2. Monitoring Program

As previously mentioned, several projects have already been completed or will soon begin within the Lake Fork watershed that will ultimately result in improved water quality within the watershed. These projects include:

- Dinero Mine Waste Dump Reclamation (Completed in 2004)
- Nelson Mine Waste Dump Reclamation (Completed in 2002)
- Dinero Bulkhead Project (Completed Fall 2009)
- Tiger Mine Complex Project (Summer 2009 – 2011)
- Venture Mine Complex Project (projected to begin Summer 2011)

Long term monitoring will provide quantifiable data to measure the overall improvement of the watershed. The LFWWG and CMC have established numerous monitoring sites throughout the Lake Fork Watershed that will be included as part of this effort. Current monitoring efforts include site specific and large scope (Lake Fork High/Low Flow) monitoring that generate a significant quantity of data used to measure water quality. The most comprehensive monitoring program is the Sugarloaf Mountain BMP Monitoring Project which includes more than 70 sites where hydrologic, chemical, and biological measurements and analysis will occur through 2012. These sites are depicted in Map A10 of Appendix A.

A comprehensive monitoring program will need to be implemented, beginning in 2013, which will include not only sites within the Sugarloaf Mountain area but other tributaries, such as Halfmoon Creek and the tributaries above Turquoise Reservoir. The California Gulch NRDA Trustees have approved funding for monitoring that will begin in 2013 in the Sugarloaf Mountain area as part of monitoring the Dinero Tunnel Bulkhead project that will focus on a subset of sites identified in the Sugarloaf Mountain BMP Monitoring project. Therefore, funding for those sites not funded through California Gulch NRDA will need to be located. The cost for this monitoring program is approximately $17,000 per year.

A comprehensive long-term monitoring plan will focus on the following constituents and measurements that are related to impairment and health of the watershed. All of these constituents have historic data from past and current monitoring activities:

- Water Quality (pH, specific conductance, total dissolved solids, temperature, and oxidation-reduction potential)
- Metals (Al, As, Cd, Cu, Mn, Pb, Zn) that include both total recoverable and dissolved fractions
- Major anions (PO$_4^{2-}$, NO$_3^{-}$, NO$_2^{-}$, Cl$^-$, F$^-$, and SO$_4^{2-}$)
- Wet chemistry (alkalinity, hardness, acidity, dissolved oxygen, and sulfate)
- Discharge
- Aquatic sampling (BMI and Fish)
All monitoring activities will follow a SAP and QAPP developed for the comprehensive monitoring program that will include aspects from the current Lake Fork SAP/QAPP (Appendix J and K, respectively) and the Sugarloaf Mountain BMP Performance Monitoring project. Data collected as part of the comprehensive monitoring program will be stored in the main Lake Fork database maintained by CMC NRM for the LFWWG.

Sites to be used as part of the comprehensive monitoring program on the Lake Fork include: above Turquoise Reservoir (LF-00), below Turquoise Reservoir (LF-01), below Sugarloaf Gulch inlet (LF-03), above or below Strawberry Gulch inlet depending on beaver activity (LF-05 or LF-06), below Colorado Gulch inlet (LF-08), below Hunt Gulch inlet (LF-09), and before the confluence with Arkansas River (LF-11). Additional sites include Halfmoon Creek (HC) and Willow Creek (WC) (most of the mentioned sites can be found on Map A11 in Appendix A). High flow typically occurs in mid-May and low-flow in September. Some of these sites have been or are currently monitored as part of one of the several projects in the Lake Fork watershed, while others (HC, WC, and LF-00) will be sampled primarily to fill data gaps.

6.3. Evaluation Framework

The evaluation framework, depicted in Figure 43, incorporates adaptive management, prioritization of sites, identification of missing data, collection of data, site reclamation, which then utilizes the management remediation plan (Figure 3), and monitoring of the conformance site as the methodology to improve water quality within the Lake Fork. This evaluation framework was created to adjoin adaptive management procedures to routine environmental management practices with modification, as appropriate, upon analysis of the projected loading reductions associated with future projects (interim measurable milestones). In addition, the continual reprioritization of sites, filling of data gaps, and reclamation of priority sites will continue until the conformance sites meet water quality standards as discussed below.

As discussed in Section 6.2, LF-11, which is on the Lake Fork directly before the confluence with the Arkansas River, will be monitored and assessed annually during high flow. The loading from this site will be compared to previously collected data. All results other than those indicating conformance with the aforementioned water quality standards (Table 3) will determine that continuance of the evaluation framework is necessary. Current data, as presented in Table 32, show a needed reduction of 168.6 µg/L of Zn, 1.3 µg/L of Cd and 8.1 µg/L of Cu for this water to meet TVS set for stream segment 5. Once the water quality standards are met at LF-11, LF-08 will become the new conformance site and the evaluation framework will continue until water quality and biological goals are met. When the water quality standards are met at LF-08, LF-03 will become the new conformance site and the evaluation framework will continue until the same goals are met. As seen in Table 30 and 31, water quality in those segments will require a significant decrease in Zn, Cd, Al, and Cu. When water quality goals have been met at LF-03 for five consecutive years, the LFWWG will decide if any further monitoring is necessary. Upon reaching these goals and the completion of work within the Lake Fork Watershed, it is expected that aquatic health of the stream should also become more prolific.
The objective is to reach water quality TVS in the Lake Fork; the LFWWG is aware that this goal is optimistic. The Sugarloaf Mining District was an active mining site from the 1890s through the 1920s due to mineral deposits located in the region. Accordingly, water quality may remain below water quality standards, regardless of the efforts taken at reclamation. The LFWWG is not aware of pre-mining water conditions in the Lake Fork (documentation of a thriving fishery, etc.) and therefore it is hard to quantify realistic remediation goals, which would reflect pre-mining water quality conditions. Therefore, the LFWWG will continue with the goal, to bring the Lake Fork under water quality TVS, until further scientific research deems otherwise.

![Evaluation Framework](image)

Figure 43. Lake Fork Watershed Plan Evaluation Framework.
7. Works Cited

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