SECTION 319 NONPOINT SOURCE POLLUTION CONTROL PROGRAM

WATERSHED PROJECT
FINAL REPORT

Bullion King Mine Waste Remediation Project

WQC 60522

By

Peter Butler, Ph.D.
Coordinator for Animas River Stakeholders Group
In conjunction with the San Juan Resource Conservation and Development Council
(Project sponsor)

May, 2018

This project was conducted in cooperation with the State of Colorado and the United States Environmental Protection Agency, Region 8.

EXECUTIVE SUMMARY

PROJECT TITLE: Bullion King Mine Remediation Project

FUNDING:

TOTAL (NON-FEDERAL + EPA) BUDGET	$648,916.26
ARSG NONPOINT SOURCE GRANT	$221,355.00
(Invoiced Amount)	$221,389.30
DRMS NONPOINT SOURCE 2013 TMDL	$142,206.00
MINIMUM MATCH REQUIRED	$242,396.87
WATER QUALITY IMPROVEMENT FUNDS	$67,884.00
(Invoiced Amount)	$67,723.96
SECTION 319 NON-FEDERAL MATCH ACCRUED FROM DRMS	$217,597.00
TOTAL MATCH	$285,320.60

SUMMARY OF ACCOMPLISHMENTS

All six tasks of this project have been accomplished. Approximately 92% of the total budget went to Tasks 1 and 2 for the Bullion King mine waste remediation. The mine waste pile was re-sloped, covered with a liner and topsoil and then revegetated. Located at 12,300 feet above sea level, the Bullion King is a difficult and challenging site, and there were complications in completing the work.

The other four tasks included evaluating impacts to water quality and river health of the Bullion King and other remediation projects completed in upper Mineral Creek, evaluating water quality conditions for possible future remediation projects in Arrastra Gulch, project administration, and public education and outreach. The remediation projects in the Mineral Creek watershed, most of which were funded through section 319, have resulted in cadmium, copper, and zinc concentration reductions by 50-70% in Mineral Creek. Trout have been discovered in reaches earlier devoid of aquatic life. Arrastra Gulch has very complicated water quality issues that are now better understood. Public education and outreach about historical mining impacts to rivers, mine remediation, and the Animas River Watershed in general became a much larger and more successful task than originally envisioned because of the publicity surrounding the Gold King Mine release in August 2015.

I. INTRODUCTION

The Animas River Watershed, located in southwest Colorado, begins in the heavily mineralized Silverton Caldera. The Caldera encompasses the Animas River from slightly below the town of Silverton to the headwaters, including two major tributaries – Mineral Creek and Cement Creek. This part of the watershed, often referred to as the Upper Animas Basin is characterized by remote, high elevations (9,200 – 13,800 feet above sea level), steep mountains and heavy annual snowfall.

Originally, the region was part of the Ute Indian territory. In the 1860's Anglo prospectors began exploring the area for minerals. By the early 1870's initial mining began. The Utes were coerced into signing the Brunot Agreement in 1873, ceding the land to the U.S., although they still retain rights for hunting and gathering.

In the following decades, a several hundred mines began operation. By the late 1920's most of them had shutdown with a few exceptions. The largest and last operating mine, the Sunnyside, shutdown in 1991. Today, the town of Silverton, population 600, is the only population center in the Upper Animas Basin. Once the hub of mining activity, Silverton's economy is now primarily based on tourism.

One legacy of the past mining activity is the addition of metals into the aquatic system beyond what naturally occurs. Mining exposes ores to water and air, greatly accelerating the natural processes that create acid and leach metals. The metals are either leached from mine waste piles (mine dumps outside of portals or tailings) or from mine waste and ore bodies within mine workings which are carried by drainage through tunnels and adits to the surface or through groundwater pathways.

In the 1990's, participants in the Animas River Stakeholders Group (ARSG) did initial characterization of approximately 160 draining mines and 170 mine waste piles. These sites were ranked in terms of metal loading (weighted towards metals of particular concern). The group found that 32 of the draining mine accounted for 90% of the load from all draining mines and 33 of the waste piles accounted for 90% of the metal load from all waste piles.

In 2001, ARSG proposed water quality standards in different segments of the Upper Animas Basin based upon at least some remediation of all the top sites noted above. Those standards were adopted by the Colorado Water Quality Control Commission and approximately 27 Total Daily Maximum Daily Loads (TMDL's) were developed by the Water Quality Control Division based upon ARSG's work. Today's water quality standards for the Animas Basin have changed little since 2001.

Starting in the 1990's, participants in ARSG initiated mine remediation projects through different financial avenues. Most of the 33 mine waste sites have been remediated - many of which utilized the 319 program. Overall, about 60 mine remediation projects have been completed.

The Bullion King mine waste site was one of the very top mine waste sites in terms of size and leachability of metals. But because of its high elevation (12,300 ft. above sea level) and difficulty of access, many other sites were remediated first. This 319 grant was used to remediate the Bullion King and characterize water quality and macroinvertebrate improvements seen downstream of this project and many other nearby 319 projects done in years past.

In addition, this grant supported efforts to better characterize Arrastra Gulch, a tributary of the upper Animas River that doesn't meet current water quality standards, to determine if any future remediation projects would be productive in that sub-basin. Much of the mining activity in this drainage was tied to ASARCO, a mining and smelting company. In 2008, ASARCO entered into a settlement agreement with the U.S. Government for cleanup of a number of sites around the U.S. for which well over a billion dollars was set aside in a trust for this purpose. Four million dollars was designated for properties in the Upper Animas Basin, most of which are in Arrastra Gulch.

This 319 grant also supported education and outreach efforts related to water quality and mine remediation in the Upper Animas Basin. Because of the Gold King spill in August 2015, there has been a tremendous upsurge in public interest in these issues. ARSG has given thirty-eight tours and presentations to various groups through 2017, not including regular ARSG meetings.

II. BULLION KING MINE REMEDIATION

The Bullion King Mine is located high (12,300 ft. elevation) in the Mineral Creek watershed in the Porphyry Gulch sub-basin. Of the 160+ mine waste sites sampled in the Animas River watershed, it is one of larger piles and ranked by ARSG as one of the highest in terms of total potential metal loading to the surface water bodies. Access is limited to about four months during the year by snow and by a rough, extremely narrow four-wheel drive road.

Figure 1a - Bullion King before Remediation

Figure 1b - Bullion King before Remediation

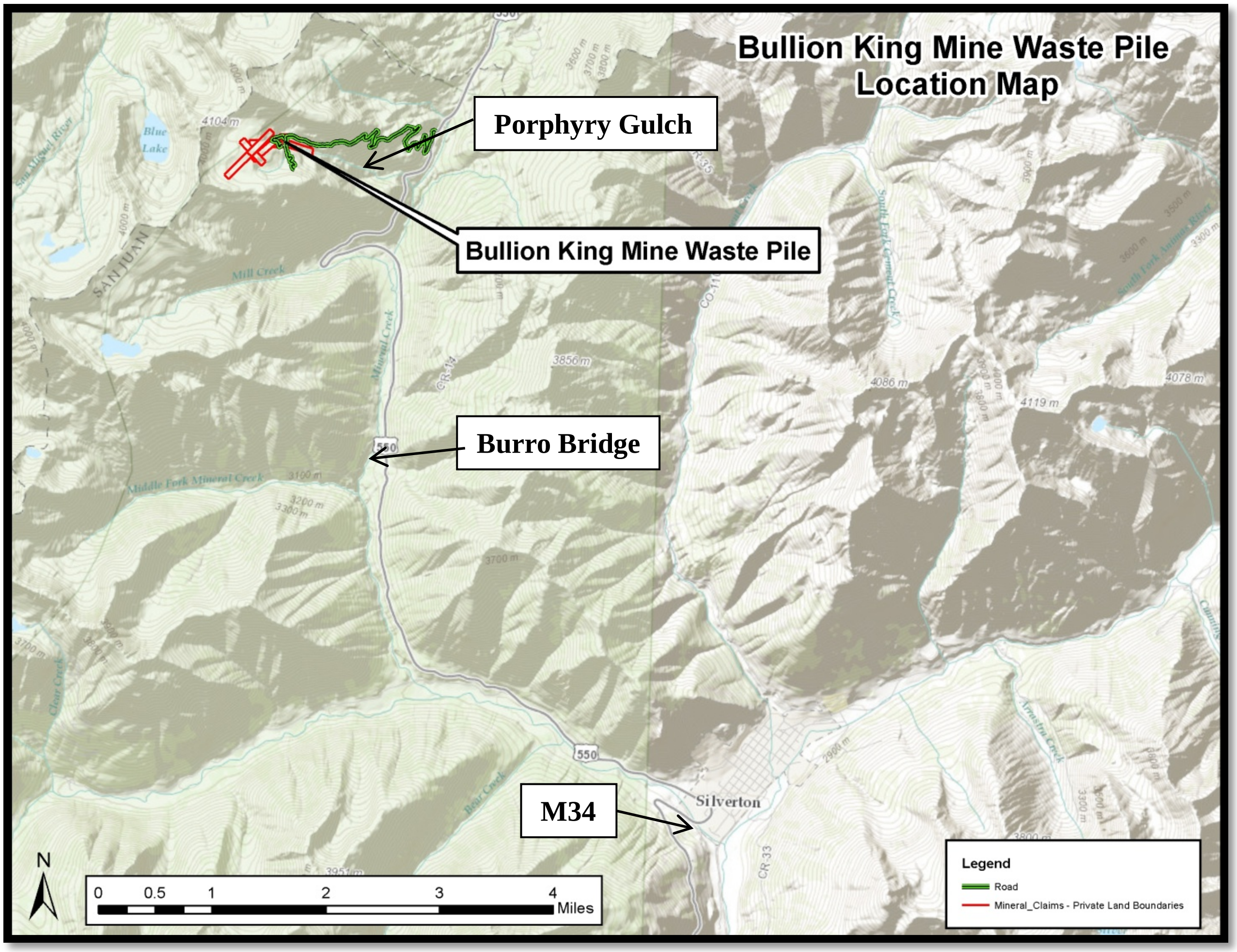


Figure 2 – Mineral Creek and Bullion King Location

Initial funding for the Bullion King remediation project was a combination of a Section 319 and Water Quality Improvement Funds allocated to ARSG through the group's fiscal agent, San Juan Resource Conservation and Development Council (SJRCD). The Division of Reclamation, Mining, and Safety (DRMS) provided matching funds through severance tax funds and personal for supervising and managing the remediation project. DRMS also utilized 319 funding from the Water Quality Control Division.

Creating an on-site repository to isolate the mine waste from precipitation and surface runoff was determined to be the least expensive method of remediation. Under the initial plan, the mine waste would be graded to slopes no more than 3H:1V, and then covered with approximately 30,000 square feet of geotextile liner. Six inches of topsoil and a native vegetative cover would be placed over the liner. (For more details on the liner and coverings, see the DRMS Closeout Report in Appendix A.) Mine drainage from the portal would be routed around the repository.

Site characterization and evaluation (Task 1) was conducted in 2014 by DRMS, ARSG, and U.S. Forest Service (USFS). Appendix A summarizes the initial work (p. 3):

The Bullion King project is located on private lands, on the Arthur Britton MS 17462 and Cargill MS 19447 claims. An environmental covenant was signed by the landowner in August 2014. The majority of the road to the mine is located on USFS lands. DRMS and Mountain States Historical collected historical survey information in 2014 and USFS consulted with SHPO. The USFS analyzed the site for wildlife, plants, roads, and recreational considerations and completed a Decision Memo in November 2014, allowing the improvement of the access road to the site. The DRMS and ARSG designed the mine waste reclamation project, prepared bid documents, and bid the project in October 2014 for construction in 2015.

Construction began in July 2015. To provide safer access, about ¼ mile of road was widened from just over six feet to between eight and nine feet using a small excavator with a hammer and bucket. USFS would not allow the use of explosives. Only smaller equipment could be brought to the site.

Typically, most high elevation areas in the Upper Animas Basin have little topsoil. Fortunately, large quantities of topsoil were found on site, and no additional soil needed to be hauled in.

The amount of mine waste proved to be much extensive than anticipated. In an attempt to keep within the slope parameters, the repository had to be expanded to almost twice the initial size. Even with the expansion, the southeast corner exceeded the desired slope because of topography and other physical constraints at the site. After equipment had been demobilized, soil began to slip off and expose the liner. It was too late in the fall to re-mobilize and fix the issue.

Figure 3 – Soil Slippage – July 2016

In 2016, a new bidding process was initiated to fix the site. A different contractor was chosen for the work. Funding included a portion of the ARSG 319 grant, DRMS severance tax and additional DRMS 319 monies.

Of the nearly 60,000 square feet of liner, 10,000 square feet was removed from the steeper sloped portion. The cover material in this area was removed and stockpiled. Ninety tons of Portland cement was mixed in the top six inches of mine waste to neutralize pH and bind the material. Rock and the stockpiled topsoil were used to cover the material. Finally wood mulch, native seed and Biosol fertilizer were applied to the entire site. Overall, the Bullion King mine waste remediation cost $599,038.80 or 92% of project.

III. EVALUATING INSTREAM IMPACTS OF MINE SITE REMEDIATION

The instream impacts of remediating mine waste sites can be evaluated in different ways. The two methods discussed below are water quality and macroinvertebrate sampling. Overall water quality monitoring information is much more extensive in the Mineral Creek watershed than macroinvertebrate information.

Directly evaluating environmental improvements due to remediation of an individual mine waste site through water quality monitoring can be challenging. Generally, a large temporal dataset needs to be collected. Mine waste sites usually leach metals during precipitation events. Catching major precipitation events and collecting water samples above and below a site is difficult, especially when the site is so remote. Collecting samples during spring runoff can be dangerous because of high flows or spring snow avalanche conditions.

Sampling below mine waste piles during major precipitation events may show high metal concentrations in the water column, but a short, initial flush of metals may not have a significant environmental impacts. However, metals leached from mine waste during these events can settle in sediments downstream where they may be re-mobilized during instream flow fluctuations and changes in pH throughout the course of the year. Higher instream metal concentrations may persist over weeks or months because of re-mobilization. Thus, the full benefits of remediating a mine waste pile may not be realized for several years until metals available for re-mobilization have moved farther downstream and have been diluted or dispersed.

To fully evaluate remediation of a mine waste site requires collecting stream samples for several years, throughout the calendar year, to capture varying hydrographic and acidity conditions both before and after the remediation. Because of both time and funding considerations, this level of sampling effort was not conducted in Porphyry Gulch. While the small alpine stream in this sub-basin flows directly past the Bullion King Mine, this small waterway was not the main target for environmental improvements. The main target was the much larger Mineral Creek and the Animas River itself.

The Bullion King Mine remediation project constitutes the most recent of many remediation projects designed to improve water quality in Mineral Creek. The other projects include: the removal of three mine waste piles and the onsite remediation of five other mine waste sites; the purchase of water rights from a transbasin diversion that seeped into mine workings and subsequent removal of the diversion ditch and dedication of those rights to instream flow; and the bulkheading of the Koehler Tunnel - one of the most significant, mining-related sources of metals in the Animas River watershed - and its subsequent ring-grouting for a better seal. Most of these projects were completed with 319 funds. (See Appendix B for the list of projects.)

Because of the watershed approach that has been taken towards improving water quality in Mineral Creek over the past twenty-five years, only a small amount of temporal data has been collected in Porphyry Gulch, a somewhat larger temporal data set has been collected part way down Mineral Creek at Burro Bridge, and very large, twenty-five year data set has been collected near the mouth of Mineral Creek (M34). See Figure 2 above for locations. Each of these data sets will be discussed below.

Porphyry Gulch Data

Water quality samples have been collected above and below the Bullion King in Porphyry Gulch during Sept. 2000, and July and Aug. 2013. Additional samples were collected almost 1.5 miles downstream from the mine site where Porphyry Gulch crosses Hwy 550, a much easier location to access for sampling. Collection dates at Hwy 550 were July and Aug. 2013, July and Oct. 2015, and Nov. 2016. A sample was also collected in Aug. 2013 from the small drainage coming from the Bullion King adit. (See Appendix C for data.) Other than small prospect holes, there are no other mining features between the Bullion King and Hwy 550.

The only aluminum and zinc concentrations found to be consistently above Table Value Standards (TVS) – standards that are designed to be protective of 95% percent of the aquatic species found in Colorado's waters. Although hardness is quite low in Porphyry Gulch, the high pH (around 8.0) keeps many of the dissolved metal concentrations – generally the more toxic fraction – quite low. Some of these metals may dissolve downstream in Mineral Creek where pH can drop to 4.5.

The samplers caught two afternoon storm events. Unfortunately, the storm event sample taken just below the mine site in Porphyry Gulch in Sept. 2000 only includes total metal concentrations. Lead, arsenic, and iron concentrations all jumped tenfold from their non-storm event levels. Copper and aluminum concentrations tripled, and zinc increased as well.

Another storm event sample was collected at Hwy 550 in July 2013. Metals concentrations approximately tripled when compared to non-storm time periods, but, with the exception of aluminum, were not as high as the other storm event sample. Of course this sample was taken 1.5 miles downstream where there would be dilution during a rain event from the rest of the watershed. The total aluminum concentration was double the concentration seen in earlier storm sample, suggesting that aluminum may not be as closely associated with the Bullion King as the other metals. There may be natural sources aluminum. On the same afternoon in July 2013, other samples were collected an hour and half later above and below the Bullion King site, but in examining the concentrations, it appears those samples may have missed the main flush from the storm.

Non-storm event samples collected from Porphyry Gulch at Hwy 550 in Aug. 2013 and in 2015-16 have very similar concentrations. The samples in Oct. 2015 and in 2016 were taken after remediation of the Bullion King mine waste.

Burro Bridge Data

In 2015, ARSG collected data under this grant at a number of locations in the Mineral Creek watershed to help with evaluation of the effects of mine remediation to Mineral Creek. Many tributaries had not been sampled in ten to fifteen years. However, as part of the Bonita Peak Superfund investigations, EPA also began targeted sampling in Mineral Creek which was much more extensive than ARSG could do. There were large synoptic sample events during high and low flow time periods, capturing detailed snapshots of water quality twice a year. ARSG switched its approach to sample almost monthly at one key location to better capture the temporal effects of remediation. The location chosen was Burro Bridge.

Burro Bridge is approximately the mid-point of the Mineral Creek drainage, and unlike most other locations, it is a relatively easy place to sample the stream in winter. Except for the Bonner Mine, all of the remediation projects in the Mineral Creek watershed (Appendix B) are upstream of the bridge. About a quarter mile below the bridge, the geology changes. Ground and surface water entering the creek, especially from the Middle Fork of Mineral Creek, contribute high concentrations of aluminum and iron, and low pH which negatively affects the creek and the Animas River itself below the confluence.

Historically, quite a bit of data has been collected at Burro Bridge. The Colorado Water Quality Control Division (WQCD) collected samples periodically at Burro Bridge from 1991 to mid-1996, before any remediation occurred. USGS collected samples from Nov. 1998 through July 1999. This was after Sunnyside Gold removed the Koehler Tunnel mine waste pile, mucked out the nearby pond and remediated the Longfellow waste pile on site as part of the consent decree between Sunnyside Gold and CDPHE. Those two mine waste piles were probably the most reactive and highly mineralized piles in the entire Animas River watershed. ARSG collected samples mostly in 2017, after all remediation had been completed. EPA collected two samples just downstream of the bridge in 2016. (See Appendix D for data and analysis.)

Table 1 below demonstrates the significant improvements in concentrations of metals of concern in this stream reach due to mine remediation. Percentiles of each of the three data sets were calculated to correspond with percentiles used in standard setting by Colorado Water Quality Control Commission (WQCC). Those percentiles are compared with TVS, and the only exceedances were cadmium and zinc. Concentrations of both metals, which generally occur in ore together in the Silverton Caldera, have dropped 72%. Copper concentrations dropped an impressive 96%.

Table 1 - Mineral Creek at Burro Bridge (ug/l)

	Tot Aluminum (50th percentile)	Dis. Cadmium (85th percentile)	Dis Copper (85th percentile)	Dis Lead (85th percentile)	Dis Zinc (85th percentile)
1991-96 WQCD (N=8)	640	5.55	193.0	Poor data	1710
1998-99 USGS (N=9)	No data	4.81	84.2	Poor data	1245
2016-17 ARSG & EPA (N=12)	424	1.54	7.7	2.92	481
TVS (Hardness = 157 for 2016-17)	909	1.01	13.20	4.11	183
% drop from 1991-96 to 1998-99	No data for 1998-99	13%	56%		27%
% drop from 1998-99 to 2016-17	No data for 1998-99	68%	91%		61%
% drop from 1991-96 to 2016-17	34%	72%	96%		72%

Data from M34

By far the most robust data set for Mineral Creek are the samples collected near the mouth at the USGS gaging station just below the Hwy 550 bridge next to Silverton. Water samples have been collected monthly at this site since 1992, mostly by the River Watch program.

ARSG analyzed this data by grouping samples into four time periods:

- 1991-mid-1996 ~ No remediation had taken place in Mineral Creek. Sunnyside Gold had undertaken some remediation around Gladstone up Cement Creek and the Mayflower tailings ponds along the Animas River above Silverton.

- 1998-2001 ~ First bulkhead in the American Tunnel had been installed, and a number of remediation projects had been completed by Sunnyside Gold under the consent decree. Sunnyside Gold was treating all of Cement Creek at Gladstone during low-flow and the residual flow from the American Tunnel. Because it was a historic drought year, 2002 was not included.

- 2007-2011 ~ New adit flows above Gladstone had stabilized, and the time period corresponded with WQCD's review of water quality in the basin.

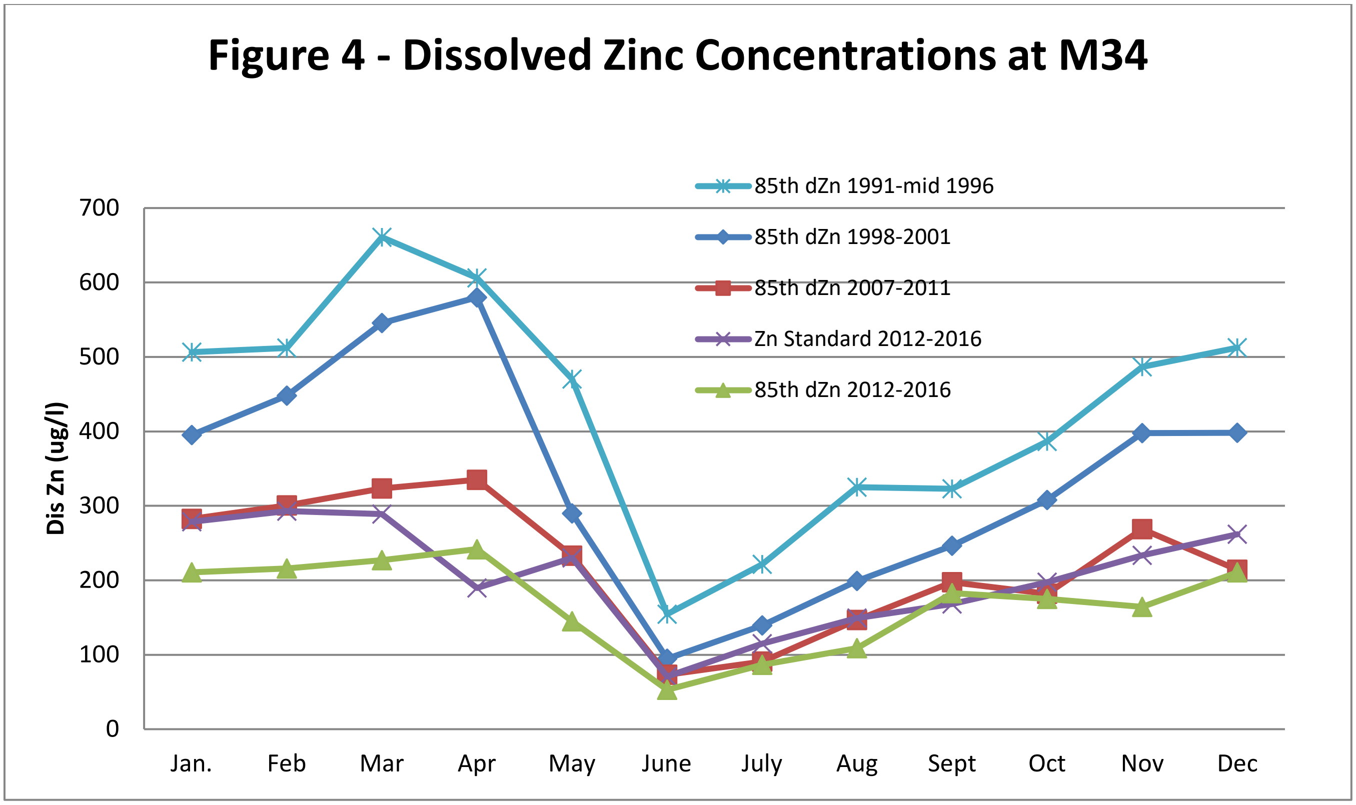
- 2012-2016 ~ Also corresponds with WQCD's review of the basin.

The analysis included the main metals of concern in the Animas Basin; aluminum, cadmium, copper, iron, lead, manganese, zinc, plus pH. Aluminum, iron, manganese, and pH have not appreciably changed at M34 over the twenty-five year time period. Sources for these constituents are generally much more natural than mining-related. Manganese concentrations are well below TVS. The accuracy of the lead data is questionable because the River Watch lab has a relatively high reporting limit, and River Watch data is often quite a bit higher than data collected by other entities such as EPA, USGS, and Bureau of Reclamation on the same days. The River Watch lead concentrations jump up and down dramatically from month to month. All M34 data and graphical analyses of different metals reside in Appendix E.

The three constituents that are associated with mining activity and whose concentrations were far above TVS before remediation began are cadmium, copper, and zinc. Those metals have all reacted similarly to remediation, so only zinc will be discussed in detail here.

The graph below shows the 85^{th} percentile of dissolved zinc data collected each month over a certain time period. During winter months, only one sample was collected per month. So over five years, the 85^{th} percentile may be calculated on only five samples. During the rest of the year, there were often multiple samples collected by various entities each month which should be more representative of actual water quality.

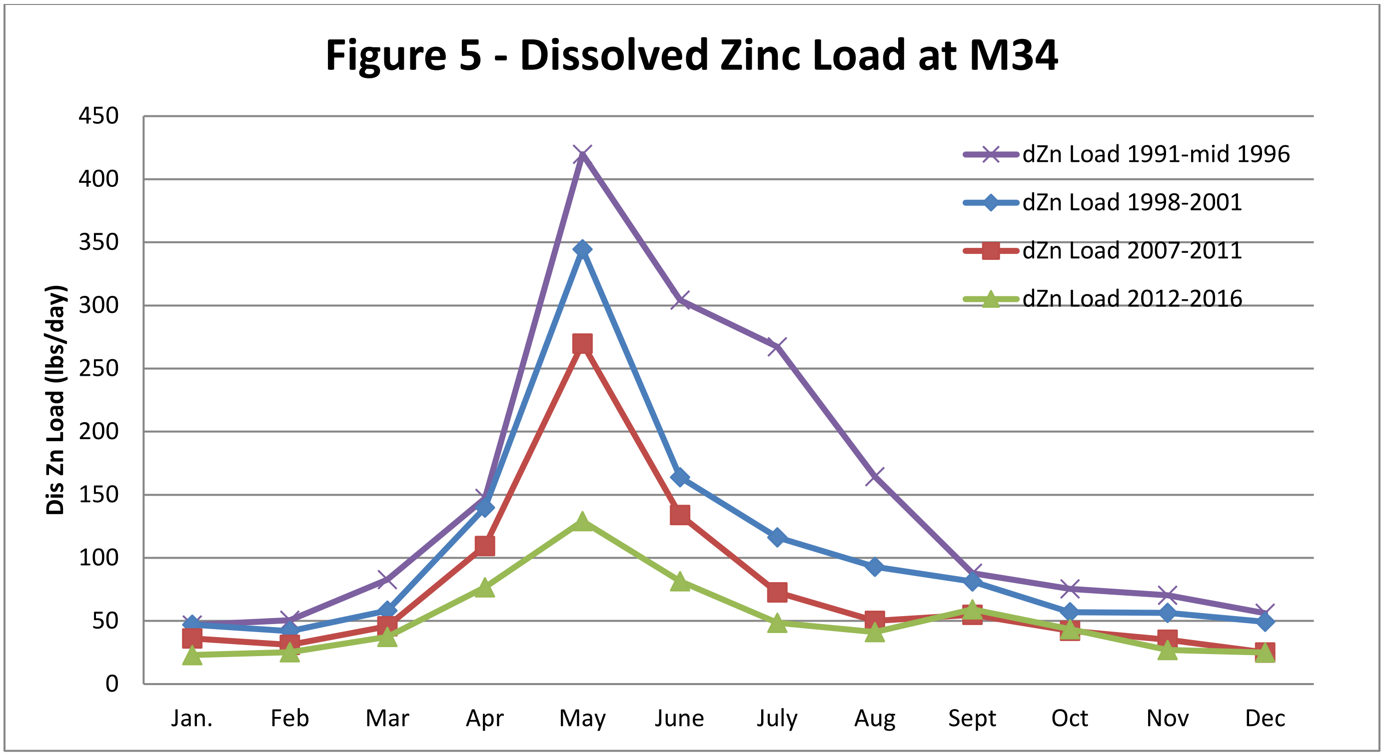
The water quality standard for zinc is also depicted. The standard is TVS, calculated for each month using the average hardness for that month over the specified years. May is an exception. The standard is 230 ug/l for that month as specified by WQCC at a hearing in 2001.



The percentage drop in dissolved zinc concentrations from 1991-mid 1996 to 2012-2016 varies from month to month but is generally between a 60-70%. The one exception is September where concentrations fell only 43%. In addition, dissolved zinc meets TVS nine months of the year and is very close to meeting TVS during the other three months.

Reductions in dissolved copper concentrations are very similar in magnitude and like zinc, copper meets TVS for nine months and is very close during the other three months. Reductions in cadmium are significant but not as large as copper and zinc. However, cadmium now meets EPA's cadmium criteria year-round.

Because there is a USGS flow gaging station at M34, metal loads can be calculated. ARSG calculated the zinc load by multiplying the 85^{th} percentile concentration for each month by the average daily flow for each month during the same time periods used in the graph above to get an average pounds-per-day figure for each month. Zinc doesn't precipitate until pH is around 8.0, higher than what is seen at M34, so dissolved zinc and total zinc concentrations are generally the same at this location.



The only remediation project that occurred between 1996 and 1998 was a mine waste project by Sunnyside Gold as noted above. Not surprisingly, the project appears to have had a much greater impact during spring runoff and during the summer monsoon season than the rest of the year. In addition, the hydrograph from 1998-2001 which were quite dry years may have reduced zinc loading as well. From 2001 forward, there were many mine waste and hydrologic control projects up until the 2015 Bullion King project which together reduced loading throughout the year.

Overall, zinc loading declined 70-80% during the summer months from 1991-mid 1996 to 2012-2016. Reductions during winter months ranged between 50-60%, while reductions in September-October were only 30-40%.

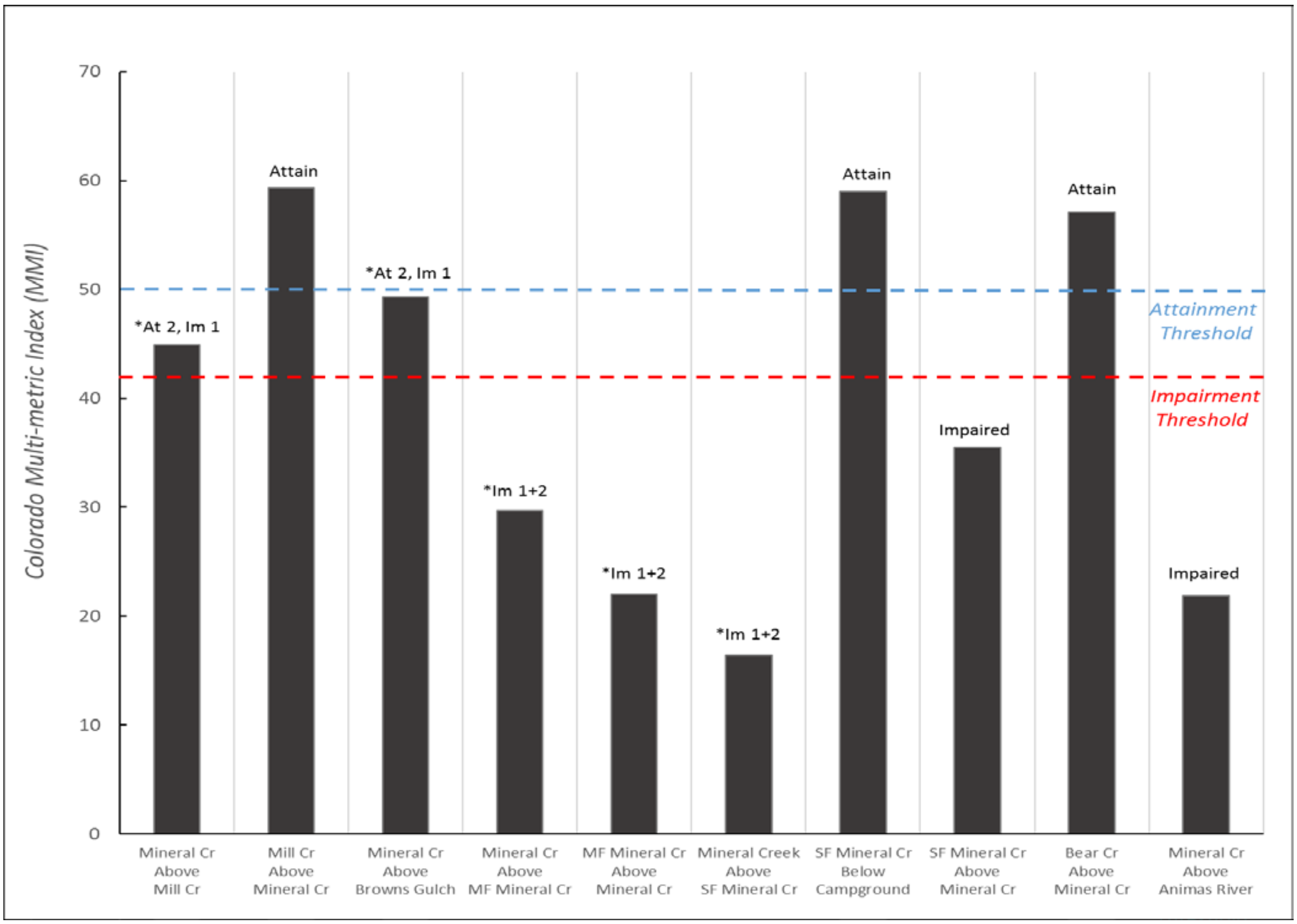
<u>Macroinvertebrate Data</u>

Using this 319 grant, ARSG contracted with the Mountain Studies Institute to sample and analyze macroinvertebrate populations in Porphyry Gulch before and after the Bullion King remediation project. Samples were collected a short distance below the site in July 2015 and July 2016. The samples showed improvement in 2016. However, macroinvertebrate populations collected in other similar streams in the Upper Animas Basin where there was no remediation also showed improvement indicating that other factors may have played a role. See Appendix F for a report on the sample analysis.

As described above, the full benefits of mine waste remediation may not be apparent for several years as an aquatic system flushes metals that may have collected in sediments in the past. A better picture of macroinvertebrate health near the Bullion King might be attained by collecting macroinvertebrates in another couple of years.

Although not part of this grant, recent macroinvertebrate work conducted for EPA shows that the improved water quality due to remediation will support some aquatic life above Burro Bridge. (See Appendices G1 & G2 for more details.) As shown below from that work in Figure 6, two locations upstream of Burro Bridge showed multi-metric index scores used by WQCD to fall between the impairment and attainment thresholds. (Burro Bridge lies between Browns Gulch and Middle Fork of Mineral Creek.) M34 shows significant macroinvertebrate impairment because of the high levels of aluminum and iron entering the creek below Burro Bridge. In addition, fish shocking by EPA in the summer of 2016 found brook trout a few yards upstream of the bridge. Currently, Mineral Creek above Burro Bridge has no aquatic life use classification under the Clean Water Act.

Figure 6 – Colorado Multi-Metric Index of Sites in Mineral Creek
(from Bonita Peak Mining District 2016 Benthic Macroinvertebrate Assessment by Scott Roberts, Appendix G1 in this Report.)



IV. CHARACTERIZING ARRASTRA GULCH – N/A

V. EDUCATION AND OUTREACH

Part of the purpose of the Bullion King Mine Waste Remediation Project was to provide outreach and education to the public about abandoned mines and mine remediation. Typically, ARSG's outreach is done through monthly or bi-monthly meetings in Silverton, occasional articles in local papers, a tour of mine sites once a year, and occasional presentations at conferences. The Gold King Mine release in August 2015 greatly expanded the audience ARSG would normally be able to reach. The group invested substantially more resources into public communication than it has done in the past. Grant money from this project funded much, but not all of the outreach conducted since the summer of 2015.

Shortly after the release, ARSG was inundated with questions from news organizations. In the span of four days directly after the spill, Peter Butler logged 120 calls from journalists on his home phone, not including calls to his cell phone. Bill Simon and Steve Fearn received a similar number of inquiries. Many of those interviews led to articles discussing the issues related to abandoned mines and remediation.

In addition, from 2015 to 2018, ARSG has given at least eleven tours and twenty-nine presentations to a wide range of audiences regarding abandoned mines, remediation and water quality. (See Appendix XX for list of those tours and presentations.) ARSG also continued to hold its typical monthly or bi-monthly meetings during this time period.