

RECLAMATION

Managing Water in the West

San Juan River Water Quality before, during and after the Gold King Mine Spill



U.S. Department of the Interior
Bureau of Reclamation
Technical Service Center
Denver, Colorado

June 2016

Mission Statements

The mission of the Department of the Interior is to protect and manage the Nation's natural resources and cultural heritage; provide scientific and other information about those resources; and honor its trust responsibilities or special commitments to American Indians, Alaska Natives, and affiliated island communities.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

The cover photograph appeared in the following EPA site on the web:
<https://www.flickr.com/photos/usepagov/20336641174/in/album-72157654862884644/>

San Juan River Water Quality before, during and after the Gold King Mine Spill

prepared by

Water Treatment Group, Technical Services Center
Frank Leitz, Chemical Engineer
Julie Korak, Ph.D., Environmental Engineer
Matt Hirschbeck, P.E., Environmental Engineer

reviewed by

Water Treatment Group, Technical Services Center
Robert Jurenka, P.E., Environmental Engineer

Four Corners Construction Office
Bart Deming, P.E., Design Group Chief
David Stoliker, P.E., Civil Engineer, Design Group
Chico Quintana, Civil Engineer, Design Group

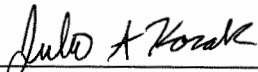


U.S. Department of the Interior
Bureau of Reclamation
Technical Service Center
Denver, Colorado

June 2016

San Juan River Water Quality before, during and after the Gold King Mine Spill

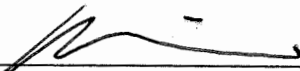
This Report was prepared by the U.S. Department of the Interior, Bureau of Reclamation, Technical Service Center, Denver, Colorado


Prepared: Julie Korak, Ph.D.
Environmental Engineer, Water Treatment Group 86-68190

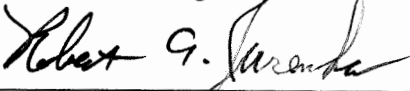
6/27/16
Date


Prepared: Frank Leitz
Chemical Engineer, Water Treatment Group 86-68190


27 Jun 2016
Date


Prepared: Matt Hirschbeck, P.E.
Environmental Engineer, Water Treatment Group 86-68190

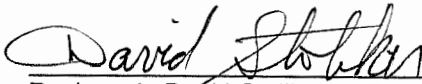
06/27/16
Date


Reviewed: Robert Jurenka, P.E.
Environmental Engineer, Water Treatment Group 86-68190

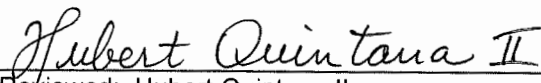
6/27/16
Date


Reviewed: Bart Deming, P.E.
Design Group Chief, Four Corners Construction Office

6/27/16
Date


Reviewed: David Stoliker, P.E.
Civil Engineer, Design Group, Four Corners Construction Office

6/27/16
Date


Reviewed: Hubert Quintana II
Civil Engineer, Design Group, Four Corners Construction Office

6/27/16
Date

Contents

	Page
List of Acronyms	x
Executive Summary	1
Introduction	1
Site Information and Hydrology.....	2
Sampling Campaigns and Surface Water Quality Data.....	7
Results	13
Water Quality at Gold King Mine Site.....	13
Turbidity.....	14
Total Recoverable Metals in Aquatic Samples.....	17
Dissolved Metals in Aquatic Samples.....	24
Total Recoverable Metals in Sediment Samples.....	29
Radionuclides.....	35
Organic Carbon.....	36
Conclusions	38
Recommendations for Future Work	39
Appendix A. Additional Figures	A-1
Appendix B. Quality Control Review of Reclamation Water Samples	B-1
Quality Control Approach.....	B-1
General Water Chemistry Analyses.....	B-1
Metals Analysis.....	B-3
Radioactive Constituents Analysis.....	B-4

List of Figures

Figure 1. Map showing the location of the Gold King Mine relative to the San Juan River in New Mexico.....	3
Figure 2. River flows above and below the confluence of the Animas and San Juan Rivers in July-September 2015.....	5
Figure 3. Observed daily precipitation for the Southwestern United States between August 25, 2015 and August 28, 2015.	6
Figure 4. Flows in Cement Creek and at various points in the Animas River during 2015.	7
Figure 5. Location of surface water sampling sites evaluated on the San Juan River.....	8

Figure 6. Sampling location for samples collected by BOR at the Hogback Diversion Channel.	10
Figure 7. Relationship between gauge height and turbidity at BOR SJHB Site in late 2015.....	15
Figure 8. Relationship between flow in the Animas River at Farmington, NM and suspended solids concentration for 1990-1993.....	16
Figure 9. Total iron measured in micrograms per liter from the three sampling locations.....	18
Figure 10. Hydrograph of the Animas River compared against total lead concentrations at EPA LVW-030.	19
Figure 11. Total lead measured in micrograms per liter from the three sampling locations.....	20
Figure 12. Total zinc measured in micrograms per liter from the three sampling locations.....	20
Figure 13. Total chromium measured in micrograms per liter from the three sampling locations..	21
Figure 14. Relationship between flow in the Animas River and select total metal concentrations prior to the Gold King Mine spill.	23
Figure 15. Hydrographs along Animas River during the days preceding and following the July 30, 2014 water quality analysis.....	24
Figure 16. Distribution of aluminum between suspended and dissolved forms during August-October 2015.	25
Figure 17. Fraction of analyte measured in the dissolved phased compared to the total recoverable metals during peak flow events at the EPA LVW-030 Site.....	26
Figure 18. Aluminum, calcium, iron, magnesium and potassium sediment concentrations at EPA LVW-030 in 2015.	30
Figure 19. Relative abundance of total recoverable metals in sediment sampled from the LVW-030 Site between August and October 2015.....	31
Figure 20. Mass of total recoverable metal at select sites along the Animas and San Juan Rivers.....	32
Figure 21. Distribution of total recoverable metals at each sampling location....	33
Figure 22. TOC and DOC at the Hogback Site following the Gold King Mine spill collected by Reclamation.....	36

Figure 23. Historical DOC concentrations measured at the Hogback Site prior to the Gold King Mine Spill collected and analyzed by USGS. 37

List of Tables

Table 1. Summary of surface water quality datasets included in evaluation 9

Table 2. Summary of water quality analyses conducted for BOR collected samples..... 11

Table 3. Average water quality for samples collected and analyzed by the EPA at the Gold King Mine Adit from August 10 – September 14, 2015..... 14

Table 4. Distribution of dissolved and total recoverable metals during spikes measured during peak flow events..... 28

Table 5. Sediment sample site collection information 31

Table 6. Percentage of total recoverable metal mass attributable to individual metals 34

Table 7. Radionuclides measured at the Hogback Site. 35

List of Supplemental Figures

Figure A- 1. Observed daily precipitation for the Southwestern United States between September 5, 2015 and September 8, 2015. A-1

Figure A- 2. Observed daily precipitation for the Southwestern United States between September 22, 2015 and September 25, 2015. A-2

Figure A- 3. Total aluminum measured in milligrams per liter from the three sampling locations.. A-3

Figure A- 4. Total antimony measured in micrograms per liter from the three sampling locations. A-3

Figure A- 5. Total arsenic measured in micrograms per liter from the three sampling locations. A-4

Figure A- 6. Total barium measured in micrograms per liter from the three sampling locations. A-4

Figure A- 7. Total beryllium measured in micrograms per liter from the three sampling locations. A-5

Figure A- 8. Total calcium measured in milligrams per liter from the three sampling locations..	A-5
Figure A- 9. Total cadmium measured in micrograms per liter from the three sampling locations..	A-6
Figure A- 10. Total cobalt measured in micrograms per liter from the three sampling locations..	A-6
Figure A- 11. Total copper measured in micrograms per liter from the three sampling locations..	A-7
Figure A- 12. Total lead measured in micrograms per liter from the three sampling locations..	A-7
Figure A- 13. Total magnesium measured in milligrams per liter from the three sampling locations..	A-8
Figure A- 14. Total manganese measured in micrograms per liter from the three sampling locations..	A-8
Figure A- 15. Total mercury measured in micrograms per liter from the three sampling locations..	A-9
Figure A- 16. Total molybdenum measured in micrograms per liter from the three sampling locations..	A-9
Figure A- 17. Total nickel measured in micrograms per liter from the three sampling locations..	A-10
Figure A- 18. Total potassium measured in milligrams per liter from the three sampling locations..	A-10
Figure A- 19. Total selenium measured in micrograms per liter from the three sampling locations..	A-11
Figure A- 20. Total silica measured in micrograms per liter from the three sampling locations..	A-11
Figure A- 21. Total silver measured in micrograms per liter from the three sampling locations..	A-12
Figure A- 22. Total sodium measured in milligrams per liter from the three sampling locations..	A-12
Figure A- 23. Total thallium measured in micrograms per liter from the three sampling locations..	A-13

Figure A- 24. Total vanadium measured in micrograms per liter from the three sampling locations. A-13

Figure A- 25. Total zinc measured in micrograms per liter from the three sampling locations. A-14

Figure A- 26. Hydrographs along Animas River during the days preceding and following the August 19, 2014 water quality analysis..... A-14

Figure A- 27. Barium, manganese and sodium sediment concentrations at EPA LVW-030 measured in 2015..... A-15

Figure A- 28. Vanadium and zinc sediment concentrations at EPA LVW-030 measured in 2015. A-15

Figure A- 29. Copper, arsenic and cobalt sediment concentrations at EPA LVW-030 measured in 2015. A-16

Figure A- 30. Chromium, lead and nickel sediment concentrations at EPA LVW-030 measured in 2015. A-16

Figure A- 31. Beryllium, cadmium and molybdenum sediment concentrations at EPA LVW-030 measured in 2015. A-17

List of Acronyms

ADW-022	Sediment sampling site (see text for location)
cfs	cubic feet per second
EPA	U.S. Environmental Protection Agency
EPA SJHB	Surface water sampling site (see text for description)
FCCO	Four Corners Construction Office
FNU	formazin nephelometric units
MCL	Maximum contaminant level
MRL	Minimum reporting level
mg/kg	milligrams of analyte per kilogram of sediment
mg/L	milligrams per liter
µg/L	micrograms per liter
LVW-030	EPA sampling site on San Juan River
MW-020	Sediment sampling site (see text for location)
NGWSP	Navajo-Gallup Water Supply Project
NTU	nephelometric turbidity units
Reclamation	Bureau of Reclamation
SJL	San Juan Lateral
SED01	Sediment sampling site (see text for location)
SED02	Sediment sampling site (see text for location)
USGS	U.S. Geological Survey
WTP	Water treatment plant

Executive Summary

On August 5, 2015, an event at the Gold King Mine (Level 7 New Adit) in Colorado released mine drainage into Cement Creek. Cement Creek flows into the Animas River near Silverton, Colorado. The Animas River converges with the San Juan River about 22 miles upstream from the Navajo-Gallup Water Supply Project's (NGWSP) proposed intake for the San Juan Lateral (S JL) Water Treatment Plant (WTP). Water diverted at the Hogback Diversion Channel is also used for irrigation purposes. Some of the chemical constituents released are hazardous and/or regulated under the Safe Drinking Water Act. As San Juan River water quality is influenced by events in contributing watersheds, the effect of the Gold King Mine spill on water quality in the San Juan River is of interest. The purpose of this study was to evaluate the effect of this spill event on water quality for the design, planning, operation and maintenance of the proposed NGWSP S JL intake and WTP near the Hogback Diversion Channel by analyzing recent and historical data as part of this project's design data collection.

Water quality measurements were taken by the Bureau of Reclamation (Reclamation) at the proposed intake site (Hogback Site) immediately after the spill between August 7-17, 2015. Chemical analyses included total and dissolved metals, turbidity, organic carbon and radionuclides. In addition to samples collected by Reclamation, extensive water and sediment analyses were conducted along the Animas and San Juan Rivers by the U.S. Environmental Protection Agency (EPA), which were publically published. For water quality analyses, Reclamation samples were compared to EPA samples collected near the Hogback Site and near Upper Fruitland, NM about 14.2 miles upstream. The U.S. Geological Survey (USGS) measured and published river flow and turbidity measurements in the affected watersheds; some data were marked provisional and are subject to revision. This report includes measurements collected through October 14, 2015. Historical data at the Hogback Site were collected in the Hogback Diversion Channel and analyzed by USGS, at Reclamation's request, between June 26, 2014, and July 29, 2015. Measurements collected by multiple agencies at similar locations and times were in good agreement with each other.

Reclamation observed a small increase in the concentration of total inorganic species (i.e., aluminum, arsenic, iron, lead, and silver among others) at the Hogback Site from August 7 to August 9, 2015, which corresponded to the estimated arrival of the drainage plume. The EPA continued almost daily sampling at a site several miles upstream from the Hogback Site through mid-October. At this site, significant increases in metals were observed at three discrete times after the spill event on August 27, September 6, and September 24, 2015, where the total concentration of multiple metals increased concomitantly (Figure ES-1). During these events, concentrations of both dissolved and total

Executive Summary

metals increased. In some cases, the dissolved metal concentrations exceeded a primary or secondary maximum contaminant level (MCL) or an Action Level, as outlined by the Safe Drinking Water Act. Although MCLs are based on total concentrations, dissolved metal concentrations were compared to the MCL, because particulate matter is likely to be removed by sedimentation and filtration water treatment processes. The observed spikes in metal concentrations corresponded with a rapid increase in the Animas River flow and the occurrence of precipitation events in the Animas River watershed.

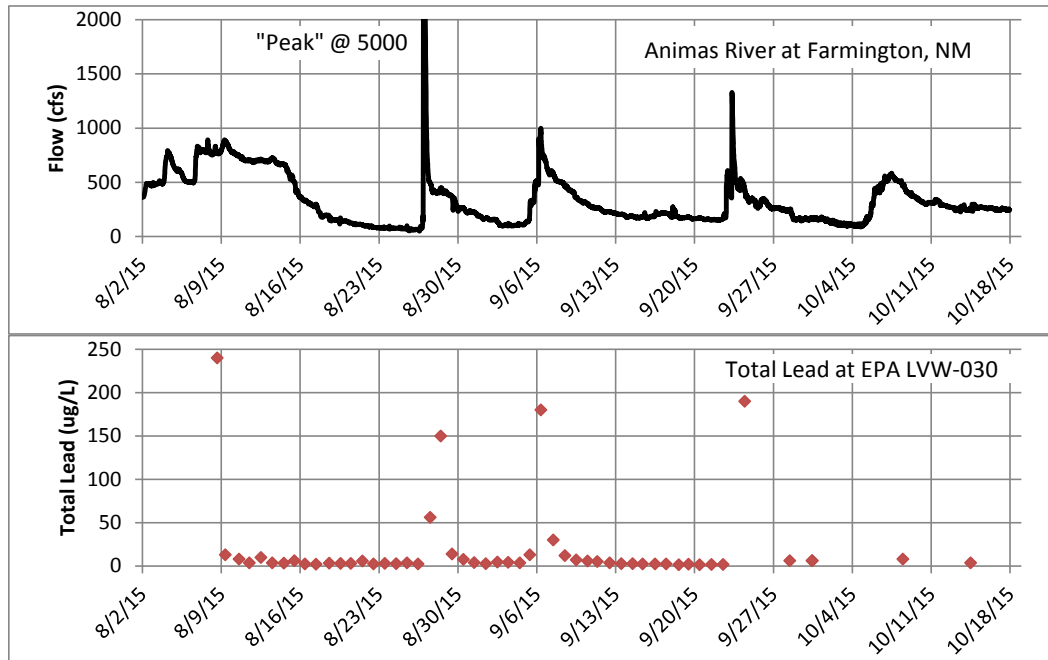


Figure ES-1. Flow in the Animas River at Farmington, NM and total lead concentration at the EPA LVW-030 sampling site 22 miles upstream from the Hogback Site.

The observed concentration increases were compared to the historical dataset (USGS) at the Hogback Site prior to the Gold King Mine spill and found a similar trend. Several historical samples exhibited similar increases in metal concentrations that correspond with flow increases in the Animas River, but these increases were not observed during spring snow run-off in April-June 2014. These results suggest that the observed concentration increases after the Gold King Mine spill cannot be fully attributed to the spill as similar historical trends were observed, and the relationship between flow and metal concentration is complex.

Sediment analyses along the San Juan and Animas Rivers suggest that sediment loadings and export in the Animas watershed have an important impact on water quality at the Hogback Site. Concentrations of total recoverable metals are greater higher up in the Animas River watershed compared to another sampling location on the San Juan River below the Animas River confluence. The chemical composition of the sediment appeared to be relatively consistent throughout the watershed by comparing the relative abundance of total recoverable metals between samples collected at various points along the Animas and San Juan

Rivers. Some trace metals exhibited measurable enrichment or depletion compared to total recoverable metals along the watershed. Since flow in the Animas River is unmanaged and subject to large variations, it is likely that these sudden, significant increases in metal concentration have been occurring historically and will continue to occur in the future.

Before the spill, the effect of flow events on the Animas River increased total and dissolved metal concentrations in the San Juan River was not well understood. The Gold King Mine spill led to a sampling campaign with daily sampling for several months, which provided the sampling resolution necessary to capture these spiking events and offer new insight to water quality fluctuations in the San Juan River.

Finally, the report provides recommendations regarding future work in this area. Due to limited funding, the scope and breadth of this report is limited. Additional work placing these results into the context of the large body of knowledge related to the water quality and geochemistry in these watersheds is needed. Temporal variations in water quality at the Hogback Site could be better understood with more frequent sampling targeting periods where the Animas River flow is volatile. A better understanding between the dissolved water quality and sediment transport is warranted.

Introduction

An incident at the Gold King Mine (Level 7 New Adit) resulted in the release of water from the mine adit. According to the US Environmental Protection Agency (EPA),

“On August 5, 2015, EPA was conducting an investigation of the Gold King Mine near Silverton, Colorado... While excavating above the old adit, pressurized water began leaking above the mine tunnel, spilling about three million gallons of water stored behind the collapsed material into Cement Creek, a tributary of the Animas River.... The large pulse of water dissipated in about an hour.¹”

The Animas River flows into the San Juan River about 22 miles upstream of the Hogback Site, where water for the San Juan Lateral (SJL) portion of the Navajo-Gallup Water Supply Project (NGWSP) is to be withdrawn. The history of mining in the watershed, prevalence of acid mine drainage and assessment of the spill are well-documented elsewhere². The purpose of this study was to evaluate the effect of this spill event on water quality for the design, planning, operation and maintenance of the proposed NGWSP SJL intake and water treatment plant (WTP) near the Hogback Diversion Channel by analyzing recent and historical data as part of this project’s design data collection.

The scope of this project included a technical review of available water quality data pertaining to the Gold King Mine spill and an assessment of possible changes in water quality as a result of the spill. Water quality data for samples collected by the Bureau of Reclamation (Reclamation) Four Corners Construction Office (FCCO) at the Hogback Site between August 7-17, 2015 were reviewed for quality control. These results were compared to other publically available water quality data from the area, including datasets collected by the US Environmental Protection Agency (EPA) and U.S. Geological Survey (USGS), to ascertain changes in water quality as a result of this spill and potential future events. While this report contains data published by EPA and USGS, neither organization was involved in the preparation or review of this report.

¹ www.epa.gov/goldkingmine/how-did-august-2015-release-gold-king-mine-happen

² Readers are referred to the following source for more information.

Church, S.E., von Guerard, Paul, and Finger, S.E., eds., 2007, Integrated investigations of environmental effects of historical mining in the Animas River watershed, San Juan County, Colorado: U.S. Geological Survey Professional Paper 1651, 1,096 p. plus CD-ROM. [In two volumes.]

Site Information and Hydrology

The Gold King Mine is located on the North Branch of Cement Creek within the Animas River watershed just north of Silverton, Colorado. The mine operated intermittently from 1887 to 1922 producing 711,144 tons of gold and silver ore³. Mine drainage from the Gold King Mine began after the nearby Sunnyside mine was closed in 1991. In a report from 2009, portals at the Gold King Mine had drainage flows ranging between 150 gpm and 300 gpm⁴. For context, 200 gpm equals about 158 million gallons per year. For perspective, if the 3,000,000 gallons estimated to be released on August 5th occurred within 2 hours, this equates to an average flow of 25,000 gpm over the short period of time. Since the spill on August 5th, 2015, drainage has continued to exit the mine adit. Following the release on August 5th, the EPA estimates that 42,525,641 gallons has flowed from Gold King Mine between 8/6/2015 and 9/21/2015 at flow rates between 300 and 800 gpm⁵.

In this report, the term ‘spill’ will be used to refer to the event that occurred on August 5th and be used to describe water quality observations before and after that event. The term ‘mine drainage’ refers to the material (suspended and dissolved) flowing from any mine adit.

The Animas River flows into the San Juan River at Farmington, New Mexico, as shown in Figure 1. The proposed intake for the NGWSP is located near the Hogback Diversion Channel, downstream of the Animas-San Juan River confluence. Understanding the influences of mine drainage and potential mine spill events within the watershed is necessary for use of the San Juan River as source water for potable and non-potable uses.

³ <http://www.epa.gov/sites/production/files/2015-08/documents/goldkingminewatershedfactsheetbackground.pdf>

⁴ <http://www.epa.gov/sites/production/files/2015-10/documents/1570604.pdf>

⁵ <http://www.epa.gov/sites/production/files/2015-10/documents/1622632.pdf>

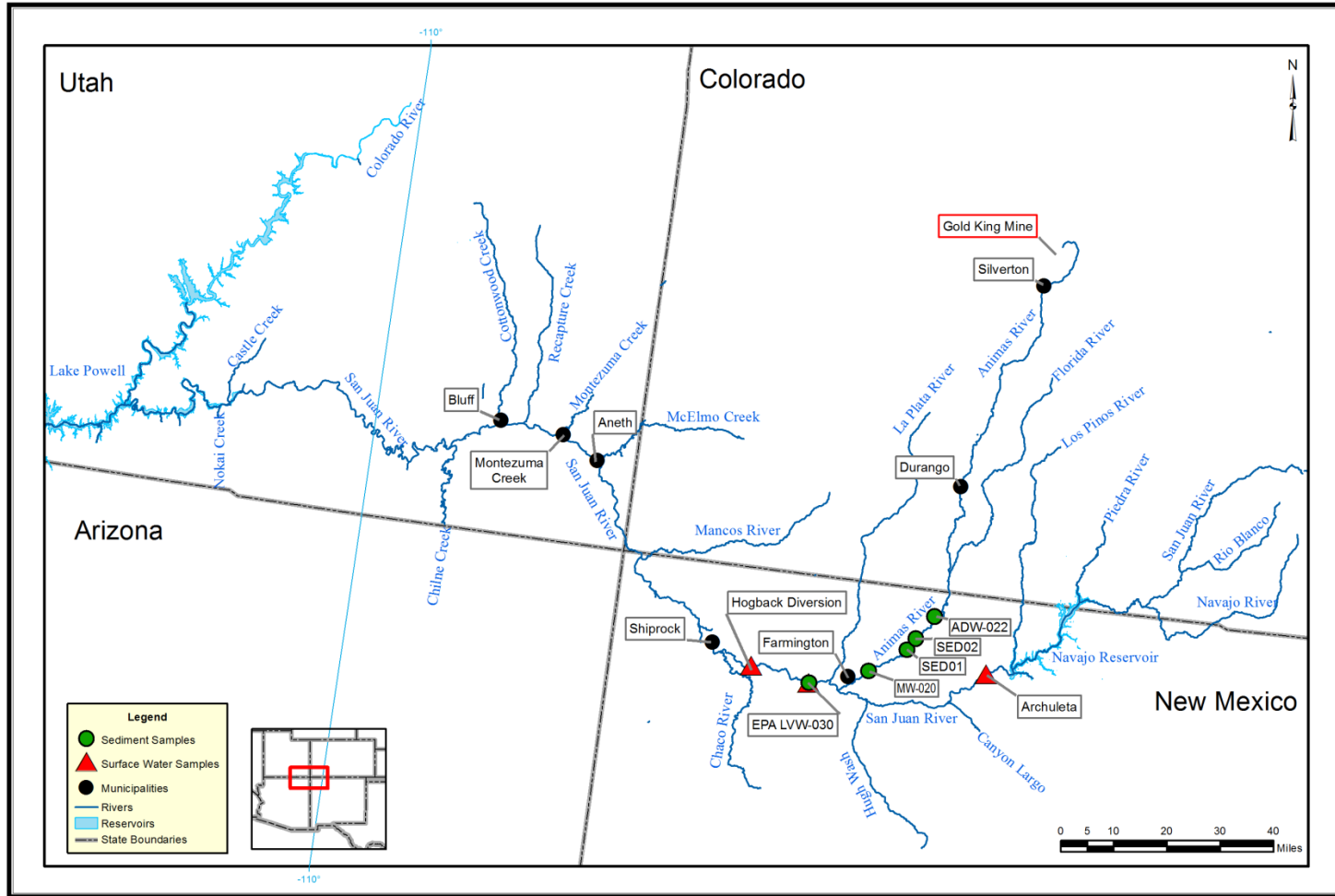


Figure 1. Map showing the location of the Gold King Mine relative to the San Juan River in New Mexico

The hydrology of the Animas and San Juan Rivers is important for understanding material transport through the watershed. Figure 2 shows USGS river hydrographs at three monitoring locations in northern New Mexico. Some data were marked provision at the time of data access⁶. Flows in the San Juan River near Archuleta, NM are rather constant due to controlled releases from the Navajo Reservoir. Water release from the reservoir was increased after the spill (August 6-10, 2015) from 670 cfs to 1330 cfs in an attempt to dilute the plume⁷. As an uncontrolled river, the Animas River exhibits large fluctuations in flow, which are also observed in the San Juan River downstream of the confluence near Shiprock, NM. Therefore, periods of higher flow on the San Juan River downstream of the confluence are largely caused by fluctuations in the tributaries. Although the spill at the mine occurred on August 5th, the effects of the primary mine drainage plume are observed at later times throughout the watershed due to the travel time between mine site and monitoring locations. For example, the main plume was observed at the Hogback Diversion on August 8th, about 3 days following the spill. Around the time of the spill (August 3 – 9, 2015) , there were several precipitation events in the four corners area causing a four-fold increase in flow in the San Juan at Shiprock, NM. Changes in river flow, dispersion within the river channel and chemical reactions within the river (e.g., precipitation) all affect the water quality as the initial plume travels down the watershed.

Rain events in the two months following the spill have a large impact of the watershed hydrology. After the spill, the sharp increases in flow observed in Figure 2 were caused by three significant precipitation events in Southwest Colorado on August 28, September 6 and September 24, 2015, as shown in Figure 3, Figure A- 1, Figure A- 2.

⁶ USGS National Water Information System (http://waterdata.usgs.gov/nm/nwis/current?parameter_cd=STATION_NM,DATETIME,00065,00060,MEAN).

⁷ <http://www.usbr.gov/rsvrWater/faces/rvrOSMP.xhtml>

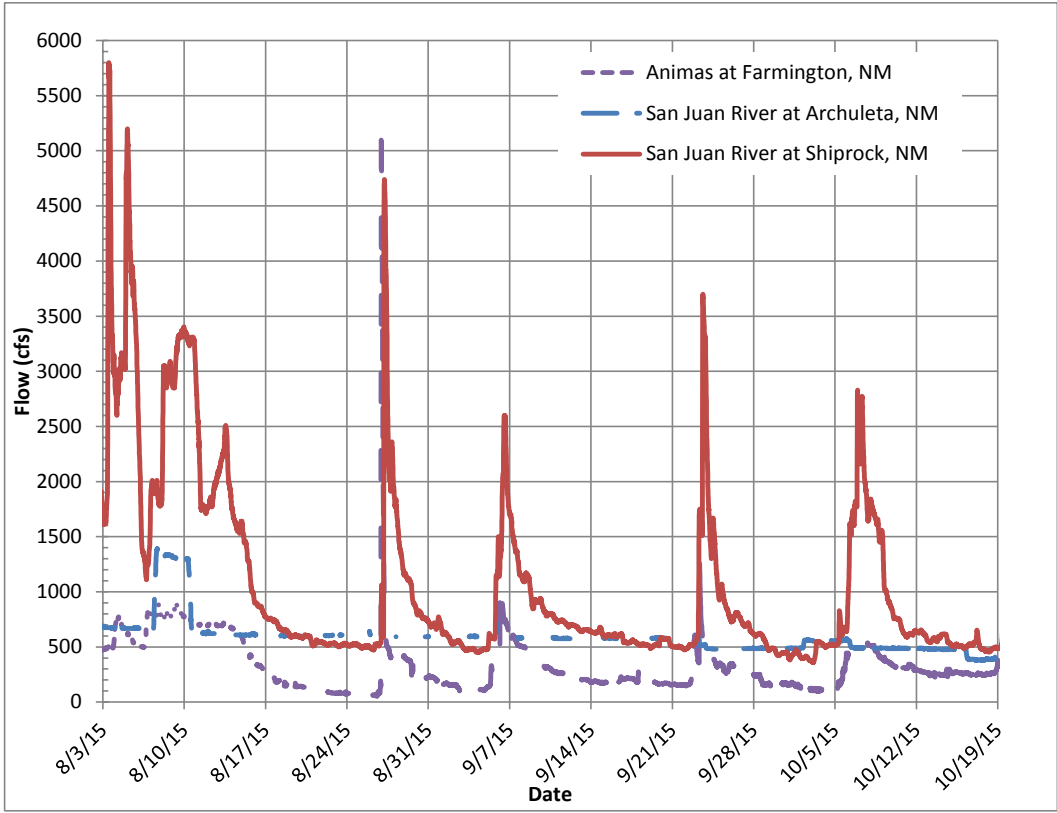


Figure 2: River flows above and below the confluence of the Animas and San Juan Rivers in July-September 2015. Some data was marked provisional by USGS at the time of report preparation.

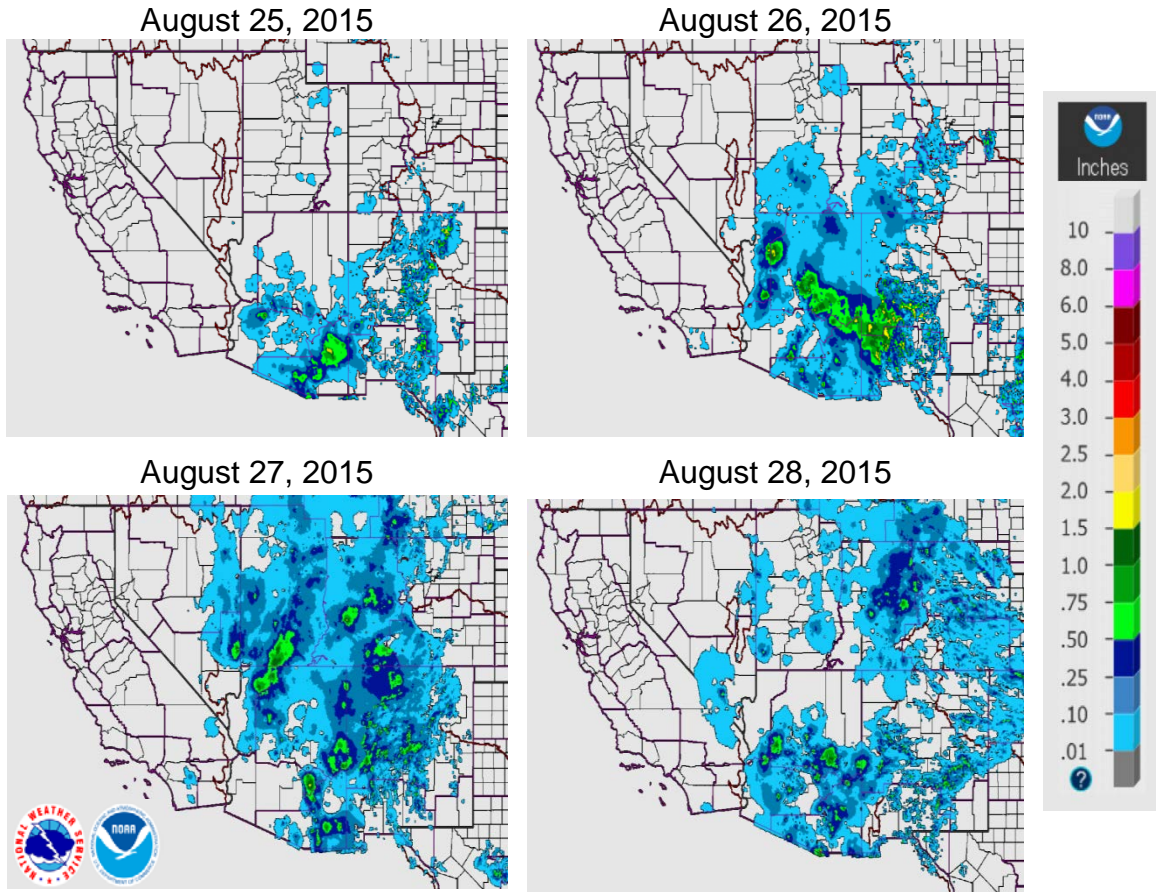


Figure 3. Observed daily precipitation for the Southwestern United States between August 25, 2015 and August 28, 2015. Figures generated from the National Weather Service and National Oceanic and Atmospheric Administration. Plots of additional precipitation events in Figure A- 1 and Figure A- 2.

Mine drainage from Gold King Mine entered Cement Creek before flowing into the Animas River. Figure 4 shows flows at various points along the Animas River relative to Cement Creek and attests to the size of the Animas River watershed. Flows in Cement Creek and the Animas River at Silverton, CO are small compared to monitoring locations lower in the watershed. During rain events, small fluctuations are recorded in Silverton but the largest fluctuations are observed in northern New Mexico.

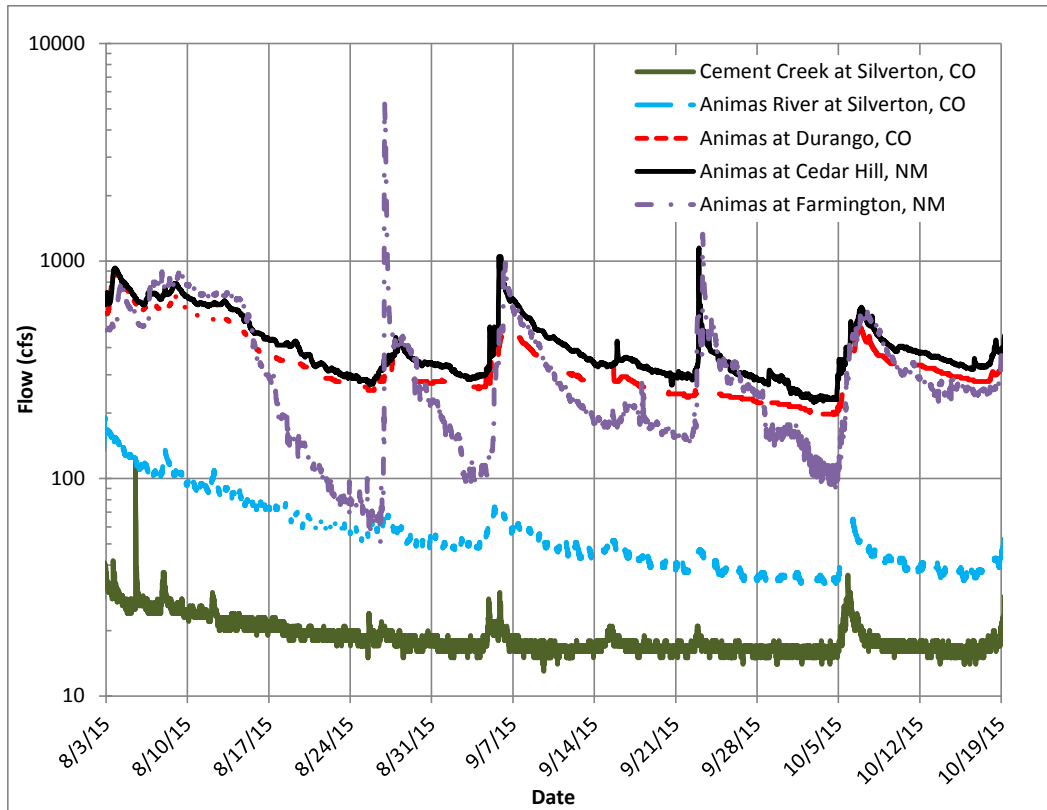


Figure 4. Flows in Cement Creek and at various points in the Animas River during 2015. Some data was marked provisional by USGS at the time of report preparation.

The EPA estimates that approximately 3 million gallons of drainage (11,000,000 liters) entered Cement Creek with a large pulse dissipating in about an hour⁸. A stream gauge located on Cement Creek at Silverton, CO recorded a rapid flow increase from about 25 cfs to 120 cfs on August 5 that returned to 25 cfs after a few hours as shown in Figure 4.

Sampling Campaigns and Surface Water Quality Data

In response to the spill and out of concern for the effects on water quality in the San Juan River, several entities collected surface water samples from the San Juan River. These datasets were analyzed in parallel in this report to demonstrate general agreement between the data and to provide a greater context to evaluate temporal water quality changes in the San Juan River. A summary of the surface water data sets included in this report is given in Table 1. A map of the San Juan River below Farmington, NM showing the relationship between sampling sites is presented in Figure 5.

⁸ < <http://www.epa.gov/goldkingmine/how-did-august-2015-release-gold-king-mine-happen> >

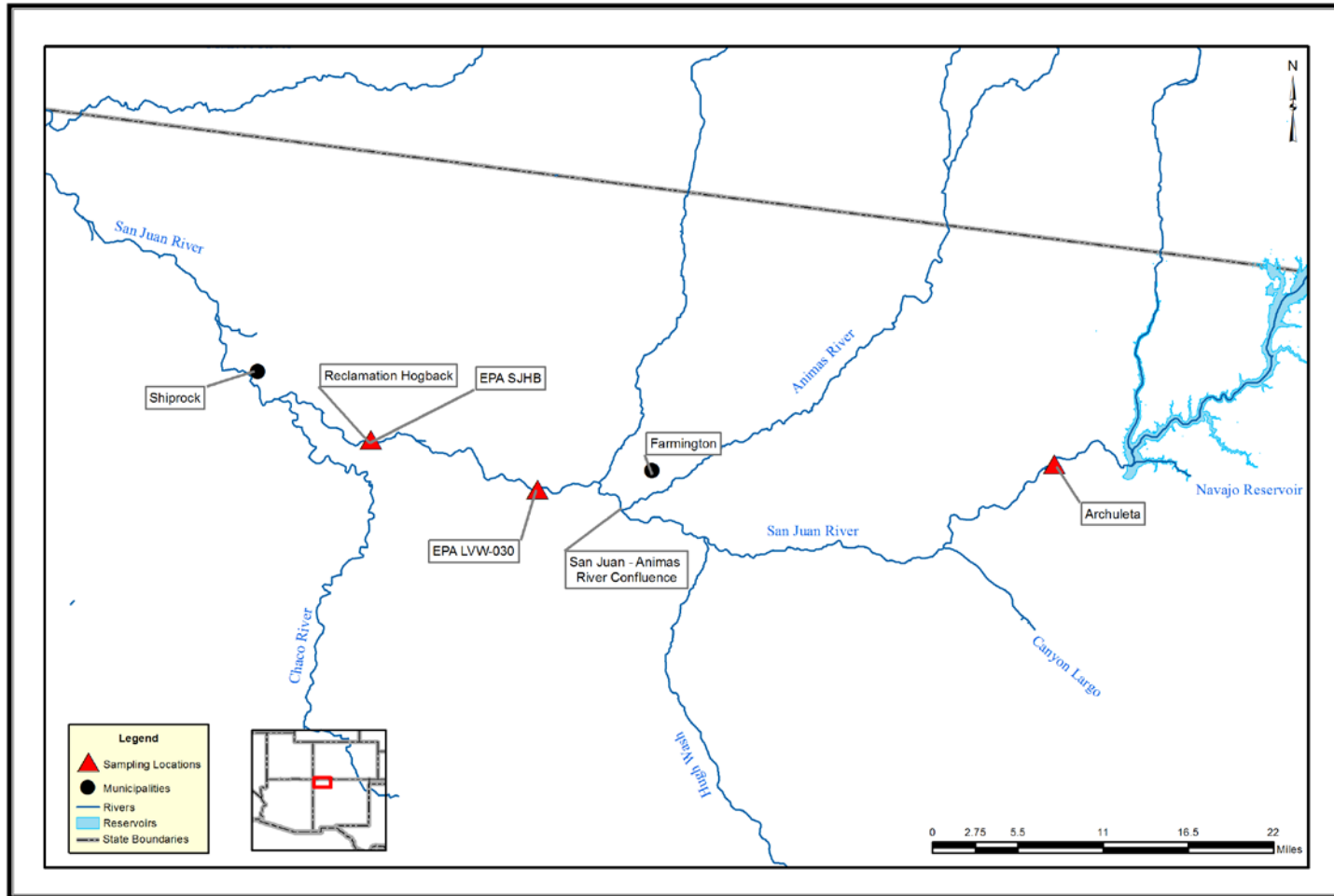


Figure 5. Location of surface water sampling sites evaluated on the San Juan River.

Table 1. Summary of surface water quality datasets included in evaluation

Site Name	Sampling Agency	Coordinates (Latitude, Longitude)	Dates Sampled	No. Samples
Reclamation Hogback	Reclamation	(36.746203, -108.537652)	8/7/15 – 8/17/15	9
Reclamation Hogback	USGS ⁹	(36.746361, -108.538028)	6/26/14 – 7/29/15	11
EPA LVW-030	EPA ¹⁰	(36.721812, -108.325933)	8/8/15 – 10/14/15	52
EPA SJHB	EPA ¹¹	(36.74519199, -108.5377578)	8/7/15 – 8/27/15	16

Reclamation collected nine (9) water samples in August 2015 from the Hogback Site that were analyzed for a suite of water quality parameters. Images of the Reclamation sampling location are presented in Figure 6. Samples were collected about 10 feet from the shore and 6-12 inches below the water surface. At the trashrack, the water depth is about 5-6 feet. Samples were collected from the south shore of the San Juan River across from the trash rack. The sampling location was near an eddy line. As the water levels rose starting on August 7th, 2015, the south shore eddy was filling a side channel in the river that was dry.

EPA analyzed samples at many locations within the affected watershed, and surface water data from two sites are evaluated in this report. The EPA SJHB sampling location is near the Reclamation Hogback Site. The EPA LVW-030 Site is located upstream of the Hogback Site near Upper Fruitland, NM. Details about sample collection at the EPA sites are not known.

Prior to the spill starting in June 2014, USGS, per Reclamation's request, collected and analyzed samples at the Reclamation Hogback Site for water quality and sediment loading to assist with the design of the SJL WTP. Samples were collected at the trashrack. Details about samples collected by USGS are not known.

⁹ Data publically available at <<http://nwis.waterdata.usgs.gov/nwis/qwdata?>>

¹⁰ Data publically available at < <http://www.epa.gov/goldkingmine/data-gold-king-mine-response>>

¹¹ Data publically available at < <http://www.epa.gov/goldkingmine/data-gold-king-mine-response>>



Figure 6. Sampling location for samples collected by BOR at the Hogback Diversion Channel.

The Reclamation-collected samples were analyzed by Green Analytical Laboratory in Durango, CO. Samples were collected in bottles provided by the lab that were appropriate for the specific method. A summary of the analytical analyses performed is provided in Table 2.

Table 2. Summary of water quality analyses conducted for BOR collected samples

General Name	Method	Specific Analytes
Total Recoverable Metals by ICP	EPA 200.7	Aluminum, Calcium, Iron, Magnesium, Potassium, Silicon, Sodium, and Silica (by calculation)
Total dissolved metals by ICP	EPA 200.7	Aluminum, Calcium, Iron, Magnesium, Potassium, Silicon, Sodium, and Silica (by calculation)
Total Recoverable Metals by ICPMS	EPA 200.8	Antimony, Arsenic, Barium, Beryllium, Cadmium, Chromium, Copper, Lead, Manganese, Nickel, Selenium, Silver, Thallium, Uranium, Zinc
Dissolved Metals by ICPMS	EPA 200.8	Arsenic, Manganese, Nickel, Zinc
Hardness	Standard Method 2340 B	Hardness (dissolved and total)
Cyanide	EPA 335.4	Total cyanide
pH	EPA 150.1	
Total Suspended Solids (TSS)	EPA 160.2	
Turbidity	EPA 180.1	
Total Mercury	EPA 245.1	
Organic Carbon	Standard Method 5310 C	Total organic carbon (TOC) and dissolved organic carbon (DOC)
²²² Radon Activity	Standard Method 7500-Rn	
Gross alpha activity	EPA 00-02	
Gross beta activity	900.0	
Radium 226 Activity	GammaRay HPGE	Total radium computed as summation.
Radium 228 Activity	GammaRay HPGE	

The Reclamation data were reviewed for quality control. Details and review results are presented in Appendix B. In brief, appropriate collection and handling procedures were used for the samples, and appropriate methods were used for each analyte. For most analytes, quality control samples (i.e., laboratory blanks, laboratory control samples and matrix spiked samples) were within specified limits. Some analyses (i.e., organic carbon, hardness, radioactive nuclides) were not reported with supplemental quality control data. A couple of quality control issues arose upon review of the data. Some pH and turbidity measurements were conducted past the method holding times, but this is not expected to significantly impact data interpretation. The turbidity value reported on 8/8/15 is likely erroneous as a turbidity of 32 NTU is not likely to occur in a sample where the total suspended solids concentration is 3370 mg/L. This turbidity value should be excluded as an outlier. One sample (8/7/15) indicated that there may be analyte suppression for sodium, but suppression does not appear to be systemic in all samples.

Since three different entities (i.e., USGS, Green Analytical Labs and EPA) analyzed samples in this composite dataset, method reporting limits (MRLs)

varied between analytical source and between days. Variations in reporting limits between days are often due to instrument performance, blank detection or sample dilution prior to analysis. In all the graphs presented in this report, samples with measured concentrations below the MRL are plotted at the MRL but with an unfilled marker to indicate the MRL. Some USGS samples from the historical Reclamation Hogback dataset were annotated as being above the detection limit but below the MRL. Without additional information regarding the MRL, these data are reported as listed with a filled marker since they were above the method detection limit. In general, the MRLs for the samples analyzed by Green Analytical were significantly higher than samples analyzed by EPA and USGS.

Results

Water Quality at Gold King Mine Site

Limited information is available regarding the water quality of the mine drainage that entered Cement Creek on August 5, 2015, but thirteen water quality samples collected between 8/10/15 and 9/14/15 from the mine adit were reported by EPA¹². Table 3 reports the average values and shows that the mine drainage is enriched in metals, such as aluminum, iron, manganese and zinc. The term ‘metals’ will be used to refer to a broad range of inorganic moieties measured by the EPA 200.8 and 200.7 methods, even though several species are not true metals. Although it has been reported that treatment ponds have been used to neutralize the drainage and precipitate solids¹³, it is assumed that the data reported is representative of the drainage composition prior to treatment given the low pH values. Trace metals (i.e., arsenic, cadmium, and lead) that are regulated under the Safe Drinking Water Act were measured in the mine drainage.

¹² <http://www.epa.gov/sites/production/files/2015-10/documents/1622632.pdf>

¹³ <https://www.epa.gov/goldkingmine/frequent-questions-related-gold-king-mine-response>

Table 3. Average water quality for samples collected and analyzed by the EPA at the Gold King Mine Adit from August 10 – September 14, 2015.

Parameter	Units	Total	Dissolved
Alkalinity	(mg/L)	5 U	
Aluminum	(µg/L)	31,083	30,417
Antimony	(µg/L)	3.39	1.95
Arsenic	(µg/L)	45.8	21.8
Barium	(µg/L)	10.2	9.49
Beryllium	(µg/L)	9.6	9.37
Cadmium	(µg/L)	72.2	74.7
Calcium	(µg/L)	362,500	355,000
Chloride	(mg/L)	0.363 J	
Chromium	(µg/L)	4.6	3.71
Cobalt	(µg/L)	111	111
Copper	(µg/L)	5,892	5,983
Fluoride	(mg/L)	10.5	
Iron	(mg/L)	141,667	125,750
Lead	(µg/L)	41.9	34.3
Magnesium	(µg/L)	25,500	24,917
Manganese	(µg/L)	34,083	34,667
Mercury	(µg/L)	0.08 U	0.08 U
Molybdenum	(µg/L)	5.21	2.85
Nickel	(µg/L)	67.4	67.1
Nitrate as N	(mg/L)	0.042	
pH	SU	3.02	
Potassium	(µg/L)	2525	2483
Selenium	(µg/L)	4.97	5.465
Silver	(µg/L)	0.162	0.153
Sodium	(µg/L)	3,384	3,067
Sulfate	(mg/L)	1758	
Thallium	(µg/L)	0.331	0.338
Total Hardness	(mg/L)	1,010	
Vanadium	(µg/L)	31.3	14
Zinc	(µg/L)	25,750	26,000
U indicates the analyte was analyzed for but not detected above the quantitation limit. Quantitation limit is listed.			
J Result is less than the reporting limit but greater than or equal to the method detection limit and the concentration is an approximate value.			

Turbidity

Turbidity and gage height meters located in the Hogback Diversion Channel recorded changes in the months following the spill. Since these measurements were taken in the channel and not the main channel of the San Juan River, interpretation of the data is subject to whether or not the diversion gates were reported to be open. The diversion gates reportedly were closed around August 7, 2015 in anticipation of the drainage plume and were never reopened through the remainder of 2015. After gate closure, changes in gage height are assumed to be from changes in hydrostatic pressure between the river and channel and subsequent gate leakage, and therefore are not representative of the conditions as if the gates were open. The USGS turbidity measurements are also subject to

whether or not the probe was submerged. Missing data is assumed to correspond to sampling times when the probe was not submerged.

Increases in gage height and turbidity in the channel were observed as shown in Figure 7. Gauge height is presented in Figure 7, because flow data is not available past August 19. The USGS site states that the relationship between gage height and discharge is, “being developed or revised”. The dates of these turbidity spikes correspond with significant precipitation events in the area that caused rapid flow increases in the Animas River (Figure 2 and Figure 3). While the data in Figure 7 must be interpreted in the context of the diversion gates being closed, they do show a relationship between increases in river flow and turbidity. Turbidity increases can be a surrogate measure for increases in suspended material in the San Juan River.

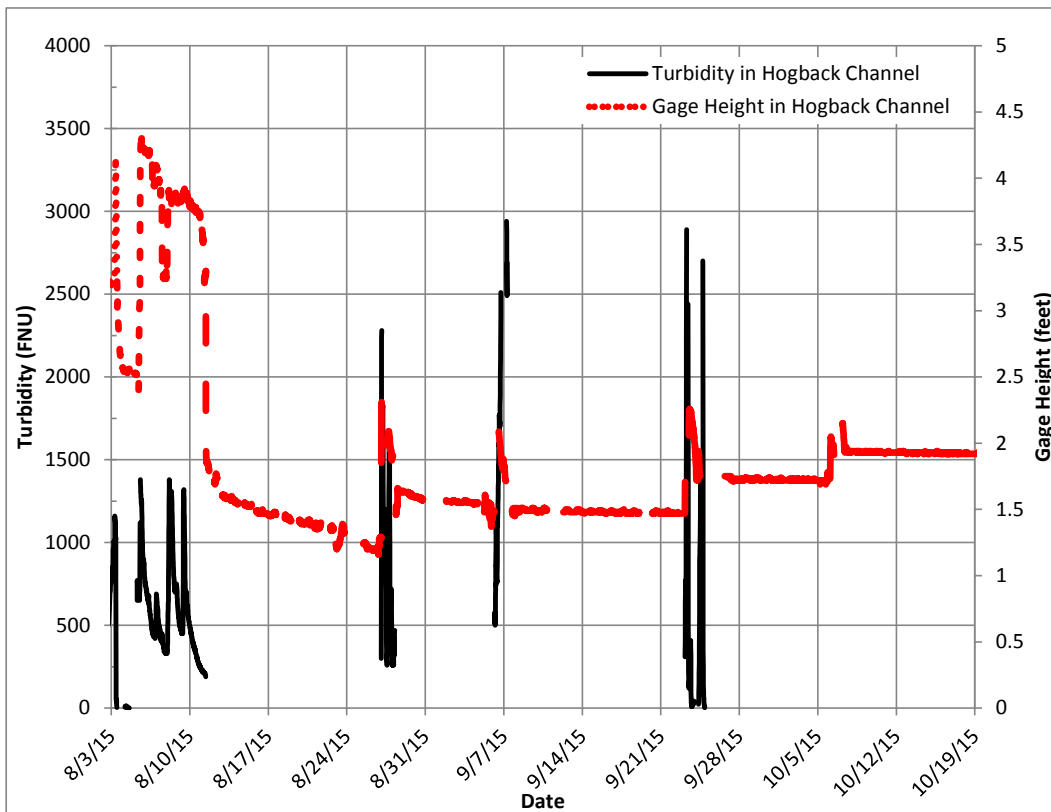


Figure 7. Relationship between gauge height and turbidity at BOR SJHB Site in late 2015.¹⁴ Some data in figure is still provisional. Upper range for turbidimeter is 3000 FNU. Some data was marked provisional by USGS at the time of report preparation.

The relationship between flow and suspended solids in the Animas River can be further supported using historical data from a USGS stream gauge that measured both parameters from 1990 to 1993. Figure 8 shows that flow increases in the

¹⁴http://nwis.waterdata.usgs.gov/nm/nwis/uv/?cb_00060=on&cb_00065=on&cb_63680=on&format=rdb&site_no=09367580&period=&begin_date=2015-07-15&end_date=2015-11-16

Animas River can produce higher suspended sediment concentrations. This data in conjunction with the 2015 data at the Hogback Site demonstrate that rapid changes in river flow can have a significant impact on water quality by increasing suspended solids concentration.

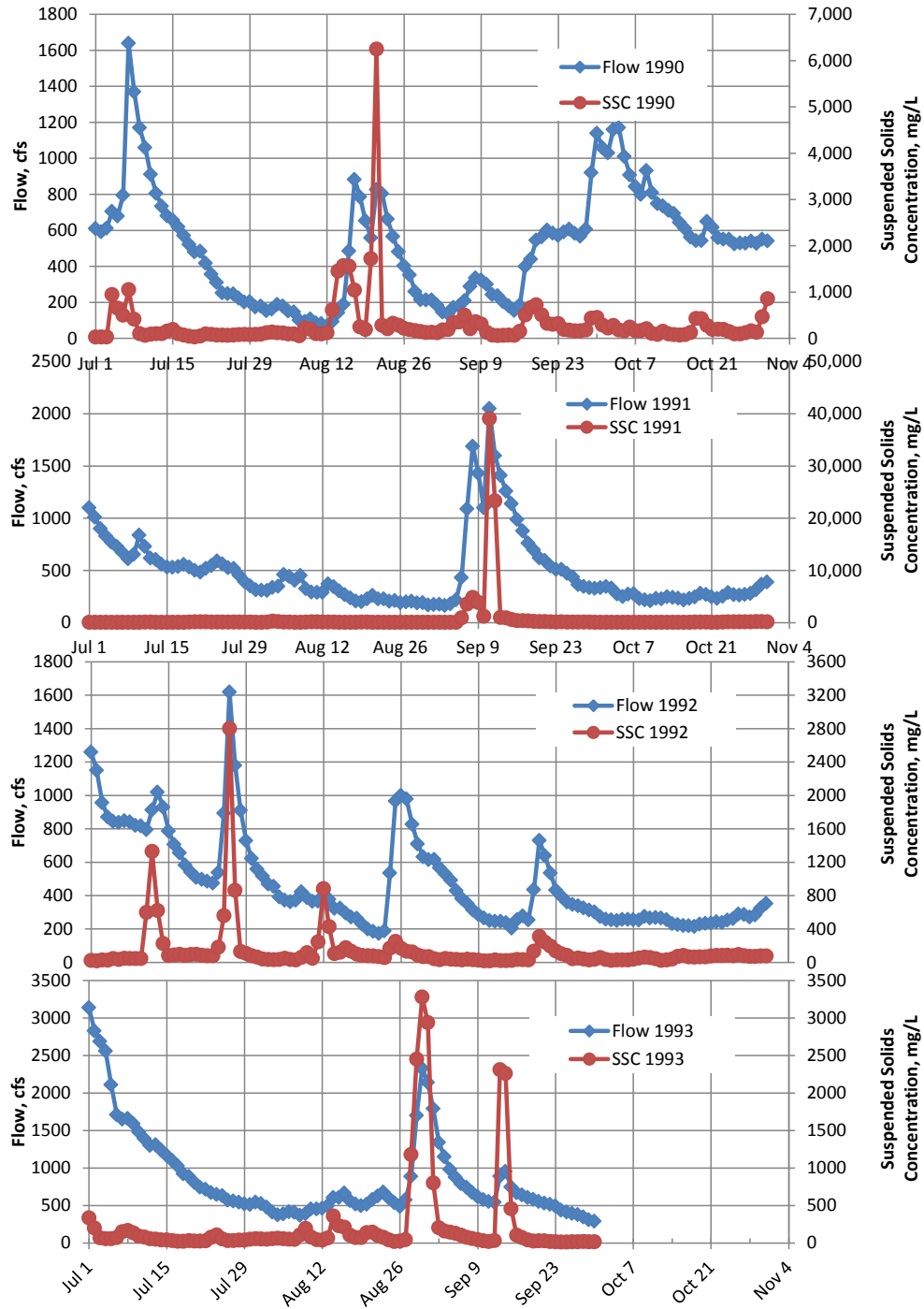


Figure 8. Relationship between flow in the Animas River at Farmington, NM and suspended solids concentration for 1990-1993.

Total Recoverable Metals in Aquatic Samples

Metals are a primary concern given the nature of the drainage with iron being one of the most abundant constituents. The term ‘metals’ will be used to refer to a broad range of inorganic moieties measured by the EPA 200.8 and 200.7 methods, even though several species are not true metals. Figure 9 through Figure 13 show how the total concentration (dissolved plus particulate) of iron, lead, zinc and chromium varied during the weeks following the spill. Data for all metals analyzed are included in Appendix A (Figure A- 3 to Figure A- 25). In general, the data show good agreement between the three sampling sites with one exception, which is addressed below.

According to local news reports, the mine drainage plume reached the confluence with the San Juan River on the evening of August 7¹⁵. Samples collected on August 8 from all three sites indicate elevated levels of total metals compared to the preceding days. In the days following the plume arrival (August 16- August 23), concentrations decreased and were relatively constant during this time period. The EPA SJHB sample collected on August 11 was in poor agreement with the Reclamation Hogback and EPA LVW-030 samples collected on the same day. The EPA SJHB sample showed a spike in total concentration for multiple metals that the other two samples did not. Differences in concentration were also observed for samples collected by the EPA on the same day between the EPA SJHB and EPA LVW-030 sites. Discrepancies in sample concentration between samples could be due to a number of factors, including sampling times and river hydraulics at each sampling site. If the concentration of metals spiked rapidly (as observed weeks later and discussed below), samples collected hours apart can yield very different results. Additionally, river hydraulics and sampling location within the water column can also yield very different water quality results. For suspended particulate material, more material can be suspended in faster moving water compared to slow. Even though the EPA and Reclamation samples were collected 3 hours apart, different concentrations may be observed if samples were collected from different hydrologic regimes in the river.

While the Reclamation Hogback and EPA SJHB Sites stopped sampling after the third week of August, the EPA continued to collect and analyze samples from the EPA LVW-030 Site through mid-October. These results suggest that the effects of metal loading in the watershed extend beyond the passing of the mine drainage plume. Significant spikes in metal concentrations were measured at the EPA LVW-030 Site on 8/28/15, 9/6/15 and 9/24/15. In general, these increases are greater than those observed on August 8-9 right after the approximate date the plume reached the San Juan River. These increases in concentration correspond with periods where the Animas River and San Juan River flow rates increased significantly over a short period of time due to a rain event in the watershed. Recall that Figure 2 shows the hydrograph for the Animas River in Farmington

¹⁵ <http://www.ladaily.com/content/contaminated-plume-gold-king-mine-toxic-spill-expected-pass-aztecfarmington-area-evening>

(before the confluence with the San Juan River) and the San Juan River at Shiprock, NM between August and mid-October 2015. The occurrence of increased metal concentrations aligns with periods of high flows as illustrated for lead in Figure 10. There is roughly a one-day lag time between the rise in the Animas River flow and observed increases in metals at the EPA LVW-030 Site. Precipitation data from the National Weather Service also show large precipitation events during this time in Southwest Colorado and Northwest New Mexico corresponding to river flow increases (Figure 3, Figure A- 1 and Figure A- 2).

Total Iron

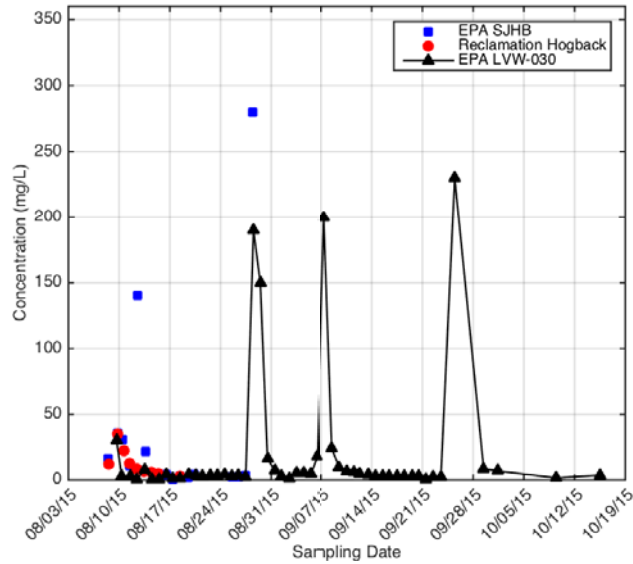


Figure 9. Total iron measured in micrograms per liter from the three sampling locations. No EPA data prior to August 2015 is available at the Reclamation Hogback Site.

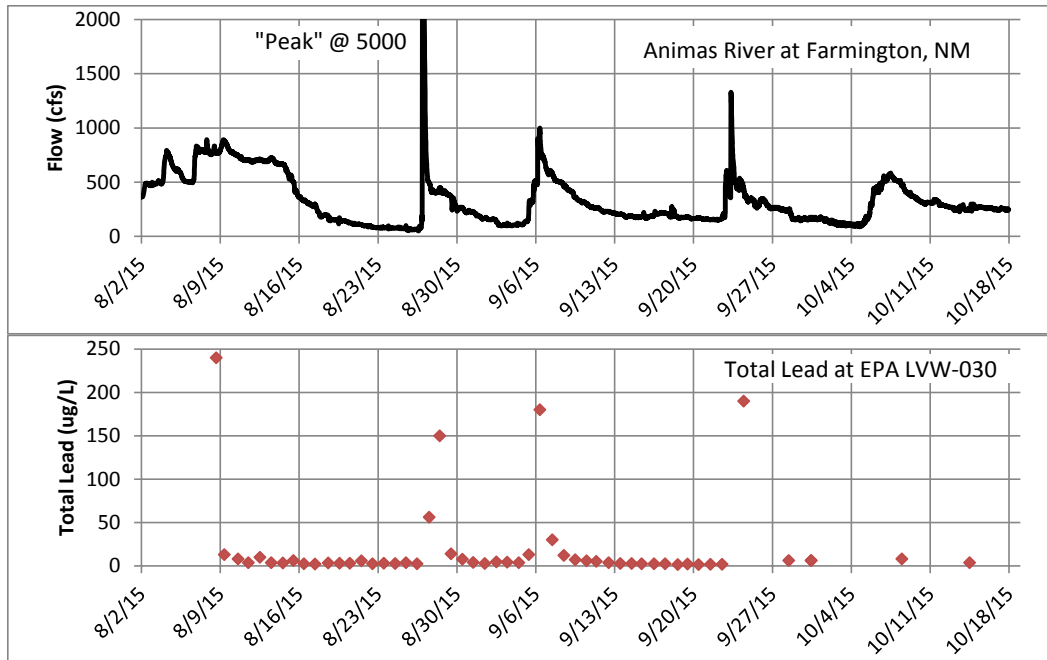


Figure 10. Hydrograph of the Animas River compared against total lead concentrations at EPA LVW-030. USGS data flow data was marked provisional at the time of report preparation.

The observed concentrations for measured trace metals on August 8-9, 2015 were compared to historical data from the Reclamation Hogback Site to determine how the elevated levels compare to past measurements. For most metal species, at least one historical sample occurred with a higher measured concentration than the concentrations observed when the mine drainage plume reached the San Juan River. For *total* metal concentration, the analytes for which historical measurements exceeded August 8-9 peak values include: aluminum, arsenic, barium, calcium, chromium, copper, manganese, nickel, silver, sodium, uranium and zinc. Historical measurements were also greater than August 8-9 measurements for the following *dissolved* constituents: calcium, manganese and nickel. The concentrations observed on August 8-9 do not exceed historical values for most analytes. The only inorganic analytes where August 8-9 values exceeded the limited historical values include total arsenic, lead, potassium, iron and silica. There are no historical data to compare results to for total calcium, cyanide, hardness (by the EPA 200.2 metals method), magnesium, silicon, and sodium.

Total Lead

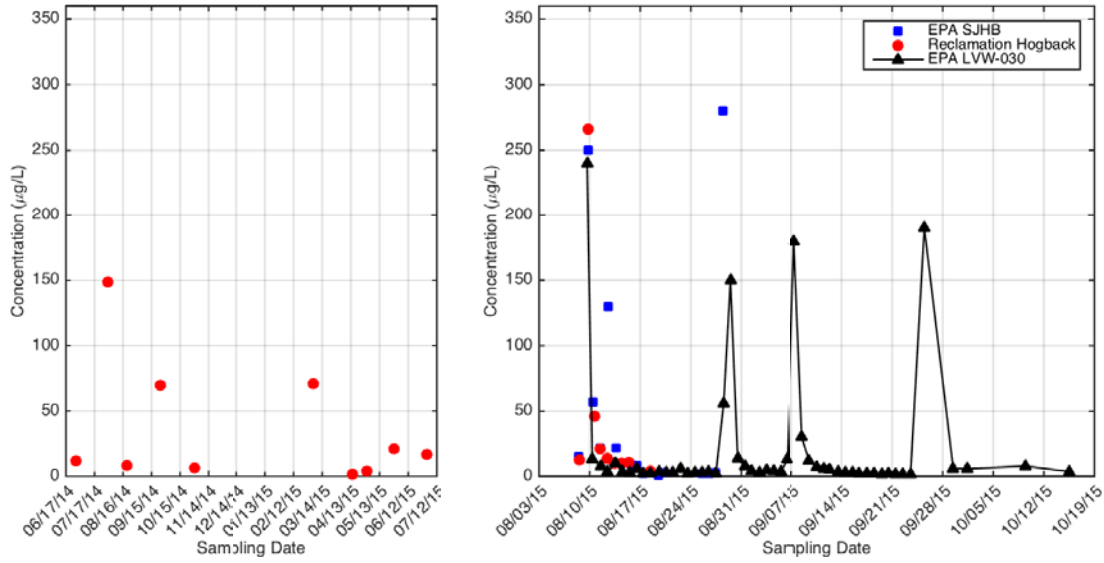


Figure 11. Total lead measured in micrograms per liter from the three sampling locations. The left pane indicates pre-spill data and the right pane indicates post-spill data.

Total Zinc

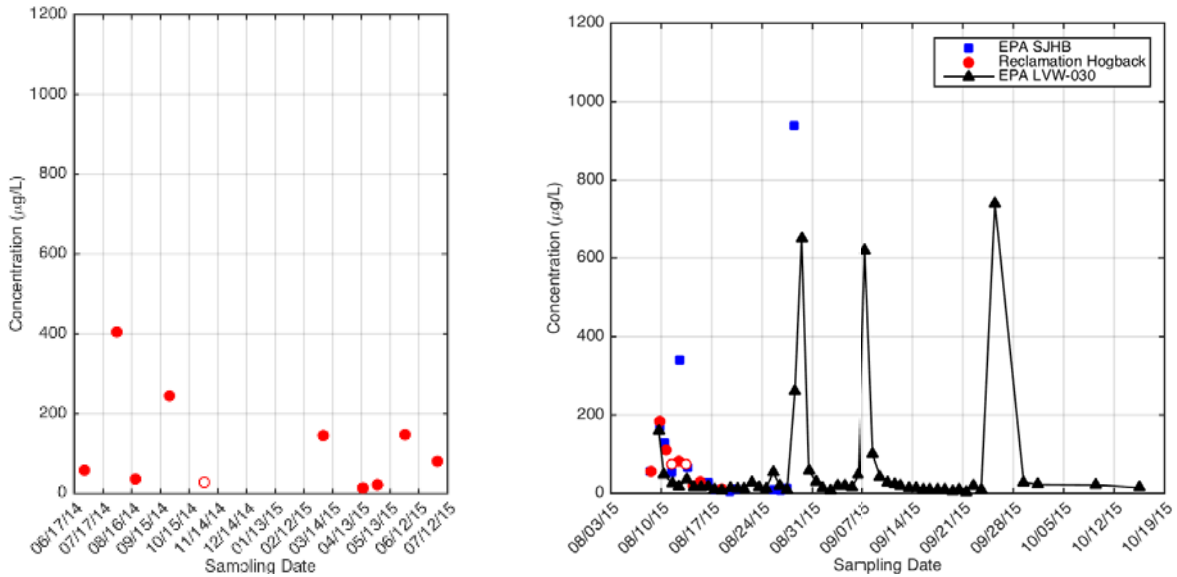


Figure 12. Total zinc measured in micrograms per liter from the three sampling locations. The left pane indicates pre-spill data and the right pane indicates post-spill data. Unfilled markers indicate values reported at the MRL.

Total Chromium

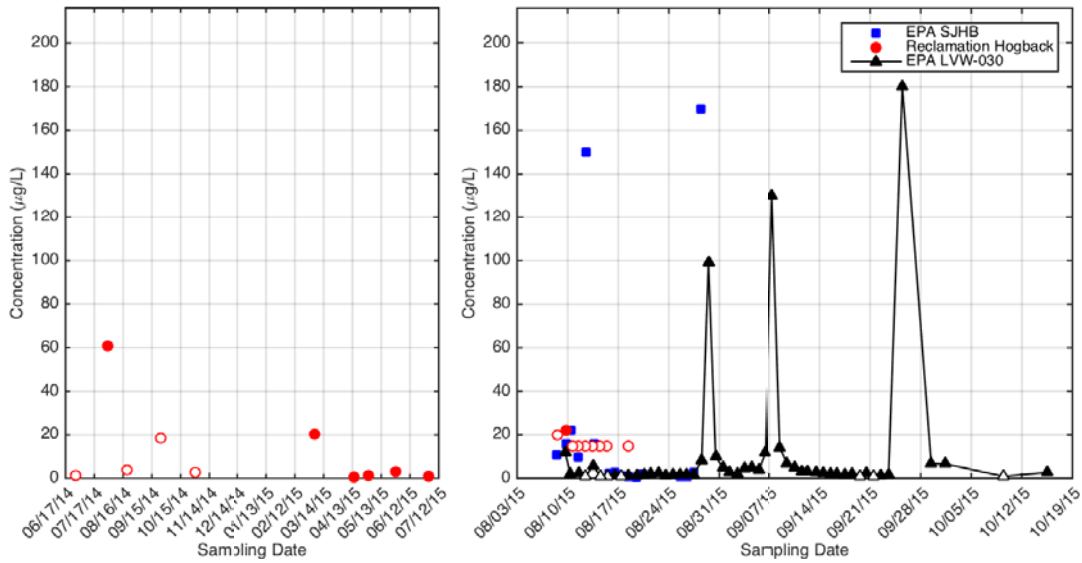


Figure 13. Total chromium measured in micrograms per liter from the three sampling locations. The left pane indicates pre-spill data and the right pane indicates post-spill data. Unfilled markers indicate values reported at the MRL.

It is difficult to determine if the increased metals observed during increased flow events in August-September, 2015 originated from the Gold King Mine or from the other abandoned mines within the Animas River watershed. According to a report studying mining effects in the Upper Animas watershed, there are at least 375 mines, mills and mill-tailings in a study site that only included a relatively small 143 square mile region surrounding Silverton, CO¹⁶.

Historical data show that metal concentrations in the San Juan River before the spill are similar in magnitude to concentrations observed post-spill, suggesting that the spill event is not solely responsible for the elevated metal concentrations observed in August-September, 2015. A sample collected on 7/30/14 recorded total metal concentrations similar to spikes post-spill as shown for total lead in Figure 11. When this sample was collected, a similar hydraulic episode occurred in the Animas River where there was a rapid increase in flow on the same day as sampling.

The relationship between flow in the Animas River and total metal concentrations in the San Juan River is complex and not mutually exclusive. While an increase in San Juan River metal concentration is often accompanied by an increase in Animas River flow, the opposite is not necessarily true (i.e., an increase in flow yielding an increase in metals) as shown in Figure 14. Elevated metal concentrations observed in 7/2014, 9/2014 and 3/2015 were accompanied by a

¹⁶ Church, S.E., von Guerard, Paul, and Finger, S.E., eds., 2007, Integrated investigations of environmental effects of historical mining in the Animas River watershed, San Juan County, Colorado: U.S. Geological Survey Professional Paper 1651, 1,096 p. plus CD-ROM.

rapid increase in Animas River flow. Figure 15 illustrates that the Animas River rose sharply at the time of sampling of the 7/30/14 sampling event that recorded elevated metal concentrations. In contrast, the low total metal concentrations measured on August 19, 2014 correspond to low, stable flows in the watershed as shown in Figure A- 26. For the 3/2015 sample, the daily average flow in the Animas increased from 835 cfs to 965 cfs (a 15% increase) overnight, which may have provided a sufficient increase in river velocity to promote sediment transport. However, samples collected during snow run-off (April – June 2015) do not exhibit the same increases in concentration. This effect is likely a result of the complex relationship between the rate of metal loading, transport and dilution in the watershed.

A recommendation is made to increase sampling frequency in the San Juan River to coincide with precipitation and run-off events. Elevated metal concentrations are likely to be observed more often simply due to the extent of mining impact in the Animas River watershed, and the relationship between concentration and flow can be better understood.

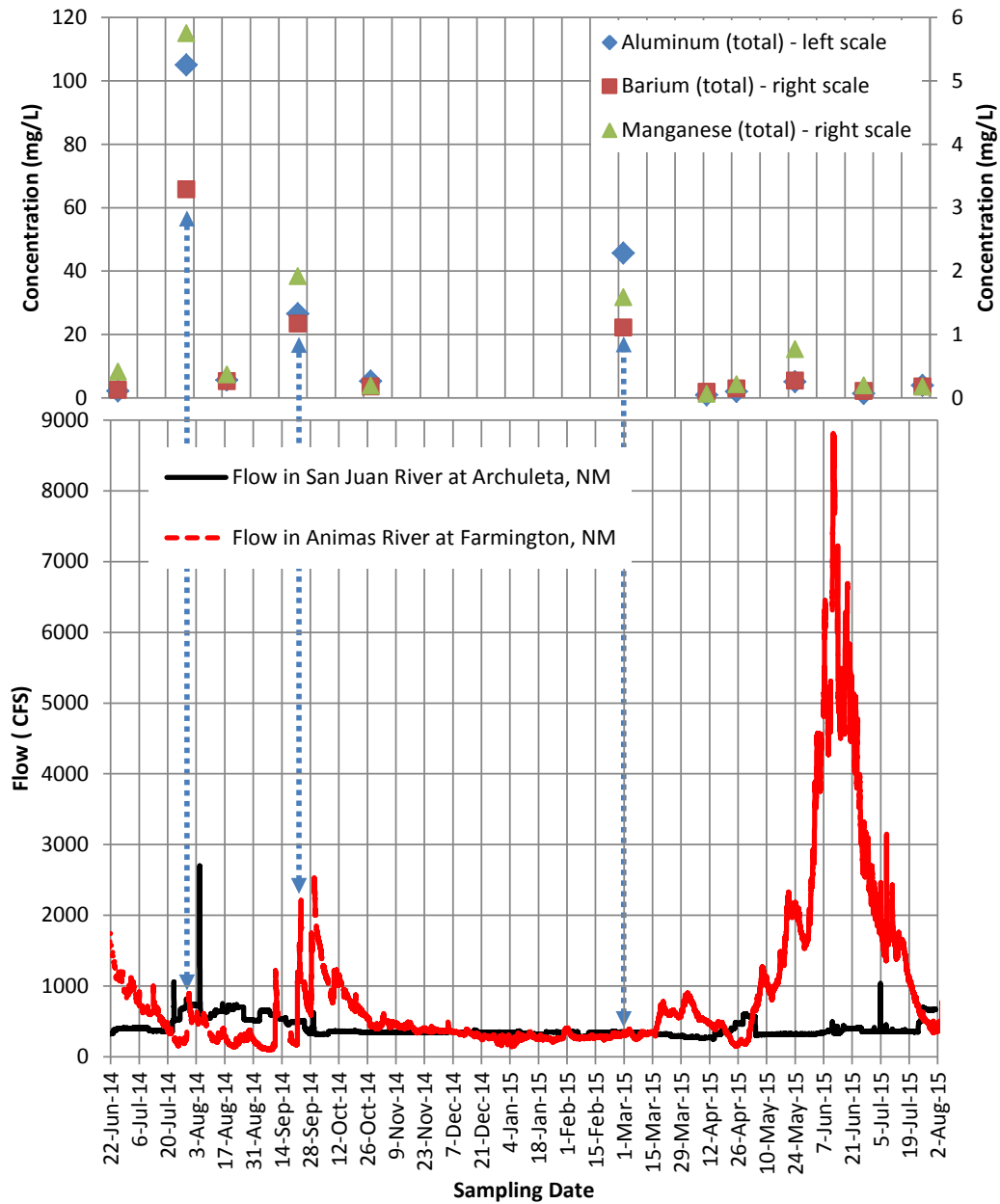


Figure 14. Relationship between flow in the Animas River and select total metal concentrations prior to the Gold King Mine spill. Metal concentrations were measured at the Hogback Site by USGS.

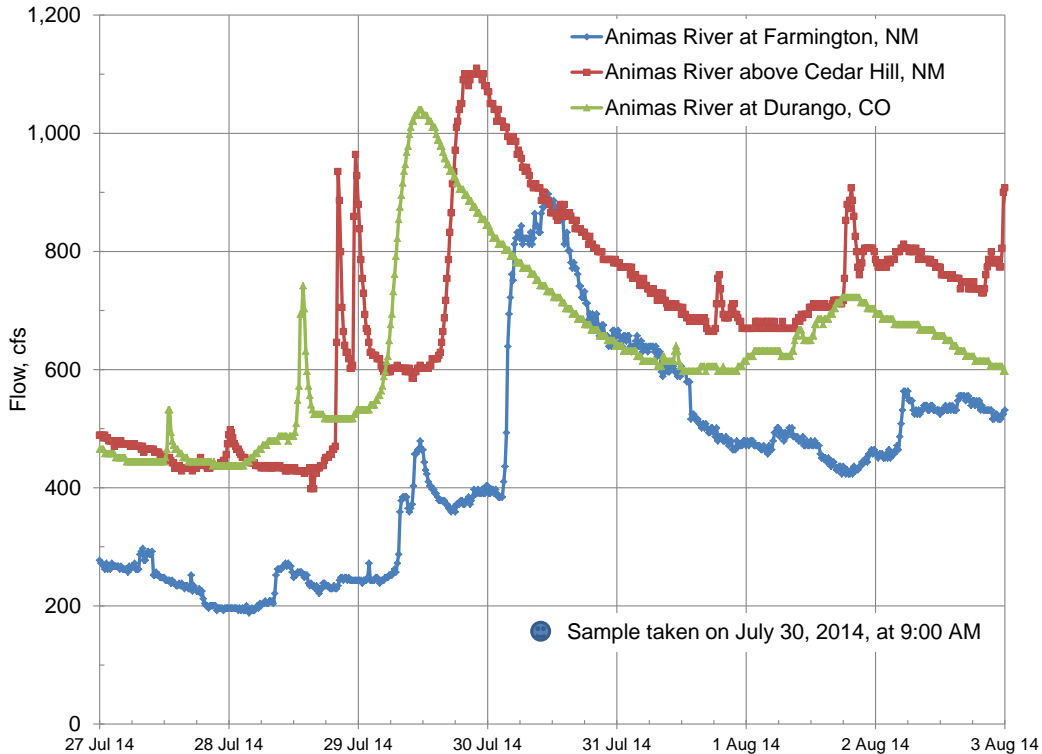


Figure 15. Hydrographs along Animas River during the days preceding and following the July 30, 2014 water quality analysis. Marker indicates time of sampling event.

Dissolved Metals in Aquatic Samples

Since suspended solids are often amenable to removal by settling and filtration, changes in the dissolved metal concentrations are of interest for evaluating potential finished water quality. Figure 16 shows that during low flow and falling limb segments of the hydrograph, total aluminum concentrations range between 1 mg/L and 10 mg/L. Corresponding dissolved concentrations are 1-2 orders of magnitude lower. During peak flow events where total concentrations increase, dissolved and total aluminum concentrations increase by about an order of magnitude. These results suggest that not only do increased flow events in the Animas River cause a sudden rise in the total metal concentrations, but the dissolved concentrations are also significantly impacted.

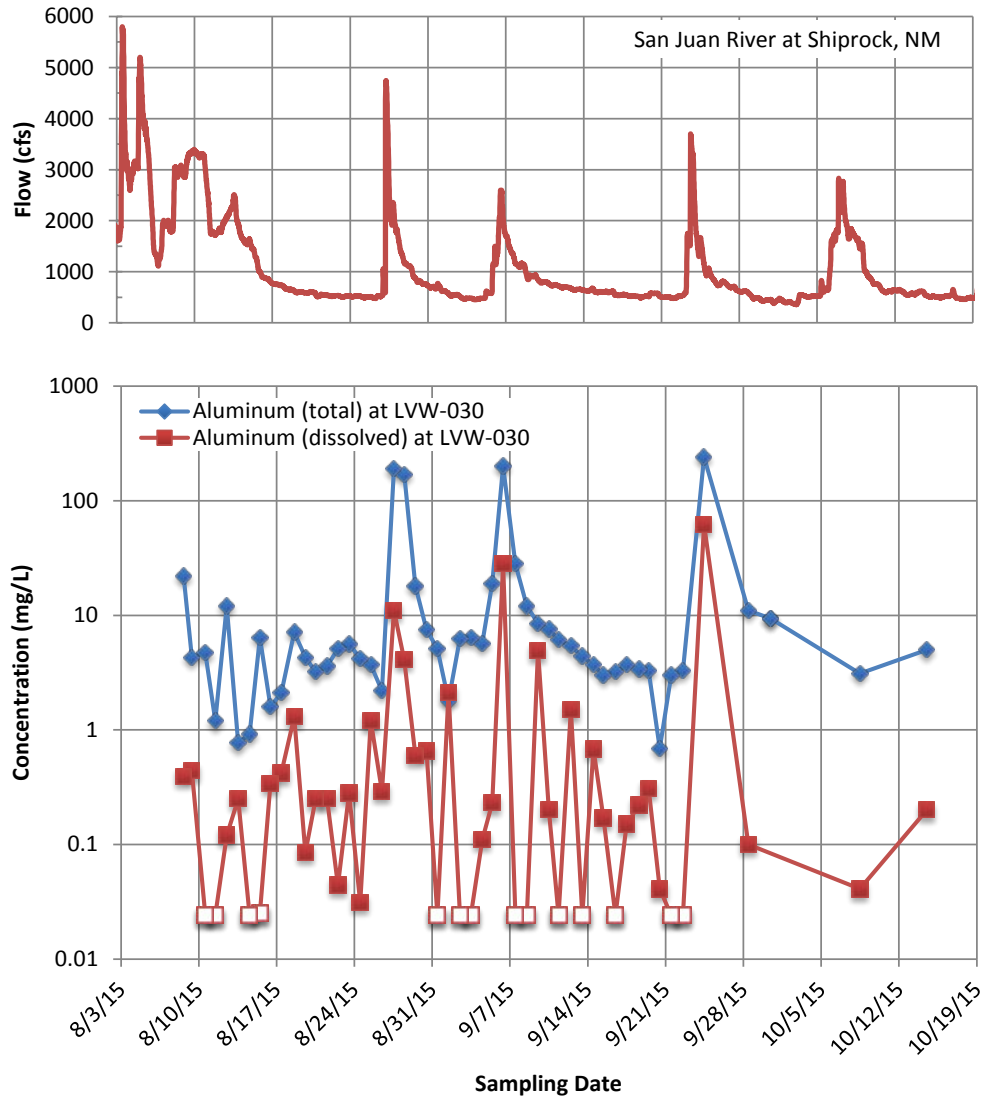


Figure 16. Distribution of aluminum between suspended and dissolved forms during August-October 2015. Unfilled markers indicate data plotted at the MRL. USGS flow data was marked provisional at the time of report preparation.

Based on the trends observed in Figure 16, the distribution of dissolved and particulate metals were compared further by focusing on the peaks following precipitation events. During these events, most of the metals detected were in the form of particulate matter rather than dissolved species with the exception of two analytes (Figure 17). Molybdenum and potassium were primarily found in the dissolved phase although molybdenum concentrations were near the detection limit and did not show the same concentration spikes as other compounds (Figure A- 16). Another observed trend is that the later sampling date (9/24/15) had a relatively larger proportion of the analytes found in the dissolved phase relative to particulate material. In isolated events, both arsenic and selenium were measured as nearly 50% dissolved.

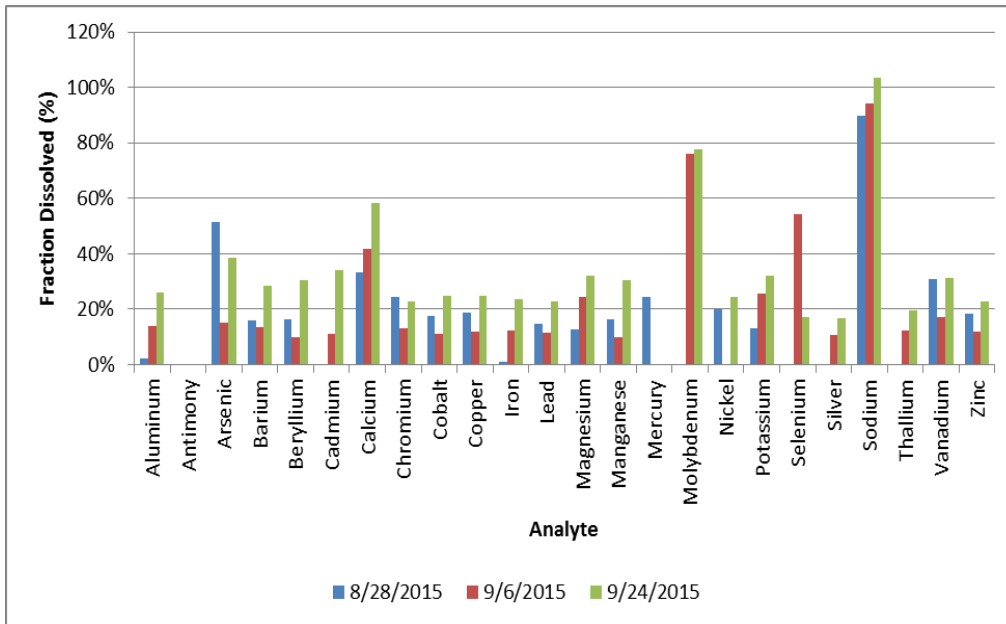


Figure 17. Fraction of analyte measured in the dissolved phase compared to the total recoverable metals during peak flow events at the EPA LVW-030 Site.

While the relative proportion of dissolved species is predominantly low, the concentrations measured during these peak events were compared to Safe Drinking Water Act MCLs listed in Table 4. For drinking water compliance, MCLs are based on total concentrations. Dissolved concentrations are compared to the MCL as solids are removed by sedimentation and filtration processes in a conventional treatment plant. The dissolved concentrations are more representative of potential concentrations after a media filtration process and thus compared to the MCL. Dissolved arsenic and dissolved beryllium concentrations were either at or above the primary MCL on 9/24/15. Dissolved lead exceeded the action level during the three 2015 precipitation events after the spill. Aluminum, iron and manganese exceeded the secondary MCL during all post-spill peak flow events. It is important to note that the concentrations listed in Table 4 may not be the peak concentration in the river due to the sampling frequency. The actual peak in concentration may have occurred in the hours before or after sample collection. Therefore, the reported values may underestimate the maximum concentration.

The post-spill peak flow events were compared to the pre-spill data from June, 2014 to July, 2015 collected at times when the San Juan River flows increased rapidly similar to the peak flow events post-spill. For the data collected pre-spill, only aluminum, manganese and iron exceeded secondary MCL limits on one of three measured peak flow events. For data collected post-spill, at least four MCLs or action levels were exceeded for samples collected during 3 different events. The aluminum, iron and manganese concentrations measured during peak events after the spill were higher than concentrations measured on 9/23/2014 before the spill. These results suggest that concentration increases after the spill may be more frequent and larger in magnitude, but it is difficult to attribute these differences directly to the spill for several reasons.

Before the spill, the frequency of flow events in the Animas River leading to increased total and dissolved metals concentrations in the San Juan River was not well understood and sampling was not designed to capture these effects. The Gold King Mine spill in 2015 led to a sampling campaign with daily sampling for several months, which provided the sampling resolution necessary to capture these spiking events and offer new insight to water quality fluctuations in the San Juan River. More frequent samples collected pre-spill would be needed to assess direct impacts of the Gold King Mine Spill.

There may be additional environmental factors impacting the flux and biogeochemistry of metals in the watershed that are not accounted for in this limited dataset, such as annual snow pack, rainfall, and temperature. Therefore, it cannot be concluded, without significant speculation, that the dissolved metals increase is solely due to the incremental discharge from the Gold King Spill.

Table 4. Distribution of dissolved and total recoverable metals during spikes measured during peak flow events. Pre-spill samples were collected by USGS at the Hogback Site. Post-spill samples were collected by EPA at the LVW-030 Site.

Metal	Pre-Spill Concentrations (µg/L)						Post-Spill Concentrations (µg/L)						MCL or Action Level (µg/L)
	7/30/2014		9/23/2014		3/3/2015		8/28/2015		9/6/2015		9/24/2015		
	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total	
Aluminum	28.8	105,000	2,380	26,500	19	NR	4,100	170,000	28,000	200,000	62,000	24,000	50-200 ²
Antimony	0.307	0.18	0.107	0.22	0.208	0.18	<2.5	<2.5	<0.4	NR	<0.4	NR	6 ¹
Arsenic	0.98	NR	1.1	NR	0.89	NR	3.4	6.6	6.7	44	10	26	10 ¹
Barium	87.2	3,290	157	1,170	75.2	1,110	620	3,900	370	2,700	1,200	4,200	2,000 ¹
Beryllium	0.02	9.55	0.246	2.39	0.02	5.56	2.1	13	1.8	18	6.4	21	4 ¹
Cadmium	0.03	1.99	0.142	1.23	0.03	0.442	<1.3	2.3	0.35	3.1	1.4	4.1	5 ¹
Calcium	53,400	NR	65,500	NR	68,300	NR	70,000	210,000	100,000	240,000	140,000	240,000	TDS = 500,000 ²
Chromium	0.3	60.7	1.2	18.6	0.3	20.4	24	99	17	130	41	180	100 ¹
Cobalt	0.454	80.3	1.83	23.7	0.424	33.6	16	92	11	100	35	140	
Copper	1.9	183	4.6	49.4	1.2	81	43	230	30	250	72	290	1,300 ³
Iron	49.5	NR	2,630	NR	21.4	NR	1,300	150,000	25,000	200,000	54,000	230,000	300 ²
Lead	0.096	149	5.36	69.7	0.08	71.2	22	150	21	180	43	190	15 ³
Magnesium	6,220	NR	1,070	NR	8,700	NR	7,800	62,000	16,000	66,000	25,000	78,000	TDS = 500,000 ²
Manganese	1.64	5,750	151	1,920	4.1	1,590	820	5,000	490	5,000	2,300	7,600	50 ²
Mercury	NR	0.273	NR	0.082	NR	0.127	0.11	0.45	<0.08	0.21	<0.08	0.51	2 ¹
Molybdenum	2.67	0.7	0.774	0.97	1.99	0.45	<2.5	<2.5	1.9	2.5	1.4	1.8	N/A
Nickel	1.3	99.7	3.4	32.1	1.4	35	28	140	18	140	46	190	N/A
Potassium	3,160	NR	3,820	NR	2,960	NR	4,100	31,000	9,200	36,000	15,000	47,000	TDS = 500,000 ²
Selenium	1.1	1.18	0.51	0.982	1.5	1.47	<2.5	5.4	7.6	14	1.9	11	50 ¹
Silver	0.02	1.57	0.04	0.374	0.02	0.423	<2.5	<2.5	0.14	1.3	0.22	1.3	100 ²
Sodium	53,000	NR	29,000	NR	86,100	NR	52,000	58,000	49,000	52,000	60,000	58,000	TDS = 500,000 ²
Thallium	0.03	0.86	0.044	0.49	0.03	0.55	NR	NR	0.3	2.4	0.59	3	2 ¹
Vanadium	2.1	NR	5	NR	1.3	NR	46	150	39	230	84	270	N/A
Zinc	2	404	22	244	2	145	120	650	74	620	170	740	5,000 ²

Analytes not detected reported as less than the MRL. Causes for dissolved concentrations greater than total concentrations for molybdenum and antimony concentrations pre-spill are unknown and may be questionable data. **Bold** values indicate dissolved concentrations that are greater than or equal to the relevant EPA MCL or action level.

NR - Not reported

N/A - Regulation not applicable

¹ Primary MCL

² Secondary MCL

³ Action Level

Total Recoverable Metals in Sediment Samples

If metal-rich sediment transported during increased flow events is a major source of metals measured in the San Juan River, further investigation of sediments is warranted to better understand the spatial and temporal variations throughout the watershed. At the EPA LVW-030 Site, sediment samples were taken almost daily, between August 11 and September 29, 2015. Total recoverable metal concentrations from this site are plotted in Figure 18 and Figure A- 27 to Figure A- 31. For most of the 23 metals analyzed, no temporal trends were observed in the weeks following the Gold King Mine spill. Based on slope p-values for regressions relating sediment concentration to time, statistically significant temporal increases in sediment concentration were observed at the 95% confidence level for four elements (i.e., sodium ($p=0.0018$), potassium ($p=0.038$), magnesium ($p=0.015$) and aluminum ($p=0.018$)). The five samples collected after 9/24/15 drive the relationship between sediment concentration and time. Since the sampling frequency was lower during these weeks, it is unknown if the same statistical relationship would have been observed with increased sampling frequency between precipitation events. Another limitation is that there are no known data of sediment concentrations of these materials prior to the incident. While it is expected that sediment in the river moves downstream slower than the water, more data are needed to evaluate temporal variations in sediment composition at a single site.

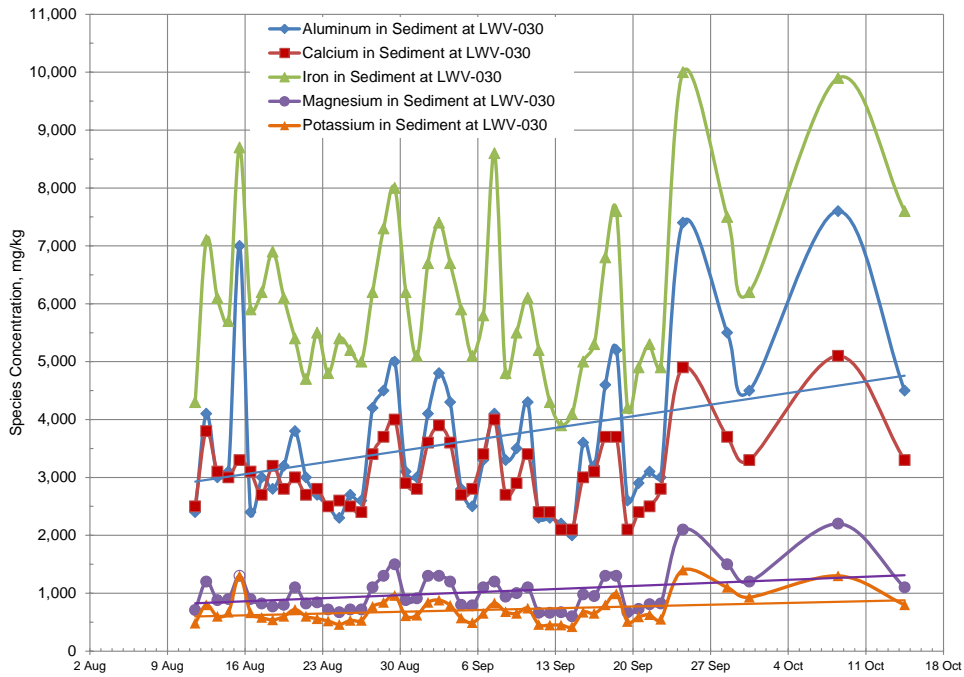


Figure 18. Aluminum, calcium, iron, magnesium and potassium sediment concentrations at EPA LVW-030 in 2015.

Temporal variations in the relative abundance of total recoverable metals at the LVW-030 Site were compared and found no significant trends as shown in Figure 19. In general, sediment was comprised predominantly of iron, aluminum and calcium with all other metals present at less than 10%. In the absence of any temporal trends, it appears that the precipitation events that increase suspended solids have little effect on both the sediment concentration and composition at a single sampling point.

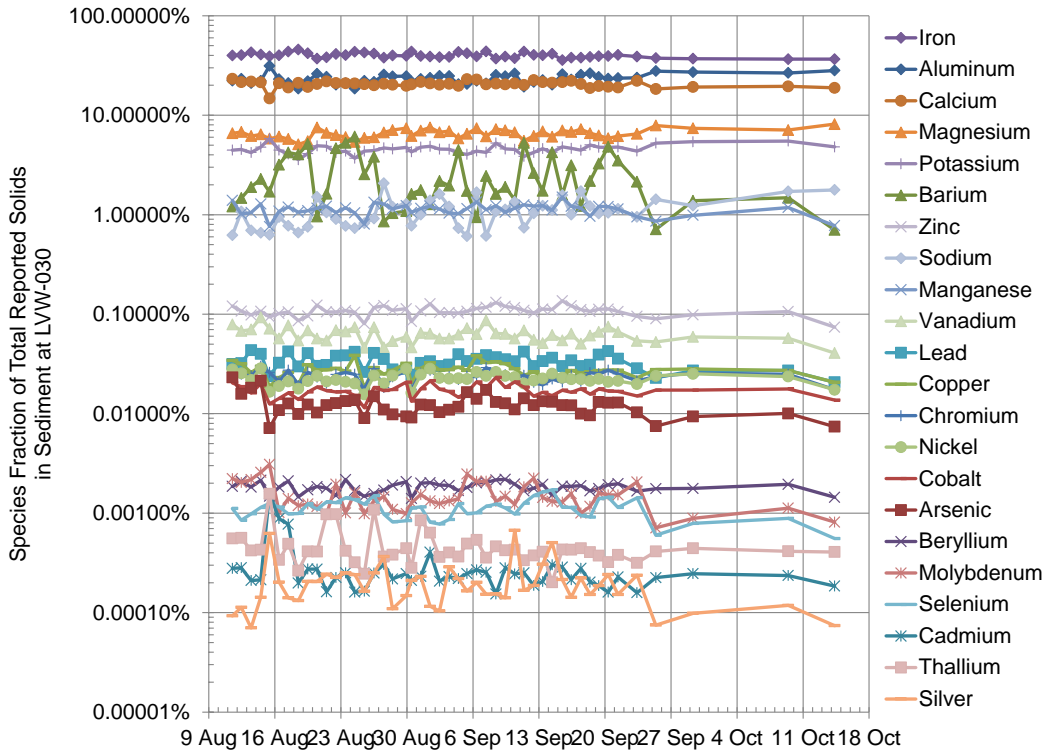


Figure 19. Relative abundance of total recoverable metals in sediment sampled from the LVW-030 Site between August and October 2015.

In addition to the LVW-030 Site, the EPA collected sediment samples from a range of locations along the Animas and San Juan Rivers in New Mexico. To evaluate spatial variations in total recoverable metal concentration and composition along the watershed, data from four additional Sites were analyzed. A summary of these sample sites is provided in Table 5.

Table 5. Sediment sample site collection information

Site Name	Sampling Agency	Latitude	Longitude	Nearest Municipality
ADW-022	EPA	36.933295	-107.909073	Just west of Cedar Hill, NM
LVW-030	EPA	36.721812	-108.325933	East of Kirtland, NM
MW-020	EPA	36.771913	-108.118956	Farmington, NM
SED01	EPA	36.838270	-107.992770	North of Aztec, NM
SED02	EPA	36.870511	-107.964815	Further North of Aztec, NM

Samples collected between August 27 and October 14, 2015 were compared to evaluate spatial variations. Earlier samples were not included in the average, because the primary interest was trends in apparent steady state values after the spill. Moving downstream along the watershed, total recoverable metal concentrations decrease from 40,000 mg/kg at ADW-020 to 15,000 mg/kg at LVW-030 as shown in Figure 20. These results demonstrate the distribution of metals along the watershed in New Mexico decreases along the length of the rivers.

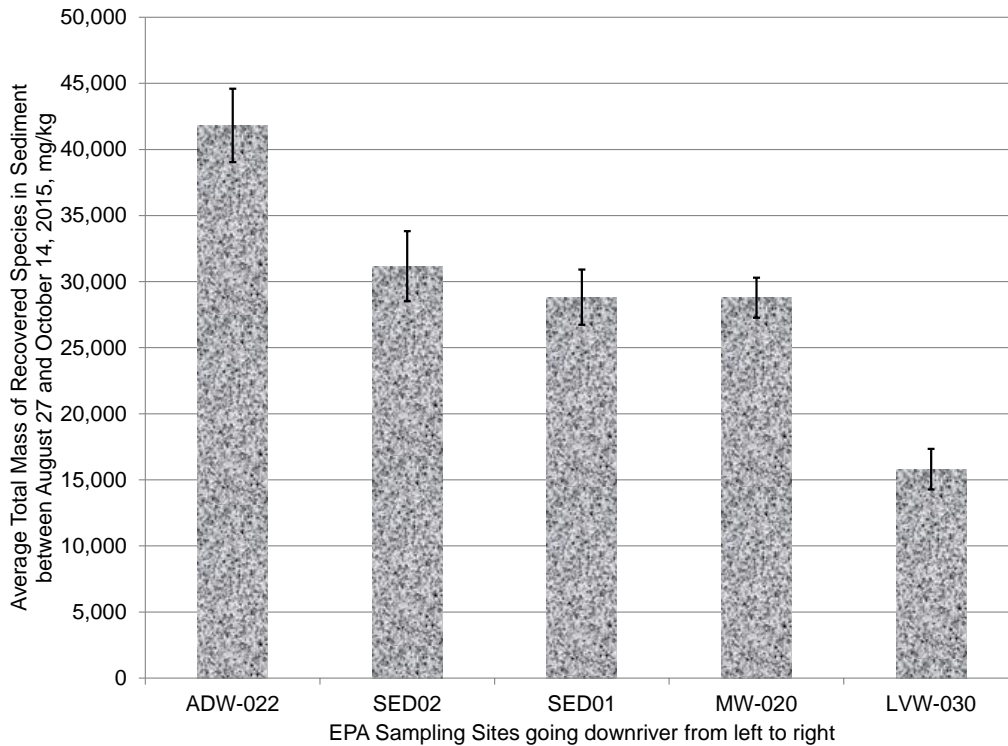


Figure 20. Mass of total recoverable metal at select sites along the Animas and San Juan Rivers. Error bars represent 95% confidence intervals.

While the mass of total recoverable metals decreased along the river, the relative abundance did not change significantly as shown in Figure 21 and Table 6. Relative abundance is a percent calculated as the mass of one metal compared to the total mass of all recoverable metals. For example, aluminum accounted for 24.4-28.1% of all recoverable metals along the watershed. For the sampling sites along the Animas River, the relative abundance of aluminum increased from 25.1% to 28.4%. The relative abundance of aluminum in the San Juan River at LVW-030 was lower than all the Animas River sampling sites at 24.4%. Other analytes, however, showed increased abundance at LVW-030, such as arsenic and iron.

One way to compare site variability for each analyte is to calculate the coefficient of variance (CV, standard deviation divided by average). Analytes with a large CV exhibit more variability relative to the average. Using this metric to screen the analytes, several metals are identified as exhibiting the most variability along the watershed: barium, copper, lead, vanadium and zinc. Barium shows higher relative abundances in the San Juan River (LVW-030) compared to the Animas River sites. Copper, lead and zinc show the greatest relative abundance at sampling sites higher in the watershed (i.e., ADW-022), and vanadium shows increasing relative abundances downstream compared to upstream. These results suggest that sediments are enriched or depleted in some trace metals spatially along the watershed. These changes may be due to environmental processing

within the benthic zone (i.e., biotic and abiotic reactions), but the causes and significance of such changes warrant further investigation.

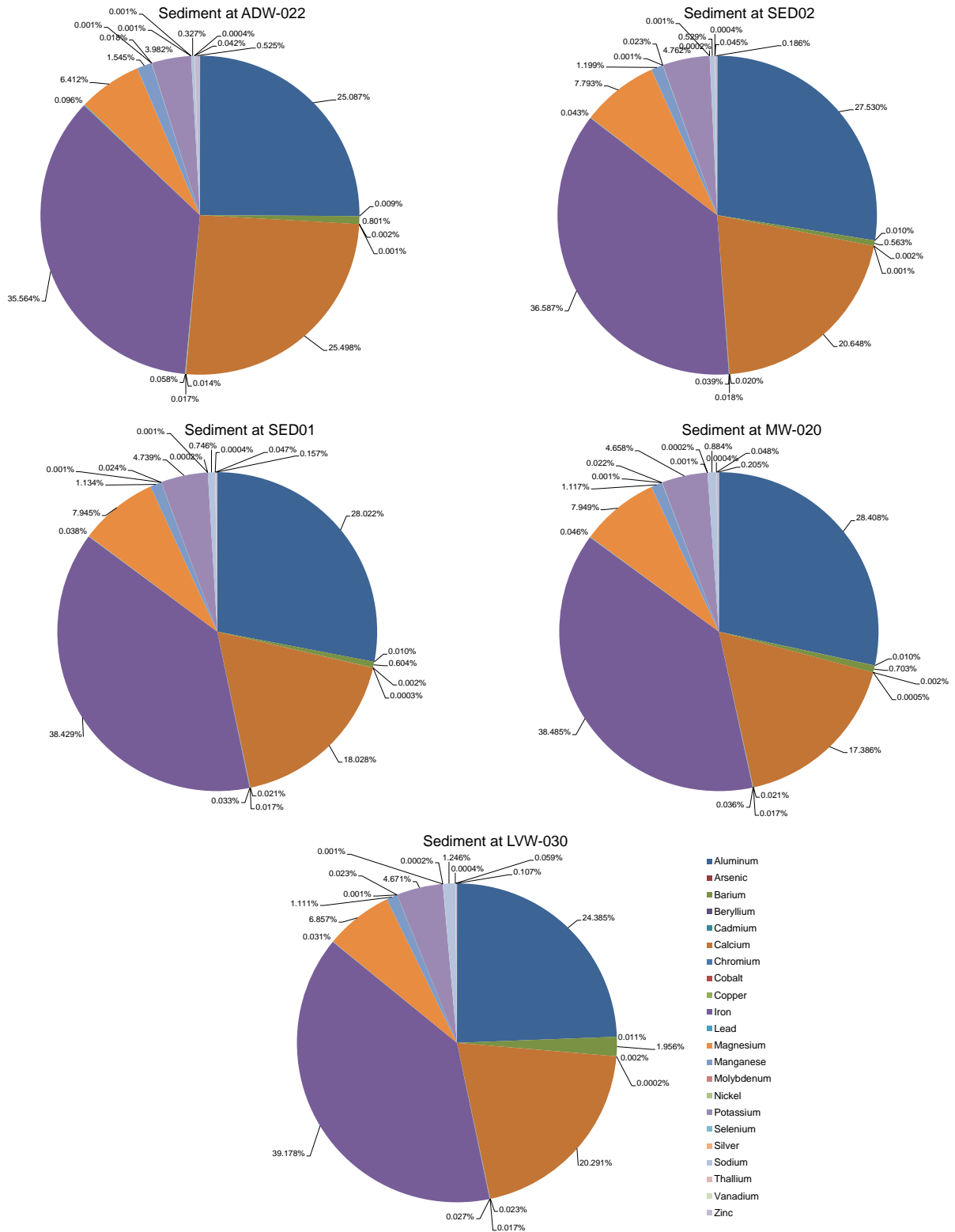


Figure 21. Distribution of total recoverable metals at each sampling location.

Table 6. Percentage of total recoverable metal mass attributable to individual metals

Analyte	Site					Statistics		
	ADW-022	SED02	SED01	MW-020	LVW-030	Average	Standard Deviation	CV
Aluminum	25.1%	27.5%	28.0%	28.4%	24.4%	26.7%	1.8%	7%
Arsenic	0.0088%	0.010%	0.010%	0.011%	0.011%	0.010%	0.001%	10%
Barium	0.80%	0.56%	0.60%	0.70%	1.96%	0.93%	0.58%	62%
Beryllium	0.0018%	0.0020%	0.0020%	0.0021%	0.0018%	0.0019%	<0.001%	
Cadmium	0.0014%	0.0010%	<0.001%	<0.001%	<0.001%	<0.001%	0.001%	
Calcium	25.5%	20.6%	18.0%	17.4%	20.3%	20.4%	3.2%	16%
Chromium	0.014%	0.020%	0.021%	0.021%	0.023%	0.020%	0.003%	15%
Cobalt	0.017%	0.018%	0.017%	0.017%	0.017%	0.017%	0.001%	6%
Copper	0.058%	0.039%	0.033%	0.036%	0.027%	0.039%	0.012%	31%
Iron	35.6%	36.6%	38.4%	38.5%	39.2%	37.6%	1.5%	4%
Lead	0.10%	0.043%	0.038%	0.046%	0.031%	0.051%	0.026%	51%
Magnesium	6.4%	7.8%	7.9%	7.9%	6.9%	7.4%	0.7%	9%
Manganese	1.5%	1.2%	1.1%	1.1%	1.1%	1.2%	0.2%	17%
Molybdenum	0.0012%	0.0010%	0.0010%	<0.001%	0.0014%	0.0011%	<0.001%	
Nickel	0.018%	0.023%	0.024%	0.022%	0.023%	0.022%	0.002%	9%
Potassium	4.0%	4.8%	4.7%	4.7%	4.7%	4.6%	0.3%	7%
Selenium	0.0006%	0.0010%	0.0010%	<0.001%	0.0010%	<0.001%	<0.001%	
Silver	0.001%	<0.001%	<0.001%	<0.001%	<0.001%	<0.001%	0.000%	
Sodium	0.33%	0.53%	0.75%	0.88%	1.25%	0.75%	0.35%	47%
Thallium	<0.001%	<0.001%	<0.001%	<0.001%	<0.001%	<0.001%	<0.001%	
Vanadium	0.04%	0.05%	0.05%	0.05%	0.06%	0.05%	0.01%	20%
Zinc	0.52%	0.19%	0.16%	0.21%	0.11%	0.24%	0.17%	71%

Radionuclides

Radionuclides were measured at the Hogback Site by Reclamation. These analytes were not included in historical monitoring by USGS or in the suite of samples analyzed by EPA. Table 7 summarizes the activity levels measured for a range of radioactive constituents.

Gross alpha, gross beta and total radium are regulated under the Safe Drinking Water Act. Gross alpha and total radium both have MCLs that are based on activity in units of pCi/L. No samples exceeded the MCL for either constituent. Gross beta is regulated based on exposure (mrem/yr) rather than activity. An activity level of 50 pCi/L, however, is a threshold to initiate further testing and monitoring. No sample exceeded a gross beta activity of 50 pCi/L. ²²²Rn is not currently regulated in drinking water, and no sample exceeded the reporting limit of the analytical method. Based on this data, no samples collected immediately after the spill presented radionuclide concentrations in exceedance of current regulations. However, samples were not collected during precipitation events when the highest total recoverable metals concentrations were observed, indicating that additional sampling for radionuclides is needed to better understand fluctuations in water quality.

Table 7. Radionuclides measured at the Hogback Site between 8/7/15 and 8/17/15.

Sampling Date	²²² Radon Activity (pCi/L)	Gross Alpha Activity (pCi/L)	Gross Beta Activity (pCi/L)	Radium 226 Activity (pCi/L)	Radium 228 Activity (pCi/L)	Total Radium (pCi/L)
8/7/2015	<15.0	3.1 ± 0.6	12.3 ± 2.7	< 0.6	<0.9	<0.9
8/8/2015	<14.0	4.4 ± 0.7	6.9 ± 1.7	<0.6	<0.9	<0.9
8/9/2015	<14.0	5.8 ± 0.8	9.7 ± 1.7	0.8 ± 0.3	<0.9	0.8 ± 0.3
8/10/2015	<14.0	4.8 ± 0.7	5.1 ± 1.5	1.1 ± 0.3	0.9 ± 0.4	2.0 ± 0.5
8/11/2015	<15.0	2.7 ± 0.5	7.0 ± 1.7	<0.6	<0.9	<0.9
8/12/2015	<15.0	2.1 ± 0.5	7.2 ± 1.7	0.8 ± 0.3	1.2 ± 0.4	2.0 ± 0.5
8/13/2015	<15.0	2.7 ± 0.5	4.1 ± 1.5	< 0.6	1.3 ± 0.4	1.3 ± 0.4
8/14/2015	NR	2.0 ± 0.7	2.8 ± 0.8	0.6 ± 0.2	<0.7	0.6 ± 0.2
8/17/2015	<15.0	2.6 ± 0.8	2.7 ± 0.9	<0.4	<0.7	<0.7
MCL	NR	15	50*	--	--	5.0

* MCL for gross beta is based on dose (4 mrem/yr) rather than activity. 50 pCi/L is a monitoring trigger for additional actions.
NR: Not regulated

Organic Carbon

Total organic carbon (TOC) and dissolved organic carbon (DOC) were measured at the Hogback Site both historically by USGS and immediately following the spill by Reclamation. Figure 22 shows that both TOC and DOC increased about 0.5 mg/L from August 7th to August 9th, 2015. By August 11th, both TOC and DOC returned to concentrations similar to those observed on August 7th. Water quality data from the Gold King Mine adit does not report organic carbon concentrations (Table 3), so it cannot be concluded whether this fluctuation in organic carbon is due to the spill or other processes within the watershed. There were precipitation events in the Animas watershed during the same period of time, which may have increased carbon transport to the rivers, independent of events at the mine. Since the TOC and DOC concentrations are similar, nearly all the carbon in the samples was in the dissolved form rather than particulate form, suggesting that the large transport of sediment and colloidal material in the watershed is largely inorganic in nature. Since no samples collected during the precipitation events in late August and September were analyzed for organic carbon, more data are needed to better understand the relationship between sediment transport and organic matter concentrations at the Hogback Site.

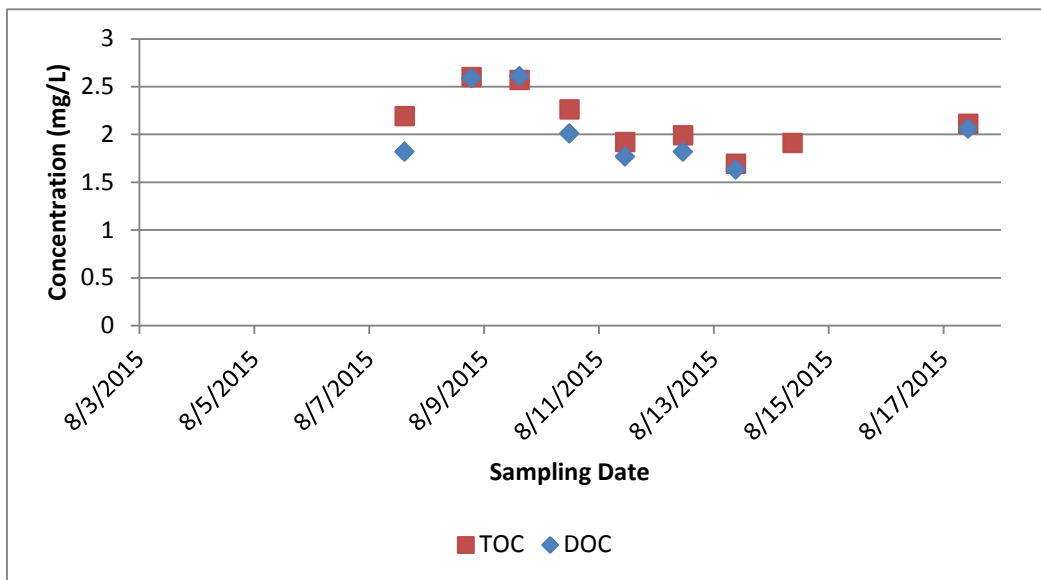


Figure 22. TOC and DOC at the Hogback Site following the Gold King Mine spill collected by Reclamation.

Compared to historical values, the DOC concentrations in August 2015 were similar to historic values. Figure 23 shows that most samples collected had concentrations between 2.5 mg/L and 3 mg/L, which are slightly higher than concentrations observed in August 2015. If anything, the formation of iron and aluminum hydroxide colloids in the river may have acted to lower dissolved organic matter concentrations through adsorption mechanisms, similar to coagulation in a water treatment plant.

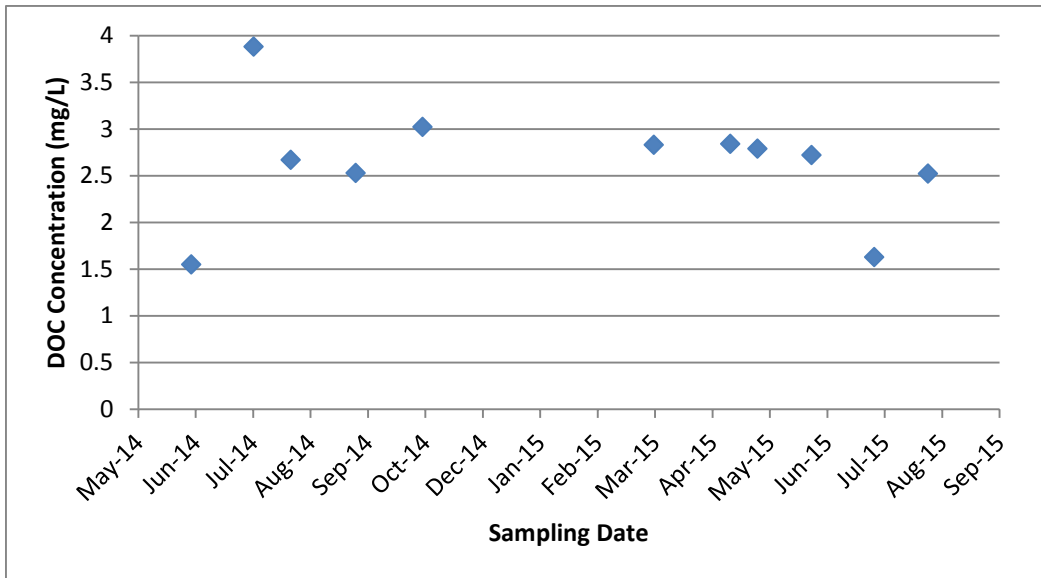


Figure 23. Historical DOC concentrations measured at the Hogback Site prior to the Gold King Mine Spill collected and analyzed by USGS.

Conclusions

In response to the Gold King Mine spill, independent sampling campaigns by both Reclamation and EPA generated a dataset that yielded valuable insights to the water quality in the San Juan River. Data collected for both surface water and sediments along the watershed provided a glimpse into temporal and spatial variations in metals. These results lead to a better understanding of the variable water quality conditions at the Reclamation Hogback Site, a potential intake for the NGWSP.

As the drainage plume passed the Hogback Site (August 8-9, 2015), increases in total metal concentrations were observed. These concentration increases, however, were not larger than historical measurements at the site. In the months after the spill (August-October, 2015), occasional spikes in total metal concentrations were observed. These spikes coincided with precipitation events that led to a rapid increase in Animas River flow. Turbidity also increased during these flow events signifying a resuspension and transport of metal-laden sediment. Turbidity may be a valuable surrogate for rapidly determining when total metal concentrations are expected to increase.

During these peak flow events, dissolved metals also increased. In some cases, the measured concentrations exceeded regulatory limits for drinking water. All three precipitation events after the spill led to aluminum, iron and manganese concentrations that exceeded the secondary MCL. Before the spill, one sample had dissolved concentrations above the MCLs. The dissolved concentrations observed post-spill are 1-2 orders of magnitude greater than pre-spill data. These data suggest that the spill may have had an effect on the presence of dissolved metals in the San Juan River, but it is difficult to attribute these differences directly to the spill for several reasons. Sampling frequency before the spill was lower and not designed to capture peak flow events in the Animas River. Almost daily sampling after the spill provided an opportunity through improved sampling frequency to catch these peaks, whereas pre-spill only one sampling event was perfectly timed with a coinciding rise in the San Juan River. There may be additional confounding factors impacting the biogeochemistry in the watershed that are not accounted for in this limited dataset, such as annual snow pack, rainfall, and temperature. Therefore, it cannot be concluded at this time, without significant speculation, that the dissolved metals increase is solely due to the incremental discharge from the Gold King Spill. What can be concluded, however, is that metal accumulation and transport in the San Juan River watershed has been dynamic and significant both before and after the spill.

Recommendations for Future Work

Understanding the effects of mine drainage on San Juan River water quality is important for water supply projects that utilize this river. This report revealed that trends exist between flow in the watershed and the metal concentrations in the San Juan River. This report also illustrated that the system dynamics are complex and depend on a number of factors (i.e., different trends observed during precipitation events compared to spring run-off). The following additional work is recommended which if performed would lead to a better understanding of San Juan River water quality:

- Review other studies conducted in the watershed, specifically those by USGS, to identify knowledge gaps related to San Juan River water quality.
- Increase Reclamation's existing sampling program at the Hogback Site and other strategic locations on the Animas and San Juan Rivers to gain a better understanding of water quality during baseflow and naturally fluctuating flow conditions.
- Assess implications of fluctuating water quality on the proposed NGWSP's SJL intake and WTP, and develop a strategic monitoring plan to identify fluctuations in real-time.
- Determine if sediment sampling in the upper reaches of the watershed could increase our understanding of San Juan River water quality.
- Evaluate effects of water quality fluctuations on water use for irrigation and potable drinking water.
- Evaluate operations and maintenance strategies for the SJL WTP raw water intake that could minimize sediment and dissolved metal loading to the treatment facility. Strategies may include periodic shutdown of the raw water intake based on triggered water quality parameters in the San Juan River, such as online turbidity.

Appendix A. Additional Figures

This appendix contains figures which are referred to in the text and which amplify the text but which would unduly impede the flow of the text. They are referred to in the text by number at the appropriate points.

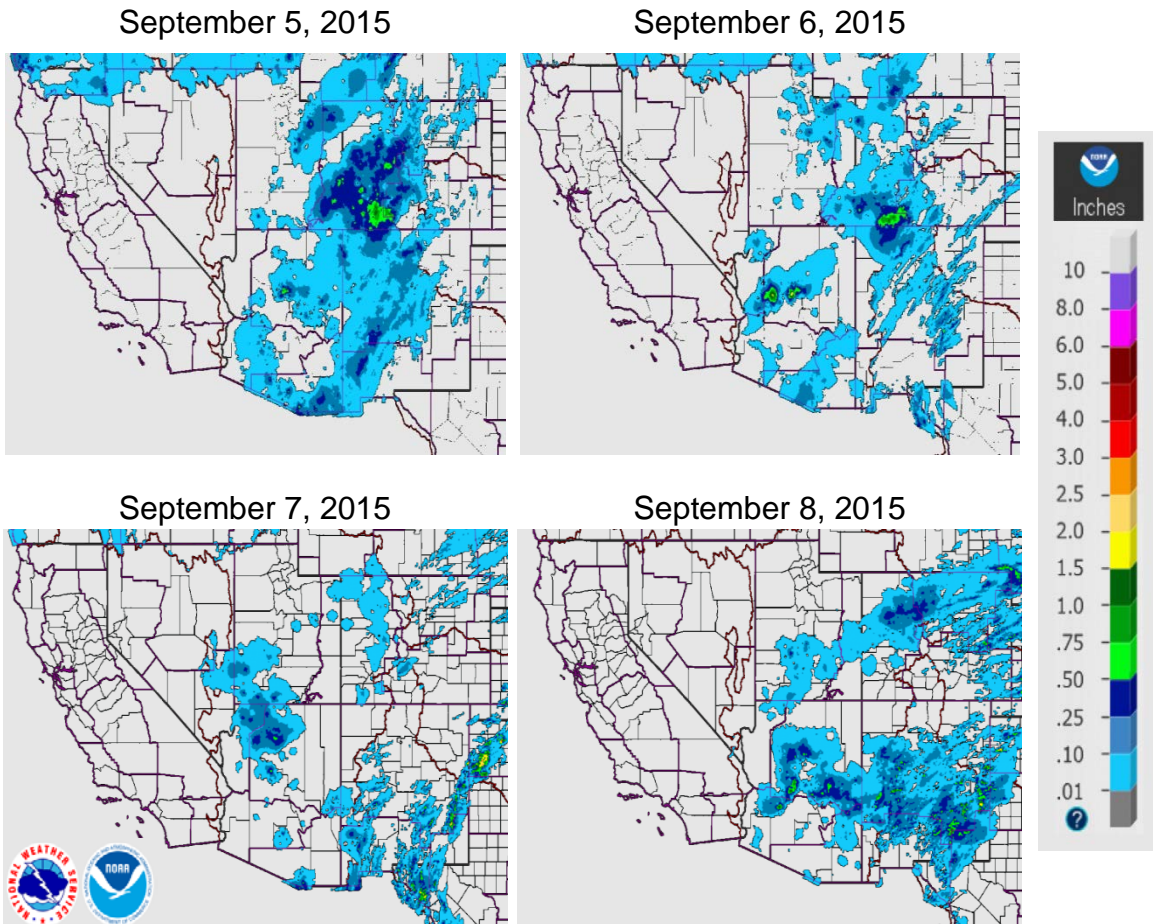


Figure A- 1. Observed daily precipitation for the Southwestern United States between September 5, 2015 and September 8, 2015. Figures generated from the National Weather Service and National Oceanic and Atmospheric Administration.

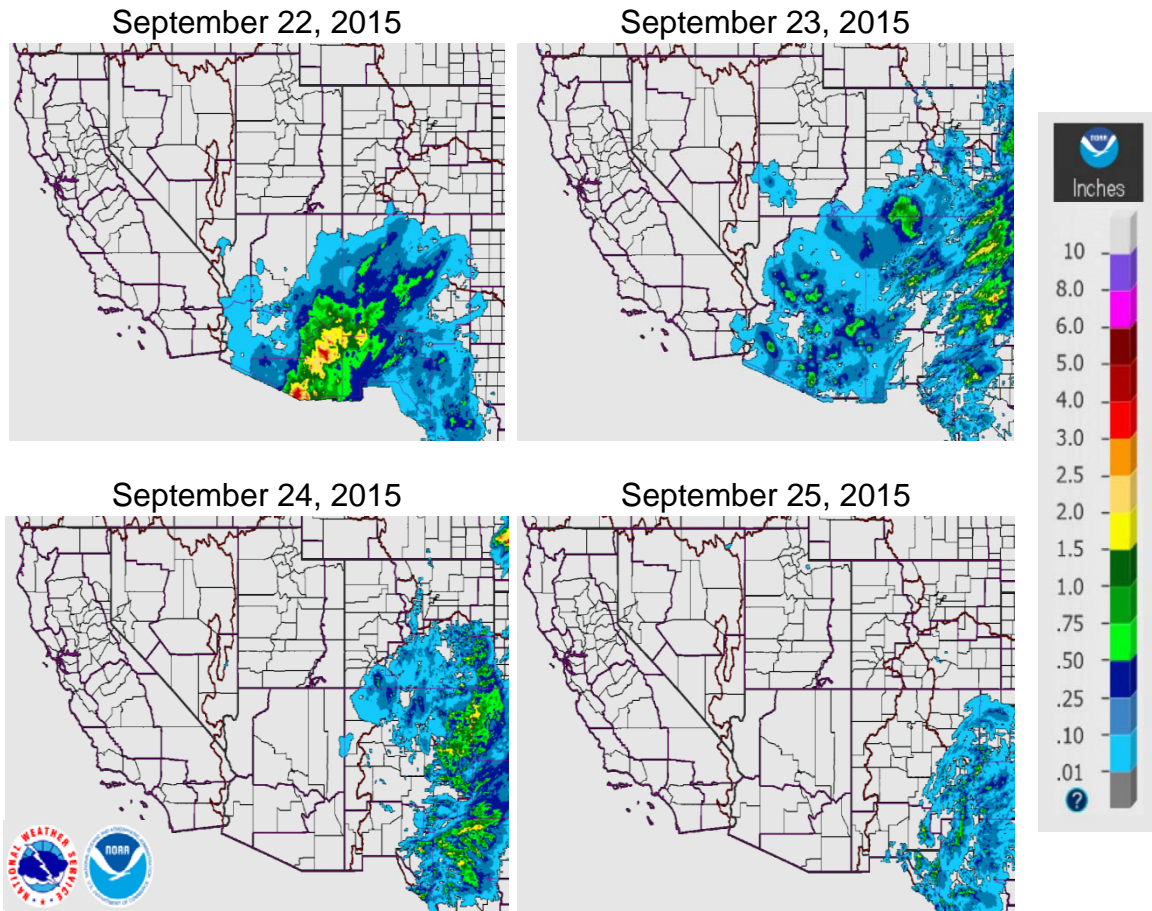


Figure A- 2. Observed daily precipitation for the Southwestern United States between September 22, 2015 and September 25, 2015. Figures generated from the National Weather Service and National Oceanic and Atmospheric Administration.

Total Aluminum

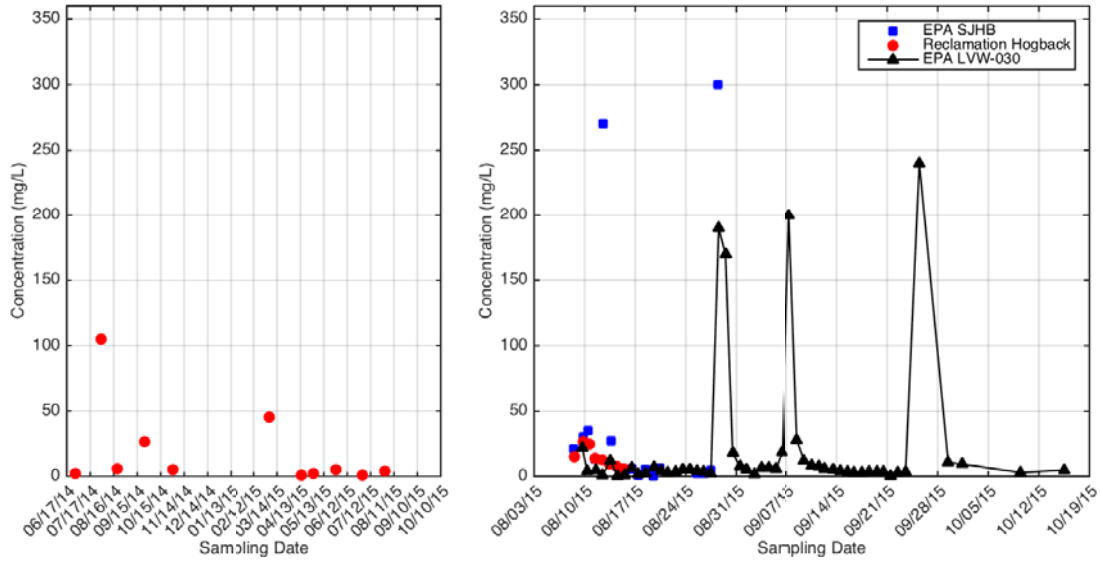


Figure A- 3. Total aluminum measured in milligrams per liter from the three sampling locations. The left pane indicates pre-spill data and the right pane indicates post-spill data. Unfilled markers indicate values reported at the MRL.

Total Antimony

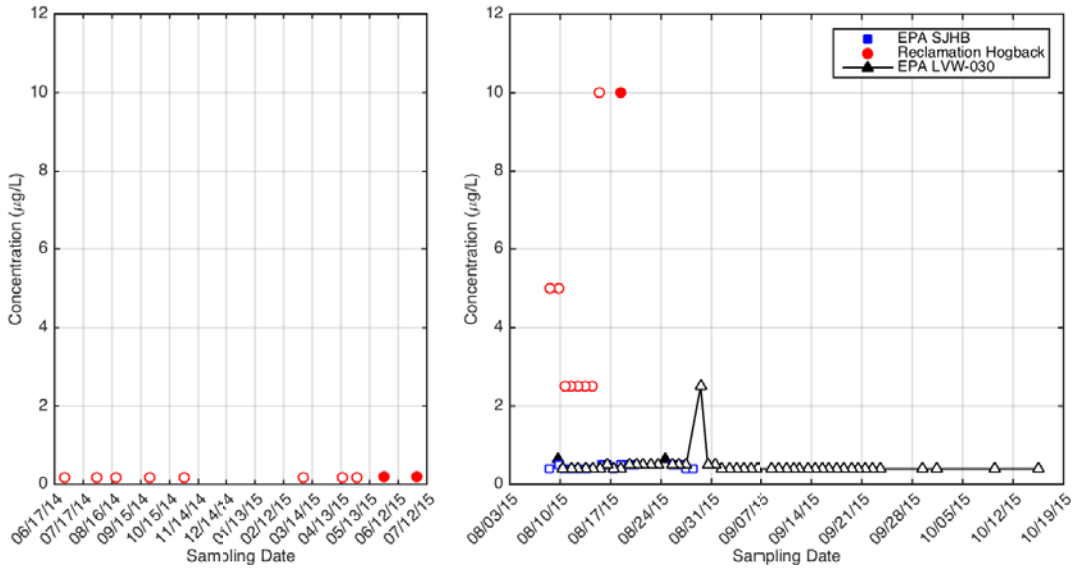


Figure A- 4. Total antimony measured in micrograms per liter from the three sampling locations. The left pane indicates pre-spill data and the right pane indicates post-spill data. Unfilled markers indicate values reported at the MRL.

Total Arsenic

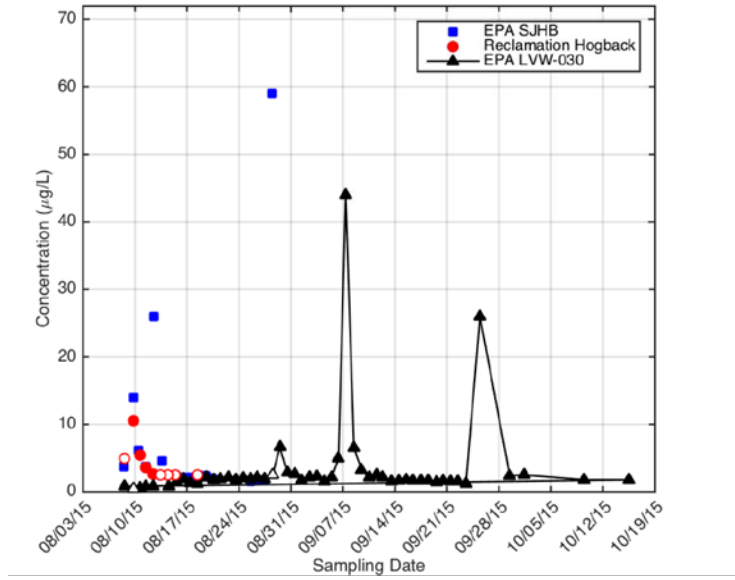


Figure A- 5. Total arsenic measured in micrograms per liter from the three sampling locations. Unfilled markers indicate values reported at the MRL.

Total Barium

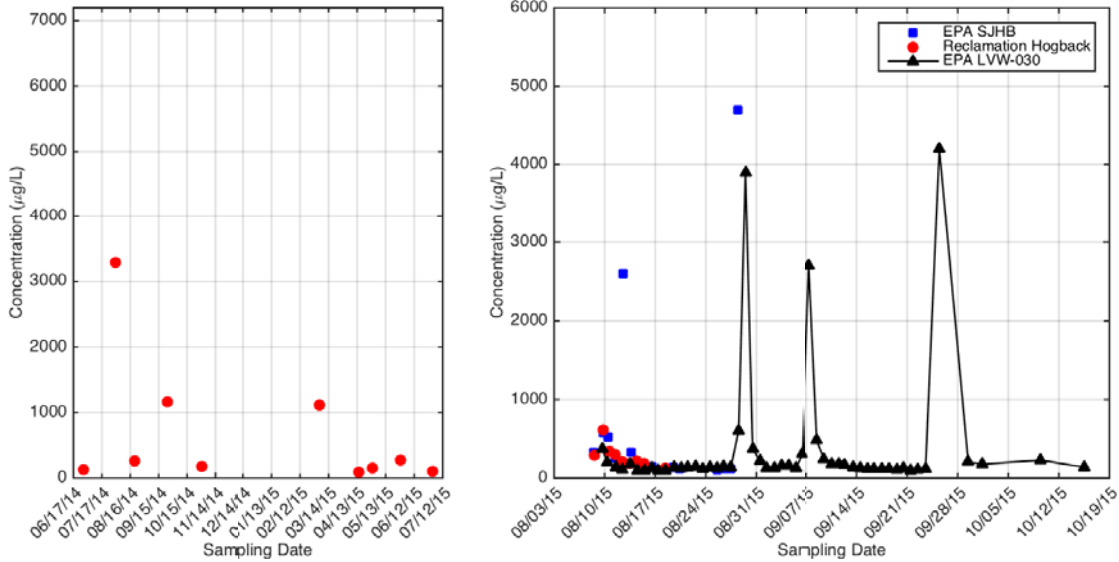


Figure A- 6. Total barium measured in micrograms per liter from the three sampling locations. The left pane indicates pre-spill data and the right pane indicates post-spill data. Unfilled markers indicate values reported at the MRL.

Total Beryllium

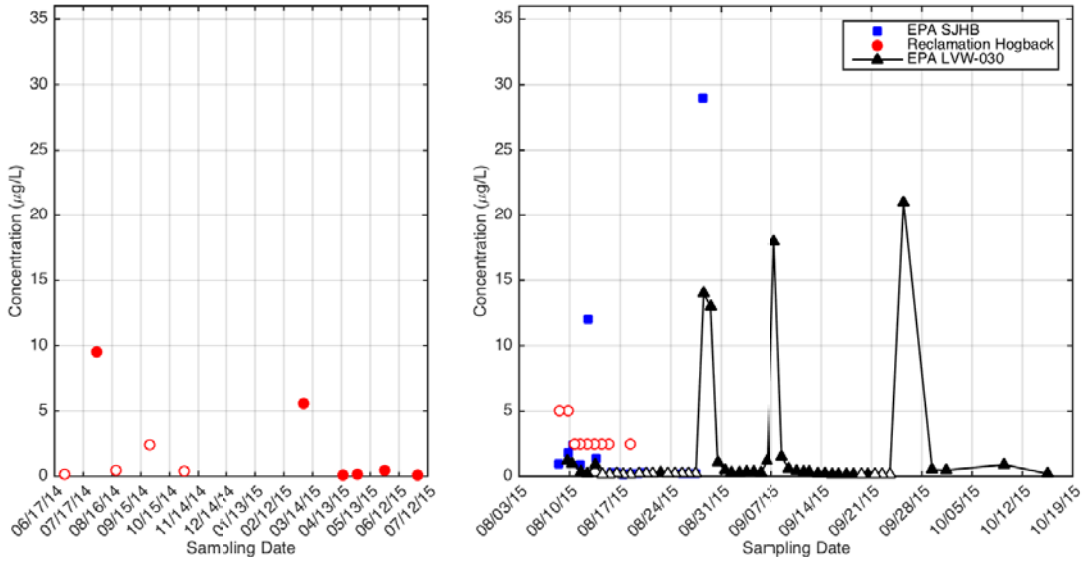


Figure A- 7. Total beryllium measured in micrograms per liter from the three sampling locations. The left pane indicates pre-spill data and the right pane indicates post-spill data. Unfilled markers indicate values reported at the MRL.

Total Calcium

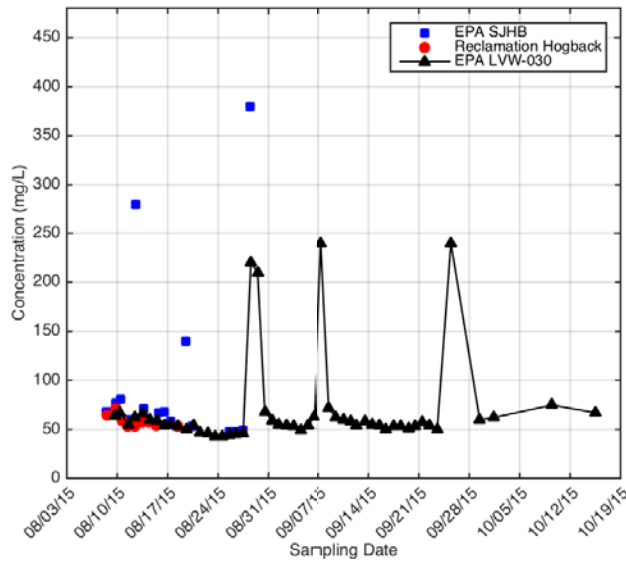


Figure A- 8. Total calcium measured in milligrams per liter from the three sampling locations. Unfilled markers indicate values reported at the MRL.

Total Cadmium

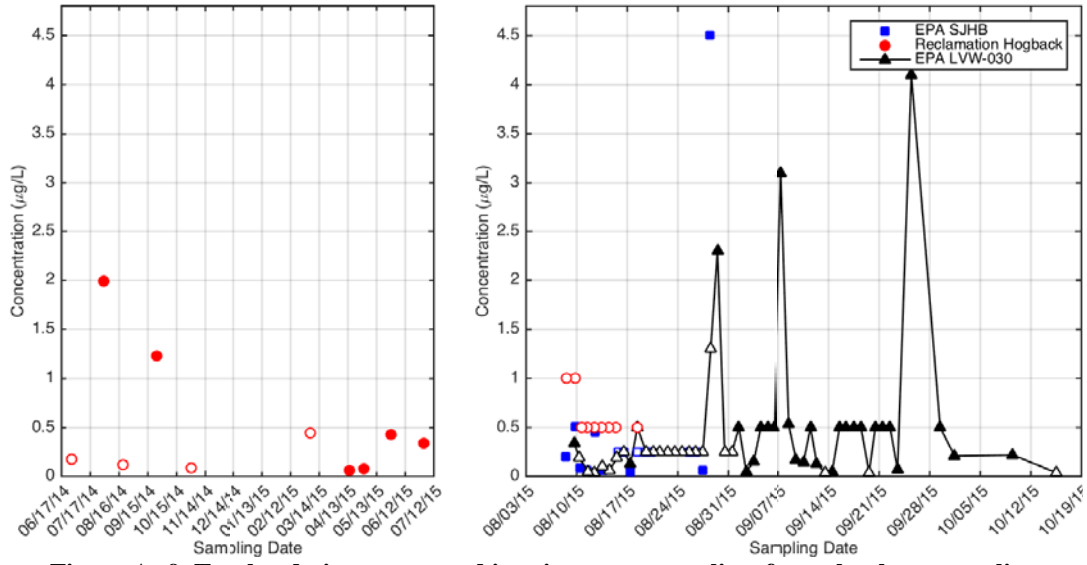


Figure A- 9. Total cadmium measured in micrograms per liter from the three sampling locations. The left pane indicates pre-spill data and the right pane indicates post-spill data. Unfilled markers indicate values reported at the MRL.

Total Cobalt

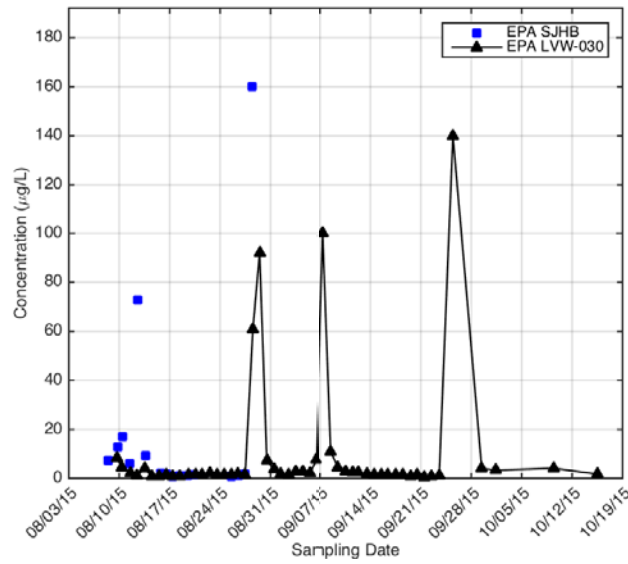


Figure A- 10. Total cobalt measured in micrograms per liter from the three sampling locations. Unfilled markers indicate values reported at the MRL.

Total Copper

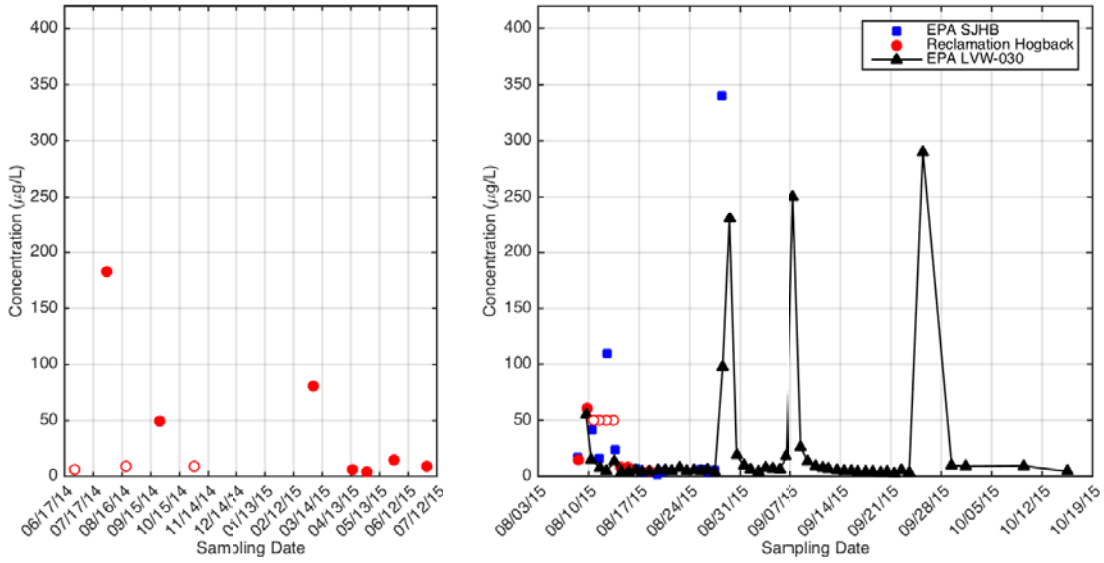


Figure A- 11. Total copper measured in micrograms per liter from the three sampling locations. The left pane indicates pre-spill data and the right pane indicates post-spill data. Unfilled markers indicate values reported at the MRL.

Total Lead

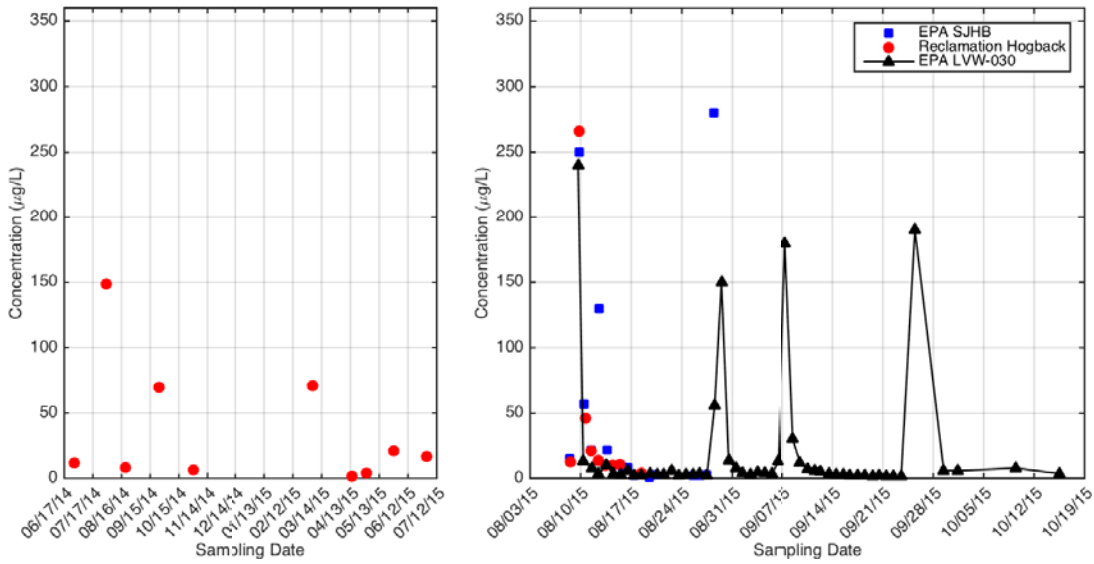


Figure A- 12. Total lead measured in micrograms per liter from the three sampling locations. The left pane indicates pre-spill data and the right pane indicates post-spill data. Unfilled markers indicate values reported at the MRL.

Total Magnesium

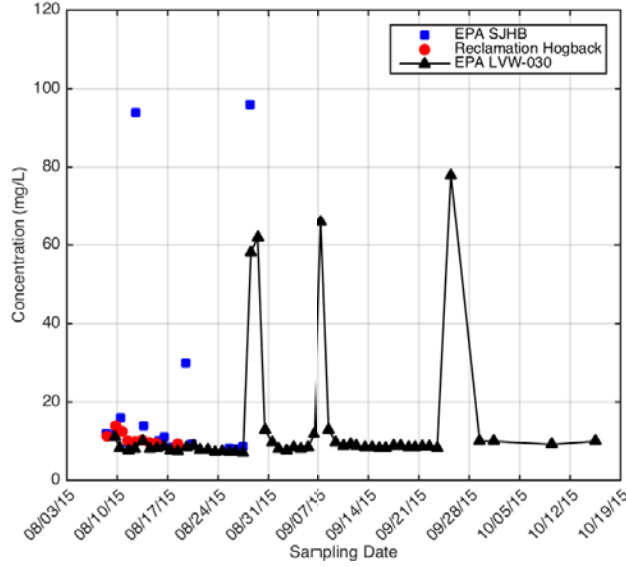


Figure A- 13. Total magnesium measured in milligrams per liter from the three sampling locations. The left pane indicates pre-spill data and the right pane indicates post-spill data. Unfilled markers indicate values reported at the MRL.

Total Manganese

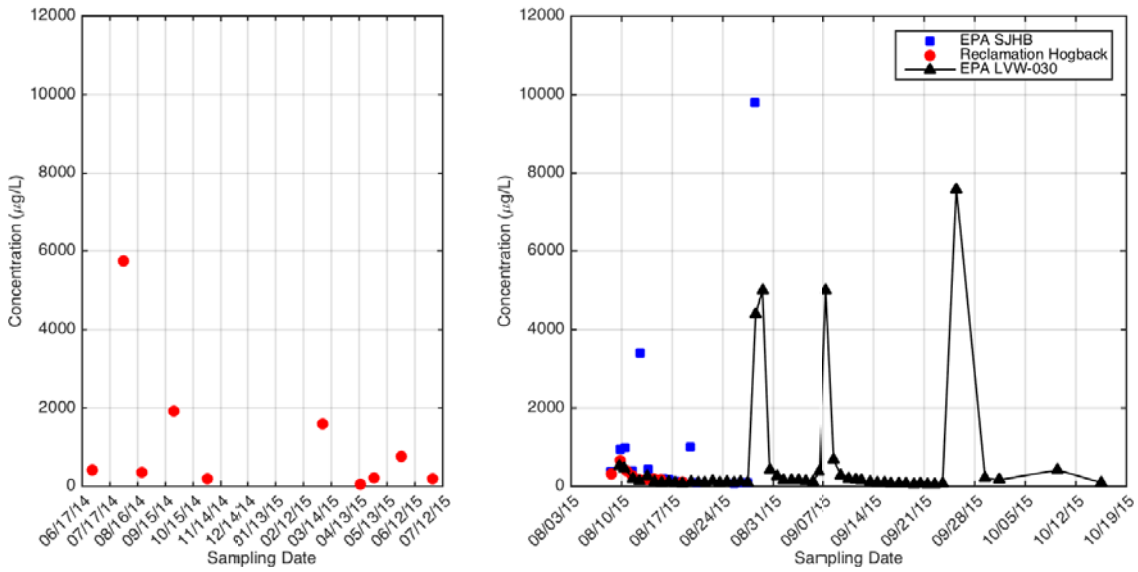


Figure A- 14. Total manganese measured in micrograms per liter from the three sampling locations. The left pane indicates pre-spill data and the right pane indicates post-spill data. Unfilled markers indicate values reported at the MRL.

Total Mercury

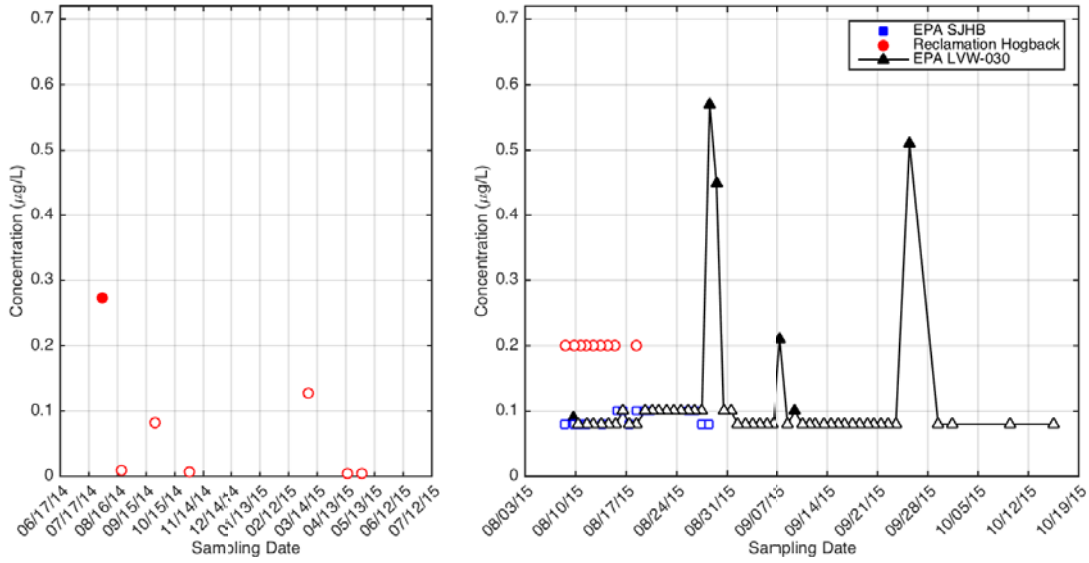


Figure A- 15. Total mercury measured in micrograms per liter from the three sampling locations. The left pane indicates pre-spill data and the right pane indicates post-spill data. Unfilled markers indicate values reported at the MRL.

Total Molybdenum

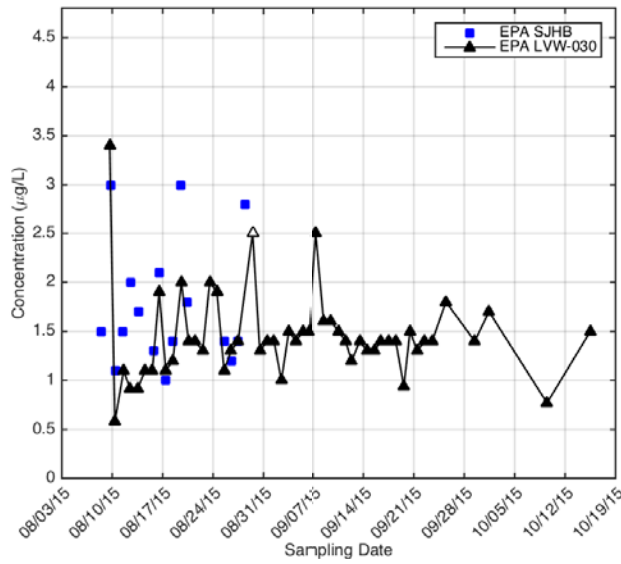


Figure A- 16. Total molybdenum measured in micrograms per liter from the three sampling locations. Unfilled markers indicate values reported at the MRL.

Total Nickel

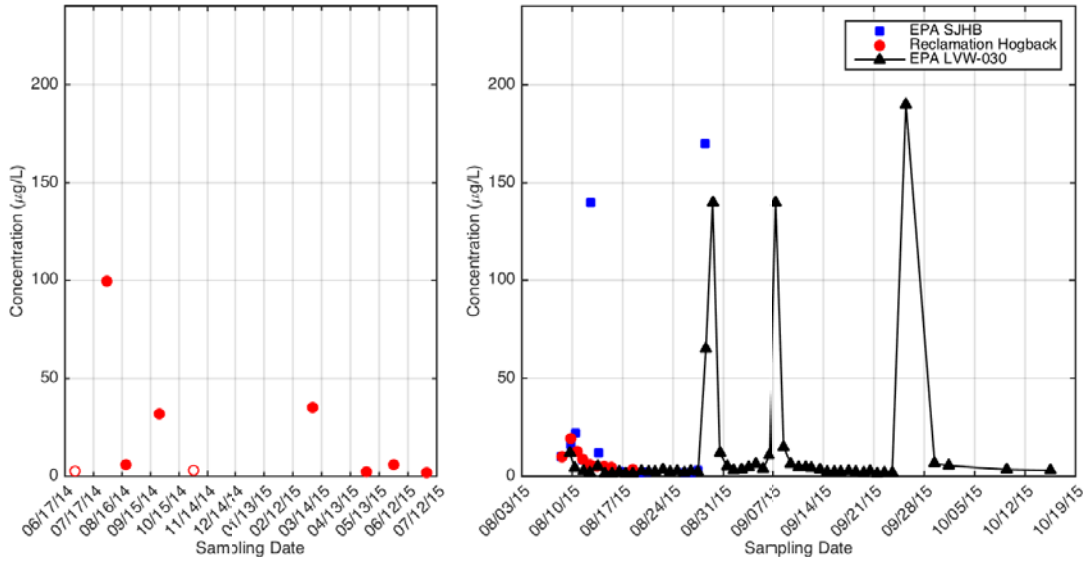


Figure A- 17. Total nickel measured in micrograms per liter from the three sampling locations. The left pane indicates pre-spill data and the right pane indicates post-spill data. Unfilled markers indicate values reported at the MRL.

Total Potassium

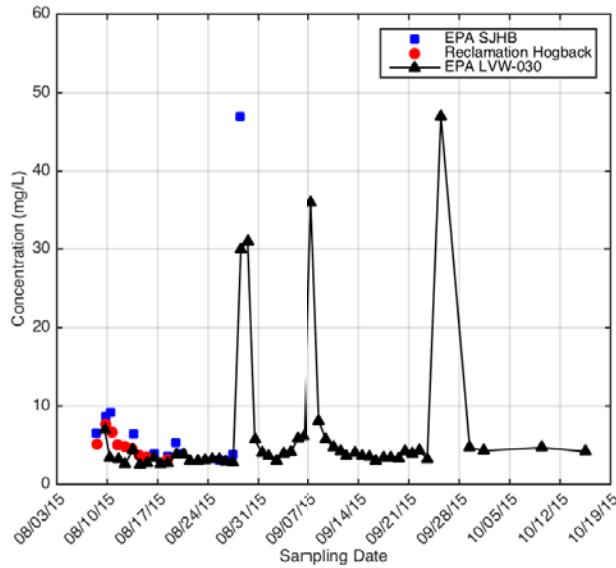


Figure A- 18. Total potassium measured in milligrams per liter from the three sampling locations. The left pane indicates pre-spill data and the right pane indicates post-spill data. Unfilled markers indicate values reported at the MRL.

Total Selenium

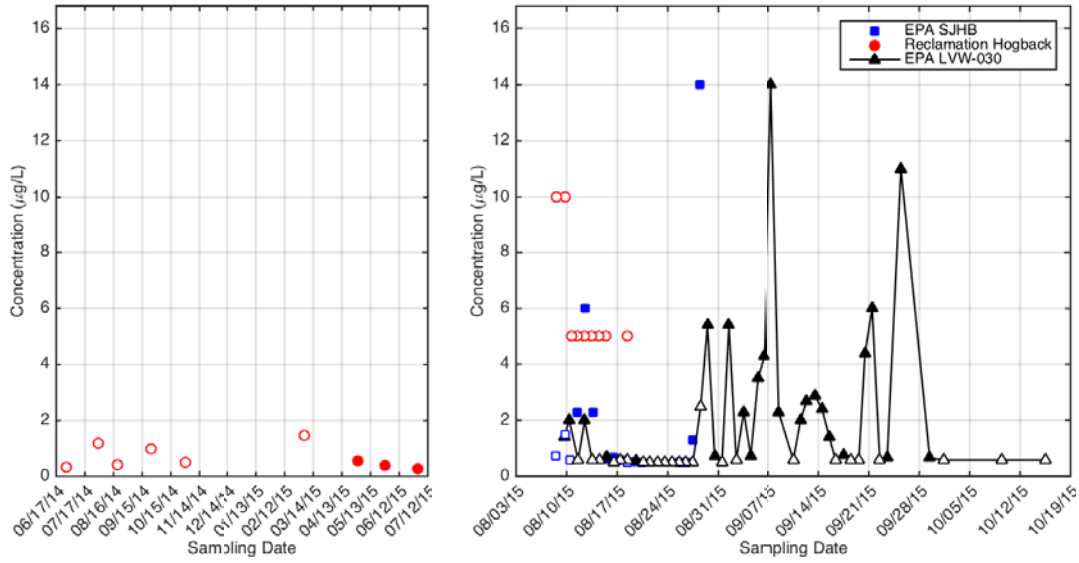


Figure A- 19. Total selenium measured in micrograms per liter from the three sampling locations. The left pane indicates pre-spill data and the right pane indicates post-spill data. Unfilled markers indicate values reported at the MRL.

Dissolved Silica

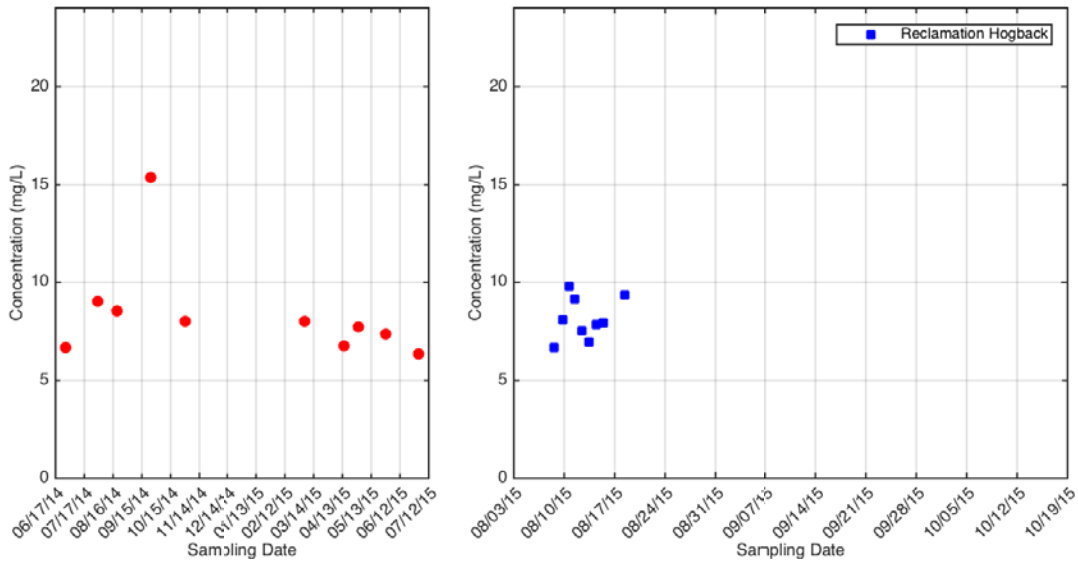


Figure A- 20. Total silica measured in micrograms per liter from the three sampling locations. The left pane indicates pre-spill data and the right pane indicates post-spill data. Unfilled markers indicate values reported at the MRL.

Total Silver

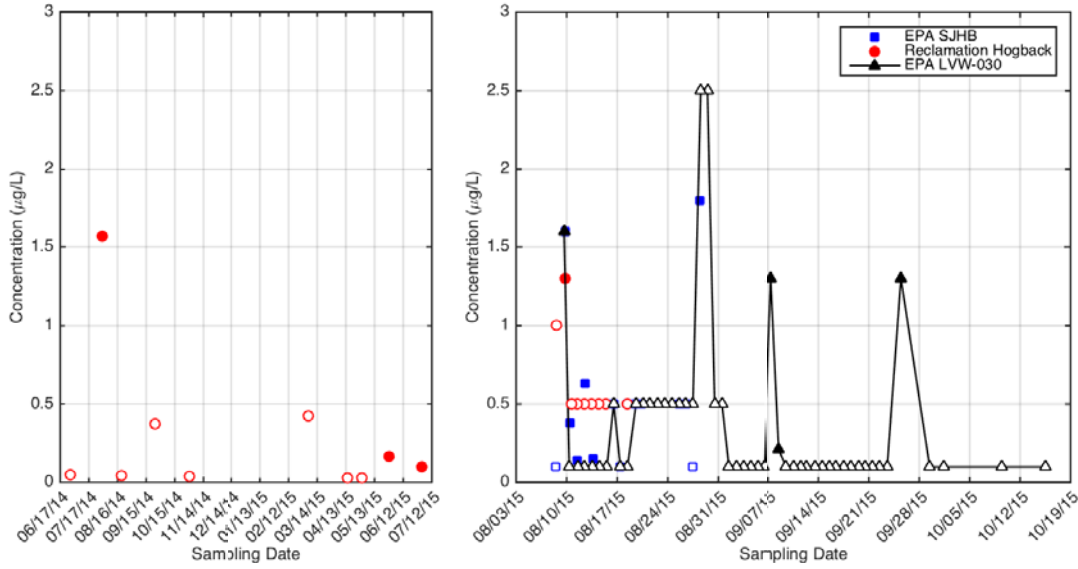


Figure A- 21. Total silver measured in micrograms per liter from the three sampling locations. The left pane indicates pre-spill data and the right pane indicates post-spill data. Unfilled markers indicate values reported at the MRL.

Total Sodium

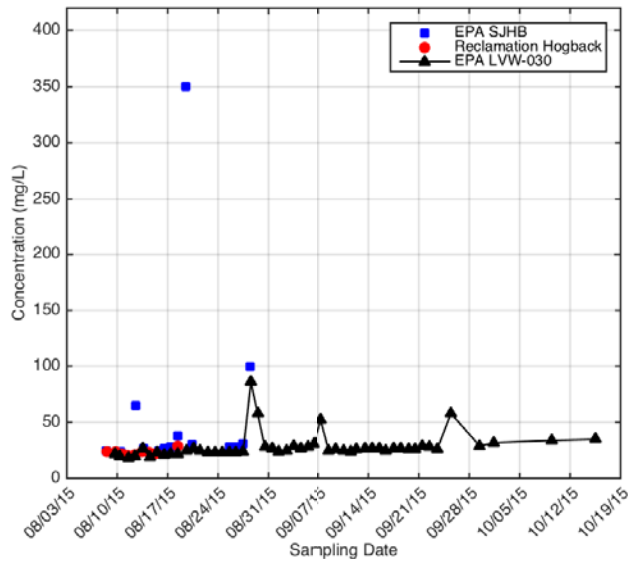


Figure A- 22. Total sodium measured in milligrams per liter from the three sampling locations. The left pane indicates pre-spill data and the right pane indicates post-spill data. Unfilled markers indicate values reported at the MRL.

Total Thallium

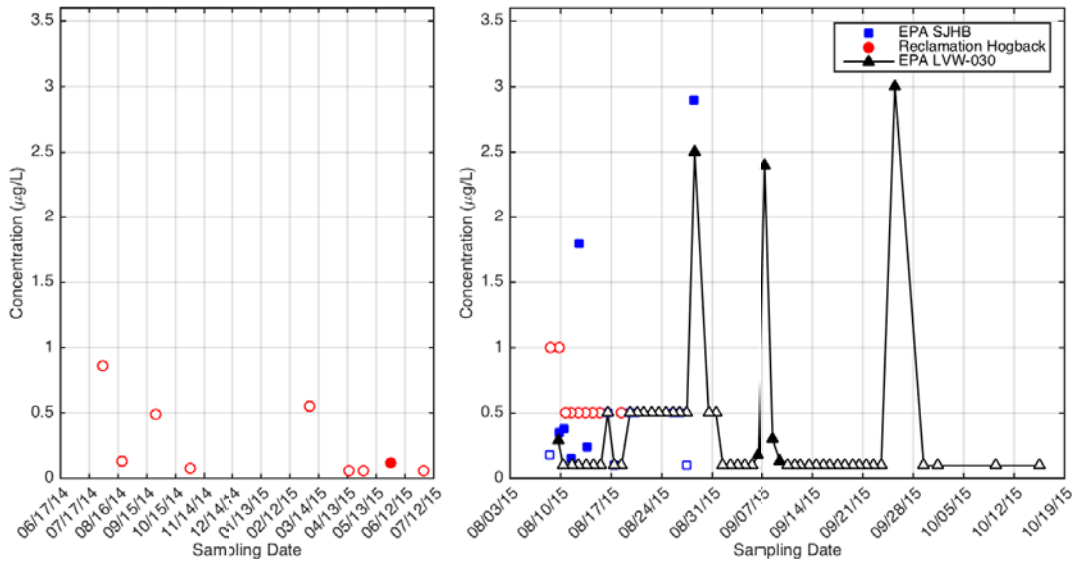


Figure A- 23. Total thallium measured in micrograms per liter from the three sampling locations. The left pane indicates pre-spill data and the right pane indicates post-spill data. Unfilled markers indicate values reported at the MRL.

Total Vanadium

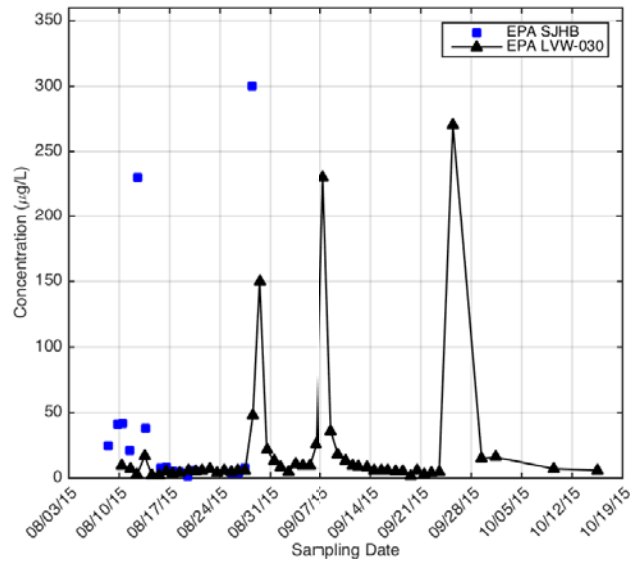


Figure A- 24. Total vanadium measured in micrograms per liter from the three sampling locations. The left pane indicates pre-spill data and the right pane indicates post-spill data. Unfilled markers indicate values reported at the MRL.

Total Zinc

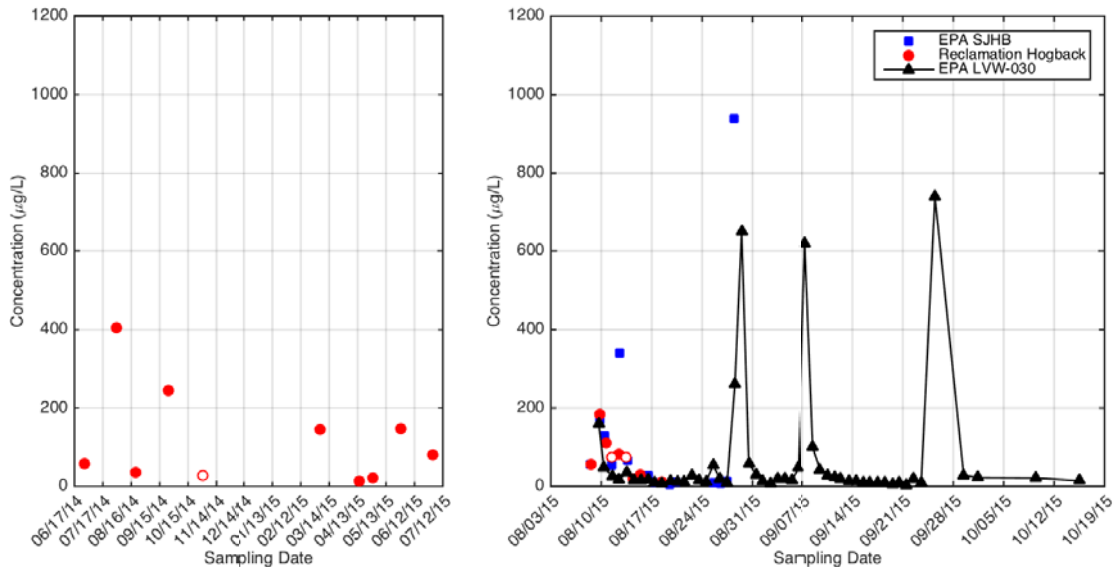


Figure A- 25. Total zinc measured in micrograms per liter from the three sampling locations. The left pane indicates pre-spill data and the right pane indicates post-spill data. Unfilled markers indicate values reported at the MRL.

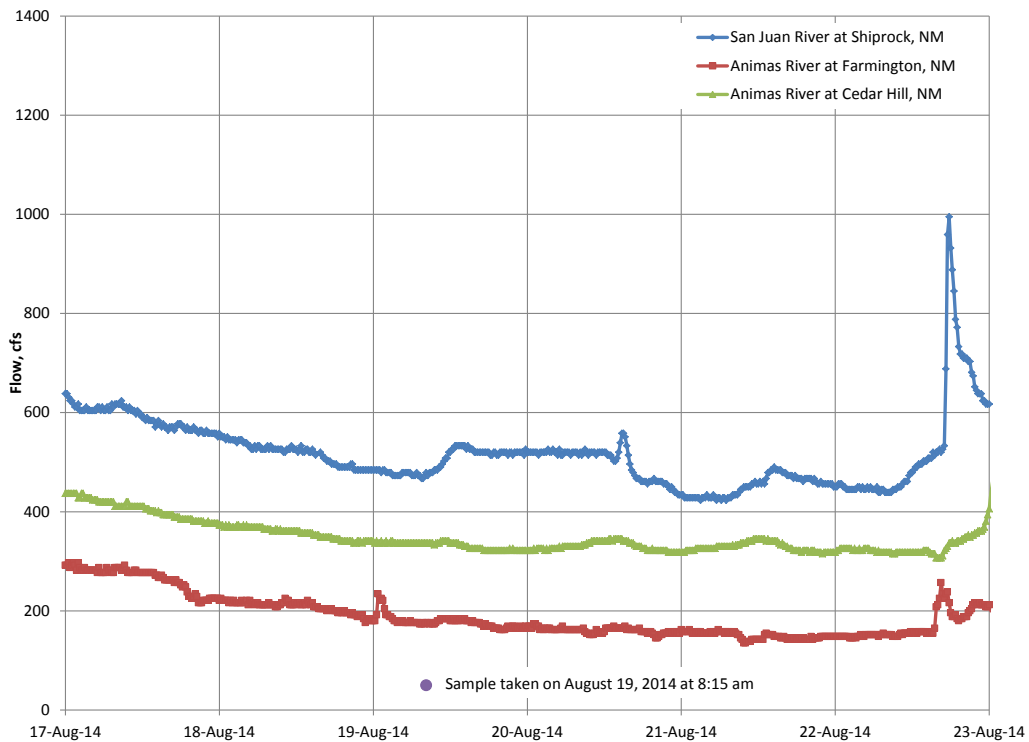


Figure A- 26. Hydrographs along Animas River during the days preceding and following the August 19, 2014 water quality analysis. Marker indicates time of sampling event.

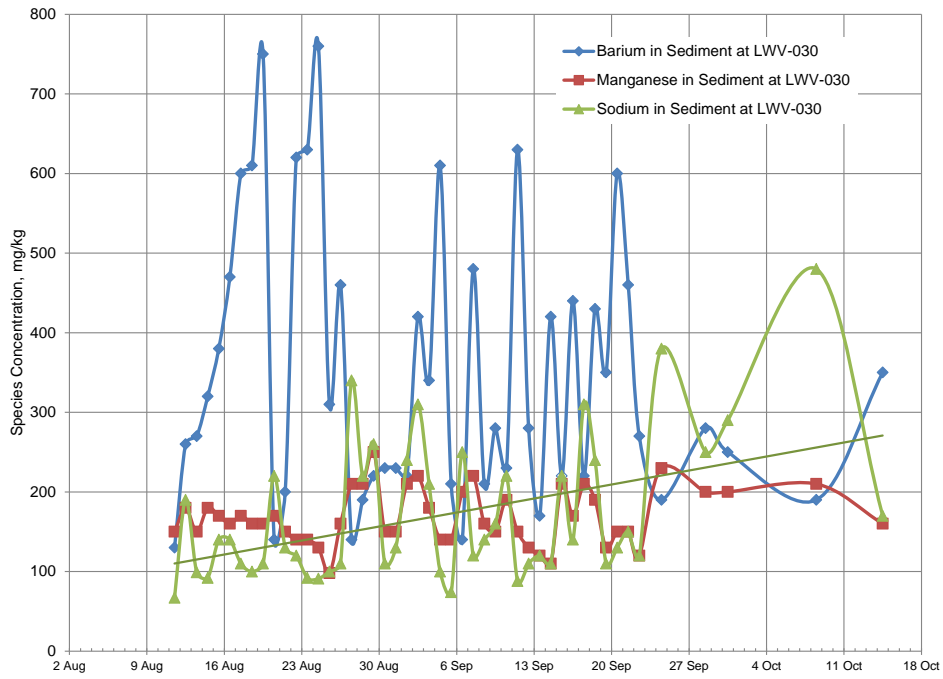


Figure A- 27. Barium, manganese and sodium sediment concentrations at EPA LVW-030 measured in 2015.

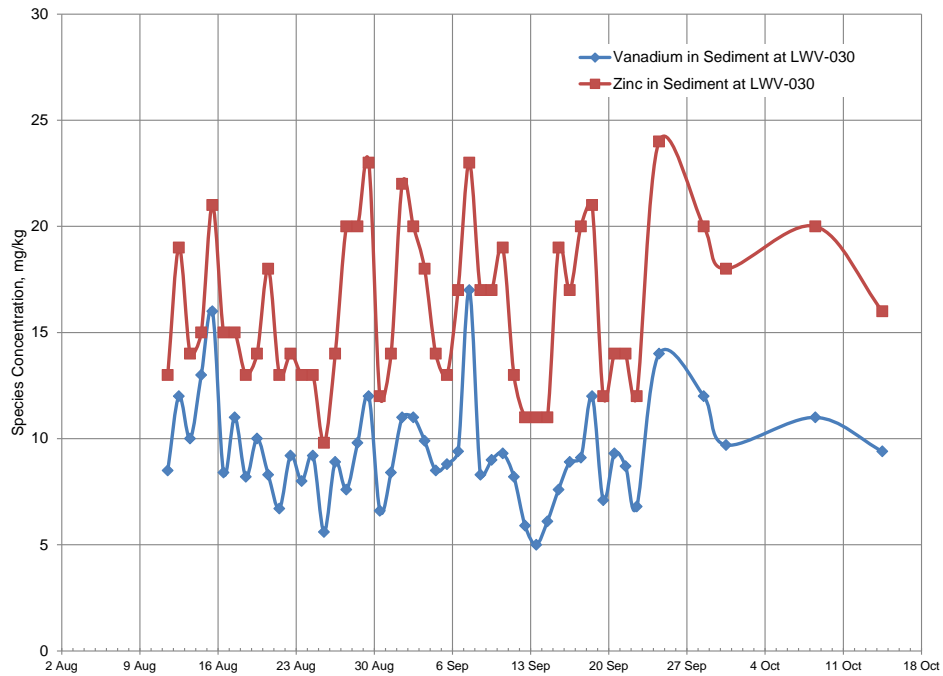


Figure A- 28. Vanadium and zinc sediment concentrations at EPA LVW-030 measured in 2015.

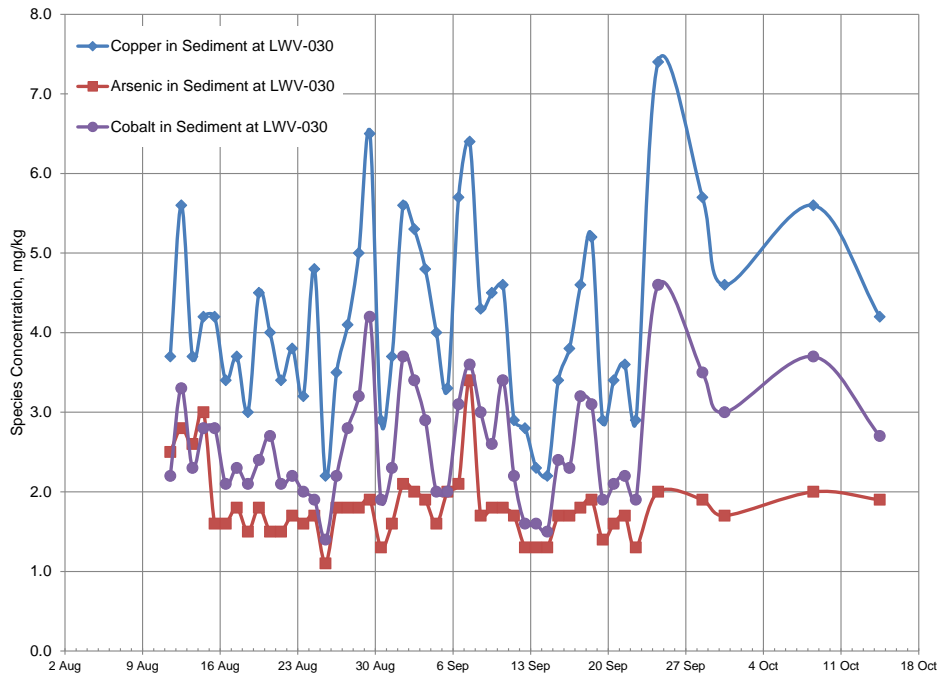


Figure A- 29. Copper, arsenic and cobalt sediment concentrations at EPA LVW-030 measured in 2015.

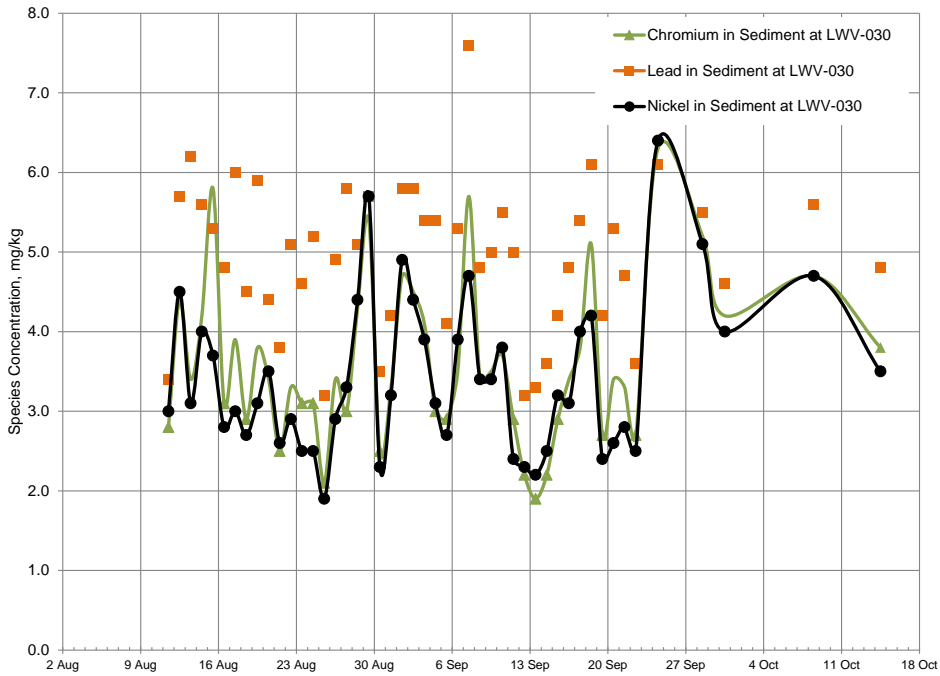


Figure A- 30. Chromium, lead and nickel sediment concentrations at EPA LVW-030 measured in 2015.

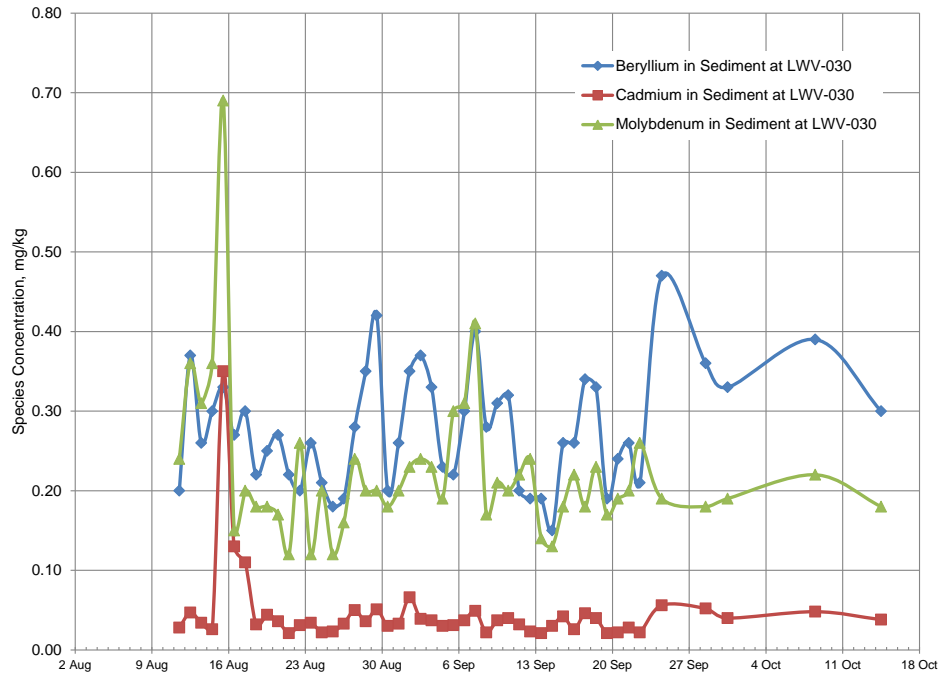


Figure A- 31. Beryllium, cadmium and molybdenum sediment concentrations at EPA LVW-030 measured in 2015.

Appendix B. Quality Control Review of Reclamation Water Samples

Quality Control Approach

Several steps were taken to validate the analytical results for the water quality analyses. The sample collection and handling procedures were reviewed to confirm that proper procedures were taken prior to analytical analysis. The analytical methods were reviewed to confirm that they were appropriate for the analyte of interest and that the method reporting limits (MRLs) are reasonable compared to published methods by cross referencing the National Environmental Methods Index (NEMI). All reported values were compared to the lab-determined MRL to verify that no concentrations were reported below the specified MRL. It was also confirmed that the MRL was adjusted appropriately for sample dilution. For duplicate analyses, the relative percent difference values were reviewed to confirm that the method reproducibility was adequate. For all measurements performed by Green Analytical Laboratories, the acceptable limit for RPD is $\pm 20\%$. Where data was available, quality assurance data was reviewed to confirm method performance. These data included the laboratory control samples (LCS), laboratory blanks and matrix spikes. Laboratory blanks are samples consisting of lab-grade water with no expected detection of a specific analyte. LCS samples are samples with a known concentration of a specific analyte in lab-grade water, and recovery of the analyte should fall within 85-115% of the expected value. Detection of a method analyte may lead to an MRL adjustment for that analysis batch unless the measure analyte in the sample is sufficiently greater than the concentration measured in the blank. Finally, matrix spikes are environmental samples that are spiked with a known concentration of a specific analyte to investigate interference effects from the sample matrix (either enhancement or suppression). Analyte recovery for matrix spiked samples should be between 70-130% of the expected value.

General Water Chemistry Analyses

General water quality analytical results include total cyanide, pH, total suspended solids (TSS), organic carbon and turbidity analyses. The appropriate method was applied for each of these analyses. Although some pH and turbidity analyses were performed beyond the method holding time, one quality control issue was identified that would significantly affect interpretation of the data. The turbidity measurement from 8/8/15 is likely greatly under reported based on trends in other analytes. Detailed summaries for each method are following.

pH was measured using an electrometric method. Duplicate analyses were performed with each analysis batch for at least one sample, although the Reclamation supplied sample was often not the sample used for the duplicate analysis. RPD values between duplicate analyses were well within the 20% limit. Several pH samples (8/7/15, 8/8/15, 8/9/15, 8/11/15, 8/14/15) were analyzed past their 48 hour holding time, but the effect of holding time is not indicated in the standard method. Check standards were not documented in the laboratory reports.

Turbidity measurements were performed using a turbidimeter. Like pH measurements, a duplicate analysis was performed with each analysis batch, but the replicated sample was often not a Reclamation supplied sample. RPD values between duplicates were within quality control limits. Two samples had higher, yet still acceptable, RPD values (10.5% on 8/11/15 and 18.2% on 8/13/15), but these values are likely inflated relative to other samples due to the low measurements (<0.12 NTU). Many samples with higher turbidity were diluted prior to analysis. The EPA method 180.1 recommends that measurements fall within a 0-40 NTU range. Several samples after dilution had turbidities greater than the recommended upper range (8/10/15, 8/11/15, 8/12/15, 8/13/15, 8/14/15, 8/17/15). Samples above 40 NTU likely have increased uncertainty associated with the reported value. The holding time was exceeded for some turbidity samples (8/7/15, 8/8/15, 8/9/15, 8/10/15, 8/11/15, 8/12/15, 8/14/15), but the effects of longer holding times is not stated in the method. Another unusual result is that the sample with the highest TSS concentration (8/8/15, 3370 mg/L) also had the lowest turbidity (32 NTU), which suggests a turbidity measurement error.

TSS was quantified gravimetrically by measuring oven dried, non-filterable residue. For each analysis batch, laboratory blanks were analyzed, and TSS values were below the MRL. One duplicate analysis was reported for each batch, but the sample selected for duplicate analysis was often not the Reclamation collected sample. All reported RPD values between duplicates were less than 3% and within quality control specifications demonstrating method reproducibility.

Total cyanide was analyzed using a colorimetric method and no known interferences were identified. Quality control samples were both within specifications. All blank sample analyses were below the detection limit. Laboratory control samples with a known concentration had recovery values within the specified range demonstrating instrument accuracy. Duplicate samples were analyzed with all batches, except batches associated with the 8/13/15 and 8/14/15 samples. While the duplicate samples were not the Reclamation provided sample, the RPD values were within the specified limit and demonstrate method reproducibility.

Total organic carbon (TOC) and dissolved organic carbon (DOC) was analyzed using the persulfate oxidation method. DOC was not analyzed for the sample collected on 8/14/15. Review of the chain of custody found that DOC was not a requested analysis for that day. For the 8/9/15 sample, reported DOC was slightly greater than TOC (RPD = 1.5%), but the difference is within expected analytical

error for this method. Only the lab results were reported, and no quality control data is included in the reports to verify analytical method performance.

Metals Analysis

Metals were quantified either by inductively coupled plasma – atomic emission spectrometry (ICP-AES) following EPA method 200.7 or inductively coupled plasma – mass spectrometry (ICPMS) following EPA method 200.8. Both methods are appropriate for the reported analytes. The data was validated by reviewing quality control samples performed at the time of analysis, which include blank samples, laboratory control samples and matrix spiked samples. Matrix spiked samples were only performed for a selected number of Reclamation supplied samples, but these results were reviewed to identify potential interference effects.

For analytes quantified by ICP-AES, no quality control issues were identified. For analysis of total recoverable metals, calcium and iron were commonly detected in the blank analysis. Annotations of the lab report indicate that an appropriate response was taken to account for analyte detection in the blanks. The sample concentration was either more than 10 times the blank concentration suggesting that the blank detection should have little effect on the reported sample concentration. In other cases, the MRL was increased for the batch as a conservative measure. For the dissolved analyses, no analytes were detected in the blank samples. For both total and dissolved analyses, recoveries for laboratory control samples and the RPD between duplicate analyses were within quality control specifications. Duplicate analyses were performed with each analysis batch, although not necessarily using Reclamation supplied samples. Duplicate RPD values were within quality control specification, usually less than 6%.

Select Reclamation samples were used for the matrix spike analysis for ICP-AES analysis to evaluate potential interference effects. For the total recoverable metals analysis, 8/7/15 and 8/11/15 samples were spiked with aluminum, calcium, iron, magnesium, silicon and sodium. Analyte recoveries for calcium and sodium were outside of the specified range for the 8/7/15 sample. Implications for the poor calcium recovery are inconclusive, because the spiked level was too low compared to the sample concentration. The sodium recovery was low, which is indicative of some analyte suppression. Both the samples had similar sodium concentrations but a potential matrix interference was only detected in one sample, suggesting that these effects are likely minor and not systemic. Due to matrix interferences, the reported sodium concentration may be underestimated. Analyte recoveries for the 8/11/15 sample were outside the limits for aluminum, calcium and silica but the implications are inconclusive, because the spiked amount was too low compared to the sample concentration. For the dissolved analysis, a Reclamation samples was used as the matrix was analyzed on 8/11/15. The calcium recovery was out of range, but the implications are inconclusive. The spiked amount was small relative to amount of analyte in the sample. Recovery of

sodium was low and may indicate matrix interferences leading to analyte suppression. Reported values may be underestimated.

For the metals analyzed by ICPMS, quality control samples were reviewed for both total and dissolved analyses. In the analysis of total recoverable metals, several analytes (i.e., cadmium, chromium, manganese and zinc) were routinely detected in the laboratory blank samples. Antimony was detected in two samples (8/14/15 and 8/17/15). In each case, appropriate measures were taken in reporting the sample data. In many cases, the sample concentration was more than 10 times greater than the concentration detected in the blank suggesting that the effect of the blank detecting is negligible. In other cases, the MRL was increased to account for the blank detecting yielding conservative reporting limits. One sample from each batch (not necessarily a Reclamation sample) was analyzed in duplicate and the RPD between measurements was less than 10% in all batches. For the dissolved metal analysis, no analytes were detected in the blank samples, LCS recoveries were all within range, and the RPD between duplicate LCS samples were less than 7.1%.

Hardness was quantified by EDTA titration. No quality control data (i.e., replicate analyses or laboratory control samples) are provided in the report.

Mercury was analyzed by cold vapor absorption spectrometry. Some metals have been identified as potential interferences, specifically sulfide, chloride, copper, tellurium and organic matter (EPA method 245.1). No matrix spike data is provided to evaluate potential interferences. No mercury was detected in any laboratory blank samples analyzed. Laboratory control samples were run in duplicate with each analysis batch. Analyte recovery and RPD values between replicates were within quality control specifications.

Radioactive Constituents Analysis

A range of radionuclides were analyzed using the methods listed in Table 2, all of which are appropriate for the analytes. Analytical uncertainties are reported for analytes above the MRL. According to communications with Green Analytical Laboratories, these ranges represent confidence intervals (percentage unknown) and not standard deviations, demonstrating that all reported values are likely statistically significant. No additional quality control data is provided in the analytical reports.