Literature Review and Sampling Plan Development for the San Juan River Quality Study

Research and Development Office
Science and Technology Program
Final Report-2016-SJR16-01

U.S. Department of the Interior
Bureau of Reclamation
Research and Development Office

September 2016

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REPORT DOCUMENTATION PAGE		*Form Approved* *OMB No. 0704-0188*
T1. REPORT DATE September 2016	**T2. REPORT TYPE** Research	**T3. DATES COVERED** May 2016 to September 2016
T4. TITLE AND SUBTITLE Literature Review and Sampling Plan Development for the San Juan River Quality Study		**5a. CONTRACT NUMBERS** 16XR0680A1-RY1541AW201120400 **5b. GRANT NUMBER** **5c. PROGRAM ELEMENT NUMBER** 1541 (S&T)
6. AUTHOR(S) Julie Korak, PhD, jkorak@usbr.gov, 303-445-2264		**5d. PROJECT NUMBER** SJR16 **5e. TASK NUMBER** **5f. WORK UNIT NUMBER** 86-68190
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Julie Korak, Bureau of Reclamation		**8. PERFORMING ORGANIZATION REPORT NUMBER**
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) Research and Development Office U.S. Department of the Interior, Bureau of Reclamation, PO Box 25007, Denver CO 80225-0007		**10. SPONSOR/MONITOR'S ACRONYM(S)** R&D: Research and Development Office BOR/USBR: Bureau of Reclamation DOI: Department of the Interior **11. SPONSOR/MONITOR'S REPORT NUMBER(S)** 1

12. DISTRIBUTION / AVAILABILITY STATEMENT
Final report can be downloaded from Reclamation's website: https://www.usbr.gov/research/

13. SUPPLEMENTARY NOTES

14. ABSTRACT *(Maximum 200 words)*
The San Juan Lateral water treatment plant is one component of the Navajo-Gallup Water Supply Project, which will treat San Juan River water and deliver potable water. Past sampling efforts and data analysis projects have demonstrated that flow variations due to snowmelt and monsoon events cause abrupt changes in sediment transport and water quality. This study conducted a literature review focusing on water quality in the San Juan River watershed and collected data from previous efforts. Knowledge gaps pertinent to the design and operation of the San Juan Lateral water treatment plant are identified. Past sampling efforts at the Hogback Diversion Channel are summarized, and a modified sampling plan is proposed for fiscal years 2017 and 2018.

15. SUBJECT TERMS
San Juan River, Water Quality, Monitoring, Navajo-Gallup Water Supply Project

16. SECURITY CLASSIFICATION OF: U			**17. LIMITATION OF ABSTRACT** U	**18. NUMBER OF PAGES** 68	**19a. NAME OF RESPONSIBLE PERSON** Julie Korak
a. REPORT U	**b. ABSTRACT** U	**c. THIS PAGE** U			**19b. TELEPHONE NUMBER** 303-445-2264

S Standard Form 298 (Rev. 8/98)
P Prescribed by ANSI Std. 239-18

PEER REVIEW DOCUMENTATION

Project and Document Information

Project Name Literature Review and Sampling Plan Development for the San Juan River Quality Study WOID SJR16

Document Final Report 2016-SJR16-01

Document Author(s) Julie Korak Document date: 9/29/2016

Peer Reviewer Frank Leitz

Review Certification

Peer Reviewer: I have reviewed the assigned items/sections(s) noted for the above document and believe them to be in accordance with the project requirements, standards of the profession, and Reclamation policy.

Reviewer /s/ Frank Leitz Date reviewed 9/27/2016
(Signature)

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Executive Summary

The Navajo-Gallup Water Supply Project (NGWSP) is a Bureau of Reclamation (Reclamation) infrastructure project that will convey water to the Navajo Nation, part of the Jicarilla Apache Nation and the city of Gallup, New Mexico. One component of the project is the design and construction of the San Juan Lateral (SJL) water treatment plant, which will treat San Juan River water and deliver potable water to the aforementioned entities. The proposed intake for the SJL water treatment plant is at the Hogback Diversion Channel, located on the San Juan River between Farmington, NM, and Shiprock, NM.

In preparation for the design and construction of the SJL water treatment plant, Reclamation has been collecting and analyzing water quality samples through online sensors and manually collected samples. Following the Gold King Mine Spill, analysis of water quality data through summer 2015 identified a need to better understand water quality fluctuations during monsoon rain events, especially in late summer and early fall with respect to metals concentrations (Bureau of Reclamation, 2016). Past sampling efforts and data analysis projects have demonstrated that flow variations due to snowmelt and monsoon events cause abrupt changes in sediment transport and water quality. Depending on the treatment process, the observed fluctuations may impact finished water quality and solids disposal.

To develop an operational strategy to manage sediment and metals intake to the SJL water treatment plant, additional data is needed to understand the duration and magnitude of water quality fluctuations. The objectives of this portion of the project are to:

1. Conduct a literature review regarding water quality in the San Juan River watershed with a particular focus on sediment and metals transport
2. Summarize current and previous sampling efforts within the San Juan River watershed
3. Develop and propose a sampling plan for fiscal years 2017 and 2018 that fills any knowledge gaps identified by the literature review

The San Juan River is a tributary to the Colorado River, and its watershed lies in the Four Corners Area (Colorado, Utah, Arizona and New Mexico) of the United States. The entire drainage area of the San Juan River watershed (hydrologic unit 1408) covers 64,577 km^2. Upstream of the Hogback Diversion Channel, five subbasins drain into the San Juan River. Based on the literature review, two subbasins, Animas and Blanco Canyon, are the largest contributors of sediment and metals to the main stem of the San Juan River.

The Animas Subbasin is the most studied subbasin with respect to water quality in the San Juan River watershed. Historical mining activity around Silverton, CO, lead to hundreds of abandoned mines, mine tailings and waste sites that contribute to acid mine drainage (AMD) within the headwaters of the watershed. The Upper

Animas River was the studied extensively during fiscal years 1997 through 2001 as a part of the U.S. Geological Survey (USGS) Abandoned Mine Lands Initiative (AMLI), which was a coordinated effort between the U.S. Department of the Interior and U.S. Department of Agriculture (Church et al., 2007b).

AMD and acid rock drainage (ARD) in the headwaters of the Animas River produce acidic water with high concentrations of metals. Iron and aluminum are the most abundant metals followed by zinc, manganese and other trace metals (e.g., cadmium, lead). At the confluence of acidic streams with non-acidic streams, iron, aluminum and manganese hydroxide complexes form and precipitate as solids. Other trace metals can partition to the solids through adsorptive mechanisms leading to an accumulation of trace metals in the bed sediment (Church et al., 1997; Paschke et al., 2005; Schemel et al., 2000). One study estimated that 256 kg/day of aluminum and 234 kg/day of iron accumulated in the bed sediment downstream of the convergence of Mineral Creek with the Animas River (Church et al., 1997). Hydrology plays an important role in the accumulation of metal-rich sediment in the Animas River with an accumulation of sediment in lower-velocity, braided sections that has a potential for future mobilization at higher flows.

While most of the investigations in the Animas River watershed have focused on the upper reaches near Silverton, CO, this area represents a small geographic region (181 km^2) relative to the entire subbasin (3548 km^2) (Church et al., 2007b). Downstream of Silverton, CO, additional tributaries converge with the Animas River, namely the Florida River. In general, bed sediment metal concentrations decrease between Silverton, CO and Aztec, NM due to dilution with lower metal content sediment from the Florida River (Church et al., 1997).

Blanco Canyon Subbasin (HUC 14080103) is located south of the San Juan River and east of Farmington, NM. Cañon Largo, the subbasin's tributary to San Juan River, is one of the largest contributors of suspended sediment and salinity to the San Juan River watershed. While the Animas River Subbasin draws attention due to the water quality issues related to trace metals, it is not a major contributor of total suspended sediment. Of the total sediment load at Shiprock, NM, (downstream of the Hogback Diversion Channel), the Animas River Subbasin accounts for 43% of the total flow but only 9% of the total sediment load (Abell, 1994). Water quality data collected between 1977 and 1981 exhibited large increases in suspended sediment and trace metals during monsoon events. Comparing Cañon Largo water quality to the Animas River data showed that iron, manganese and aluminum can be mobilized and transported to the San Juan River from both subbasins. In developing a strategic monitoring plan for the NGWSP SJL water treatment plant, it must be suspected that multiple contributing subbasins can have mobilization events leading to high sediment and trace metal concentrations at the proposed intake site.

The literature review identified three knowledge gaps with respect to water quality during monsoon events that are pertinent to the future design and operations of the SJL water treatment plant:

1. Both the Animas and Blanco Canyon Subbasins produce flows with high suspended sediment and metal (i.e., aluminum, iron and manganese) concentrations, and the relative contribution of each subbasin is unknown.
2. Thresholds between changes in river flow and suspended sediment concentrations at the proposed intake are unknown.
3. The interplay between increased sediment loads and dissolved metals concentration at the Hogback Diversion site is poorly understood.

After reviewing the sampling approach conducted at the Hogback Diversion Channel between 2014 and 2016, it is recommended that several modifications and augmentations be made to the current sampling plan. The sampling plan proposed in this study is designed to meet the following objectives:

1. Continue the Reclamation and USGS previous sampling approach (baseline and spring runoff) with a modification that moves water quality sampling to the San Juan River at a location such that sampling is not contingent on flow in the Hogback Diversion Channel.
2. Augment the previous sampling approach to measure suspended solids and metal (total, dissolved and sediment) concentrations *during monsoon events* in the San Juan watershed with a sampling frequency capable of defining a peak event.
3. Evaluate the relative contribution of the Animas Subbasin relative to the Upper San Juan and Blanco Canyon Subbasins by leveraging other efforts in the watershed.

To better understand the suspended solids and water chemistry of monsoon peak turbidity events, it is proposed than an autosampler be implemented to collect high frequency samples. Autosamplers can be programmed to be triggered remotely or based on real-time turbidity measurements. By expanding the frequency of data collection during these events, the following questions can be answered:

1. What is the *maximum concentration* of suspended solids and associated metals observed during a peak event?
2. What is the *total mass* of solids and associated metals that would have entered an intake settling basin during a peak event?
3. What is the *duration* of a peak event as quantified by the amount of time required to return to the baseline turbidity values?

Implementing the proposed plan will be valuable for the design and operation of the NGWSP SJL water treatment plant by providing tools to plan for high solids events in San Juan River. It is anticipated that this augmented sampling plan will be conducted during fiscal years 2017 and 2018 through a Reclamation Science & Technology research project.

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Introduction and Objectives

The Navajo-Gallup Water Supply Project (NGWSP) is a Bureau of Reclamation (Reclamation) infrastructure project that will convey water to the Navajo Nation, part of the Jicarilla Apache Nation and the city of Gallup, New Mexico. One component of the project is the design and construction of the San Juan Lateral (SJL) water treatment plant, which will treat San Juan River water and deliver potable water to the aforementioned entities. The proposed intake for the SJL water treatment plant is at the Hogback Diversion Channel, located on the San Juan River about 12 river miles above Shiprock, NM, and about 22 river miles below Farmington, NM, as indicated in Figure 1.

In preparation for the design and construction of the SJL water treatment plant, Reclamation has been collecting water quality data to provide a design basis for future efforts. This work has included collecting water quality samples from the San Juan River and Hogback Diversion Channel, monitoring for turbidity and total suspended solids in the Hogback Diversion Channel, performing settling tests, and facilitating water treatment pilot tests at the proposed intake site.

Following the Gold King Mine Spill, data analysis of water quality samples through summer 2015 identified a need to better understand water quality fluctuations during monsoon events, especially in late summer and early fall with respect to metals concentrations (Bureau of Reclamation, 2016). Past sampling efforts and data analysis projects have demonstrated that flow variations due to snowmelt and precipitation events cause abrupt changes in sediment transport and water quality. During these peak events, one to two order of magnitude increases in total and dissolved metal concentrations have been observed. The fluctuations lead to dissolved metal concentrations greater than the Safe Drinking Water Act (SDWA) maximum contaminant level (MCL). Depending on the treatment process, these concentrations may impact finished water quality and solids disposal. These monsoon events also cause a resuspension and transport of total suspended solids during irrigation season, which are well documented in Hogback Diversion Channel through past efforts, but the fluctuations in dissolved metals concentrations are not well documented.

These peak events are potentially problematic for water treatment operations due to changing influent water concentrations. During water treatment, operational parameters, such as chemical dosing and filter run times, are dependent on influent water quality conditions. To develop an operational strategy to manage sediment and metals intake to the water treatment plant, additional data is needed to understand the duration and magnitude of water quality fluctuations. The objectives of this project are to:

1. Conduct a literature review regarding water quality in the San Juan River watershed with a particular focus on sediment and metals transport
2. Summarize current and previous sampling efforts within the San Juan River watershed

3. Develop and propose a sampling plan for fiscal years 2017 and 2018 that fills any knowledge gaps identified by the literature review

The Water Treatment Group in collaboration with the Four Corners Construction Office (FCCO) submitted a proposal to the Reclamation Science and Technology Program to support the augmented efforts outlined in this sampling plan. If funded, it is anticipated that this sampling plan would be implemented starting in January 2017 and be conducted through December 2018.

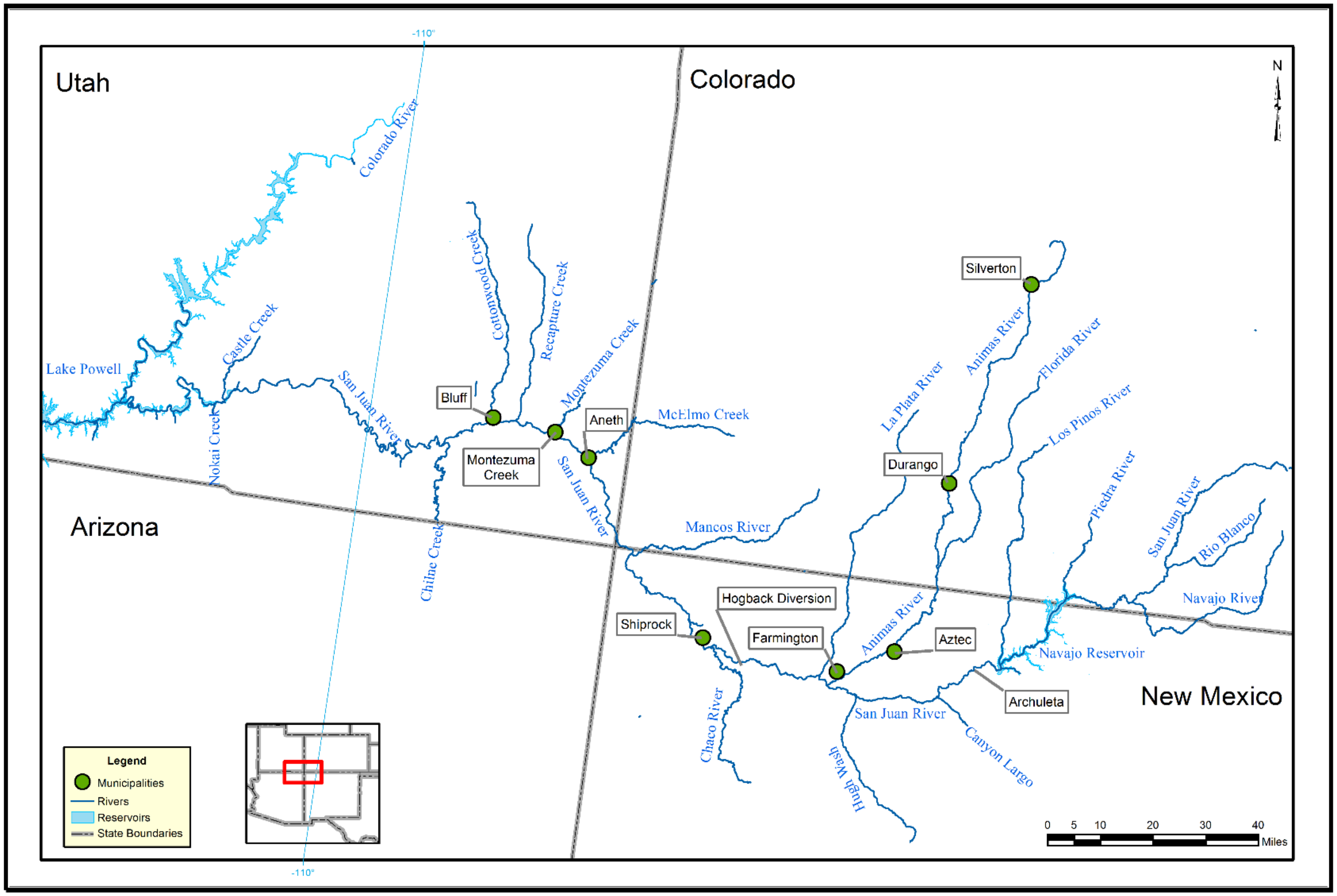

Figure 1. Map of San Juan River Watershed with select municipalities and Hogback Diversion

Watershed Overview

The San Juan River is a tributary to the Colorado River, and its watershed lies in the Four Corners Area (Colorado, Utah, Arizona and New Mexico) of the United States as illustrated in Figure 2. The entire drainage area of the San Juan River watershed (hydrologic unit 1408) covers 64,577 km^2. Both perennial and ephemeral tributaries are found within the watershed. Perennial tributaries (e.g., Animas River) flow year-round, whereas ephemeral streams (e.g., Cañon Largo) flow intermittently after precipitation events.

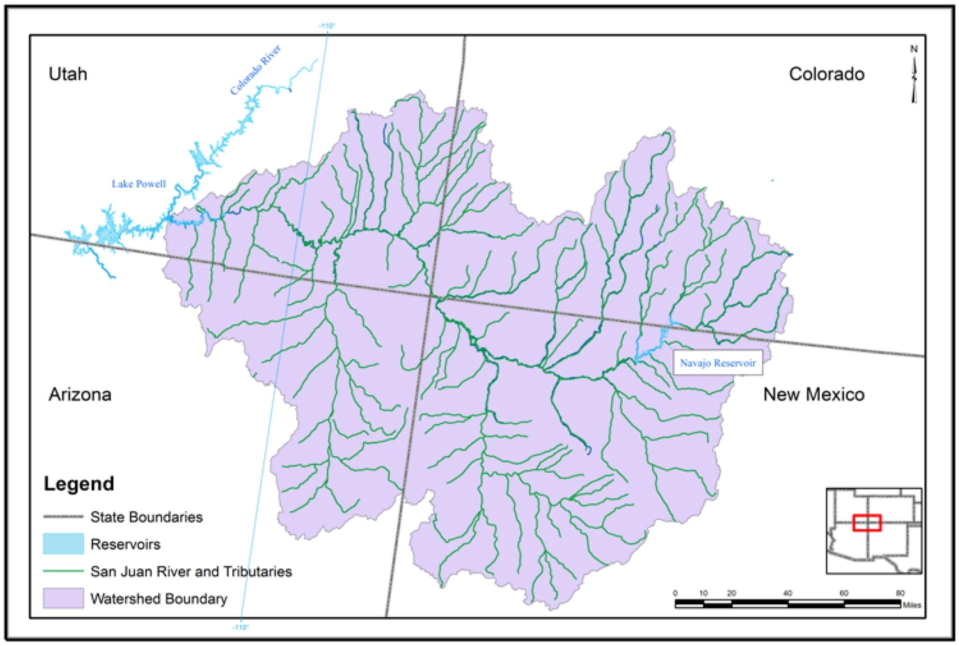

Figure 2. San Juan River watershed boundary and primary tributaries. Data source: USGS Watershed Boundary Dataset Hydrologic Unit (HUC) 1408.

The Hogback Diversion Channel, the location of the proposed NGWSP SJL intake, is located in northwest New Mexico along the San Juan River. At the Hogback Diversion Channel, several subbasins lie within the drainage area illustrated in Figure 3, each of which affects the water quality at the proposed intake site.

The Upper San Juan and Piedra subbasins (depicted together in Figure 3) account for the largest area within the watershed at 8887 km^2 and 1752 km^2, respectively. This subbasin included Navajo Reservoir, which covers about 63 km^2 and leads to managed flow within the upper portion of the subbasin.

The Blanco Canyon subbasin covers 4439 km^2 of the watershed and is the second largest drainage basin in the watershed. Cañon Largo, the primary tributary to the San Juan River in this subbasin, is an ephemeral stream that flows only during summer precipitation events (USDA Natural Resources Conservation Service, 2007a).

The third largest subbasin within the drainage area above the Hogback Diversion Channel is the Animas subbasin covering 3,550 km^2. The headwaters of the Animas River lie north of Silverton, CO, in the Rocky Mountains. Several tributaries, including the Florida River, flow into the Animas River before it reaches the San Juan River in Farmington, NM. This subbasin does not contain any reservoirs along the main reach of the Animas River to manage flow, although the Durango Pumping Plant diverts some water through the Animas-La Plata Project. As a result, temporal variations in water quality and flow are not attenuated in this subbasin before entering the San Juan River.

The Middle San Juan subbasin is located west of Farmington, NM, and includes the La Plata River as a primary tributary covering a total of 5,042 km^2 (USDA Natural Resources Conservation Service, 2007b). The La Plata is the last major tributary to the San Juan above the Hogback Diversion.

Parts of the Middle San Juan Subbasin lie to the west of the Hogback Diversion where runoff would enter the San Juan River downstream of the proposed intake. Runoff water quality in this portion of the subbasin west of the proposed intake at the Hogback Diversion does not affect influent water quality for the SJL plant. One notable example, Chaco River is an ephemeral stream draining a large dry wash system (Brown, 2008) that enters the San Juan River downstream of the Hogback Diversion.

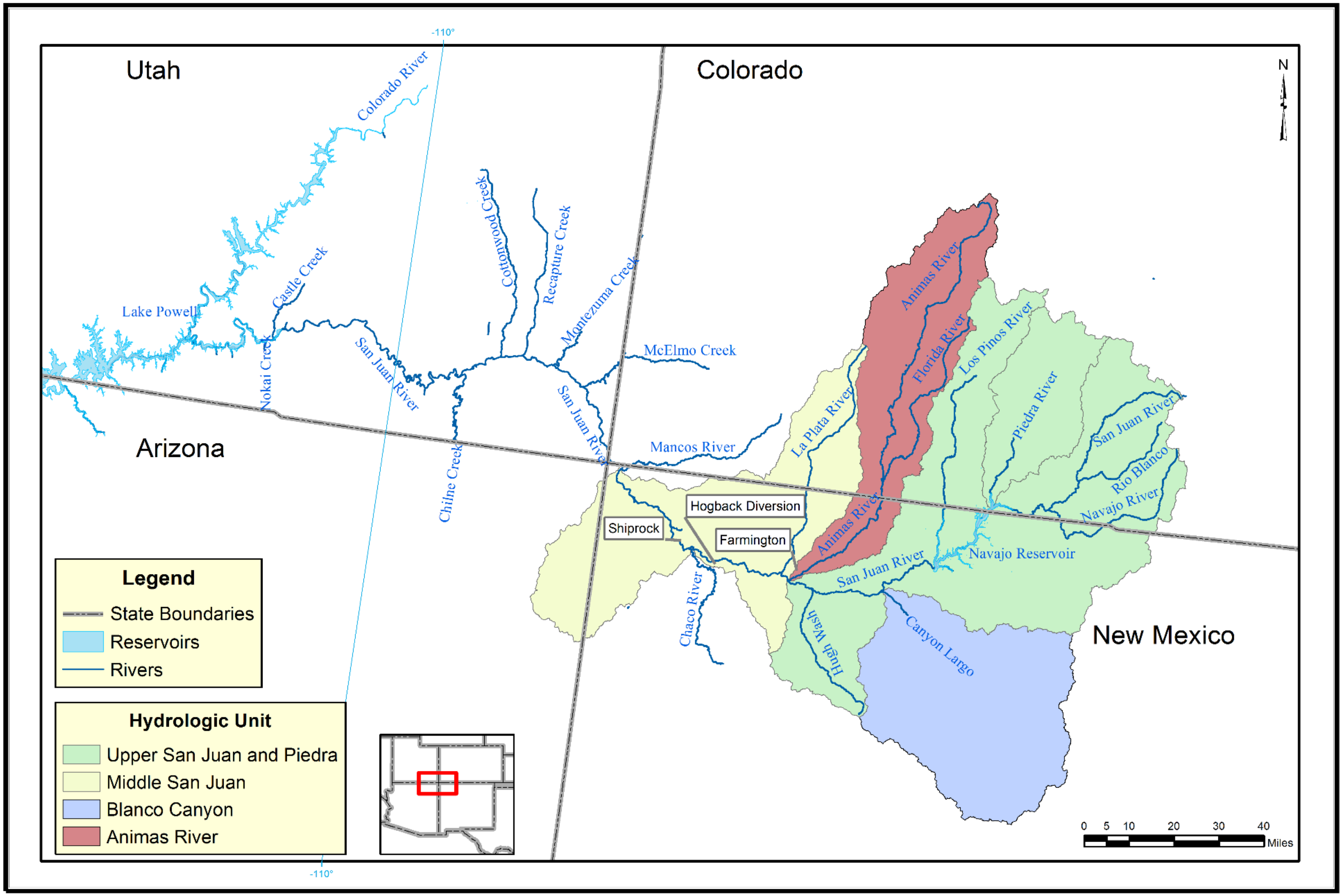

Figure 3. San Juan River Watershed boundaries (8-digit) upstream of the Hogback Diversion. Data source: USGS National Hydrology Dataset.

Literature Review

A literature review was conducted to gather relevant information and to identify knowledge gaps related to temporal variations in water quality in the San Juan River watershed with respect to water treatment operations of the NGWSP SJL plant. Based on the observations from previous efforts (Bureau of Reclamation, 2016), the literature review focused on the following objectives:

- Summarize publically available water quality data for the watershed and identify differences between watershed subbasins
- Review literature related to the accumulation and transport of sediment and metals in the San Juan River watershed
- Investigate the impact of hydrology on water quality during spring runoff and isolated precipitation events

In order to develop a strategic monitoring plan and control intake operations at a proposed plant, it is important to understand which subbasins have the greatest effect on overall water quality of the San Juan River at the Hogback Diversion. The literature review investigated each of the watershed subbasins to better understand what environmental or anthropogenic factors may impact San Juan River water quality.

Approach

To summarize available water quality data for the watershed, three main sources of information was used. Three Reclamation reports are referenced for water quality data in the Upper San Juan, Animas and Middle San Juan Subbasins. As a part of Reclamation's Animas-La Plata Project, two supplements to the 1980 Final Environmental Impact Statement (FEIS) were published in 1996 and 2000. The 1996 Final Supplement to the FEIS has a specific objective to investigate trace elements to comply with Public Law 99-294 (Bureau of Reclamation, 1996). The 2000 Final Supplement to the FEIS was prepared to evaluate the potential impacts of implementing the Colorado Ute Indian Water Rights Settlement Act of 1988 (Public Law 100-585) (Bureau of Reclamation, 2000). Lastly, water quality data from the FEIS for Navajo Reservoir Operations (Bureau of Reclamation, 2006). Relevant data from these reports are reproduced and tabulated in this review to summarize the breadth of water quality data available through the Animas-La Plata Project and Navajo Unit that are also relevant to future work through the NGWSP.

The U.S. Geological Survey (USGS) National Water Information System (NWIS) was queried for more recent water quality data spanning January 2000 through August 2016 (U.S. Geological Survey, 2016). Several filters were applied in calculating statistics. Zero values were not included, because they do not incorporate a realistic method detection limit, which questions data validity. In calculating the mean value, one-half the reporting limit was used for values reported as less than the method reporting limit. Values reported at the reporting limit were excluded from determinations of the maximum value to avoid older data with higher reporting limits from influencing the maximum value.

A summary of the data available through the Environmental Protection Agency (EPA) following the Gold King Mine Spill is included, but readers are referred to the readily available electronic data sources as the dataset is practicably too large to reproduce in print[1]. Lastly, San Juan River water quality data from the water treatment pilot testing conducted in 2012 are also included (Malcolm Pirnie/Arcadis, 2013).

Data from several sources are reported, because each compiled dataset has advantages and disadvantages. The data presented in Reclamation (1996) has the most sampling sites throughout the watershed, but the dataset is more limited with respect to number of samples collected. The suite of water quality parameters reported is also smaller than that of other studies. Within each watershed subbasin, there are more discrete sampling sites in the 1996 report than in other studies. This study also reported sediment analysis data that was not included in Reclamation (2000). A disadvantage of this dataset is that mean values are reported that cannot be related to hydrologic conditions to investigate historical relationships between concentration and flow. Only aggregate values on a monthly or seasonal basis are provided. The Reclamation (2000) report is a larger dataset but values are only reported as a mean value, with no indication of variability. This study compiled a comprehensive dataset from the STOrage and RETrieval (STORET) water quality database spanning 1950-1998. More recent data from NWIS can be related to hydrologic conditions, but the dataset is much smaller. The EPA dataset is extensive with respect to sampling sites and has the ability to be correlated directly to stream flow data from USGS. The disadvantage is that it does not provide historical data before August 2015 or after October 2015.

To provide perspective for the summarized data, the reported values were compared to water quality standards in both the Clean Water Act (CWA) and the Safe Drinking Water Act (SDWA). The CWA regulates surface water quality in rivers and streams based on criteria developed for designated uses. Designated uses include domestic water supply, irrigation supply, recreation, and multiple aquatic life criteria among others. New Mexico criteria for domestic water supply and irrigation for metals are summarized in Table 1 (New Mexico Water Quality Control Commission, n.d.). These criteria are used by states to identify waterbodies that are impaired, or not meeting the criteria based on designated use. Through Section 303(d) classification, waterbodies can be classified on a scale from ‘fully-supporting,’ ‘partially supporting,’ ‘water quality limited,’ to ‘not supporting’. Comparing the CWA standards to surface water concentrations can identify constituents that warrant further investigation in the treatment process.

The SDWA regulates water quality standards in treated drinking water. Primary (enforceable) and secondary (non-enforceable) maximum contaminant levels (MCLs) for select inorganic constituents are summarized in Table 2. SDWA

[1] https://www.epa.gov/goldkingmine/emergency-response-monitoring-data-gold-king-mine-incident#samplingdataresults

standards are based on total concentrations, rather than dissolved. In practice, the particulate fraction in treated drinking water is negligible after filtration processes. Therefore, comparing dissolved concentrations in the watershed to SDWA standards can identify constituents that warrant further investigation during treatment plant design or plant operation. With respect to copper and lead, concentrations measured below the SDWA action level may still be of concern, because regulations are based on concentrations at the point-of-use (not leaving the plant).

Comparing compiled water quality data to CWA or SDWA standards does not imply any regulatory implications or non-compliance. Compiled data is not representative of data that would be collected for CWA compliance with respect to sampling frequency or location. Untreated surface waters are also not subject to the SDWA. Comparisons are only included to provide contextual perspective to the data.

Table 1. New Mexico state criteria for surface water protection via the Clean Water Act (NMAC 20.6.4.900)

	Designated Use	
Parameter	Domestic Water Supply (µg/L)	Irrigation (µg/L)
Aluminum, dissolved		5000
Antimony, dissolved	6	
Arsenic, dissolved	10	100
Barium, dissolved	2000	
Beryllium, dissolved	4	
Boron, dissolved		750
Cadmium, dissolved	5	10
Chromium, dissolved	100	100
Cobalt, dissolved		50
Copper, dissolved	1300	200
Lead, dissolved	15	5000
Mercury	2	
Molybdenum, dissolved		1000
Nickel, dissolved	700	
Nitrate as N	10000	
Selenium, dissolved	50	(1)
Thallium, dissolved	2	
Uranium, dissolved	30	
Vanadium, dissolved		100
Zinc, dissolved	10500	2000
(1) If SO_4 < 500 mg/L, criterion is 0.13 mg/L. If SO_4 > 500 mg/L, criterion is 0.25 mg/L		

Table 2. Select Safe Drinking Water Act Maximum Contaminant Levels (MCL)

Parameter	Primary MCLs	Secondary MCLs
Aluminum		0.05-0.2 mg/L
Antimony	0.006 mg/L	
Arsenic	0.01 mg/L	
Barium	2 mg/L	
Beryllium	0.004 mg/L	
Cadmium	0.005 mg/L	
Chloride		250 mg/L
Chromium	0.1 mg/L	
Color		15 color units
Copper	1.3(1) mg/L	
Fluoride	4.0 mg/L	2.0 mg/L
Iron		0.3 mg/L
Lead	0.015(1) mg/L	
Manganese		0.05 mg/L
Mercury	0.002 mg/L	
Nitrate	10 mg/L as N	
Nitrite	1 mg/L as N	
pH		6.5-8.5
Selenium	0.05 mg/L	
Silver		0.1 mg/L
Sulfate		250 mg/L
Thallium	0.002 mg/L	
Total Dissolved Solids		500 mg/L
Zinc		5 mg/L
(1) Action level		

Upper San Juan and Piedra Subbasins (Navajo Reservoir)

Background

The subbasins encompassing Navajo Reservoir and its tributaries are located in the Upper San Juan (HUC 14080101) and Piedra (HUC 14080102) Subbasins shown in Figure 4. For the purposes of this report, both subbasins will be referred to collectively as the Upper San Juan Subbasin for simplicity. Water quality and hydrology in the Upper San Juan Subbasin is largely dictated by Navajo Reservoir. Navajo Reservoir covers about 63 km^2 and extends about 35 miles upstream from Navajo Dam. Much of the drainage area in these subbasins lie upstream of Navajo Reservoir, including the Los Pinos, Piedra, Rio Blanco and Navajo River tributaries. Runoff from these rivers enters Navajo Reservoir where irregularities in flow and water quality within the rivers are dampened by a long residence time in the reservoir. Additional environmental processing within the reservoir also changes water quality compared to tributaries. Water is released from the dam year-round and adjusted to meet downstream water demands. Portions of the Upper San Juan Subbasin, including Hugh Wash, are located downgradient from the Navajo dam where runoff directly enters the San Juan River without reservoir attenuation.

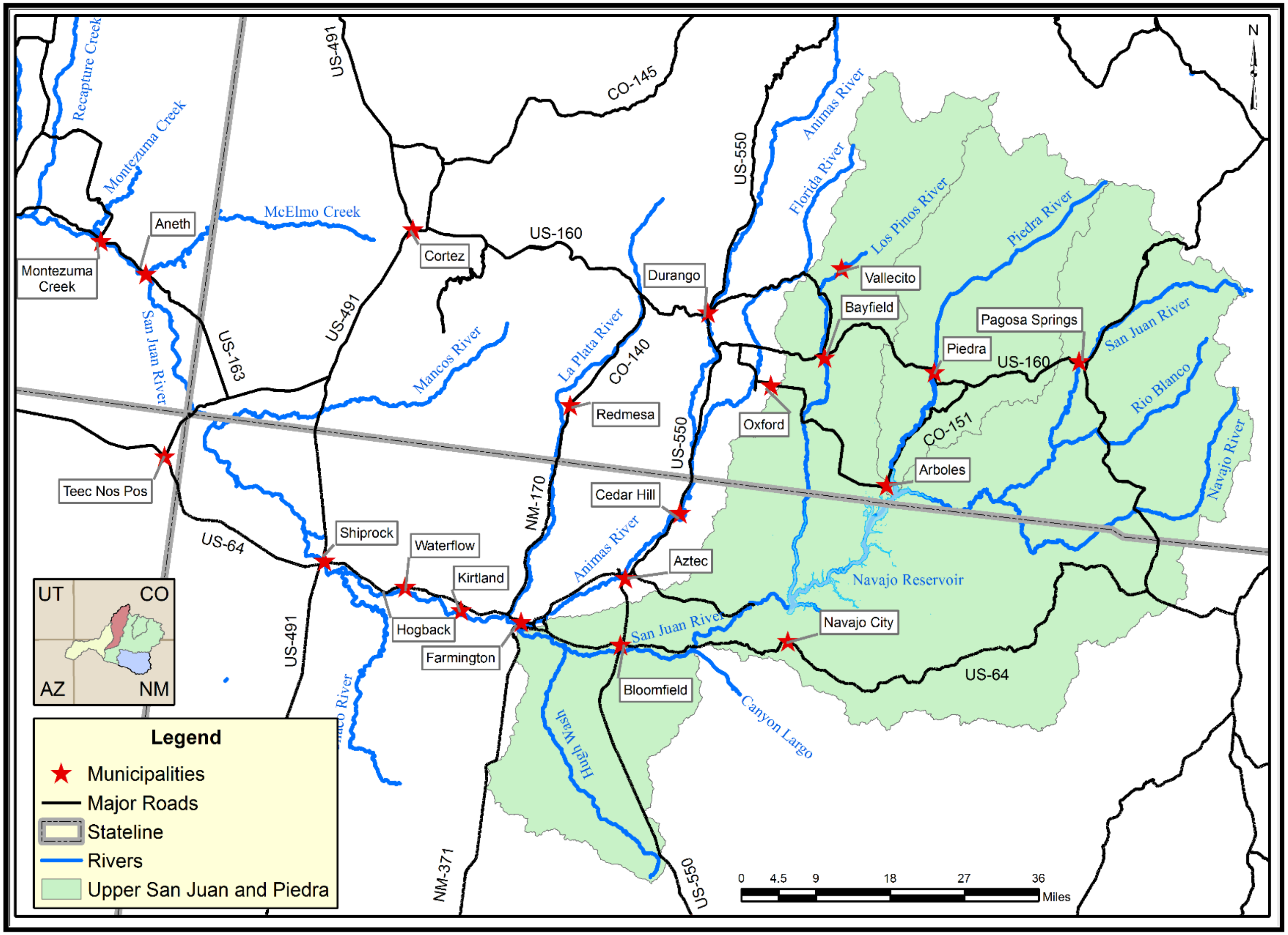

Figure 4. Map of Upper San Juan and Piedra Subbasins

In the 2016 Colorado water quality assessment, tributaries in the Upper San Juan Subbasin (Piedra River, Los Pinos River, Rio Blanco, etc) were evaluated to identify impaired sections under Section 303(d) of the CWA. Of the segments with sufficient data to make a determination, all segments were identified as fully supporting for the designated uses of domestic water supply and irrigation (Colorado Water Quality Control Division, 2016). Likewise in New Mexico, Navajo Reservoir and the San Juan River between the Animas River and Cañon Largo were identified as fully supporting for irrigation uses but were not assessed as a public water supply. The San Juan River reach between Navajo Reservoir and Cañon Largo was not assessed for either designated use (New Mexico Water Quality Control Commission, 2016).

Historical Data

Historical data is available in Upper San Juan Subbasin for Navajo Reservoir and downstream of Navajo Reservoir in the San Juan River. Table 3 tabulates water quality data in Navajo Reservoir published in Reclamation (2000). With only mean values reported, assessing the water quality variability in Navajo Reservoir is not possible. Compared to other tributaries in the watershed, reservoir water quality is likely to be the least variable due to long residence times. No reported mean concentrations exceeded the CWA or SDWA screening thresholds, indicating that water quality upstream of Navajo Dam is not expected to present water quality issues related to NGWSP water treatment operations.

Table 4 summarizes water quality data for the San Juan River near Archuleta, NM. This data best represents the water quality in the San Juan River directly downstream of the Navajo Reservoir, before the convergence with other subbasins. No measurements exceeded either the CWA or SDWA standards.

Table 3. Water quality data for the Navajo Reservoir. Data reproduced from Reclamation (2000).

		Reclamation (2000)	
Parameter	**Units**	**Number**	**Mean**
Alkalinity, Total	(mg/L as $CaCO_3$)	26	81.1
Aluminum, Dissolved	(µg/L as Al)	25	18.4
Aluminum, Total	(µg/L as Al)	25	221.6
Arsenic, Dissolved	(µg/L as As)	71	1.8
Arsenic, Total	(µg/L as As)	71	2.1
Boron, Dissolved	(µg/L as B)		
Cadmium, Dissolved	(µg/L as Cd)		
Cadmium, Total	(µg/L as Cd)		
Calcium, Dissolved	(mg/L as Ca)	26	38.6
Calcium, Total	(mg/L as Ca)	1	31.9
Chloride, Total	(mg/L)	1	1.0
Chromium, Dissolved	(µg/L as Cr)		
Chromium, Total	(µg/L as Cr)		
Cobalt, Dissolved	(µg/L as Co)		
Cobalt, Total	(µg/L as Co)		
Copper, Dissolved	(µg/L as Cu)	26	2.7
Copper, Total	(µg/L as Cu)	26	4.4
Hardness Calc.	(mg/L as $CaCO_3$)	26	124
Hardness, Total	(mg/L as $CaCO_3$)		
Iron, Dissolved	(µg/L as Fe)		
Iron, Total	(µg/L as Fe)		
Lead, Dissolved	(µg/L as Pb)	71	0.4
Lead, Total	(µg/L as Pb)	71	1.2
Magnesium, Dissolved	(mg/L as Mg)	26	6.7
Magnesium, Total	(mg/L as Mg)	1	7.4
Manganese, Dissolved	(µg/L as Mn)	1	2.5
Manganese, Total	(µg/L as Mn)	1	48
Mercury, Dissolved	(µg/L as Hg)	71	0.11
Mercury, Total	(µg/L as Hg)	71	0.1
Nickel, Dissolved	(µg/L as Ni)	25	5.2
Nickel Total	(µg/L as Ni)	25	6.8
Nitrite + Nitrate Total	(mg/L as N)	1	0.01
Oxygen, Dissolved	(mg/L)	69	9.1
pH Lab	(Standard Units)		
pH Field	(Standard Units)	71	7.76
Phosphorus, Total	(mg/L as P)		
Total Dissolved Solids	(mg/L)	25	251
Selenium, Dissolved	(µg/L as Se)	71	0.5
Selenium, Total	(µg/L as Se)	71	0.6
Selenium, Total Recoverable	(µg/L as Se)	9	0.5
Silver, Dissolved	(µg/L as Ag)		
Silver, Total	(µg/L as Ag)		
Sodium, Dissolved	(mg/L as Na)	2	15.5
Sodium, Total	(mg/L as Na)	1	14.5
Total Suspended Solids	(mg/L)	69	10
Specific Conductance at 25°C	(µmhos/cm)		
Sulfate, Total	(mg/L as SO_4)		
Temperature Water	(ºC)	71	8.7
Zinc, Dissolved	(µg/L as Zn)	71	6.8
Zinc, Total	(µg/L as Zn)	71	15

Table 4. Water quality data for the San Juan River at Archuleta, NM. Data reproduced from NWIS (2016).

Parameter	Units	NWIS Database San Juan River at Archuleta (1970-2016)				
		Number	No > MDL	Min	Max	Mean
Alkalinity, Total	(mg/L as $CaCO_3$)	–	–	–	–	–
Aluminum, Dissolved	(µg/L as Al)	30	23	1	9	2.8
Aluminum, Total	(µg/L as Al)	–	–	–	–	–
Arsenic, Dissolved	(µg/L as As)	61	40	0.61	9	1.325
Arsenic, Total	(µg/L as As)	28	24	1	2	1.5
Barium, Total	(µg/L as Ba)	21	11	100	300	155
Beryllium, Dissolved	(µg/L as Be)	31	0	–	–	–
Bicarbonate, Dissolved	(mg/L)	115	115	70	155	93
Boron, Dissolved	(µg/L as B)	163	120	10	640	38
Cadmium, Dissolved	(µg/L as Cd)	46	4	0.018	0.029	0.022
Cadmium, Total	(µg/L as Cd)	18	0	–	–	–
Calcium, Dissolved	(mg/L as Ca)	–	–	–	–	–
Calcium, Total	(mg/L as Ca)	257	257	16.7	83	30
Chloride, Dissolved	(mg/L)	257	257	0.7	19	2.8
Chromium, Dissolved	(µg/L as Cr)	48	7	0.03	20	5.8
Chromium, Total	(µg/L as Cr)	21	8	4	20	14.9
Cobalt, Dissolved	(µg/L as Co)	48	22	0.034	10	0.5
Cobalt, Total	(µg/L as Co)	16	1	1	30	30.0
Copper, Dissolved	(µg/L as Cu)	33	22	0.7	1.6	1.2
Copper, Total	(µg/L as Cu)	15	7	20	500	91
Hardness Calc.	(mg/L as $CaCO_3$)	–	–	–	–	–
Hardness, Total	(mg/L as $CaCO_3$)	257	257	54.5	261	100
Iron, Dissolved	(µg/L as Fe)	165	98	2.9	120	21
Iron, Total	(µg/L as Fe)	40	35	10	19000	891
Lead, Dissolved	(µg/L as Pb)	41	7	0.024	0.46	0.2
Lead, Total	(µg/L as Pb)	13	0	–	–	–
Magnesium, Dissolved	(mg/L as Mg)	257	257	3.12	13	5.8
Magnesium, Total	(mg/L as Mg)	–	–	–	–	–
Manganese, Dissolved	(µg/L as Mn)	47	31	1.16	40	7.5
Manganese, Total	(µg/L as Mn)	28	22	10	270	30
Mercury, Dissolved	(µg/L as Hg)	27	9	0.1	1.3	0.37
Mercury, Total	(µg/L as Hg)	71	16	0.008	1.1	0.34
Nickel, Dissolved	(µg/L as Ni)	32	20	0.06	1.7	0.80
Nickel Total	(µg/L as Ni)	1	0	–	–	–
Nitrite + Nitrate Total	(mg/L as N)	134	103	0.01	0.3	0.072
Oxygen, Dissolved	(mg/L)	268	268	6.6	15.6	11
pH Lab	(Standard Units)	152	152	7.4	8.8	8.2
pH Field	(Standard Units)	308	308	7.2	9.5	8.3
Phosphorus, Total	(mg/L as P)	128	113	0.006	0.24	0.036
Total Dissolved Solids	(mg/L)	237	237	114	388	168
Selenium, Dissolved	(µg/L as Se)	62	39	0.33	8	1.38
Selenium, Total	(µg/L as Se)	65	33	0.372	2	0.90
Selenium, Total Recoverable	(µg/L as Se)	–	–	–	–	–
Silver, Dissolved	(µg/L as Ag)	47	3	0.008	2	1.01
Silver, Total	(µg/L as Ag)	15	3	1	8	3.33
Sodium, Dissolved	(mg/L as Na)	257	257	6.73	32	14
Sodium, Total	(mg/L as Na)	–	–	–	–	–
Suspended Solids	(mg/L)	59	59	1	56	13.1
Specific Conductance	(µmhos/cm @ 25ºC)	313	313	180	480	264
Sulfate, Total	(mg/L as SO_4)	257	257	27	150	48
Temperature Water	(ºC)	370	370	2	19.2	8.2
Zinc, Dissolved	(µg/L as Zn)	48	28	0.8	50	9.6
Zinc, Total	(µg/L as Zn)	24	20	10	80	30.0

Animas River Subbasin

Background

The Animas Subbasin (HUC 14080104) primary drainage is the Animas River, but the Florida River is a significant tributary with a confluence just north of the CO-NM state border (Figure 5). The Animas Subbasin is the most studied subbasin with respect to water quality in the San Juan River watershed. Historical mining activity around Silverton, CO lead to hundreds of abandoned mines, mine tailings and waste sites that contribute to acid mine drainage (AMD) within the headwaters of the watershed. The Upper Animas River was the studied extensively during fiscal years 1997 through 2001 as a part of the USGS Abandoned Mine Lands Initiative (AMLI), which was a coordinated effort between the U.S. Department of the Interior and U.S. Department of Agriculture (Church et al., 2007b).

The Upper Animas Watershed has a high concentration of abandoned mine lands from historical mining activities between 1871 and 1991. A survey conducted through the AMLI identified more than 5,000 sites related to mines, mine tailings or waste sites in a study area surrounding Silverton, CO (Church et al., 2007b). Mining activities impact water quality due to biogeochemical reactions that occur between rocks and the surrounding environment. AMD forms when water and oxygen react with sulfide containing minerals, such as pyrite, which produces acidic water (low pH) by releasing protons (H^+) and ferrous iron (Equation 1). Ferrous iron is oxidized to ferric iron under acidic conditions (Equation 2), which can form solid precipitate through hydrolysis (Equation 3). The formation of ferric iron also promotes the oxidation of pyrite (Equation 4). The net reaction (Equation 5) summarizes the oxidation of pyrite to form ferric hydroxide solids and acidic conditions. Acidic water ($pH<4$) dissolves other metals from rocks, which leads to water with high concentrations of iron, aluminum, cadmium, arsenic and other elements found in the local geological formations. The chemical and microbiological reactions that form AMD occur naturally in the absence of mining, which is called acid rock drainage (ARD). Mining increases the prevalence and impact of these weathering processes, because mining activities expose new rock surfaces upon which these reactions occur.

$$2FeS_2\,(s) + 7O_2 + 2H_2O \rightarrow 2Fe^{2+}\,(aq) + 4SO_4^{2-}\,(aq) + 4H^+ \quad (1)$$

$$4Fe^{2+}\,(aq) + O_2 + 4H^+ \rightarrow 4\,Fe^{3+}\,(aq) + 2H_2O \quad (2)$$

$$Fe^{3+}\,(aq) + 3H_2O \rightarrow Fe(OH)_3\,(s) + 3H^+ \quad (3)$$

$$FeS_2\,(s) + 14Fe^{3+}\,(aq) + 8H_2O \rightarrow 15Fe^{2+}\,(aq) + 2SO_4^{2-}\,(aq) + 16H^+ \quad (4)$$

$$4FeS_2\,(s) + 15O_2 + 14H_2O \rightarrow 16H^+\,(aq) + 8SO_4^{2-}\,(aq) + 4Fe(OH)_3\,(s) \quad (5)$$

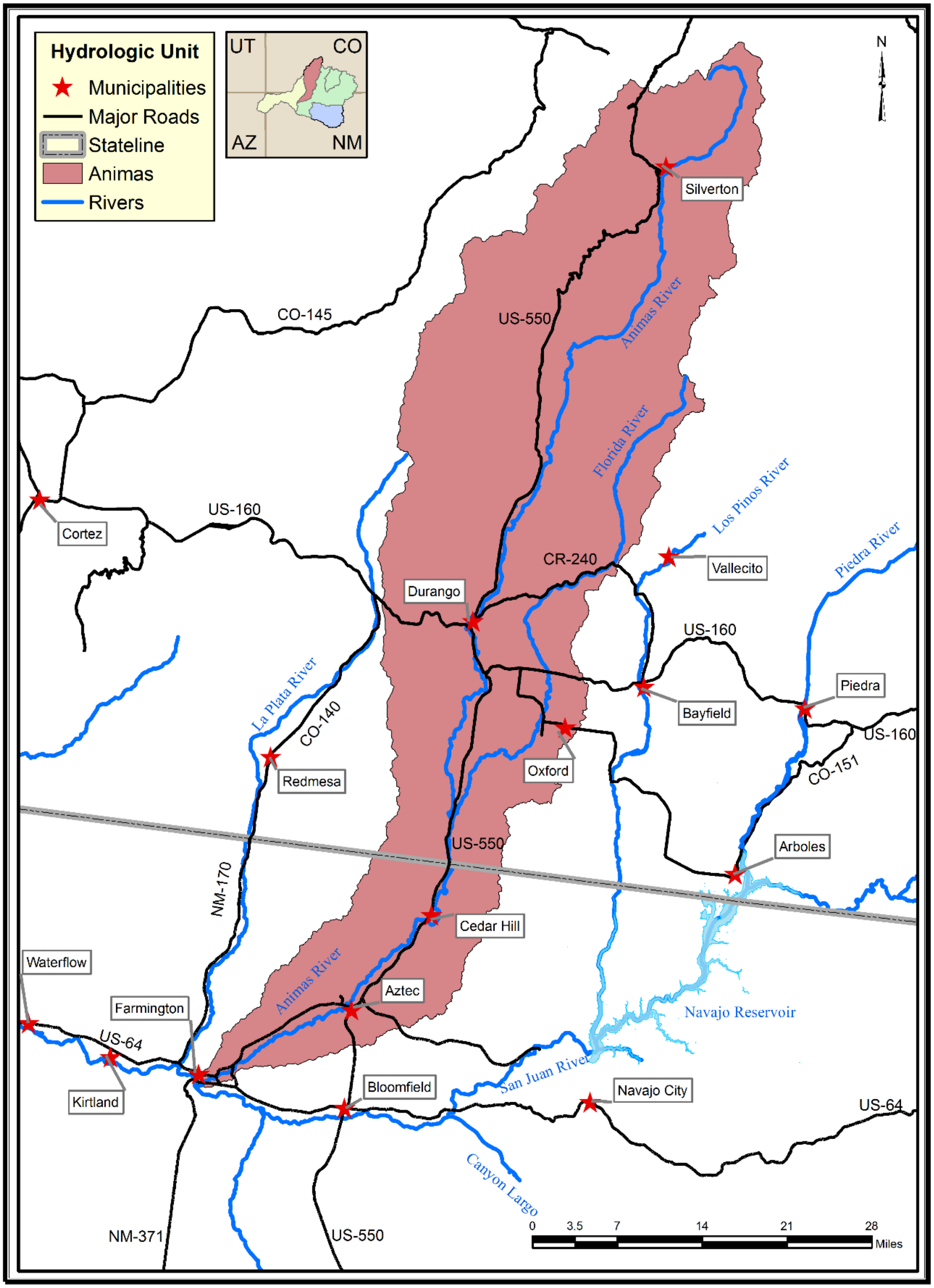

Figure 5. Map of Animas Subbasin

AMD and ARD produce water with higher concentrations of metals compared to surface water not impacting by these processes. Metals commonly found in the Upper Animas River watershed include aluminum, arsenic, cobalt, copper, iron, manganese, lead, strontium, antimony and vanadium (Church et al., 1997). Among these metals, aluminum, iron, zinc and manganese are typically found in the highest concentrations (Church et al., 1999, 1997).

From a CWA impairment standpoint, segments that have been designated as public water supply or irrigation uses have been assessed as fully supporting in Colorado. With that being said, many of the upper reaches north of Durango, CO have been identified as impaired due to metals for supporting aquatic life and have not been designated as a public water supply (Colorado Water Quality Control Division, 2016). In New Mexico, the Animas River has not been assessed for a public water supply designated use (New Mexico Water Quality Control Commission, 2016).

The geochemistry behind AMD drainage within the watershed warrants further review, because it has a large impact on the water quality in San Juan River beyond what can be captured in a CWA assessment. Studies published exploring the scientific aspects of water quality were reviewed to provide a better understanding of the chemistry that dictate water quality and transport of metals within the watershed.

There are local variations of AMD and ARD throughout the upper Animas River watershed due to geologic differences. The upper Animas River watershed north of Silverton, CO, has two volcanic calderas (Uncompahgre-San Juan and Silverton) that formed 35 to 28.2 million years ago (Church et al., 2007b). Faults and veins within the formations underwent mineralization and hydrothermal alteration processes changing the mineral assemblages of the primary lava flows. Tributaries originating in areas of early propylitic altered rocks have near neutral pH due to the acid neutralizing capacity of the minerals. On the other hand, tributaries from regions with mineralization events producing assemblages rich in pyrite have minimal acid neutralizing capability and low pH (Church et al., 2007a). Low pH tributaries have high dissolved metal concentrations. In some areas, naturally exposed and weathered rock produces significant ARD independent of mining operations. A significant portion of the metal load in the Animas River is derived from natural processes producing ARD compared to mining related AMD (Church et al., 1999, 2007a). Cement Creek was determined to be unable to support aquatic life due to naturally occurring ARD, independent of mining activities (Church et al., 2007a). The localized variations in geology lead to spatially complex water chemistry within the upper Animas River watershed.

In terms of metal accumulation and transport in the watershed, mass balances of material throughout the watershed focus on three distinct phases: dissolved species in the water column, particulate species suspended in the water column and sediment on the river bed. In addition to geology impacting the initial dissolution of metals, the speciation of metals between phases is pH dependent. At low pH, metals are found in the dissolved phase. As pH increases, iron and aluminum form metal-hydroxide complexes that precipitate from solution to form colloids. Iron hydroxide colloids form around pH 5.3, and aluminum hydroxide colloids form around pH 6.5 (Schemel et al., 2000). Colloids aggregate and increase in size from a few nanometers to micrometers in diameter, which eventually form particles large enough to settle as sediment in the river bed (Church et al., 1997; Paschke et al., 2005; Schemel et al., 2000). The colloidal fractions are predominantly composed of iron, aluminum and manganese hydroxide complexes. Manganese and zinc are largely soluble in the dissolved phase at circumneutral pH but can partition to the solid phase along with copper through adsorption mechanisms to the iron- and aluminum-rich colloids (Church et al., 1997; Paschke et al., 2005; Schemel et al., 2000). These mechanisms lead to an accumulation of trace metals in the bed sediment.

Spatial variations in hydrology within the watershed play an important role in the accumulation of solids and associated metals in the Animas River watershed. Colloidal material settles and accumulates in river sediment at the confluence of acidic reaches with circumneutral pH reaches, such as at the confluence of Cement Creek with the Animas River (Schemel et al., 2000). One study estimated that 256 kg/day of aluminum and 234 kg/day of iron accumulated in the bed sediment downstream of the convergence of Mineral Creek with the Animas River (Church et al., 1997). Significant attenuation of metals in the water column also occurs in braided sections of the river where water velocity decreases (Paschke et al., 2005). These processes remove metals from the water column and lead to an accumulation in the sediment with the potential for future transport.

Seasonal variations in hydrology play an important role in the accumulation and transport of metals in the watershed. Metal-rich sediments accumulate during periods of low flow. During baseflow conditions in the winter, groundwater is main source of water in the Animas River (Leib et al., 2003). Dissolved metal concentrations are greatest during low flow conditions and colloidal material accumulates in the sediment during this time (Leib et al., 2003; Paschke et al., 2005; Schemel et al., 2000). Accumulated sediment is resuspended during periods of high flow, such as spring runoff and precipitation events, which increases the metal load in the particulate phase of the river (Church et al., 1997; Schemel et al., 2000). Although metal concentrations are highest in low flow conditions, total dissolved metal loads increase during runoff events. Leib et al (2003) developed water quality profiles for the Upper Animas River watershed to investigate the seasonal variations in dissolved metal concentration and load. At a site downstream of Silverton below the Mineral Creek confluence, zinc concentrations decreased from about 0.75 mg/L in baseflow conditions to about 0.2 mg/L during snowmelt runoff. Despite lower concentrations, total metal load increased from about 113 kg/day during baseflow to 794 kg/d during runoff. Similar trends were observed for hardness, copper, and cadmium (Leib et al., 2003). In addition to dissolved metal concentrations, colloidal metal concentrations also increase during high flow events. For example, Church et al (1997) found that colloidal lead mass loads increase from 3 to 220 kg/day between low and high flow events (Church et al., 1997). While the dissolved and colloidal loads increase during high flow, the mass transport of metals in the suspended bed sediment phase far exceeds the transport associated with the other phases (Church et al., 1997).

During snowmelt runoff, there is a hysteresis effect between flow and dissolved metal concentrations. On the rising limb of snowmelt (increasing flow), dissolved metal concentrations downstream of Silverton, CO, had higher concentrations (2-3x) compared to the same stream discharge on the falling limb (Besser and Leib, 1994). This same study found that copper and metal concentrations decreased sharply between April and July followed by a more gradual increase as runoff flows receded.

Interannual hydrological variations also impact water quality due to differences in snowpack (Leib et al., 2003). The Upper Animas watershed receives about 45 inches of precipitation, of which about 70% is snow. In comparing metal concentrations between two years, Paschke et al (2005) notes that concentrations were higher in 1998 when the stream flow was lower. Similarly, another study found differences in bed sediment composition between consecutive years due to differences in snowpack (Church et al., 1997). Bed metal concentrations were found to be 10-50% greater in 1996, which had low snowpack, compared to the previous year due to the low volume of spring runoff in 1996. Church et al (1997) recommended against using bed sediment as a monitoring tool for water quality, because sediment concentrations are an annual integrated parameter and not representative of instantaneous water quality.

While most of the investigations in the Animas River watershed have focused on the upper reaches near Silverton, CO, this area represents a small geographic region (181 km^2) relative to the entire subbasin (3,548 km^2) (Church et al., 2007b). Downstream of Silverton, CO, additional tributaries converge with the Animas River, namely the Florida River. These inputs also change the water chemistry and sediment load along the Animas River down to the convergence with the San Juan River. An investigation of annual suspended sediment concentrations on the Animas River in Farmington, NM, between 1950-1990 found a statistically significant decrease in sediment over this time period, which is attributed to farming practices that decreased erosion (Abell, 1994). Church et al (1997) evaluated metal partitioning and transport in the lower reaches between Silverton, CO, and Aztec, NM. Just south of Silverton, the river passes through Animas Canyon, which is dominated by Precambrian bedrock that is resistant to weathering. Metals and suspended sediments are transported through this section with little attenuation through settling or contributions from tributaries. In the lower reaches of the Animas River, the river enters a wide flood plain with sedimentary rocks that are more easily weathered, contributing suspended sediment. In general, bed sediment metal concentrations decrease between Silverton, CO and Aztec, NM due to dilution with low metal content sediment (Church et al., 1997). One exception was lead, which showed an increase in concentrations in Aztec, NM. It is postulated that the increased concentrations are due to an accumulation of iron hydroxide sorbed particulates from the Animas headwater rather than tributaries.

Church et al (1997) used lead isotope data to assess the relative contribution of bed sediment from different tributaries in the lower reaches of the Animas River. The study concluded that Hermosa Creek and Florida River are major contributors of bed sediment to the Animas River. Due to the differences in geology lower in the watershed, the metal abundance in bed sediment decreases from Silverton to Aztec as sediment depleted in iron, copper and zinc accumulates. For example, at Durango, CO, it is estimated that 80% of the metals in the colloidal component of bed sediment were derived from above Silverton, CO. At Aztec, NM, only 57% of the metals can be attributed to the area above Silverton, CO (Church et al., 1997). These results indicate that the origin of sediments within the Animas River subbasin plays an important role in the amount of metals associated with the sediment.

Historical Data

Of all the subbasins in the San Juan River watershed, the largest amount of historical data exists for the Animas River. While there is a large dataset through USGS and AMLI for the upper reaches of the Animas River north of Silverton, CO, this section documents historical data from the Animas River focusing on a USGS sampling location near Farmington, NM. This point best represents the water quality of the subbasin prior to the confluence with the San Juan River and also incorporates water quality effects after the convergence of the Florida River. Table 5 presents compiled data from the Reclamation (2000) and NWIS datasets.

Reclamation (2000) tabulated mean concentrations grouped by state. For the segments analyzed in Colorado, the mean dissolved manganese concentration was higher than the SDWA secondary MCL screening threshold. The mean dissolved manganese concentration in the New Mexico segments (48 µg/L) was just below the secondary MCL (50 µg/L). Although this dataset does not provide any information regarding statistical range or variability, high mean values may be an indication that dissolved manganese concentrations above the SDWA secondary MCL occur at a high enough frequency to impact San Juan River water quality. In the New Mexico segments, dissolved aluminum concentrations were observed above the SDWA secondary MCL. This observations indicates that dissolved aluminum may also be a metal of concern to monitor for at the proposed intake of the NGWSP SJL water treatment plant.

The NWIS dataset from 2000-2016 is a smaller dataset but one that offers statistical context for the data. Maximum value for dissolved manganese was also observed at concentrations above the SDWA secondary MCL, but mean values were significantly lower indicating variability with respect to these parameters is important.

Aluminum and manganese have SDWA secondary MCLs due to aesthetic implications in treated drinking water rather than human health impacts. Understanding the variability of these metals in the lower reaches of the San Juan River will be important for NGWSP SJL water treatment plant operations to ensure that treated water meets the aesthetic standards for consumer confidence in addition to primary health standards.

Table 5. Water quality data for the Animas River. Data reproduced from Reclamation (2000) and compiled from the NWIS for 2000-2016.

		Reclamation (2000)				NWIS 2000-2016				
		Colorado		New Mexico		Animas River at Farmington, NM				
Parameter	Units	No.	Mean	No.	Mean	No.	No > MDL	Min	Max	Mean
Alkalinity, Total	(mg/L as $CaCO_3$)	468	106	304	130	--	--	--	--	--
Aluminum, Dissolved	(µg/L as Al)			113	65.1(1)	29	22	1.0	41	9.4
Aluminum, Total	(µg/L as Al)	2	0	56	2806	3	3	1270	4490	2407
Arsenic, Dissolved	(µg/L as As)	493	6.7	356	3.5	30	13	0.2	2.0	0.3
Arsenic, Total	(µg/L as As)	243	21.1	304	8.8	3	3	1.3	26.3	9.7
Bicarbonate, Dissolved	(mg/L)	--	--	--	--	41	41	61.0	214	155
Boron, Dissolved	(µg/L as B)	7	71.4	197	86.4	38	32	10.0	145	47.2
Cadmium, Dissolved	(µg/L as Cd)	255	0.2	74	1.3	30	10	0.02	1.0	0.02
Cadmium, Total	(µg/L as Cd)	345	0.7	21	3.9	3	3	0.2	0.9	0.4
Calcium, Dissolved	(mg/L as Ca)	857	64	822	74.1	--	--	--	--	--
Calcium, Total	(mg/L as Ca)	244	56.6	122	56.9	38	38	26.6	131.0	71.2
Chloride, Dissolved	(mg/L)					38	38	2.8	42.6	17.0
Chloride, Total	(mg/L)	248	14.4	410	17	--	--	--	--	--
Chromium, Dissolved	(µg/L as Cr)	253	2.8	58	3.8	30	9	0.1	10.3	0.4
Chromium, Total	(µg/L as Cr)	1	4	22	13.3	3	3	0.9	3.9	1.9
Cobalt, Dissolved	(µg/L as Co)			65	1.3	30	21	0.1	0.6	0.2
Cobalt, Total	(µg/L as Co)	2	1.5	19	21.1	3	3	1.0	2.7	1.6
Copper, Dissolved	(µg/L as Cu)	492	4.1	252	3.4	30	24	0.6	5.9	1.5
Copper, Total	(µg/L as Cu)	585	15.6	205	15.6	3	3	4.7	113	42.0
Hardness Calc.	(mg/L as $CaCO_3$)	4	125	684	238	--	--	--	--	--
Hardness, Total	(mg/L as $CaCO_3$)	4	125	561	242	38	38	81	431	223.4
Iron, Dissolved	(µg/L as Fe)	258	42.1	226	32.7	38	21	2.8	65.8	6.8
Iron, Total	(µg/L as Fe)	344	501	26	3650	3	3	2000	36500	13697
Lead, Dissolved	(µg/L as Pb)	243	2.6	231	1.7	30	18	0.0	0.3	0.1
Lead, Total	(µg/L as Pb)	338	13.5	198	29.4	3	3	6.6	552	192.4
Magnesium, Dissolved	(mg/L as Mg)	857	10.1	820	11	38	38	3.6	24.9	11.0
Magnesium, Total	(mg/L as Mg)	244	9.8	122	10.1	--	--	--	--	--
Manganese, Dissolved	(µg/L as Mn)	757	87.9(1)	211	48.3	30	24	1.7	91(1)	23.6
Manganese, Total	(µg/L as Mn)	244	416	148	231	3	3	141.0	448	250
Mercury, Dissolved	(µg/L as Hg)	485	0.1	324	0.11	--	--	--	--	--
Mercury, Total	(µg/L as Hg)	581	0.15	314	0.14	34	10	0.01	0.05	0.01
Nickel, Dissolved	(µg/L as Ni)	248	2.7	120	4.6	30	20	0.1	2.7	0.8
Nickel Total	(µg/L as Ni)	263	5.7	67	6.4	3	3	1.3	3.7	2.1
Nitrite + Nitrate Total	(mg/L as N)	575	1.01	107	0.2	29	19	0.02	0.4	0.1
Oxygen, Dissolved	(mg/L)	31	7.7	343	9.7	41	41	7.0	12.5	9.3
pH Lab	(Standard Units)	34	8	680	7.89	38	38	7.7	8.3	8.1
pH Field	(Standard Units)	905	7.49	373	7.97	42	42	8.0	8.7	8.3
Phosphorus, Total	(mg/L as P)			178	0.14	29	27	0.019	0.6	0.1
Total Dissolved Solids	(mg/L)			565	397	6	6	119.0	473	340
Selenium, Dissolved	(µg/L as Se)	216	0.9	309	0.9	30	11	0.3	1.0	0.2
Selenium, Total	(µg/L as Se)	255	1.1	245	1	38	15	0.2	3.0	0.4
Selenium, Total Recover	(µg/L as Se)	336	1	129	1.4	--	--	--	--	--
Silver, Dissolved	(µg/L as Ag)	487	0.1	167	0.25	30	2	0.008	0.1	0.005
Silver, Total	(µg/L as Ag)	512	0.26	126	0.66	3	3	0.03	3.6	1.3
Sodium, Dissolved	(mg/L as Na)	855	16	737	29.8	38	38	3.9	78.6	25.5
Sodium, Total	(mg/L as Na)	244	13.4	122	18.3	--	--	--	--	--
Suspended Solids	(mg/L)			155	108	241	241	13.0	30300	633.5
Specific Conductance	(µmhos/cm)	1498	455	952	549	43	43	187.0	1120	585.6
Sulfate, Total	(mg/L as SO_4)	4	67	291	154	38	38	32.9	390(1)	145.4
Temperature Water	(ºC)	557	10.3	189	10.9	94	94	-0.2	33.0	11.6
Zinc, Dissolved	(µg/L as Zn)	489	31.3	361	13	30	20	1.4	15	3.8
Zinc, Total	(µg/L as Zn)	587	122	307	97.9	3	3	40.0	363	148.5
(1) Concentration exceeds SDWA primary or secondary MCL										

There are several datasets that have analyzed sediment composition in the Animas River. Table 6 summarizes elemental composition data from the Reclamation (1996) report using a method that does not rely on the dissolution of metals. Note that the total sum of the percentages in Table 6 do not add up to 100%, because many elements commonly found minerals are not reported (e.g., carbon, oxygen, sulfur etc). Reclamation (1996) also provided baseline data tabulated for the western United States by Shacklette and Boerngen (1984) for context. Based on the baseline range, the sediments collected at Cedar Hill, NM, and Aztec, NM, exceeded the upper baseline range for manganese and lead suggesting a local enrichment with respect to these minerals. Reclamation (2016) tabulated sediment composition data published by the EPA following the Gold King Mine spill. The data published by the EPA included a total recovered metals analysis, which is not directly comparable to Table 6. A recoverable metals analysis includes leaching material from a solid phase under acidic conditions, but only a fraction of the solid material dissolves in the process.

Table 6. Elemental analysis for sediment collected in the Animas River. Data reproduced from Reclamation (1996).

	Reclamation (1996)			
	Western States Baseline		Location	
Element	Mean	Range	Cedar Hill, NM	Aztec, NM
Al (%)	5.8	1.5-23	5.9	5.9
Ca (%)	1.8	0.17-17	1.4	1.7
Fe (%)	2.1	0.55-8.0	2.9	2.9
K (%)	1.8	0.38-3.2	1.9	2
Mg (%)	0.74	0.15-3.6	0.54	0.52
Na (%)	0.97	0.26-3.7	1.03	0.9
P (%)	0.032	--	0.06	0.06
Ti (%)	0.22	0.069-0.7	0.27	0.3
Mn (ppm)	380	97-1500	1517	1148
Ag (ppm)	<0.5	--	<2	<2
As (ppm)	5.5	1.2-22	7.4	5.6
Au (ppm)	--	--	<8	<8
B (ppm)	23	5.8-91	--	--
Ba (ppm)	580	200-1700	947	1228
Be (ppm)	0.68	0.13-3.6	1	1.4
Cd (ppm)	<0.1	--	<2	<2
Ce (ppm)	65	22-190	63	82
Co (ppm)	7.1	1.8-28	11.3	10.6
Cr (ppm)	41	8.5-200	23	25
Cu (ppm)	21	4.9-90	66	42
Ga (ppm)	16	5.7-45	15	15
Hg (ppm)	0.046	0.0085-0.25	0.04	0
La (ppm)	30	8.4-110	34	45
Li (ppm)	22	8.8-55	20	18
Mo (ppm)	0.85	0.18-4.0	<2	<2
Nb (ppm)	--	--	8	10
Nd (ppm)	36	12-110	28	35
Ni (ppm)	15	3.4-66	10	10
Pb (ppm)	17	5.2-55	105	71
Sc (ppm)	8.2	2.7-25	7	7
Sn (ppm)	--	--	<5	<5
Sr (ppm)	200	43-930	193	210
Th (ppm)	9.1	4.1-20	7	12
U (ppm)	2.5	1.2-5.3	2.53	2.71
V (ppm)	70	18-270	73	69
Y (ppm)	22	8.0-60	16	17
Yb (ppm)	2.6	0.98-6.9	2	2
Zn (ppm)	55	17-180	443	322
Note: Major elements presented as percent mass (%). Trace elements presented as parts per million (ppm)				

Blanco Canyon Subbasin

Background

Blanco Canyon Subbasin (HUC 14080103) is located south of the San Juan River and east of Farmington, NM, as shown in Figure 6. The main drainage, Cañon Largo, is an ephemeral stream and one of the largest contributors of suspended sediment and salinity to the San Juan River watershed. Cañon Largo, Chaco River and Chilne Wash are the dominant sediment load sources to the San Juan River, but only Cañon Largo is located upstream of the Hogback Diversion Channel. While the Animas River Subbasin draws attention due to the water quality issues related to trace metals, it is not a major contributor of total suspended sediment. Of the total sediment load at Shiprock, NM (downstream of the Hogback Diversion), the Animas River Subbasin accounts for 43% of the total flow but only 9% of the total sediment load (Abell, 1994).

Although pre-dating most of the agricultural development in the region, a 1965 study identified the Blanco Canyon Subbasin as contributing a disproportionate amount of salinity to the San Juan River watershed relative to flow (Abell, 1994). High salinity is attributed to the mobilization and transport of weathered soils in the ephemeral watershed. Even though the total dissolved solids loads calculated in the 1965 study are no longer representative due to changing land use, the results do show that the underlying geology of Cretaceous and Tertiary period sandstones, mudstones and shales in this subbasin are conducive to producing high total dissolved solids loads (USDA Natural Resources Conservation Service, 2007b).

The geology in this basin is also highly susceptible to erosion contributing suspended solids to the San Juan River watershed (USDA Natural Resources Conservation Service, 2007b). A sampling campaign in 1991 investigated the contribution of Cañon Largo to the total suspended sediment load in the main stem of the San Juan River between Bloomfield, NM, and Shiprock, NM, (Abell, 1994). Before the storm, nutrients and suspended solids concentration were 'low to moderate' and decreased downstream. During the runoff event, suspended solids concentrations increased by a factor of 80 in the San Juan River.

Historical Data

Little historical data exists for this subbasin, due in part to the intermittent flow throughout the year. USGS sampled Cañon Largo between 1977 and 1981 recording flows, suspended sediment concentrations and basic water quality parameters (U.S. Geological Survey, 2016). Figure 4 shows that the Cañon has highly variable flows that spike during the summer. Accompanying these fluctuating flows are high suspended solids concentrations (Figure 8) with peak concentrations between 100,000 mg/L and 500,000 mg/L.

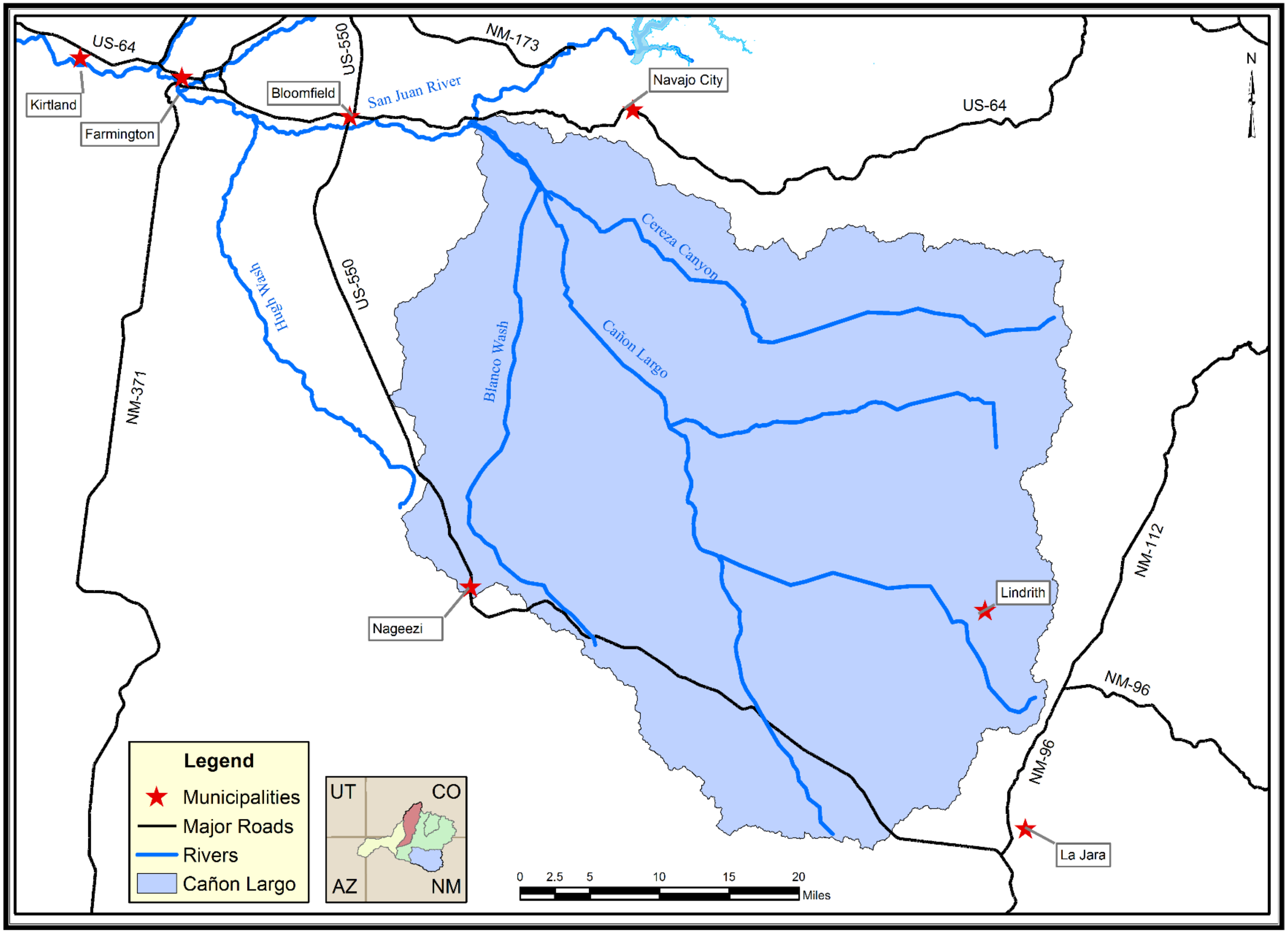

Figure 6. Map of Blanco Canyon Subbasin

Water quality data collected concomitantly during 1977 and 1981 show variable water quality, especially with respect to trace metals (Table 7). Mean and maximum concentrations for dissolved aluminum, dissolved manganese and sulfate exceeded secondary SDWA MCLs. Maximum dissolved iron concentrations exceeded the secondary SDWA MCL, and maximum total mercury concentrations exceeded the CWA limit for a domestic water supply. Comparing Cañon Largo water quality data to the Animas River data shows iron, manganese and aluminum can be mobilized and transported to the San Juan River from both subbasins. In developing a strategic monitoring plan for the NGWSP SJL water treatment plant, it must be suspected that multiple contributing subbasins can have mobilization events leading to high sediment and trace metal concentrations at the proposed intake site.

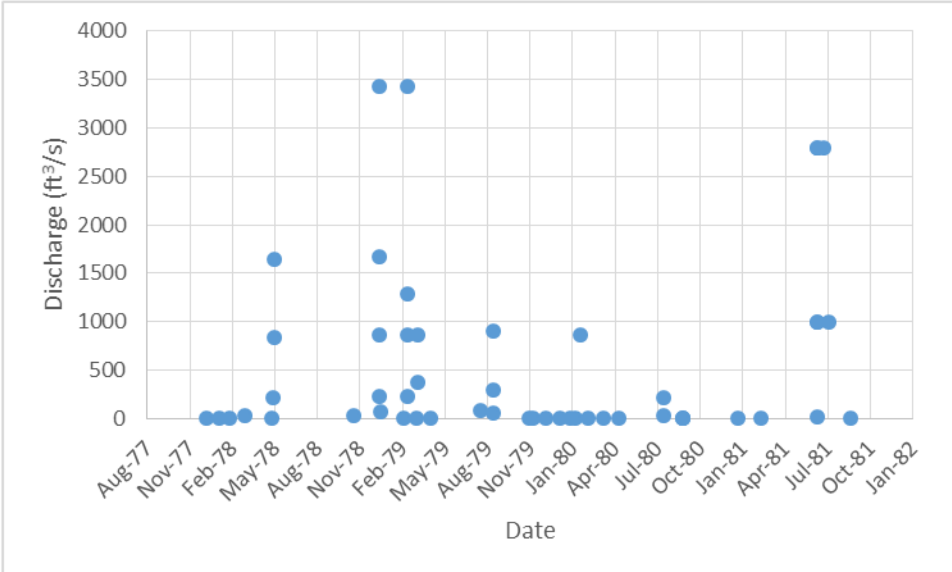

Figure 7. Hydrograph for Cañon Largo from NWIS database.

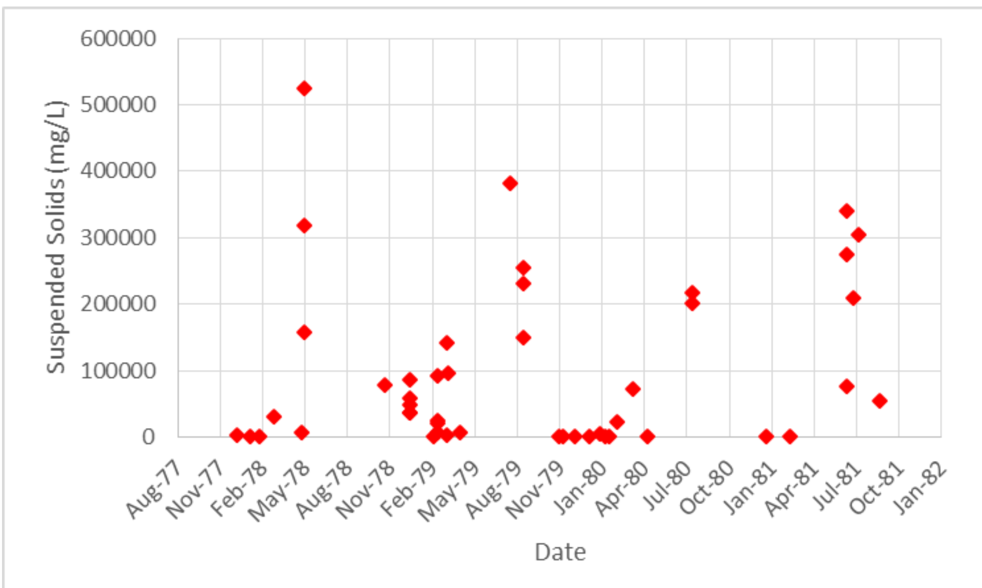

Figure 8. Total suspended solids concentrations for Cañon Largo from NWIS database.

Table 7. Water quality data for Cañon Largo. Data reproduced from the NWIS for 1977-1981.

Parameter	Units	NWIS Database Cañon Largo (Dec 1977 - Sept 1981)				
		Number	No > MDL	Min	Max	Mean
Alkalinity, Total	(mg/L as $CaCO_3$)	--	--	--	--	--
Aluminum, Dissolved	(µg/L as Al)	4	2	30	200(1)	115(1)
Aluminum, Total	(µg/L as Al)	--	--	--	--	--
Antimony, Total	(µg/L as Sb)	--	--	--	--	--
Arsenic, Dissolved	(µg/L as As)	6	6	2	3	2.3
Arsenic, Total	(µg/L as As)	21	21	2	480	69
Barium, Total	(µg/L as Ba)	5	5	100	10,000	2,400
Beryllium, Total	(µg/L as Be)	5	5	10	50	23
Bicarbonate, Dissolved	(mg/L)	--	--	--	--	--
Boron, Dissolved	(µg/L as B)	22	22	50	630	230
Cadmium, Dissolved	(µg/L as Cd)	5	0	--	--	--
Cadmium, Total	(µg/L as Cd)	3	0	--	--	--
Calcium, Dissolved	(mg/L as Ca)	--	--	--	--	--
Calcium, Total	(mg/L as Ca)	24	24	22	410	167
Chloride, Dissolved	(mg/L)	23	23	5	83	25
Chromium, Dissolved	(µg/L as Cr)	5	3	10	20	13
Chromium, Total	(µg/L as Cr)	5	5	4	400	143
Cobalt, Dissolved	(µg/L as Co)	1	0	--	--	--
Cobalt, Total	(µg/L as Co)	1	1	50	50	50
Copper, Dissolved	(µg/L as Cu)	2	2	10	10	10
Copper, Total	(µg/L as Cu)	4	4	20	1200	503
Hardness Calc.	(mg/L as $CaCO_3$)	--	--	--	--	--
Hardness, Total	(mg/L as $CaCO_3$)	24	24	61	1300	587
Iron, Dissolved	(µg/L as Fe)	28	24	10	970(1)	133
Iron, Total	(µg/L as Fe)	7	7	300	890,000	409,900
Lead, Dissolved	(µg/L as Pb)	2	0	--	--	--
Lead, Total	(µg/L as Pb)	2	2	300	500	400
Magnesium, Dissolved	(mg/L as Mg)	24	24	1.4	110	41.3
Magnesium, Total	(mg/L as Mg)	--	--	--	--	--
Manganese, Dissolved	(µg/L as Mn)	12	9	0	4,400(1)	1,872(1)
Manganese, Total	(µg/L as Mn)	8	8	180	48,000	22,318
Mercury, Dissolved	(µg/L as Hg)	6	3	0.1	0.6	0.33
Mercury, Total	(µg/L as Hg)	20	18	0.1	4(1)	2.0
Nickel, Dissolved	(µg/L as Ni)	2	0	--	--	--
Nickel Total	(µg/L as Ni)	2	2	200	600	400
Nitrite + Nitrate Total	(mg/L as N)	4	4	0.09	0.98	0.54
Oxygen, Dissolved	(mg/L)	19	19	6.4	11.6	9.36
pH Lab	(Standard Units)	3	3	7.9	8.2	8.07
pH Field	(Standard Units)	45	45	6.8	8.7	7.91
Phosphorus, Total	(mg/L as P)	23	23	0.01	9.5	1.80
Total Dissolved Solids	(mg/L)	23	23	615	10,200	3,853
Selenium, Dissolved	(µg/L as Se)	7	7	1	5	2.8
Selenium, Total	(µg/L as Se)	20	20	1	35	12
Selenium, Total Recover.	(µg/L as Se)	--	--	--	--	--
Silver, Dissolved	(µg/L as Ag)	--	--	--	--	--
Silver, Total	(µg/L as Ag)	--	--	--	--	--
Sodium, Dissolved	(mg/L as Na)	24	24	160	2,800	964
Total Suspended Solids	(mg/L)	47	47	42	525,000	97,306
Specific Conductance	(µmhos/cm @ 25ºC)	45	45	770	11,200	3,304
Sulfate, Total	(mg/L as SO_4)	23	23	300(1)	6,000(1)	2,336(1)
Temperature Water	(ºC)	25	25	0.5	29	9.9
Zinc, Dissolved	(µg/L as Zn)	6	6	20	50	35
Zinc, Total	(µg/L as Zn)	5	5	20	2,400	786

(1) Concentration exceeds SDWA primary or secondary MCL

Middle San Juan Subbasin

Background

The Middle San Juan Subbasin (HUC 14080105) begins at the Animas River convergence and extends downstream to the CO-NM state line (Figure 9). Within this subbasin, the La Plata River is the primary tributary to the San Juan River upstream of the Hogback Diversion Channel. The headwaters of the La Plata River lie in the La Plata Mountains in southwest Colorado. Water quality in this subbasin is impacted by both agricultural and mining activities (Abell, 1994). While mining impacted, resource extraction in the La Plata watershed was less extensive than the headwaters of the Animas River.

According to the 2016 State of Colorado CWA Assessment, all segments of the La Plata river from the source to the CO-NM state border were assessed as ‘fully supporting’ as a domestic water source (Colorado Water Quality Control Division, 2016). In New Mexico, two segments of the La Plata were evaluated in the 2016 CWA state assessment. Both segments were fully supporting for agricultural designated uses, and neither segment was designated or assessed as a domestic water source. The segment of the San Juan River between the Animas River confluence and Navajo Nation boundary at the Hogback was assessed as ‘fully supporting’ for irrigation uses and not assessed as a public water supply designated use (New Mexico Water Quality Control Commission, 2016).

Historical Data

Within this subbasin, historical data exists from a number of sources at different locations. On the La Plata River, two extensive water quality and sediment datasets from Reclamation reports are summarized in Table 8 and Table 9 from the Reclamation (2000) and (1996) reports. On the San Juan River, historical data from Shiprock, NM, Farmington, NM and the Hogback Site are available in the Reclamation (2000), Reclamation (2006) and NWIS datasets (Tables 10-12). The Hogback Site samples were collected just inside the diversion gate headworks and do not include any winter samples (November to February) when the diversion gates are closed. Monthly and seasonal San Juan River water quality data at Farmington, NM, and Shiprock, NM, from the Reclamation (1996) report is summarized in Table 11 and Table 13. Data collected during the 2012 water treatment pilot studies conducted by Malcolm Pirnie/Arcadis is tabulated in Table 14. The pilot study is the only dataset that specifically measured a sample during a high suspended solids monsoon event.

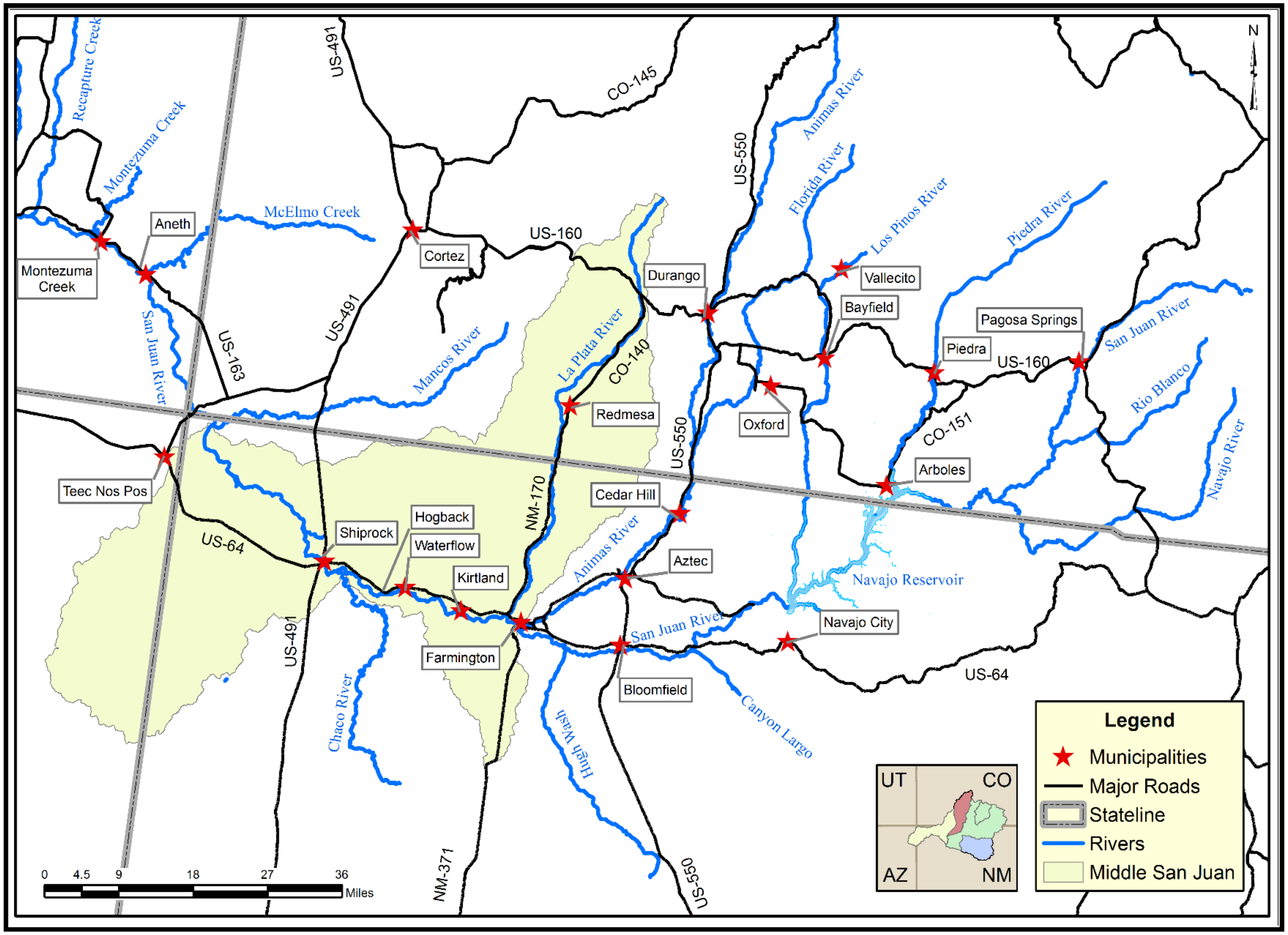

Figure 9. Map of Middle San Juan Subbasin

Data collected from the La Plata River shows that this tributary to the San Juan River has the potential to be moderately saline and enriched in select metals (Table 8). Both datasets observed high total dissolved solids concentrations above the secondary SDWA MCL of 500 mg/L. High sulfate concentrations were also observed above the secondary SDWA MCL of 250 mg/L. If salinity becomes a concern for NGWSP SJL water treatment operations, mobilization events in this watershed may become an important parameter to monitor. La Plata River data also shows that the water has a potential to contain arsenic and manganese at concentrations of interest. Dissolved manganese concentrations in both datasets exceeded the secondary SDWA MCL limits by 3-5 times. While the dissolved concentrations in the New Mexico segments were higher than the Colorado segments in the Reclamation (2000) dataset, no fair comparison can be made without temporal data to demonstrate samples were collected in each portion of the river at similar times. In the Reclamation (1996) dataset, twelve samples were analyzed for dissolved arsenic of which 3 samples were above the method detection limit. One of these three samples has a dissolved arsenic concentration 7 times higher than the secondary SDWA MCL. This observation suggests that the La Plata River may have isolated events that produce high arsenic concentrations. Even though the La Plata River before the confluence with the San Juan River has shown high salinity and dissolved manganese concentrations, it is important to note that the La Plata River is a minor contributor to the overall flow in the San Juan River. Peak flow conditions are typically between 100-400 cubic feet per second. As a result, variations in La Plata River water quality will be subjected to significant dilution upon convergence with the San Juan River.

Table 8. Water quality data for samples collected in the La Plata River. Data reproduced from Reclamation (1996) and Reclamation (2000).

Parameter	Units	Reclamation (2000)				Reclamation (1996) (Mar 1992-Jan 1995 Data)				
		Colorado		New Mexico		La Plata River At Farmington, NM				
Parameter	Units	No.	Mean	No.	Mean	No.	Mean	Min.	Max.	No. > MDL
Alkalinity, Total	(mg/L as $CaCO_3$)	138	161.7	93	188					
Aluminum, Dissolved	(µg/L as Al)			83	18.9					
Aluminum, Total	(µg/L as Al)			65	2612					
Arsenic, Dissolved	(µg/L as As)	129	5.9	324	5.4	12			72[3]	3
Arsenic, Total	(µg/L as As)	135	15.4	330	19.9	13	53.3	<10	174	
Bicarbonate, Dissolved	(mg/L as HCO_3)					14	279	147	350	
Boron, Dissolved	(µg/L as B)			67	99.4					
Cadmium, Dissolved	(µg/L as Cd)			14	1.1					
Cadmium, Total	(µg/L as Cd)			8	1.8	14	189	101	293	
Calcium, Dissolved	(mg/L as Ca)	138	70	324	141					
Calcium, Total	(mg/L as Ca)			1	48	14[1]	189	101	293	
Chloride, Total	(mg/L)	136	10.6	99	82.3	14[1]	80	15	210	
Chromium, Dissolved	(µg/L as Cr)			6	10					
Chromium, Total	(µg/L as Cr)			12	79.6					
Cobalt, Dissolved	(µg/L as Co)			8	1.6					
Cobalt, Total	(µg/L as Co)			8	23.4					
Copper, Dissolved	(µg/L as Cu)	132	3.4	237	4	13			7	3
Copper, Total	(µg/L as Cu)	137	9.7	240	33	13	14.5	2.5	47	
Hardness Calc.	(mg/L as $CaCO_3$)			132	588					
Hardness, Total	(mg/L as $CaCO_3$)			93	766					
Iron, Dissolved	(µg/L as Fe)			69	143					
Iron, Total	(µg/L as Fe)			23	208,135					
Lead, Dissolved	(µg/L as Pb)			162	0.8					
Lead, Total	(µg/L as Pb)			165	18.7					
Magnesium, Dissolved	(mg/L as Mg)	138	34.4	323	61.2					
Magnesium, Total	(mg/L as Mg)			1	11	14[1]	79.8	43	116	
Manganese, Dissolved	(µg/L as Mn)	133	36.2	185	164[4]	13			292[4]	6
Manganese, Total	(µg/L as Mn)	136	107	196	2118	13	253	<50	540	
Mercury, Dissolved	(µg/L as Hg)	128	0.11	316	0.11	13			0.22	1
Mercury, Total	(µg/L as Hg)	131	0.13	325	0.15	13	<0.2	<0.2	0.37	
Nickel, Dissolved	(µg/L as Ni)			74	5.3					
Nickel Total	(µg/L as Ni)			79	24.8					
Nitrite + Nitrate Total	(mg/L as N)			49	0.38					
Oxygen, Dissolved	(mg/L)			206	8.8					
pH Lab	(Standard Units)	138	7.95	98	8					
pH Field	(Standard Units)	121	7.57	297	7.89					

Parameter	Units	Reclamation (2000)				Reclamation (1996) (Mar 1992-Jan 1995 Data)				
		Colorado		New Mexico		La Plata River At Farmington, NM				
		No.	Mean	No.	Mean	No.	Mean	Min.	Max.	No. > MDL
Phosphorus, Total	(mg/L as P)			52	0.63					
Potassium, Total	(mg/L)					14(1)	4.3	1	8	
Total Dissolved Solids	(mg/L)			74	1437(4)	14	1677(4)	770(4)	2972(4)	
Selenium, Dissolved(2)	(µg/L as Se)	38	0.8	231	1.7					
Selenium, Total(2)	(µg/L as Se)	32	0.8	218	1.3					
Selenium, Total Recover.(2)	(µg/L as Se)	36	0.9	111	1.9					
Silver, Dissolved	(µg/L as Ag)	129	0.12	153	0.1	12			0.36	1
Silver, Total	(µg/L as Ag)	137	0.13	163	0.71	13	0.23	<0.2	0.5	
Sodium, Dissolved	(mg/L as Na)	138	19.8	237	121					
Sodium, Total	(mg/L as Na)			1	8	14	238	69	454	
Suspended Solids	(mg/L)			150	706					
Specific Conductance	(µmhos/cm)	138	603	328	1674	14	1913	884	3580	
Sulfate, Total	(mg/L as SO_4)	137	218	103	889(4)	14(1)	870(4)	359	1627(4)	
Temperature Water	(ºC)			152	10.7					
Zinc, Dissolved	(µg/L as Zn)	133	6.3	324	7.2	12			76	1
Zinc, Total	(µg/L as Zn)	132	7.7	325	206	13	18.6	<10	47	

1) Species listed as total concentration because phase not specified if dissolved in Reclamation (1996) report
2) Reclamation (1996) Selenium data not reported due to quality control concerns reported in Reclamation (2000)
3) Concentration exceeds New Mexico criteria for domestic water supply designated use for the Clean Water Act
4) Concentration exceeds the Safe Drinking Water Act primary or secondary maximum contaminant level

Reclamation (1996) reported elemental sediment analysis from several locations in the La Plata River, three of which are reproduced in Table 9. May Day Mine is located furthest upstream, and Farmington, NM, is located just before the confluence with the San Juan River. The three sediment analyses in Table 9 are from one location near a historical mine (May Day Mine), the CO-NM state border and Farmington, NM. Highlighted values represent reported values that exceeded the western states baseline data (Shacklette and Boerngen, 1984). Near the mine sediment appears to be enriched in potassium, arsenic and copper. Comparing the elemental analyses of sediments in the Animas River (Table 6) to the La Plata River (Table 9) at the locations closest to the San Juan River confluence, the abundance of trace metals in the Animas River sediment is greater for nearly all metals than in the La Plata River sediment. If sediment mobilization as a source of increased metals concentration at the proposed NGWSP SJL treatment plant intake is of interest, contributions from the Animas River are probably more important due to higher river flows and higher trace metal abundance in sediment.

More extensive historical data is available for samples collected at the USGS sampling location on the San Juan River in Farmington, NM. This sampling point is located downstream of the Animas River convergence. Table 10 summarizes water quality data collected at this location from two Reclamation reports (Bureau of Reclamation, 2006, 2000). Only mean values were included in the Reclamation (2000) report, but some statistical information is provided for the more limited Reclamation (2006) dataset. From this dataset, it is difficult to ascertain variability without additional information. While no reported values exceeded CWA or SDWA thresholds, the Reclamation (2006) data does suggest that some variability in concentration (e.g., dissolved aluminum, boron) is present.

Reclamation (1996) reported metal concentrations as a function of month and season as summarized in Table 11. The report does not specify the number of data points collected or the timespan in which data was collected. Assuming that the data is representative of average monthly and seasonal concentrations, a few trends emerge. The concentration of many metals (e.g., total copper, total mercury, total manganese) is higher in the winter compared to runoff or summer conditions. In particular, concentrations spiked in March. Dissolved manganese and dissolved copper exhibited an increase during runoff in contrast to total concentrations within the same paired dataset. One limitation of this dataset is that it did not report values for aluminum or iron, which have been shown to be important in this watershed (Bureau of Reclamation, 2016). While only one dissolved manganese concentration exceeded the secondary SDWA MCL, this limited dataset does show a dynamic behavior seasonally.

Table 9. Elemental composition of sediment collected from three locations in the La Plata River. Data reproduced from Reclamation (1996).

Element	Reclamation (1996)				
	Western States Baseline		Location		
	Mean	Range	May Day Mine	USGS CO-NM	Farmington, NM
Al (%)	5.8	1.5-23	7.7	4.2	5
Ca (%)	1.8	0.17-17	0.91	1.64	1.19
Fe (%)	2.1	0.55-8.0	2.7	1.6	1.3
K (%)	1.8	0.38-3.2	5	1.8	2.6
Mg (%)	0.74	0.15-3.6	0.3	0.56	0.16
Na (%)	0.97	0.26-3.7	2.03	0.93	1.47
P (%)	0.032	--	0.08	0.06	0.04
Ti (%)	0.22	0.069-0.7	0.21	0.18	0.15
Mn (ppm)	380	97-1500	848	238	378
Ag (ppm)	<0.5	--	<2	<2	<2
As (ppm)	5.5	1.2-22	23.8	5.6	3.1
Au (ppm)	--	--	<8	<8	<8
B (ppm)	23	5.8-91	--	--	--
Ba (ppm)	580	200-1700	1275	534	1440
Be (ppm)	0.68	0.13-3.6	2	1	1
Cd (ppm)	<0.1	--	<2	<2	<2
Ce (ppm)	65	22-190	57	46	58
Co (ppm)	7.1	1.8-28	9	5	5
Cr (ppm)	41	8.5-200	17	28	7
Cu (ppm)	21	4.9-90	288	20	8
Ga (ppm)	16	5.7-45	20	9	11
Hg (ppm)	0.046	0.0085-0.25	0.01	0.12	<0.02
La (ppm)	30	8.4-110	35	26	33
Li (ppm)	22	8.8-55	21	19	8
Mo (ppm)	0.85	0.18-4.0	2	<2	<2
Nb (ppm)	--	--	12	6	4
Nd (ppm)	36	12-110	23	21	25
Ni (ppm)	15	3.4-66	8	9	4
Pb (ppm)	17	5.2-55	44	14	17
Sc (ppm)	8.2	2.7-25	5	4	2
Sn (ppm)	--	--	<5	<5	<5
Sr (ppm)	200	43-930	558	172	313
Th (ppm)	9.1	4.1-20	--	6.3	3.6
U (ppm)	2.5	1.2-5.3	--	1.5	0.6
V (ppm)	70	18-270	100	52	28
Y (ppm)	22	8.0-60	15	13	11
Yb (ppm)	2.6	0.98-6.9	2	1	1
Zn (-ppm)	55	17-180	112	46	21

Table 10. Water quality data for the San Juan River at Farmington, NM. Data Reproduced from Reclamation (2000) and Reclamation (2006).

		Reclamation (2000)		Reclamation (2006)			
Parameter	Units	No.	Mean	No.	Median	Min.	Max.
Alkalinity, Total	(mg/L as $CaCO_3$)	607	114	--	--	--	--
Aluminum, Dissolved	(µg/L as Al)	34	34.4	3	20	5	30
Aluminum, Total	(µg/L as Al)	30	5283	--	--	--	--
Arsenic, Dissolved	(µg/L as As)	76	1.9	1	4	1	2
Arsenic, Total	(µg/L as As)	78	2.8	--	--	--	--
Bicarbonate, Dissolved	(mg/L)			--	--	--	--
Boron, Dissolved	(µg/L as B)	315	49.5	44	50	20	360
Cadmium, Dissolved	(µg/L as Cd)	11	0.8	4	0.5	0	2
Cadmium, Total	(µg/L as Cd)	12	5.7	--	--	--	--
Calcium, Dissolved	(mg/L as Ca)	859	61.6	--	--	--	--
Calcium, Total	(mg/L as Ca)	5	71.5	--	--	--	--
Chloride, Total	(mg/L)	830	9.8	--	--	--	--
Chromium, Dissolved	(µg/L as Cr)	4	11.3	3	0	0	0
Chromium, Total	(µg/L as Cr)	9	51.8	--	--	--	--
Cobalt, Dissolved	(µg/L as Co)	9	1.5	3	2	0	3
Cobalt, Total	(µg/L as Co)	13	44.4	--	--	--	--
Copper, Dissolved	(µg/L as Cu)	45	3.8	4	2	1	4
Copper, Total	(µg/L as Cu)	45	29.5	--	--	--	--
Hardness Calc.	(mg/L as $CaCO_3$)	859	189	--	--	--	--
Hardness, Total	(mg/L as $CaCO_3$)	824	189	65	196	130.4	486.1
Iron, Dissolved	(µg/L as Fe)	164	47.2	--	--	--	--
Iron, Total	(µg/L as Fe)	15	25691	--	--	--	--
Lead, Dissolved	(µg/L as Pb)	67	0.7	3	0	0	4
Lead, Total	(µg/L as Pb)	79	30.3	--	--	--	--
Magnesium, Dissolved	(mg/L as Mg)	859	8.4	--	--	--	--
Magnesium, Total	(mg/L as Mg)	5	11.9	--	--	--	--
Manganese, Dissolved	(µg/L as Mn)	26	22.3	--	--	--	--
Manganese, Total	(µg/L as Mn)	20	852	--	--	--	--
Mercury, Dissolved	(µg/L as Hg)	70	0.12	3	0.5	0.1	0.5
Mercury, Total	(µg/L as Hg)	78	0.14	--	--	--	--
Nickel, Dissolved	(µg/L as Ni)	28	6.1	--	--	--	--
Nickel Total	(µg/L as Ni)	28	6.8	--	--	--	--
Nitrite + Nitrate Total	(mg/L as N)	47	0.27	--	--	--	--
Oxygen, Dissolved	(mg/L)	251	9.5	--	--	--	--
pH Lab	(Standard Units)	879	7.81	--	--	--	--
pH Field	(Standard Units)	60	8.13	75	8	7.3	8.95
Phosphorus, Total	(mg/L as P)	59	0.27	--	--	--	--
Total Dissolved Solids	(mg/L)	374	382	--	--	--	--
Selenium, Dissolved	(µg/L as Se)	81	0.6	7	1	0.5	1
Selenium, Total	(µg/L as Se)	76	0.7	3	1	1	
Selenium, Total Recover.	(µg/L as Se)	10	0.5	--	--	--	--
Silver, Dissolved	(µg/L as Ag)	2	0.75	2	1	0	2
Silver, Total	(µg/L as Ag)	2	0.75	--	--	--	--
Sodium, Dissolved	(mg/L as Na)	836	44.7	--	--	--	--
Sodium, Total	(mg/L as Na)	5	37.7	--	--	--	--
Suspended Solids	(mg/L)	57	242	--	--	--	--
Specific Conductance	(µmhos/cm)	905	550	--	--	--	--
Sulfate, Total	(mg/L as SO_4)	827	154	--	--	--	--
Temperature Water	(ºC)	60	10.6	65	9	0	25.5
Zinc, Dissolved	(µg/L as Zn)	80	9.2	7	4	0	20
Zinc, Total	(µg/L as Zn)	75	92.9	--	--	--	--

Table 11. Monthly and seasonal water quality data of the San Juan River at Farmington, NM, downstream of Animas River confluence. Data reproduced from Reclamation (1996).

Parameter	Units	Month												Season		
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Runoff	Summer	Winter
Streamflow	ft3/s	1,416	1,329	1,377	989	3,790	2,321	852	795	775	1,007	1,520	1,504	--	--	--
Conductivity	µmho/cm	415	424	543	598	312	396	480	463	546	480	402	405	--	--	--
Dissolved Solids	mg/L	289	286	370	367	220	258	296	309	345	328	304	293	294	323	311
Copper, Total	µg/L	14	7	280	10	54	27	--	14	20	19	18	20	32	18	90
Copper, Dissolved	µg/L	2.0	1.0	3.0	2.0	10.0	5.0	--	2	2	4	5	2	6	3	3
Mercury, Total	µg/L	0.21	0.18	0.38	0.20	0.13	0.06	--	0.10	0.25	0.08	0.50	0.25	0.17	0.15	0.32
Mercury, Dissolved	µg/L	0.25	0.25	0.25	0.25	0.18	0.09	--	--	0.25	0.08	--	0.25	0.20	0.13	0.25
Silver, Total	µg/L	--	--	--	--	1.0	0.5	--	--	--	0.5	--	--	1.0	0.5	--
Silver, Dissolved	µg/L	--	--	--	--	--	--	--	--	1.0	0.5	--	--	--	0.8	--
Arsenic, Total	µg/L	2.5	2.0	15.3	1.5	3.0	1.5	--	2.0	8.0	1.5	1.7	3.0	2.3	3.3	4.9
Arsenic, Dissolved	µg/L	2.0	2.0	0.8	0.8	1.7	0.8	--	1.0	1.5	1.5	1.0	2.0	1.3	1.4	1.3
Zinc, Total	µg/L	50	70	960	35	385	193	--	50	80	45	45	30	210	55	311
Zinc, Dissolved	µg/L	11	6	25	8	55	30	4	5	10	4	6	16	27	5	13
Manganese, Total	µg/L	208	125	6,025	110	840	420	--	50	550	330	175	290	475	315	1,849
Manganese, Dissolved	µg/L	23	25	13	42	50(1)	25	--	7	5	5	5	21	46	6	17

(1) Concentration exceeds SDWA primary or secondary MCL

In the San Juan River, water quality data was tabulated in aggregate (i.e., mean values) in the Reclamation (2000) report at Shiprock, NM, as summarized in Table 12. In addition, recent data collected in the Hogback Diversion Channel through a collaborative effort between Reclamation and USGS is also summarized as many of the same parameters were analyzed in both datasets. In the Reclamation (2000) dataset, the mean dissolved manganese concentration was slightly below the secondary SDWA MCL. In the NWIS dataset, average dissolved aluminum concentrations and dissolved iron concentrations fell above the SDWA secondary MCL. Maximum observed concentrations for dissolved aluminum, dissolved iron and dissolved manganese exceeded the SDWA secondary MCL. Highlighted values in Table 12 indicate water quality parameters where the maximum observed value was at least a factor of 5 greater than the mean concentration. This subset represent water quality parameters with a potential to show the most temporal variation. As discussed in Reclamation (2016), the sample exhibiting the maximum values corresponded to a sample collected during a summer monsoon event that rapidly increased river flows. The highlighted variables demonstrate that trace metals show the greatest variability during high suspended solids events and should be investigated further through a strategic monitoring program.

Table 12. Water quality data for the San Jan River at the Hogback Diversion and Shiprock, NM. Data reproduced from Reclamation (2000) and compiled from NWIS between June 2014 and June 2016.

		Reclamation, 2000		NWIS Database				
		Shiprock, NM		Hogback Diversion				
Parameter	Units	No.	Mean	No.	No > MDL	Min	Max	Mean
Alkalinity, Total	(mg/L as $CaCO_3$)	646	119	--	--	--	--	--
Aluminum, Dissolved	(µg/L as Al)	138	58.5(1)	12	12	8.6	2,380(1)	225(1)
Aluminum, Total	(µg/L as Al)	83	15,636	12	12	935	105,000	17,204
Arsenic, Dissolved	(µg/L as As)	267	2.3	12	12	0.49	1.1	0.77
Arsenic, Total	(µg/L as As)	224	4.4	6	6	1	3.7	2.05
Bicarbonate, Dissolved	(mg/L)	--	--	16	16	74.4	296	135
Boron, Dissolved	(µg/L as B)	678	103.9	12	12	19	59	41.5
Cadmium, Dissolved	(µg/L as Cd)	71	0.9	12	2	0.03	0.142	0.017
Cadmium, Total	(µg/L as Cd)	29	3.6	12	12	0.064	1.99	0.45
Calcium, Dissolved	(mg/L as Ca)	1,178	72.4	--	--	--	--	--
Calcium, Total	(mg/L as Ca)	12	70.8	12	12	38.5	76.5	60.5
Chloride, Dissolved	(mg/L)	1,084	16.9	--	--	--	--	--
Chromium, Dissolved	(µg/L as Cr)	53	3.2	12	1	0.3	1.2	0.1
Chromium, Total	(µg/L as Cr)	25	22.5	12	12	0.61	60.7	9.9
Cobalt, Dissolved	(µg/L as Co)	67	1.4	12	12	0.106	1.83	0.43
Cobalt, Total	(µg/L as Co)	29	22.9	12	12	0.6	80.3	13.5
Copper, Dissolved	(µg/L as Cu)	165	4.2	12	12	0.81	4.6	1.4
Copper, Total	(µg/L as Cu)	121	35.5	12	12	4.3	183	32
Hardness Calc.	(mg/L as $CaCO_3$)	1,154	237	--	--	--	--	--
Hardness, Total	(mg/L as $CaCO_3$)	969	245	12	12	119	239	189
Iron, Dissolved	(µg/L as Fe)	251	31.2	12	12	5.7	3,600(1)	316(1)
Iron, Total	(µg/L as Fe)	39	30,449	5	5	2,640	7,780	4,468
Lead, Dissolved	(µg/L as Pb)	256	1.5	12	8	0.04	5.36	0.52
Lead, Total	(µg/L as Pb)	222	27.6	12	12	1.88	149	32
Magnesium, Dissolved	(mg/L as Mg)	1176	13.4	12	12	5.33	11.9	9.0
Magnesium, Total	(mg/L as Mg)	12	14	--	--	--	--	--
Manganese, Dissolved	(µg/L as Mn)	110	45	12	12	0.78	151	18
Manganese, Total	(µg/L as Mn)	56	978	12	12	64.3	5,750	997
Mercury, Dissolved	(µg/L as Hg)	254	0.13	--	--	--	--	--
Mercury, Total	(µg/L as Hg)	225	0.15	15	12	0.005	0.273	0.04
Nickel, Dissolved	(µg/L as Ni)	146	4.6	12	12	0.48	3.4	1.20
Nickel Total	(µg/L as Ni)	105	12.1	12	12	1.1	99.7	16.4
Nitrite + Nitrate Total	(mg/L as N)	98	0.39	15	15	0.148	0.954	0.41
Oxygen, Dissolved	(mg/L)	455	9.8	13	13	6.8	10.3	8.7
pH Lab	(Standard Units)	1,097	7.89	12	12	7.9	8.4	8.2
pH Field	(Standard Units)	190	8.26	16	16	7.8	8.4	8.1
Phosphorus, Total	(mg/L as P)	164	0.32	15	15	0.101	7.36	1.11
Total Dissolved Solids	(mg/L)	667	498	12	12	186	550	349
Selenium, Dissolved	(µg/L as Se)	277	1	12	12	0.25	1.5	0.59
Selenium, Total	(µg/L as Se)	227	0.9	12	12	0.269	1.47	0.64
Selenium, Total Recover.	(µg/L as Se)	29	1	--	--	--	--	--
Silver, Dissolved	(µg/L as Ag)	51	0.56	12	2	0.02	0.129	0.014
Silver, Total	(µg/L as Ag)	10	1.1	12	10	0.03	1.57	0.24
Sodium, Dissolved	(mg/L as Na)	951	64.6	12	12	11.5	86.1	35.6
Sodium, Total	(mg/L as Na)	12	38.5	--	--	--	--	--
Total Suspended Solids	(mg/L)	191	956	782	782	75	127,000	2,688
Specific Conductance	(µmhos/cm)	1,136	716	21	21	235	5,560	713
Sulfate, Total	(mg/L as SO_4)	1,083	225	12	12	63.4	228	129
Temperature Water	(ºC)	227	12.2	70	70	4.7	22.9	14
Zinc, Dissolved	(µg/L as Zn)	268	9.2	12	3	2	22	2.5
Zinc, Total	(µg/L as Zn)	224	114	12	12	12.8	404	107

(1) Concentration exceeds SDWA primary or secondary MCL

Two more historical datasets provide perspective into the seasonal fluctuations in water quality in the San Juan River. Table 13 summarizes monthly and seasonal water quality data reported in Reclamation (1996) from samples collected in Shiprock, NM. It is not clear from the report how many samples were collected each month and if the reported data represent single samples or average values. Table 14 summarizes water quality data collected during the 2012 water treatment pilot tests at the Public Service of New Mexico site (Malcolm Pirnie/Arcadis, 2013). While the dataset delineated samples collected during different hydraulic regimes, the dataset is limited. Only one trace metal sample was collected in each a spring runoff and a monsoon event. The report does not specify if the metals analysis represents total or dissolved metal concentrations.

In the Reclamation (1996) dataset (Table 13), total zinc and manganese (dissolved and total) exhibited the most variability throughout the year. Without more data, however, it cannot be determined if the reported data is representative of typically flow conditions during that month. For example, a high dissolved manganese concentration was reported in September, but the sample may have been collected during a monsoon event and not be representative of a monthly average.

In Table 14, dissolved manganese concentrations exceeded the secondary MCL during both routine operation and spring runoff conditions. Aluminum, beryllium and lead were also reported at concentrations above the SDWA secondary MCL, but the significance of these concentrations cannot be evaluated without a distinction between dissolved and total concentrations.

Table 13. Monthly and seasonal water quality data for the San Jan River at Shiprock, NM. Data reproduced from Reclamation (1996).

Parameter	Units	Month												Season		
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Runoff	Summer	Winter
Streamflow	ft3/s	1,824	1,578	1,744	3,814	3,526	4,883	2,340	1,193	1,007	1,270	1,573	2,080	--	--	--
Conductivity at 25°C	µmho/cm	536	601	619	520	381	439	410	606	596	600	594	440	--	--	--
Dissolved Solids	mg/L	345	392	379	374	235	323	277	394	403	374	386	296	284	389	379
Copper, Total	µg/L	24	199	43	8	50	45	5	52	23	60	12	--	40	34	84
Copper, Dissolved	µg/L	2.7	2.7	2.9	3.7	3.8	2.0	5.0	3.5	3.3	3.0	4.8	--	3.0	4.0	3.0
Mercury, Total	µg/L	0.30	0.42	0.28	0.15	0.48	0.25	0.20	0.43	0.16	0.30	0.25	--	0.29	0.25	0.34
Mercury, Dissolved	µg/L	0.08	0.21	0.22	0.35	0.13	0.25	0.10	0.20	0.18	0.50	0.14	--	0.19	0.21	0.18
Silver, Total	µg/L	--	4.0	1.0	1.0	1.0	--	--	--	--	1.0	0.5	--	1.0	0.8	2.5
Silver, Dissolved	µg/L	0.5	0.9	0.5	1.0	0.6	--	--	0.5	0.5	0.5	0.5	--	0.7	0.5	0.6
Arsenic, Total	µg/L	3.0	19.7	3.5	2.0	5.0	22.0	2.0	28.5	11.3	3.0	2.0	--	9.7	13.4	8.4
Arsenic, Dissolved	µg/L	1.2	1.9	0.9	1.3	0.9	0.8	1.0	0.9	1.2	1.0	0.7	--	0.9	1.0	1.1
Zinc, Total	µg/L	70	477	110	60	325	370	110	190	60	130	35	--	252	114	207
Zinc, Dissolved	µg/L	7	21	11	10	12	10	10	14	12	6	11	--	11	13	13
Manganese, Total	µg/L	375	4,157	590	210	760	605	160	595	277	500	190	--	525	383	1,642
Manganese, Dissolved	µg/L	6	12	10	14	6	5	5	12	356(1)	4	9	--	7	140	10

1) Concentration exceeds the Safe Drinking Water Act primary or secondary maximum contaminant level

Table 14. Water quality data at the Public Service of New Mexico site during the 2012 Water Treatment Pilot Studies. Data reproduced from Malcolm Pirnie/Arcadis (2013).

		Routine Operation				Spring Runoff				Monsoon Events			
Parameter	**Units**	**Number**	**Mean**	**Min.**	**Max.**	**Number**	**Mean**	**Min.**	**Max.**	**Number**	**Mean**	**Min.**	**Max.**
Alkalinity, Total	(mg/L as $CaCO_3$)	45	96.5	72	157	7	72.9	53	96.4	15	106	83	137
Aluminum[1]	(µg/L as Al)	2	1,350[3]	600	2,100[3]	1	970[3]			1	65,000[3]		
Antimony[1]	(µg/L as Sb)	2	BDL	BDL	BDL	1	BDL			1	BDL		
Arsenic[1]	(µg/L as As)	2	BDL	BDL	BDL	1	1.4						
Barium[1]	(µg/L as Ba)	2	89	80	98	1	100			1	1100		
Beryllium[1]	(µg/L as Be)	2	BDL	BDL	BDL	1	BDL			1	9.7[2, 3]		
Cadmium[1]	(µg/L as Cd)	2	0.35	BDL	0.7	1	BDL			1	1.3		
Chloride[1]	(mg/L)	2	7.9	7	8.8	1	3.8						
Chromium[1]	(µg/L as Cr)	2	0.06	BDL	1.2	1	BDL			1	45		
Copper[1]	(µg/L as Cu)	1	13										
Hardness, Total	(mg/L as $CaCO_3$)	15	160.3	131	197					2	132.5	131	135
Iron, Dissolved	(µg/L as Fe)	15	40	0	220	2	120	10	160				
Iron, Total	(µg/L as Fe)	16	410	90	1200	4	420	20	1400				
Lead[1]	(µg/L as Pb)	1	15[2, 3]										
Manganese, Dissolved	(µg/L as Mn)	16	70[3]	10	200[3]								
Manganese, Total	(µg/L as Mn)	18	140	30	600	3	130	90	210				
Nickel[1]	(µg/L as Ni)	2	BDL	BDL	BDL	1	BDL			1	BDL		
Nitrate	(mg/L)	2	0.25	0.2	0.3	1	0.1						
pH Field	(Standard Units)	71	8.2	7.5	8.9	6	8	7.7	8.2	17	8.2	7.7	8.5
Total Dissolved Solids	(mg/L)	11	280	200	348								
Selenium[1]	(µg/L as Se)	1	BDL			1	BDL			1	BDL		
Suspended Solids[4]	(mg/L)	16,058	102	0.69	1420	--	172	10.1	2340	1,002		82	>100,000
Specific Conductance	(µmhos/cm)	71	439	220	806	6	298	184	358	16	503	368	890
Sulfate[1]	(mg/L as SO_4)	2	96	82	110	1	52						
Temperature Water	(ºC)	71	18.3	9.3	26.4	6	17.7	13.2	23.7	10	21.7	19.8	24.5
Thallium[1]	(µg/L as Tl)	1	BDL	BDL		1	BDL			1	BDL		

(1) Dissolved or total concentration not specified in report
(2) Concentration exceeds New Mexico criteria for domestic water supply designated use for the Clean Water Act
(3) Concentration exceeds the Safe Drinking Water Act primary or secondary maximum contaminant level
(4) Follow-up work by Reclamation concluded that the instrument calibration factor may have been incorrect.
BDL: Below detection limit

Gold King Mine Spill Related Sampling

The sampling campaign recently conducted by the EPA represents one of the most comprehensive and cohesive datasets within the San Juan River watershed. Following the Gold King Mine spill in August 2015, EPA implemented an emergency response sampling plan throughout the watershed that analyzed water quality and sediment through October 2015. During this time, surface water and sediment samples were collected from over 50 sites (based on unique site identifiers in the database) between the Gold King Mine and Lake Powell. At some sites, sampling occurred almost daily. All data is published online and uploaded to Water Quality Portal[2].

Since the event, the EPA has developed a continuing monitoring plan that is currently being implemented. This plan includes monitoring water and sediment at 30 locations within the watershed through Fall 2016 (Environmental Protection Agency, 2016). One sampling site includes a San Juan River site above the confluence with the Animas River. Reviewing this data may be informative for identifying the relative contribution of Animas and Blanco Canyon Subbasins during storm events. The EPA plan includes sampling 1-2 storm events in Summer 2016 for water and sediment chemistry. Water sample analysis will include total and dissolved metals, total organic carbon (TOC), dissolved organic carbon (DOC), total suspended solids (TSS), and hardness. The monitoring plan does not indicate how many samples will be collected during each storm event. Nonetheless, this dataset is expected to be informative and timely for better understanding water quality dynamics across the watershed. Currently, data is published through June 2016.

[2] http://waterqualitydata.us/

Knowledge Gaps

With respect to sediment and metals transport in the San Juan River watershed, a few knowledge gaps emerge that are important for the design and operation of the NGWSP SJL water treatment plant.

1. Both the Animas and Blanco Canyon Subbasins produce flows with high suspended sediment and metals (i.e., aluminum, iron and manganese). Past studies have shown that the Blanco Canyon Subbasin is the main sediment contributor to the San Juan River above the Hogback Diversion, but the Animas Subbasin has a better documented history of metal-rich sediment. There is currently no active stream gauge in Blanco Canyon to evaluate the relative contributions of runoff between subbasins during a single sediment or metal concentration spike observed at the Hogback Diversion. It is unknown if runoff from Blanco Canyon Subbasin presents the same risks with respect to metals as the Animas Subbasin.

2. Relationships between changes in river flow and suspended sediment concentrations at the proposed intake are unknown. More data and analyses are needed relating the flow in the river to the spikes in suspended sediment at proposed intake to develop prediction tools. A model that can relate changes in flow to changes in sediment loads would be informative for water treatment operations. Existing data collected by Reclamation to date could be used to build a preliminary model.

3. The interplay between increased sediment loads and dissolved metals concentration at the Hogback Diversion site is poorly understood. Depending on which subbasin (Animas or Blanco Canyon) is producing high sediment loads, the dissolved water quality with respect to other trace metals such as arsenic, zinc, and lead may be different. It is unknown if there is the possibility for high dissolved metals without suspended solids as an indicator (e.g., winter low flow conditions). While conductivity sometimes rises during an event, it does not appear to be a reliable indicator based on recent USGS data. More data is needed regarding dissolved metals concentrations in the low flow winter months when sediment concentrations are low. More data is also needed to understand the duration of metals concentrations spikes during storm events.

4. The current dataset does not capture the true magnitude of concentration fluctuations in the watershed. Historical data does not collect more than 1 sample in a 24 hour period, which is not enough information to estimate the true maximum concentration occurring during monsoon events. More frequent data is needed to understand these events.

Previous Sampling Efforts

Reclamation has been actively sampling the San Juan River since about 2007 to collect design data for the NGWSP SJL water treatment plant. For the purposes of this report, only the sampling practices since fiscal year 2014 will be discussed as recent efforts were the most comprehensive and structured. Sampling at the Hogback Diversion (Figure 6) has been a collaborative effort between Reclamation and USGS. The following sections summarize the sampling approach, sampling locations, and data collection of each agency as a part of the NGWSP SJL efforts. To provide a common frame of reference for sampling locations used by both agencies, Figure 7 and Figure 8 provide unique sample location identifiers for each location. The pre-fixed BOR and USGS indicate the sampling agency as Reclamation and USGS, respectively.

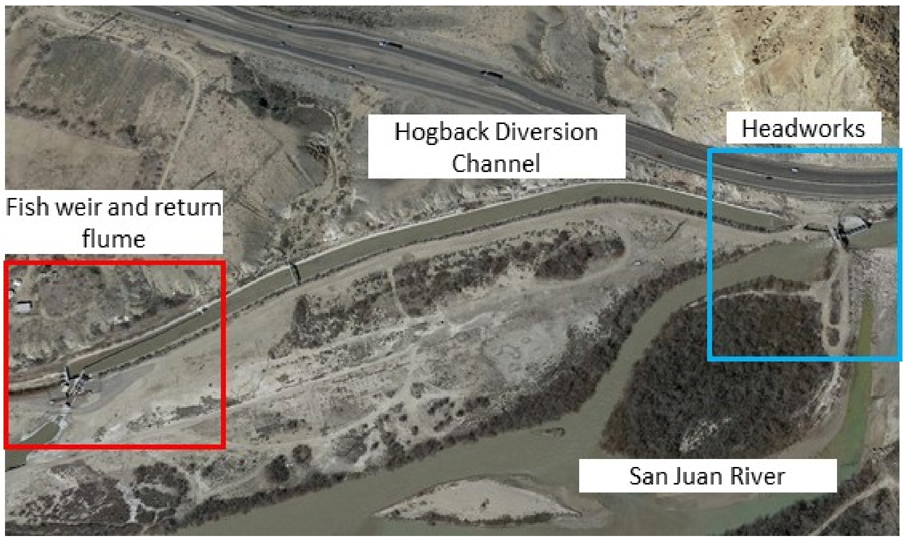

Figure 10. Aerial view of Hogback Diversion Channel with upstream and downstream structures indicated

Sampling in the Hogback Diversion Channel has occurred both at the headworks of the channel and downstream at the fish weir and return flume (Figure 6). At the Headworks, Reclamation and USGS have sampled at 2 locations depending on season (irrigation vs. non-irrigation). During irrigation season, sampling occurred within the channel behind the headworks at sites BOR1 and USGS1 (Figure 7). Outside of irrigation season, sampling occurred in the main channel of the San Juan River at sites BOR2 and USGS2 (Figure 7).

Reclamation also collected samples downstream in the Hogback Diversion Channel at locations upstream (BOR4) and downstream (BOR3 and BOR5) of the fish weir as depicted in Figure 8. USGS also has a sampling location on the return flume of the channel back to the San Juan River (USGS3).

Figure 11. Reclamation and USGS Sampling locations at Hogback Diversion headworks

Figure 12. Reclamation and USGS Sampling locations at Hogback Diversion fish weir

Reclamation Sampling

Reclamation sampling has historically used a combination of in-situ sensors and grab sample analysis as summarized in Table 15. During irrigation season, Reclamation has deployed an in-situ sensor on the downstream side of the upper end of the fish weir (BOR3) to measure either turbidity or total suspended solids (TSS). In addition to the in-situ sensor, Reclamation has also collected grab samples about weekly at several locations within the channel for TOC, DOC, turbidity and TSS analysis. During non-irrigation season when there is no flow in the channel, all sampling moves to the main channel of the San Juan River.

Table 15. Reclamation sampling approach (2014-2016)

Season	Parameter	Locations	Instrument/ Method	Sample Type	Frequency
Irrigation	TSS	BOR3 BOR4 BOR5	EPA Method 160.2	Grab	Weekly
Irrigation	Turbidity	BOR3 BOR4 BOR5	EPA Method 180.1	Grab	Weekly
Irrigation	TOC	BOR1 BOR3 BOR4	SM 5310C	Grab	Weekly
Irrigation	DOC	BOR1 BOR3 BOR4	SM 5310C	Grab	Weekly
Irrigation	TSS or Turbidity	BOR3	Sensor	In-situ	Every 30 minutes
Non-irrigation	TSS	BOR2	EPA Method 160.2	Grab	Weekly
Non-irrigation	Turbidity	BOR2	EPA Method 180.1	Grab	Weekly
Non-irrigation	TOC	BOR2	SM 5310C	Grab	Weekly
Non-irrigation	DOC	BOR2	SM 5310C	Grab	Weekly
Non-irrigation	TSS or Turbidity	BOR2	Sensor	In-situ	Every 30 minutes

USGS Sampling

Through an Interagency Agreement, USGS has implemented both in-situ monitoring and grab sample analysis at the Hogback Diversion. Downstream of the headworks, there is a sensor that measures turbidity, gage height and flow in the Hogback Diversion Channel. An ISCO sampler collects samples for suspended solids concentration every 24 hours. If the turbidity sensor records values greater than 200 FNU, the ISCO sampler increases sampling frequency to every 2 hours. Samples collected in the ISCO sampler are analyzed in an off-site lab for analysis. During irrigation season, monthly samples are collected for a suite of water quality analyses as summarized in Table 17 and Table 18.

Table 16. USGS sampling approach (2014-2016)

Season	Parameter	Locations	Instrument/ Method	Sample Type	Frequency
Irrigation	Turbidity	USGS1	Sensor	In-situ	15 minutes
Irrigation	Suspended Sediment Concentration	USGS1	ISCO Sampler	Automated grab samples	1 per day Every 2 hours when turbidity > 200 FNU
Irrigation	Water quality analysis	USGS1	See Table 17	Grab	Monthly when flow in channel.
Irrigation	Depth integrated suspended solids	USGS1	DH-81 Sampler	Grab	Monthly when flow in channel
Non-irrigation	None. In-situ monitoring data not representative without flow in channel. No water quality samples collected.				

Table 17. Suite of water quality analyses conducted by USGS (2014-2016) –part 1

Code	Parameter		Code	Parameter
P00004	Stream width		P00930	Sodium, water, filtered
P00010	Temperature, water		P00931	Sodium adsorption ratio (SAR), water
P00020	Temperature, air		P00932	Sodium fraction of cations, water
P00061	Discharge, instantaneous		P00935	Potassium, water, filtered
P00064	Mean depth of stream, feet		P00940	Chloride, water, filtered
P00065	Gage height, feet		P00945	Sulfate, water, filtered
P00080	Color, water, filtered		P00950	Fluoride, water, filtered
P00095	Specific conductance, water, unfiltered		P00955	Silica, water, filtered
P00191	Hydrogen ion, water, unfiltered		P01000	Arsenic, water, filtered
P00300	Dissolved oxygen, water, unfiltered (mg/L)		P01002	Arsenic, water, unfiltered
P00301	Dissolved oxygen, water, unfiltered (%)		P01005	Barium, water, filtered
P00400	pH, water, unfiltered, field		P01007	Barium, water, unfiltered, recoverable
P00403	pH, water, unfiltered, laboratory		P01010	Beryllium, water, filtered
P00405	Carbon dioxide, water, unfiltered		P01012	Beryllium, water, unfiltered
P00452	Carbonate, water, filtered		P01020	Boron, water, filtered
P00453	Bicarbonate, water, filtered		P01022	Boron, water, unfiltered, recoverable
P00500	Total solids dried at 105 degrees Celsius		P01025	Cadmium, water, filtered
P00600	Total nitrogen, water, unfiltered		P01027	Cadmium, water, unfiltered
P00602	Total nitrogen, water, filtered		P01030	Chromium, water, filtered
P00605	Organic nitrogen, water, unfiltered		P01034	Chromium, water, unfiltered, recoverable
P00607	Organic nitrogen, water, filtered		P01035	Cobalt, water, filtered
P00608	Ammonia, water, filtered		P01037	Cobalt, water, unfiltered, recoverable
P00613	Nitrite, water, filtered		P01040	Copper, water, filtered
P00618	Nitrate, water, filtered		P01042	Copper, water, unfiltered, recoverable
P00623	Ammonia plus organic nitrogen, water, filtered		P01045	Iron, water, unfiltered, recoverable
P00625	Ammonia plus organic nitrogen, water, unfiltered		P01046	Iron, water, filtered
P00631	Nitrate plus nitrite, water, filtered		P01049	Lead, water, filtered
P00660	Orthophosphate, water, filtered		P01051	Lead, water, unfiltered, recoverable
P00665	Phosphorus, water, unfiltered		P01055	Manganese, water, unfiltered, recoverable
P00666	Phosphorus, water, filtered		P01056	Manganese, water, filtered
P00671	Orthophosphate, water, filtered		P01057	Thallium, water, filtered
P00681	Organic carbon, water, filtered		P01059	Thallium, water, unfiltered
P00694	Carbon, suspended sediment, total		P01060	Molybdenum, water, filtered
P00900	Hardness, water		P01062	Molybdenum, water, unfiltered, recoverable
P00904	Noncarbonate hardness, water, filtered, field		P01065	Nickel, water, filtered
P00915	Calcium, water, filtered		P01067	Nickel, water, unfiltered, recoverable
P00925	Magnesium, water, filtered		P01075	Silver, water, filtered

Table 18. Suite of water quality analyses conducted by USGS (2014-2016) –part 2

Code	Parameter		Code	Parameter
P01077	Silver, water, unfiltered, recoverable		P30209	Discharge, instantaneous
P01080	Strontium, water, filtered		P39086	Alkalinity, water, filtered
P01082	Strontium, water, unfiltered, recoverable		P49570	Particulate nitrogen, suspended in water
P01085	Vanadium, water, filtered		P51285	Geosmin, water, filtered, recoverable
P01087	Vanadium, water, unfiltered		P51286	2-Methylisoborneol, water, recoverable
P01090	Zinc, water, filtered		P68288	Geosmin, water, unfiltered, recoverable
P01092	Zinc, water, unfiltered		P68289	2-Methylisoborneol, water, unfiltered, recoverable
P01095	Antimony, water, filtered		P70300	Dissolved solids, filtered
P01097	Antimony, water, unfiltered,		P70301	Dissolved solids, water, filtered, sum of constituents
P01105	Aluminum, water, unfiltered		P70302	Dissolved solids, water
P01106	Aluminum, water, filtered		P70303	Dissolved solids, water, filtered
P01130	Lithium, water, filtered		P71870	Bromide, water, filtered
P01132	Lithium, water, unfiltered, recoverable		P71890	Mercury, water, filtered
P01145	Selenium, water, filtered		P71900	Mercury, water, unfiltered, recoverable
P01147	Selenium, water, unfiltered		P80154	Suspended sediment concentration
P03515	Gross beta radioactivity, water, filtered		P80155	Suspended sediment discharge
P04126	Alpha radioactivity, water, filtered, Th-230 curve		P81366	Radium-228, water, filtered
P09511	Radium-226, water, filtered, radon method		P90095	Specific conductance, water, unfiltered, laboratory
P22703	Uranium (natural), water, filtered		P99597	Giardia, method 1623, water
P28011	Uranium (natural), water, unfiltered		P99599	Cryptosporidium, method 1623, water
P30207	Gage height, above datum			
P70331	Suspended sediment, sieve diameter, percent smaller than 0.0625 millimeters			
P70332	Suspended sediment, sieve diameter, percent smaller than 0.125 millimeters			
P70333	Suspended sediment, sieve diameter, percent smaller than 0.25 millimeters			
P70334	Suspended sediment, sieve diameter, percent smaller than 0.5 millimeters			
P70335	Suspended sediment, sieve diameter, percent smaller than 1 millimeters			
P70337	Suspended sediment, fall diameter (deionized water), percent smaller than 0.002 millimeters			
P70338	Suspended sediment, fall diameter (deionized water), percent smaller than 0.004 millimeters			
P70339	Suspended sediment, fall diameter (deionized water), percent smaller than 0.008 millimeters			
P70340	Suspended sediment, fall diameter (deionized water), percent smaller than 0.016 millimeters			
P70341	Suspended sediment, fall diameter (deionized water), percent smaller than 0.031 millimeters			

Key Results

Previous sampling efforts between Reclamation and USGS lead to several key results that provided the foundation and motivation to augment the current sampling plan. These results are summarized in this section, as they directly inform the proposed sampling plan in the following section.

Suspended Solids

The San Juan River has historically exhibited large variations in total suspended solids. Figure 9 illustrates the large variations in turbidity experienced since the installation of the USGS turbidimeter from less than 100 Formazin Nephelometric Unit (FNU) to over 3290 FNU (sensor upper limit). Sensor data was not recorded during non-irrigation season when the Hogback Diversion Channel was closed.

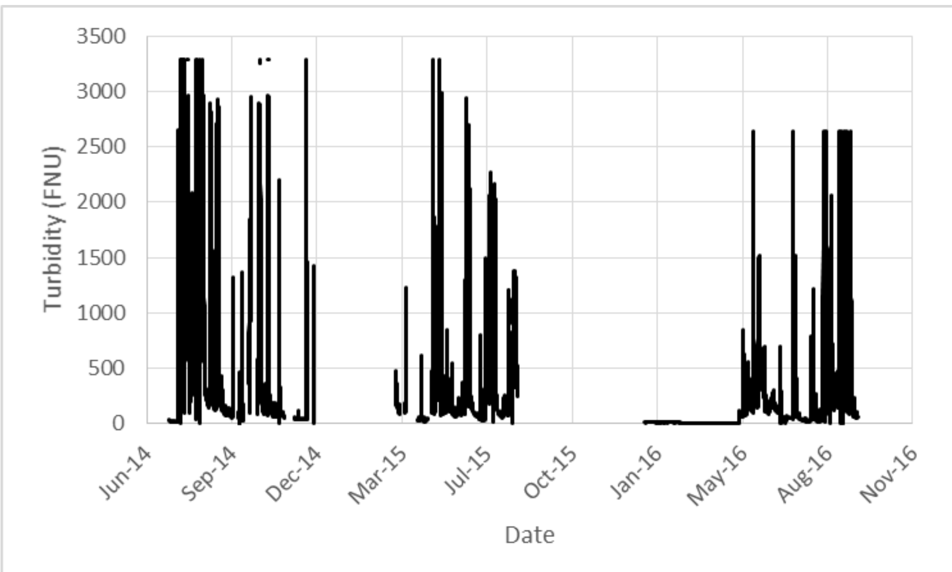

Figure 13. Online turbidity measurements between June 2014 and September 2016 from the USGS sensor installed at the Hogback Site. Sensor upper measurement range is 3290 FNU.

Past work has also demonstrated that large changes in river flow produce high suspended solids events. More work is needed to identify what hydraulic conditions in the river produce suspended solids events that may disrupt water treatment plant operations and be considered unacceptable to bring into the intake settling basins. Figure 10 superimposes flow and total suspended solids data from the 2012 Malcolm Pirnie pilot studies (Malcolm Pirnie/Arcadis, 2013). Note that the lag time between change in flow and change in total suspended solids is due to the flow gauge being located upstream of the suspended solids sensor.

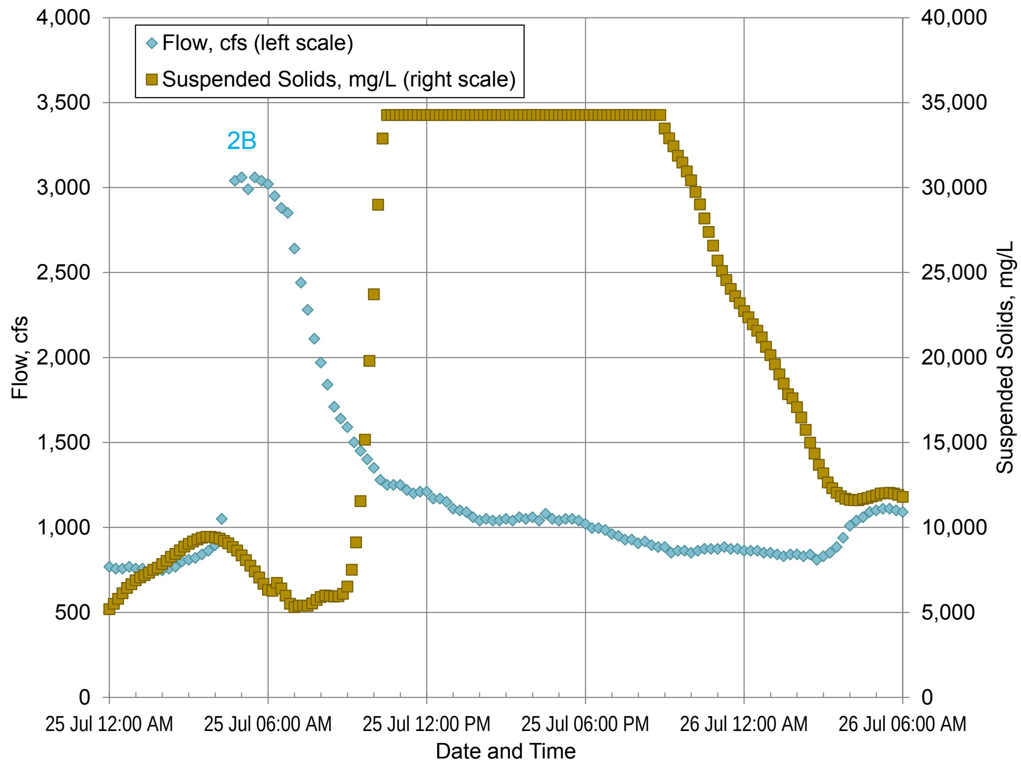

Figure 14. High total suspended solids event and river flow observed during the 2012 Malcolm Pirnie/Arcadis pilot studies. Flow was measured about 10 miles upstream from suspended solids. Total suspended solids sensor upper range is about 34,000 mg/L.

The behavior of high suspended sediment events shows variability in both frequency and magnitude. Some events show very distinct peaks, where the suspended solids concentration (or turbidity) after the event returns to the pre-event conditions (Figure 15a). Other events show multiple overlapping spikes in turbidity, where a second event begins before turbidity returns to baseline values (Figure 15b).

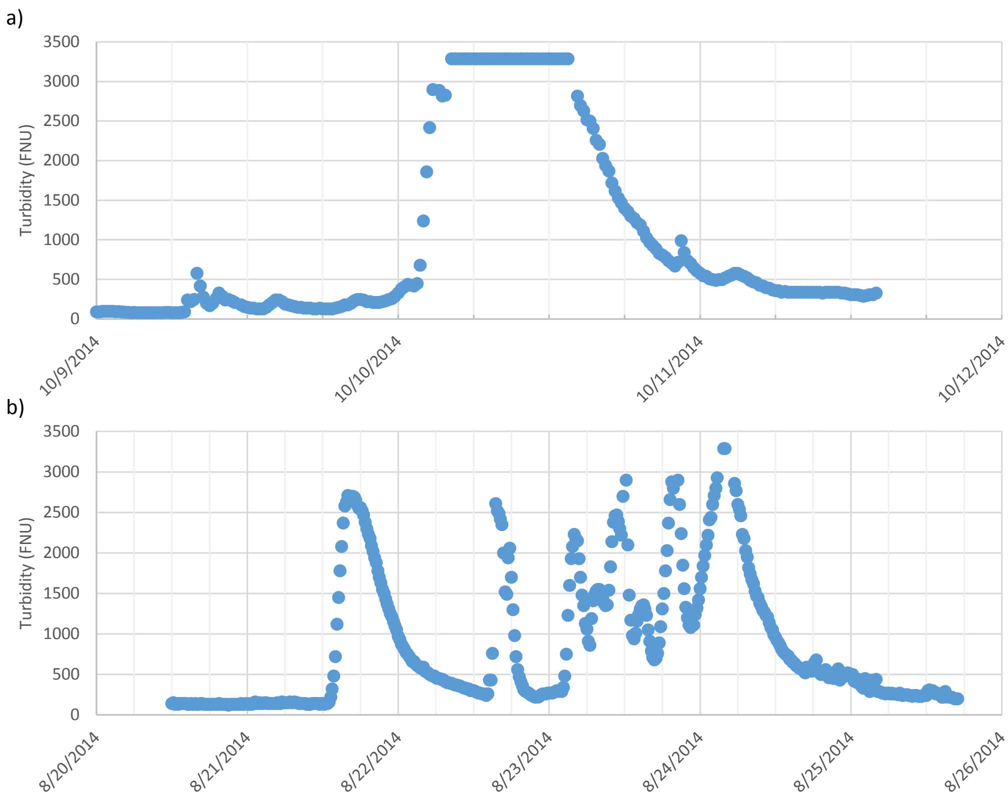

Figure 15. Select high turbidity events observed in 2014 by the USGS turbidity sensor at the Hogback Site. Sensor upper measurement range is 3290 FNU.

Between 2014 and 2016, Reclamation collected grab samples for turbidity and total suspended solids analysis on a weekly basis (Table 15). Samples were collected at three locations within the Hogback Diversion Channel to assess solids settling due to the fish weir. Samples collected at BOR3 and BOR5 (over the fish weir) were compared to samples collected at BOR4 (Bypass Gate) at the same time. Figure 12 compares paired measurements and shows there was no apparent difference. All points fall near the 1:1 line representing no systematic difference. Three high solids events are not shown in Figure 12 for clarity. A paired t-test (one-tail) was used to determine if the measurement differences were statistically different from zero. Only samples below 1000 mg/L and 1000 Nephelometric Turbidity Unit (NTU) were included in the dataset to exclude extreme outliers that violate the underlying normality assumption for t-tests. Between BOR4 and BOR3, there was no statistical difference between turbidity measurements ($p=0.3$) or total suspended solids measurements ($p=0.14$). Between BOR4 and BOR5, there was no statistical difference between turbidity measurements ($p=0.4$) or total suspended solids measurements (0.2). For the four high solids events measured, there was no systematic difference in turbidity measurements; some events exhibited increases in turbidity while others exhibited decreases.

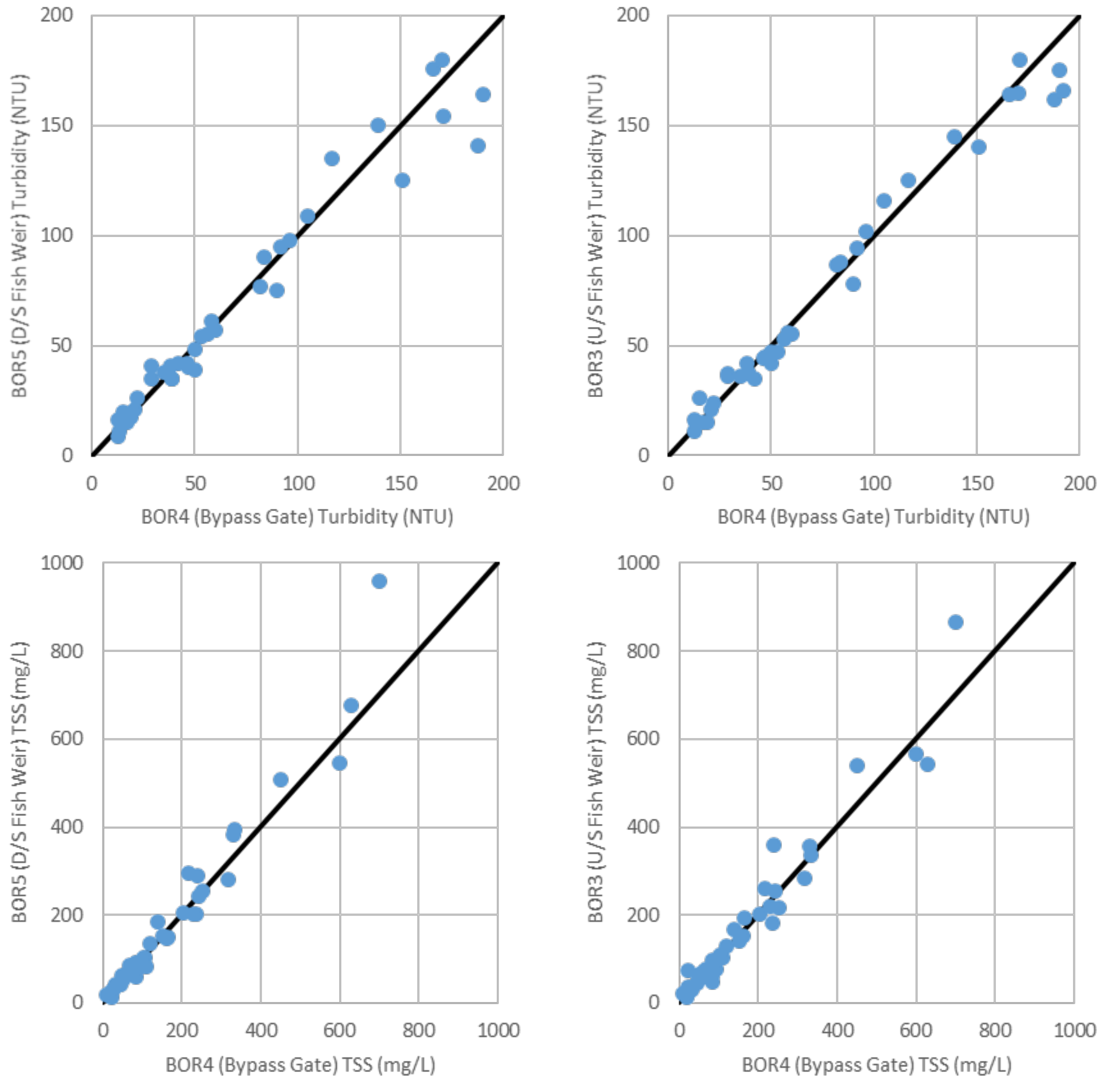

Figure 16. Comparison of TSS and turbidity samples collected upstream and downstream of the Fish Weir relative to the Bypass Gate samples. Solid line indicates 1:1 line.

Metals Concentrations

Reclamation (2016) performed a metadata analysis of EPA and Reclamation data collected after the Gold King Mine Spill and found that high suspended solids events are also accompanied by high metal concentrations. The near-daily samples collected and published by EPA after the spill captured the large increases in total and dissolved metal concentrations, which were then correlated with flow increases in the Animas River. A reexamination of USGS data collected before the spill found that high metals were also associated with samples that were collected by chance during other high solids events.

Figure 17 illustrates the trend observed for total metal concentrations both before and after the Gold King Mine Spill. Increases in concentration corresponded with increases in flow in the San Juan and Animas Rivers. A limitation of the current dataset is that the magnitude and breadth of the concentration spikes is not well understood. With solids events occurring over the course of hours to days, collecting one sample per day cannot adequately define the rise and fall in metals concentration. There is a low probability that the peak concentrations in Figure 17 were collected at the time of maximum concentration. To fully understand the magnitude and duration of these events, samples collected on an hourly timescale are needed. Improved resolution would help inform water treatment operations of the impacts related to allowing water during a high solids event into the water treatment plant settling basins.

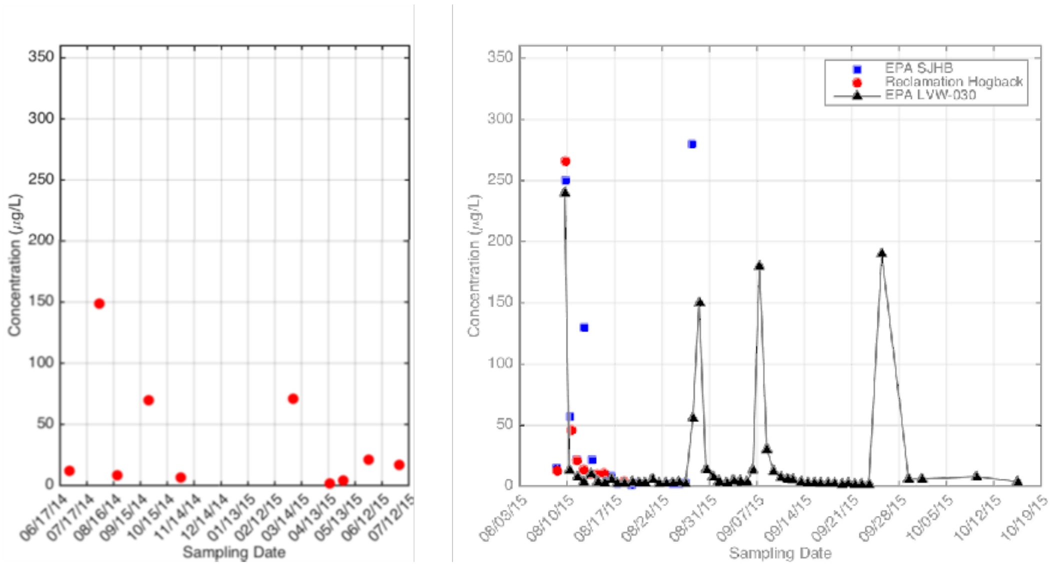

Figure 17. Total lead measured in micrograms per liter from the three sampling locations. The left pane indicates pre-spill data and the right pane indicates post-spill data.

The increases in total metal concentrations (Figure 17) also corresponded with increases in dissolved metal concentrations (Figure 18). Similar to total metal concentration trends, understanding the behavior of dissolved metals is important for water treatment operations. Dissolved metal concentrations in the raw water above regulatory thresholds are of particular interest, because only select treatment processes are designed to remove dissolved metals. The samples with elevated concentrations represent one discrete sample, and there is a low probability that the same was collected at a time representative of peak concentration.

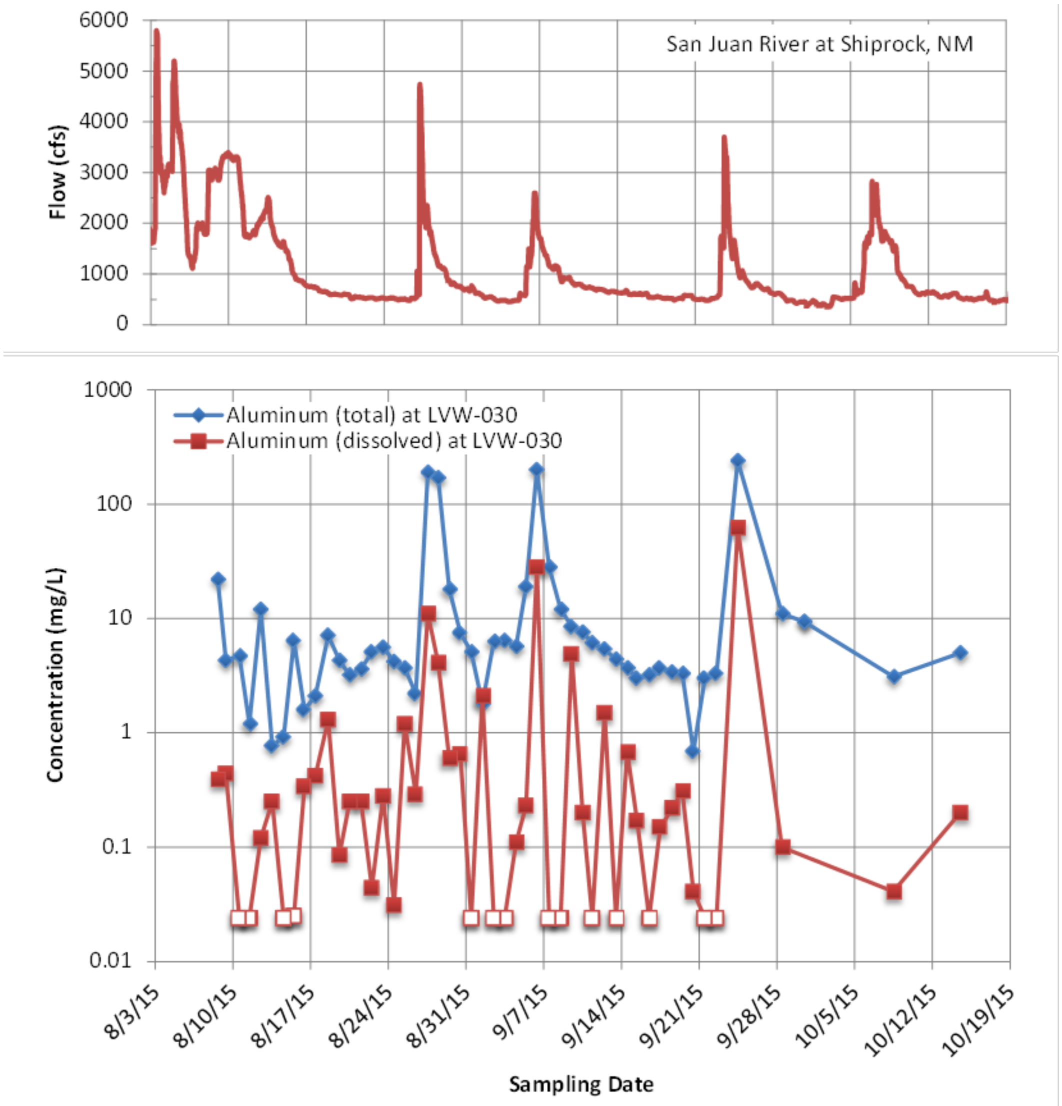

Figure 18. Distribution of aluminum between suspended and dissolved forms during August-October 2015. Unfilled markers indicate data plotted at the MRL. USGS flow data was marked provisional at the time of report preparation.

Lastly, the EPA sampling campaign was informative with respect to the metal content of sediment in the river. An important conclusion from the sediment analysis in Reclamation (2016) is that the relative abundance between elements showed little variation over a time period of several months. In particular, the ratio of sodium and potassium appeared relatively constant compared to other trace elements. Therefore, it is hypothesized that if a suspension of material leads to an increase in dissolved concentrations, dissolved sodium and potassium may also increase simultaneously. If this behavior produces a change in electrical conductivity of the water, monitoring for conductivity may be an informative tool in addition to turbidity. An analysis of data collected on the Animas River in August 2016 suggests that some suspended solids events are accompanied by a change in conductivity, while others are not (Figure 19).

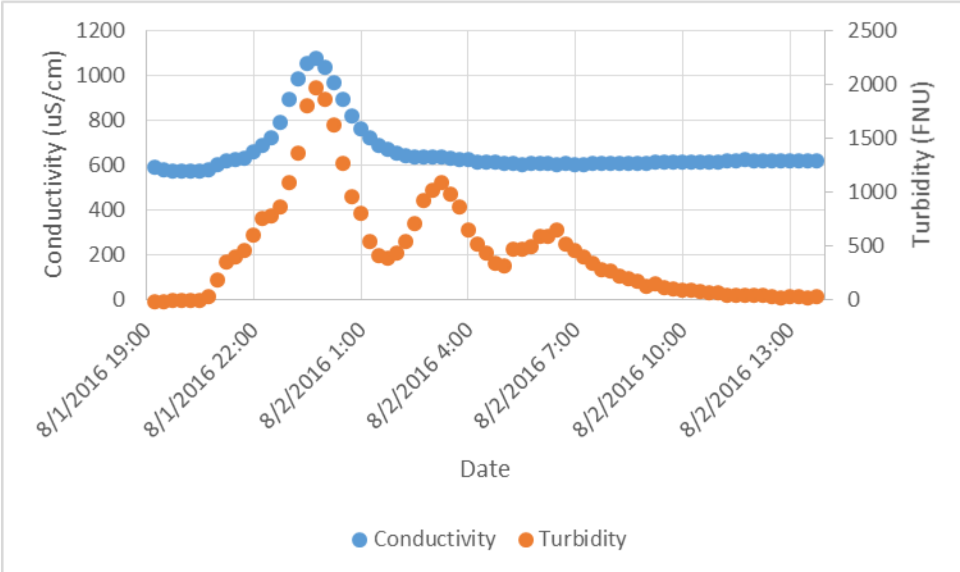

Figure 19. Conductivity responses during a series of events with spikes in turbidity measured on the Animas River near Aztec, NM (USGS 09364010). Data was marked provisional at time of publication.

Proposed Sampling Plan

Sampling Plan Objectives

Based on a review of published literature and previously collected data, a revised sampling plan should meet the following objectives:

1. Continue the Reclamation and USGS previous sampling approach (baseline and spring runoff) with a modification that moves the sampling point to the San Juan River such that sampling is not contingent on flow in the Hogback Diversion Channel.
2. Augment the previous sampling approach to measure suspended solids and metals (total, dissolved and sediment) concentrations *during monsoon* rain events in the watershed with a sampling frequency capable of defining a peak event
3. Evaluate the relative contribution of the Animas Subbasin relative to the Upper San Juan and Blanco Canyon Subbasins by leveraging other efforts in the watershed.

During a peak event where a spike in turbidity is observed, the augmented sampling plan (Objective 2) will be designed to answer the following questions:

1. What is the *maximum concentration* of suspended solids and associated metals observed during an event?
2. What is the *total mass* of solids and associated metals that would have entered an intake settling basin?
3. What is the *duration* of the peak event as quantified by the amount of time required to return to the baseline turbidity?

The proposed sampling plan is designed to collect data that is directly pertinent to the design and operation of the NGWSP SJL water treatment plant.

Sampling Locations and Analyses

To collect water quality data year-round, the proposed sampling plan would utilize sites BOR2 and USGS2 to sample the main channel of the San Juan River. If sampling equipment cannot be set-up at the previously used sites, a new suitable site will be identified and given a new unique name.

Assuming BOR2 and USGS2 are suitable and accessible, the recommended Reclamation monitoring plan is summarized in Table 19. The proposed sampling approach includes moving both turbidity/TSS sensors (both low and high range) to the main channel of the San Juan River. Co-locating both sensors will allow for turbidity to be measured throughout the entire range of historically observed values without exceeding the sensor upper range or sacrificing low range detection. Weekly TOC and DOC sample collection will also be moved to the same location in the main channel. During irrigation season, additional samples for turbidity and TSS will continue to be collected at site BOR4 (former Bypass Gate) to assess settling in the diversion channel.

Table 19. Reclamation sampling approach (2017-2018)

Season	Parameter	Locations	Instrument/ Method	Sample Type	Frequency
Year-round	TSS	BOR2, BOR4	EPA Method 160.2	Grab	Weekly
Year-round	Turbidity	BOR2, BOR4	EPA Method 180.1	Grab	Weekly
Year-round	TOC	BOR2	SM 5310C	Grab	Weekly
Year-round	DOC	BOR2	SM 5310C	Grab	Weekly
Year-round	TSS or Turbidity	BOR2	Both sensors	In-situ	Every 15 minutes
Irrigation	TSS	BOR3	EPA Method 160.2	Grab	Weekly
Irrigation	Turbidity	BOR3	EPA Method 180.1	Grab	Weekly

The proposed sampling plan also includes an augmented sampling approach collaborating with USGS. First, USGS sampling is recommended to be moved to the main channel of the San Juan River to support year-round water quality monitoring. The addition of a stream gauge to measure flow is also proposed to develop relationships between turbidity, water chemistry and flow in the San Juan River at the Hogback Diversion Channel.

For water quality sampling, the proposed sampling approach includes collecting samples to establish baseline, spring runoff, and monsoon peak event water quality. For baseline samples, it is recommended that samples be collected once per month, targeting steady flow conditions (non-storm event). For spring runoff, it is recommended that sampling be increased to biweekly from the onset of snowmelt (mid-April) through the hydrograph receding limb of spring runoff (early July). For these samples, it is proposed that samples be analyzed for the suite of analytes included in Table 17 and Table 18.

Table 20. USGS sampling approach (2014-2016)

Season	Parameter	Locations	Instrument /Method	Sample Type	Frequency
Year-round	Turbidity	USGS2	Sensor	In-situ	15 minutes
Year-round	Suspended Sediment Concentration	USGS2	ISCO Sampler	Automated grab samples	1 per day Every 2 hours when turbidity > 200 FNU
Year-round	Water quality analysis	USGS2	See Table 17 and Table 18	Grab	Monthly Biweekly samples during snowmelt
Year-round	Depth integrated suspended solids	USGS2	DH-81 Sampler	Grab	Monthly when flow in channel Biweekly samples during snowmelt
Strom Event	Water quality analysis	USGS2	See Table 21	Automated grab samples	ISCO sampler triggered based on upstream turbidimeter
Storm Event	Sediment Composition	USGS2	See Table 22	Automated grab samples	ISCO sampler triggered based on upstream turbidimeter

For monsoon events, the proposed sampling plan also includes adding another ISCO sampler(s) that can collect grab samples during a monsoon event that causes a spike in turbidity. Based on conversations with USGS, there is a planned installation of a similar system on the Animas River that will be triggered manually by USGS staff during a high turbidity event. To enhance future data analysis opportunities, it would be ideal if the new ISCO sampler on the San Juan River was triggered to collect samples during the same events as the Animas River sampler. A lag time between samplers may be necessary to collect concentration peaks at both locations. Based on the data in Reclamation (2016), the samplers need to have the capacity to collect samples over at least 48 hours, preferably 60 hours. Sampling frequency should be every 2 to 4 hours. The number of samplers in tandem will be determined based on the sample volume needed for the final suite of analytical analyses.

A peak turbidity event suitable for expanded water quality analysis will by defined by the following set of criteria:

1. Turbidity sensor shows a clearly defined, single peak that returns to pre-event baseline values as illustrated in Figure 15a.
2. Turbidity sensors observe a peak turbidity value of at least 2000 FNU.

The ISCO autosampler collecting grab samples throughout the monsoon event will be configured to identify and collect 10 to 15 samples throughout the duration of the event, starting with a pre-event baseline value. An upstream turbidimeter will be used to identify events that occur in either the Animas or Blanco Canyon Subbasins. A turbidimeter, installed on the Animas River below Aztec, NM by USGS in March 2016 (USGS 09364010), will be monitored to identify suspended solids events on the Animas River. Ideally, another flow gauge, turbidimeter and conductivity meter installed on the San Juan River upstream of the Animas River confluence would be used to identify suspended solids events originating in the Blanco Canyon Subbasin. The feasibility of adding a gauge and sensor will be determined when evaluating the final project budget. If this option is not available, responses observed at the Hogback Diversion Channel site will be compared to the Animas River gauges to infer the relative effect of the Blanco Canyon Subbasin during an event.

Immediately after a peak event during which the ISCO sampler collected samples, the real-time turbidity data will be reviewed to identify 5 to 6 samples to be analyzed for water quality and sediment composition. While adaptation to specific events is expected, the general strategy for sample selection is illustrated in Figure 16. Sample 1 will represent the water quality conditions as turbidity starts to rise. This sample may be associated with fine colloidal material. Sample 3 will be selected to best represent the peak suspended solids concentration. Sample 5 will correspond with a return to baseline conditions such that an integration of data can calculated the total mass of material that would have entered an intake settling basin. Samples 2 and 4 will be selected to best represent the concentrations at one-half the maximum observed turbidity. Samples collected at similar turbidity values will be analyzed to evaluate if there is a hysteresis effect associated with the rising and receding limbs of an event.

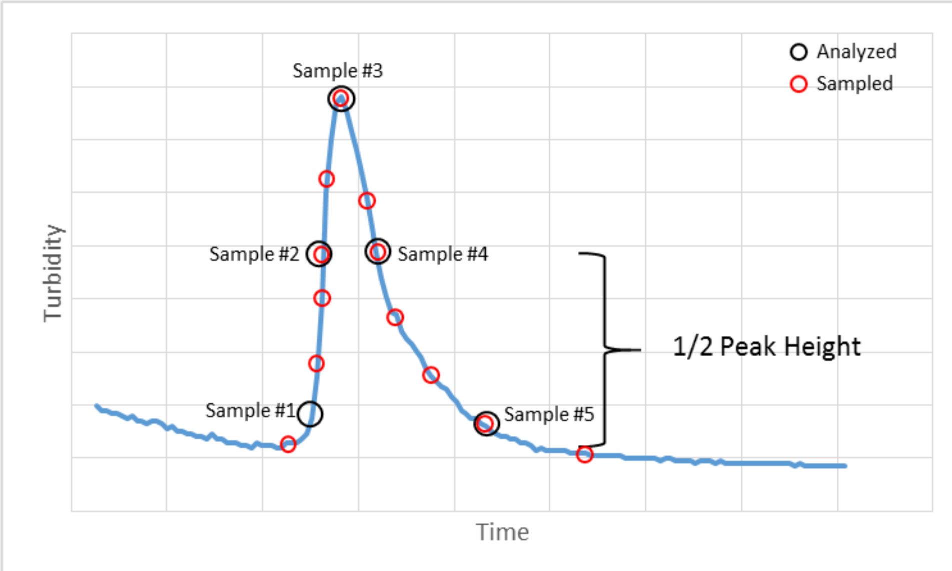

Figure 20. Strategy for selecting samples for water and sediment analysis based on an arbitrary peak turbidity event.

Samples selected for water quality and sediment composition analysis will be analyzed using a suite of parameters targeted for metals analysis. Based on preliminary data, the variation and impact of metals transport during peak events requires further investigation. Therefore, a pared down analysis suite compared to baseflow analysis will be applied. Table 21 summarizes the analytes for water quality analyses and includes general wet chemistry and metals analysis.

Table 22 summarizes the elements to be included in a sediment composition analysis. Specific methods are to be determined. Analyzing the composition of sediment transported during a peak event will provide information regarding the metal content of the sediment, which may inform handling and disposal practices.

Table 21. Suite of water quality analyses during monsoon events

Code	Analyte		Code	Analyte
p01000	Arsenic, dissolved		p01105	Aluminum, total
p01002	Arsenic, total		p01106	Aluminum, dissolved
p01005	Barium, dissolved		p01130	Lithium, dissolved
p01007	Barium, total		p01132	Lithium, total
p01010	Beryllium, dissolved		p01145	Selenium, dissolved
p01012	Beryllium, total		p01147	Selenium, total
p01020	Boron, dissolved		p00915	Calcium, dissolved
p01022	Boron, total		p00925	Magnesium, dissolved
p01025	Cadmium, dissolved		p71900	Mercury, total
p01027	Cadmium, total		p00935	Potassium, dissolved
p01030	Chromium, dissolved		p00930	Sodium, dissolved
p01034	Chromium, total		p00076	Turbidity, unfiltered
p01035	Cobalt, dissolved		p00095	Specific conductance, water, unfiltered
p01037	Cobalt, total		p00191	Hydrogen ion, water, unfiltered,
p01040	Copper, dissolved		p00300	Dissolved oxygen, water, unfiltered, milligrams per liter
p01042	Copper, total		P00400	pH, water, unfiltered, field, standard units
p01045	Iron, total		p00403	pH, water, unfiltered, laboratory, standard units
p01046	Iron, dissolved		p00405	Carbon dioxide, water, unfiltered
p01049	Lead, dissolved		p00452	Carbonate, water, filtered
p01051	Lead, total		p00453	Bicarbonate, water, filtered,
p01055	Manganese, total		p00660	Orthophosphate, water, filtered
p01056	Manganese, dissolved		p00665	Phosphorus, water, unfiltered
p01057	Thallium, dissolved		p00666	Phosphorus, water, filtered
p01059	Thallium, total		p00671	Orthophosphate, water, filtered
p01060	Molybdenum, dissolved		p00900	Hardness, water
p01062	Molybdenum, total		p00904	Noncarbonate hardness, water, filtered, field
p01065	Nickel, dissolved		p00905	Noncarbonate hardness, water, filtered, lab
p01067	Nickel, total		p00915	Calcium, water, filtered
p01075	Silver, dissolved		p00925	Magnesium, water, filtered
p01077	Silver, total		p00930	Sodium, water, filtered
p01080	Strontium, dissolved		p00935	Potassium, water, filtered
p01082	Strontium, total		p00940	Chloride, water, filtered
p01085	Vanadium, dissolved		p00945	Sulfate, water, filtered
p01090	Zinc, dissolved		p70300	Dissolved solids, water, filtered
p01092	Zinc, total		P80154	Suspended sediment concentration
p01095	Antimony, dissolved		P00010	Temperature, water
p01097	Antimony, total			

Table 22. Analytes to include in sediment composition analysis. USGS parameter codes to be determined.

Analyte		Analyte
Aluminum		Magnesium
Antimony		Manganese
Arsenic		Mercury
Barium		Molybdenum
Beryllium		Nickel
Boron		Potassium
Cadmium		Selenium
Calcium		Silver
Chromium		Sodium
Cobalt		Strontium
Copper		Thallium
Iron		Vanadium
Lead		Zinc
Lithium		

Next Steps

To prepare for augmented sampling starting in 2017, the proposed next steps are as follows:

1. Refine sampling priorities with FCCO based on the information and historical data summarized in the literature review. In particular, assess the importance of sampling upstream subbasins (i.e., Animas and Blanco).
2. Consult with USGS to determine budget for different sampling components
3. Finalize sampling plan based on approval of solicited funding from Reclamation’s Science and Technology Program
4. Modify interagency agreement with USGS to augment current sampling efforts

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