Animas River during the Gold King Mine spill (Sullivan et al.,2017)

Mining and mining legacies in the San Juan River and tributaries

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Introduction

The San Juan River is part of the Upper Colorado River Basin and flows from the West side of the Rocky Mountains to Lake Powel, as shown in Figure 1. Thousands of inactive mines dot the landscape and leave a legacy of acidic drainage and increased levels of sediments and metals in the surrounding watersheds (Church et al., 2007). The watersheds that feed the San Juan River are no exception. Efforts have been undertaken to remediate inactive mining sites. However, these projects contend with many complicating factors that make for a lengthy, and often expensive, remediation. In the meantime, acid mine drainage, sediments, and metals from the mining sites leach into nearby waterways. This slow leaching has damaged aquatic ecosystems in the San Juan and its tributaries to the point where some streams can no longer support life (Church et al., 2007). However, this contamination process can also occur quickly when the water inside the mine breaks through containing structures, releasing a pulse flow of contaminated mine drainage downstream. The Gold King Mine spill in 2015 was One such dramatic event. This well documented event provides a case study through which this paper examines the impacts of mining legacies on human and aquatic ecosystem health.

Figure 1: Map of San Juan River (Wikimedia, 2022)

Mining background

History

The discovery of placer gold in the San Juan River in the 1890s drew prospectors to the region (Aton, 2000). Placer gold is fine grained and difficult to separate from other fine sediments in the river. Many prospectors came with the hopes of quickly obtaining wealth but left disappointed. Early mining efforts tended to utilize pans, sluices, and other mechanically simple devices. These activates primarily took place in the riparian zone. When these simple methods did not provide enough gold to interest an independent miner, others sought the gold with increased investment and mechanization (Aton, 2000). Machines utilizing pumps, filters, and other technologies still failed to produce immense success. This lack of success can be partially attributed to the difficult conditions on and around the San Juan River. Steep canyons and remote locations made resupplying difficult. Boats could be used to go downstream, but rarely attempted to go upstream. Most importantly, seasonal flooding often whipped away evidence of mining (Aton, 2000). In making mining installations functionally less permanent the floods mitigated some of the environmental impacts of early gold mining.

mechanization coupled with the seasonal flood events also increased interest in moving mining away from the riparian zone and into the nearby mountains. Thus the shift to hardrock mining sought ore in the San Juan Mountains, primarily gold, silver, copper and lead (Varnes, 1963). Waste rock, also known as tailings, from mining and milling ore was typically deposited in the riparian zone (US Geological Survey, 2007a). Between the excavations for mining and large-scale rock moving hardrock mining greatly changed the water quality of the San Juan River and tributaries.

Impacts

While mining has been largely inactive since the 1990s, the water quality issues persist (Church et al., 2007). One difficulty is that some portion of the contributors to reduced water quality, such as sediment, acid, or metals, are naturally occurring. However, mining has artificially increased the amount of sediment, acid, and metals in streams. In many ways mining has accelerated naturally occurring processes.

The natural weathering process breaks down rock into sediment. However, mine and mill tailings were often deposited in the riparian zone. Seasonal high spring runoff events tend to wash tailings downstream (US Geological Survey, 2007a). This anthropogenic source of sediment is problematic for aquatic ecosystems. For example, native cutthroat trout depend on deep pools for winter habitat. Many such deep pools have been made shallower or filled in with sediment from anthropogenic sources (US Geological Survey, 2007a). As a result, native cutthroat trout have been all but eliminated from the Animas River, a tributary to the San Juan (US Geological Survey, 2007a).

Pyrite is a widespread mineral in the San Juan Mountains (US Geological Survey, 2007b). When weathered in the presence of water and oxygen pyrite forms sulfuric acid (US Environmental Protection Agency, n.d.; US Geological Survey, 2007a, 2007b). Mining accelerates acid production as it exposes more pyrite to air and water (US Geological Survey, 2007b). By contrast, naturally occurring carbonate and chlorite minerals have acid-neutralizing capacity that makes the Animas River slightly basic at pH 7.5 (Sullivan et al., 2017). Anthropogenic acid inputs to this watershed have tipped the scale to make tributaries with mining legacies more acidic. For example, the heavily mined watershed of Cement Creek, a tributary to the Animas River, has a pH regularly below 4.5 (Sullivan et al., 2017). As a result of the low pH and other water quality issues directly relating to mining legacy, Cement Creek supports little to no aquatic life (US Geological Survey, 2007a).

Similarly, extensive mining in this region sought these precious metals. In an undisturbed setting these metals would normally weather and contribute to heavy metal concentrations in the San Juan River and tributaries, but mining accelerated the weathering process and artificially contributed to heavy metal concentrations in the San Juan River and tributaries (US Geological Survey, 2007b). A study by Frederick et al. (2019) examined sediment cores from the San Juan River Delta of Lake Powell and geochemically linked the sediments to specific tributaries. The study also examined the origin of the metals present as mining or non-mining (i.e. from natural weathering). The authors found the Anamis River metals primarily from mining sources. By contrast, the Manco River, Chinle Creek, Chaco Creek, McElmo Creek contributed metals that were from both mining and non-mining sources (Frederick et al., 2019). The authors suggested that these tributaries are a mixture of water from unmined and mined watersheds. No watersheds examined contributed purely metals from nonmining sources (Frederick et al., 2019). Thus, anthropogenic metal contributions dominate the metals in the San Juan River.

Remediation

Fixing these water quality issues is not simple. The region has a long history of mine contamination from hundreds of inactive mines (Sullivan et al., 2017). In the 1990s, interest in addressing the negative environmental impacts of mining began with water quality studies in the Animas River watershed (Church et al., 2007). These studies established water quality benchmarks (Church et al., 2007). Church et al. (2007) listed 43 completed or in progress mine remediation projects as of 2004 in the Animas River watershed alone. The Environmental Protection Agency (EPA) has also implemented many projects to control such non-point sources of mining waste (Sullivan et al., 2017).

However, some factors complicate remediation efforts. The underground aspects of a site can also change with little if any surface indication (US Environmental Protection Agency, 1995). As a result, it is important to document and monitor site conditions to accurately understand site conditions. Studies to characterize mine waste, evaluate runoff, and investigate groundwater pathways can be expensive and time consuming (Church et al., 2007). Site conditional also vary between sites, so attempting to implement a one-size-fits-all solution can lead to an incomplete or incorrect understanding if a site (US Environmental Protection Agency, 1995). Such a misunderstanding can yield no improvements in water quality even after remediation. Long project timelines and limited financial resources leave little tolerance for such failure (US

Environmental Protection Agency, 1995). Some watersheds heavily impacted by mining legacies may not be capable of supporting aquatic life even with site remediation, but downstream water quality may depend on the improvements remediation could bring. In such cases selecting metrics to accurately define success and strategically completing projects to meet goals can help in assessing the real impacts of remediation efforts.

Overall, the legacy of mining in the San Juan watershed has decreased water quality. While efforts are underway to address the sources of these water quality issues, complexities of sites and funding hinder the remediation process. In the meantime, these sites remain and pose a slowly (or not so slowly) leaking threat to the health of human and aquatic ecosystems.

Case Study: Gold King Mine spill in the Animas River

The Gold King Mine spill was not the first mine spill, nor will it be the last. But it was a particularly well documented and studied spill. The highly visible discharge renewed interest in water quality issues around mining legacies (Jha et al., 2021).

Context

The Gold King Mine operated intermittently between 1887 until 1922 extracting primarily gold and silver (Sullivan et al., 2017). Figure 2 shows historic and post-spill pictures of the Gold King Mine. The mine was situated upstream of Cement Creek, a tributary to Animas River. The watershed contains several other inactive mines. As stated above, Cement Creek has a pH regularly below 4.5 (Sullivan et al., 2017). As a result of the low pH and other water quality issues directly relating to mining legacy, Cement Creek supported little to no aquatic life (US Geological Survey, 2007a).

(a) (b)

Figure 2: Historic (a) and post-spill (b) picture of Gold King Mine showing the mine waste pile outside an entrance (Sullivan et al., 2017)

Event

On August 5, 2015, crews working for the EPA were investigating water releases from the mine, treating released water, and assessing the Gold King Mine for additional remediation (Sullivan et al., 2017). In carrying out the investigation and old entrance was opened, and more than three million gallons of acid mine drainage flowed out, sweeping through a tailings pile, and traveling downstream. The path of flow and the removal of sediment is visible in Figure 2 (b). The plume flowed down Cement Creek to the Animas River then on to the San Juan River and finally to Lake Powell where it dispersed (Sullivan et al., 2017).

Plume characteristics and transport

The pulse was similar in volumetric flow to 1 to 2 days of high spring runoff, but the metals concentrations were far higher than such an event (Sullivan et al., 2017). the original plume likely had a pH as low as 3 (Sullivan et al., 2017). As the plume traveled downstream the acidic water was diluted and eventually mixed with the basic waters of the Animas River. This increased the pH, as illustrated in Figure 3, as the plume traveled further from its origin.

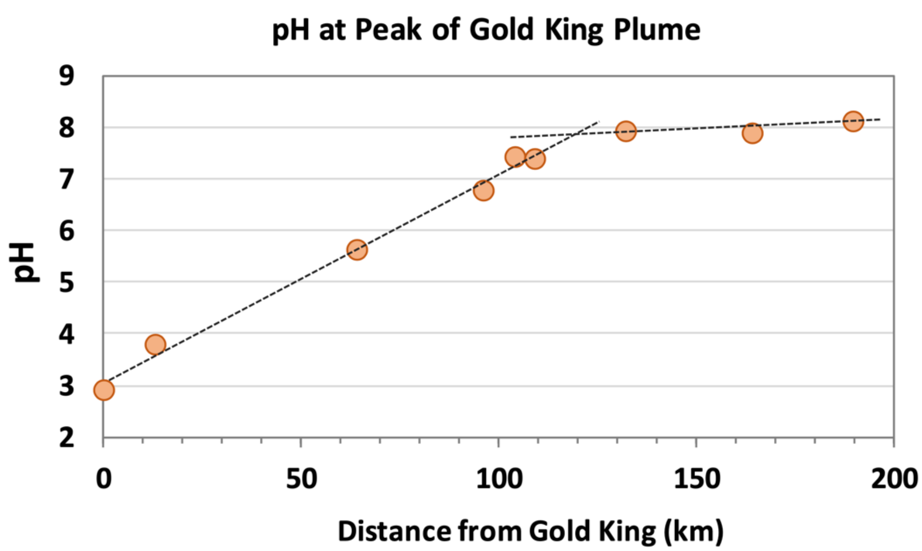

Figure 3: pH at Peak of Gold King Mine Spill Plume (Sullivan et al., 2017)

This rapid change in pH promoted precipitation of dissolved metals (Rodriguez-Freire et al., 2016). The newly neutralized water was then supersaturated with metals which began to precipitate out. This decreased the concentrations of metals in the plume. Figure 4 shows that metals concentrations mostly decreased when the plume entered and traveled down the San Juan River.

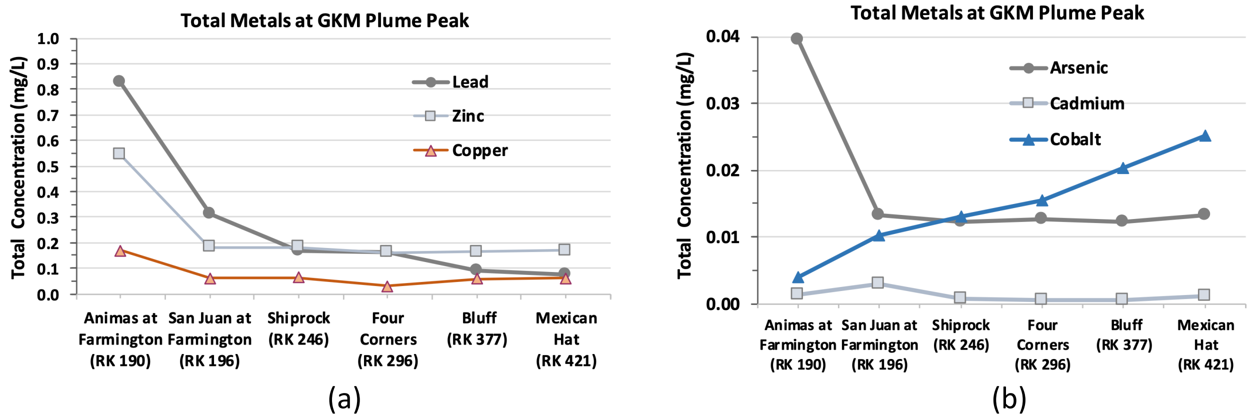

Figure 4: Gold King Mine plume metals concentrations in the San Juan River (Sullivan et al., 2017)

The decrease in metals suspended in the plume meant that the metals were deposited in the riverbed (Sullivan et al., 2017). Figure 5 shows that sediments downstream of the spill were consistently higher post-event. Figure 5 also indicates that river bed sediments were highest around Durango (100 km from the source). Figure 3 shows that around 100 km from the source the pH increased to about 7. The concurrence between these two plots and our understanding of physical-chemical processes shows that the change in pH around Durango precipitated metals out of the plume and deposited them in the river bed.

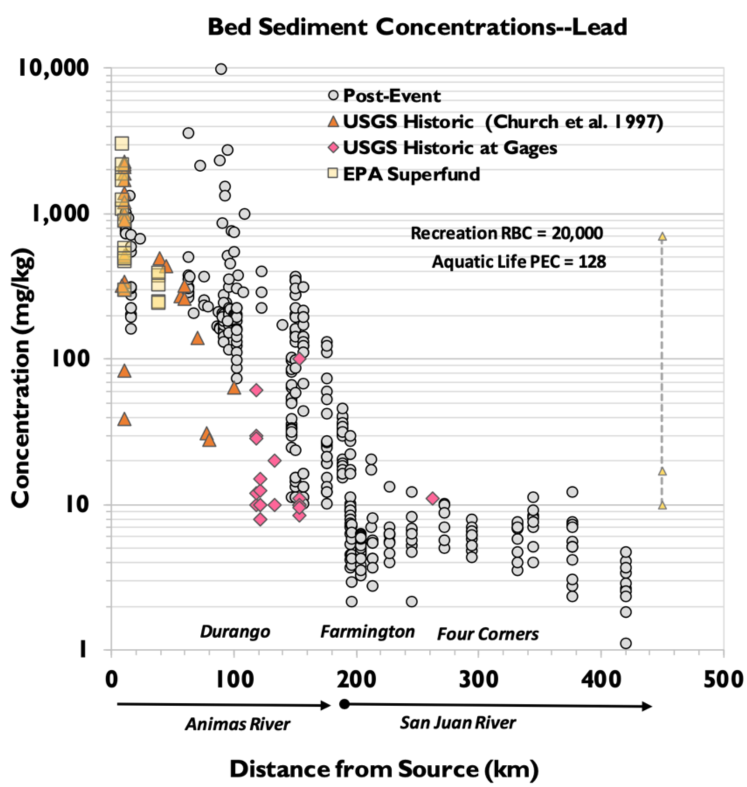

Figure 5: Bed sediment concentrations in the Animas and San Juan Rivers (Sullivan et al., 2017)

High flows during the spring snowmelt in 2016, the following year, remobilized metals deposited throughout the path of the spill (Sullivan et al., 2017). Remobilized metals were flushed further downstream until metal concentrations in water and sediment returned to levels consistent with pre-event conditions after the end of the spring snowmelt in 2017 (Sullivan et al., 2017). The sediments were ultimately deposited in the San Juan River Delta in Lake Powell (Frederick et al., 2019).

Impacts

The Gold King Mine spill had short- and long-term effects on a variety of stakeholders, including tribes, agriculture, and aquatic ecosystems. the Navajo Nation extends the length of the San Juan River that was impacted by the Gold King Mine spill (Sullivan et al., 2017). Initial analysis focused on risk in a recreational scenario of a hiker coming in to contact with contaminated water (Rodriguez-Freire et al., 2016). This hypothetical situation, however, was far less exposure than a tribesperson taking part in cultural activities, such as farming, swimming, diving, and fishing. These cultural practices elevated tribespeople's exposure, which went unexamined by other analyses (Van Horne et al., 2021). Additionally, The EPA and states base water quality standards on human and aquatic health. Tribal water quality standards are often more stringent than state or federal standards since they also consider tribal cultural uses. As a result, tribal standards are exceeded more often, due to historical background contamination (Sullivan et al., 2017). The EPA and states' water quality standards are often used to trigger action or as benchmarks. This institutional tolerance of contamination elevates the risk to tribespeople (Van Horne et al., 2021). The Gold King Mine spill also severely impacted the tribal reliance on the San Juan River. Tribespeople responded to the Gold King Mine spill by reducing the frequency and duration with which they took part in traditional activities (Van Horne et al., 2021). The spill also strained or suspended passing on cultural practices, such as farming, when the river contained elevated concentrations of metals. In these ways the Gold King Mine spill negatively impacted tribes in the area (Van Horne et al., 2021).

The Gold King Mine spill also effected agriculture throughout the region. A study by Jha et al. (2021) found elevated concentrations of metals, arsenic, chromium, copper, and lead, in agricultural soils that were irrigated with water impacted by the spill. The authors monitored the geospatial distribution of the metals over time and found that concentrations returned to acceptable regulatory thresholds by 2019 (Jha et al., 2021).

Aquatic ecosystems were largely able to absorb the negative effects of the Gold King Mine spill and persist. Macroinvertebrates and fish in the San Juan and Animas Rivers largely survived the Gold King Mine spill plume (Sullivan et al., 2017). During the plume metal concentrations remained above aquatic acute criteria for about 14 hours in the Animas River reach near Silverton and about 18 hours in the San Juan River reach near Farmington (Sullivan et al., 2017). This shows that the plume passed relatively quickly without inducing a fish kill. metals deposited in the river bed also have the potential to negatively impact aquatic life. A study by the Mountain Studies Institute (2016) indicated that macroinvertebrate community structure was not altered by the spill in the surveyed reaches of the Animas River. Additionally, The spill did not appear to increase most macroinvertebrate tissue metal concentrations (Mountain Studies Institute, 2016). These findings are consistent with other literature. A study by Duval et al. (2020) compared sites impacted by the Gold King Mine spill to a reference site that was less impacted by mining activity. The team sampled sediment, vegetation, fishes, and macroinvertebrates in 2017 after the spring snowmelt. This meant that the rivers had two spring snowmelt events since the Gold King Mine spill. Metal concentrations in the studied biota were elevated at the spill impacted sites, but still fell within a reasonable range compared to the reference site (Duval et al., 2020). Furthermore, the authors found no bioaccumulation of metals. Elevated metal concentrations found could be attributed to species specific processes, such as copper absorption through gills. However, metals persisted in the ecosystems and cycling through the biota was driven by plant uptake, invertebrates in the scraper functional group, and bottom-feeding fish (Duval et al., 2020). These finding show that metals were present but did not accumulate to dangerous levels at higher trophic levels. Together these two studies indicate that the plume passed, but aquatic ecosystems avoided disastrous outcomes.

Conclusions

The Gold King Mine spill was the product of the complicated nature of remediating the issues from a history of mining. The EPA was working to address these issues when the accidentally released the mine discharge forming a plume that traveled downstream. The plume was originally a mixture of acidic discharge laden with metals and sediments which dissipated as the plume was diluted and the constituents settled out due to physical and chemical processes. Within days the plume reached Lake Powell where the constituents settled, and the plume dispersed. The plume negatively impacted human communities, especially tribes, and agricultural water users. While some metals persist, the aquatic ecosystems were largely able to survive the immediate and long-term impacts.

References

Aton, J. M. (2000). *River Flowing From The Sunrise: An Environmental History of the Lower San Juan*. 17.

Church, S. E., Owen, R. J., von Guerard, P., Verplanck, P. L., Kimball, B. A., & Yager, D. B. (2007). The effects of acidic mine drainage from historical mines in the Animas River watershed, San Juan County, Colorado—What is being done and what can be done to improve water quality? In J. V. DeGraff, *Understanding and Responding to Hazardous Substances at Mine Sites in the Western United States*. Geological Society of America. https://doi.org/10.1130/2007.4017(04)

Duval, B. D., Cadol, D., Martin, J., Frey, B., & Timmons, S. (2020). Effects of the Gold King Mine Spill on Metal Cycling through River and Riparian Biota. *Wetlands*, *40*(5), 1033–1046. https://doi.org/10.1007/s13157-019-01258-4

Frederick, L., Johnson, W. P., Cerling, T., Fernandez, D., & VanDerslice, J. (2019). Source Identification of Particulate Metals/Metalloids Deposited in the San Juan River Delta of

Lake Powell, USA. *Water, Air, & Soil Pollution*, *230*(6), 128. https://doi.org/10.1007/s11270-019-4176-z

Jha, G., Mukhopadhyay, S., Ulery, A. L., Lombard, K., Chakraborty, S., Weindorf, D. C., VanLeeuwen, D., & Brungard, C. (2021). Agricultural soils of the Animas River watershed after the Gold King Mine spill: An elemental spatiotemporal analysis via portable X-ray fluorescence spectroscopy. *Journal of Environmental Quality*, *50*(3), 730–743. https://doi.org/10.1002/jeq2.20209

Mountain Studies Institute. (2016). *Gold King Mine Release—Benthic Macroinvertebrate Report Summary*.

Rodriguez-Freire, L., Avasarala, S., Ali, A.-M. S., Agnew, D., Hoover, J. H., Artyushkova, K., Latta, D. E., Peterson, E. J., Lewis, J., Crossey, L. J., Brearley, A. J., & Cerrato, J. M. (2016). Post Gold King Mine Spill Investigation of Metal Stability in Water and Sediments of the Animas River Watershed. *Environmental Science & Technology*, *50*(21), 11539–11548. https://doi.org/10.1021/acs.est.6b03092

Sullivan, K., Cyterski, M., Knightes, C., Kraemer, S. R., Washington, J., Prieto, L., & Avant, B. (2017). *Analysis of the Transport and Fate of Metals Released from the Gold King Mine in the Animas and San Juan Rivers*. 328.

US Environmental Protection Agency. (n.d.). *GOLD KING MINE – WATERSHED FACT SHEET*. 2.

US Environmental Protection Agency. (1995). *Historic Hardrock Mining: The West's Toxic Legacy*. US Environmental Protection Agency.

US Geological Survey. (2007a). *Environmental Effects of Historical Mining in the Animas River Watershed, Southwestern Colorado* (Fact Sheet) [Fact Sheet]. US Geological Survey.

US Geological Survey. (2007b). *Integrated Investigation of Environmental Effects of Historical Mining in the Animas River Watershed, San Juan County, Colorado* (Professional Paper No. 1651; Professional Paper). US Geological Survey.

Van Horne, Y. O., Chief, K., Charley, P. H., Begay, M.-G., Lothrop, N., Bell, M. L., Canales, R. A., Teufel-Shone, N. I., & Beamer, P. I. (2021). Impacts to Diné activities with the San Juan River after the Gold King Mine Spill. *Journal of Exposure Science & Environmental Epidemiology*, *31*(5), 852–866. https://doi.org/10.1038/s41370-021-00290-z

Varnes, D. (1963). *Geology and Ore Deposits in the South Silverton Mining Area, San Juan County, Colorado* (Professional Paper No. 378-A; Professional Paper). US Geological Survey.

Wikimedia Foundation. (2022, March 20). *San Juan River (Colorado River tributary)*. Wikipedia. Retrieved June 2, 2022, from https://en.wikipedia.org/wiki/San_Juan_River_(Colorado_River_tributary)