Upper North Fork Valley Bromide Study

Western Slope Conservation Center

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Introduction
Watersheds play a crucial role in maintaining the health and sustainability of ecosystems by providing essential services such as freshwater supply and habitat for numerous species. Anthropogenic activities have significantly impacted these delicate ecosystems, and in some cases have led to the introduction of various pollutants[1]. This report aims to highlight the importance of monitoring and understanding bromide's behavior in the North Fork of the Gunnison watershed.[2] Its presence can have significant ecological and human health implications on the Town of Somerset, which pulls its drinking water directly from the river.

Understanding the fate and transport mechanisms of bromide in the North Fork of the Gunnison River watershed will aid in the development of effective management strategies to mitigate its adverse effects and ensure the long-term sustainability of these essential ecosystems. Further research is warranted to elucidate the specific risks associated with bromide exposure and to develop appropriate regulations and mitigation measures to protect the integrity of this watershed.

North Fork of the Gunnison River
Geology, Morphology, and Characteristics
The North Fork of the Gunnison River (North Fork) is located in west-central Colorado and flows through northwestern Gunnison and eastern Delta Counties. Flanked by the West Elk mountain range to the east, the peak elevation in the North Fork watershed is 13,687 feet. The headwaters of the North Fork are in the Gunnison National Forest. The North Fork is formed by the confluence of Muddy Creek and Anthracite Creek downstream of the Paonia Reservoir Dam, and flows approximately 35.5 miles in a southwesterly direction from this point to its junction with the Gunnison River at 5,110 ft elevation, approximately 8.5 miles west of the Town of Hotchkiss in Delta County. Terror, Hubbard, Minnesota, Roatcap, Cottonwood, and Leroux Creeks enter the North Fork between Paonia Reservoir and Hotchkiss. The North Fork watershed (HUC 14020004) drains a basin of approximately 986 square miles. Three small communities line the banks of the North Fork: Somerset, Paonia, and Hotchkiss[3].

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[1] Colvin, Susan, et al. "Headwater Streams and Wetlands Are Critical for Sustaining Fish, Fisheries, and Ecosystem Services." *Fisheries Magazine*, 18 Jan. 2019, pp. 73–91.
[2] VanBriesen, Jeanne M. US Environmental Protection Agency, *Potential Drinking Water Effects on Bromide Discharges from Coal-Fired Electric Power Plants*.
[3] Crane, Jeffory P. 1997. Preliminary Assessment of the Morphological Characteristics
Of the North Fork of the Gunnison River.

The North Fork Valley consists of multiple river terraces positioned laterally along a highly dissected broad valley with gentle down-valley elevation relief. The soils along the river are deep to moderately deep, nearly level to steep, well-drained gravelly loam and stony loam that formed in outwash alluvium derived from igneous rock. Upstream of Somerset, the North Fork is incised in the Mesa Verde Formation (sandstone, shale, and coal), and downstream of Somerset, it is incised in the Mancos Shale. Near the USFWS National Fish Hatchery west of Hotchkiss, the river flows out of the Mancos Shale and is then incised in the Dakota Sandstone. The vegetation is classified as northern desert scrub and consists primarily of juniper, sagebrush, western wheatgrass, muttongrass, four-wing saltbush, and bitterbrush.

Streamflow

The North Fork of the Gunnison River is a fourth-order perennial stream, fed predominantly by snowmelt, with average bank full widths of 100 to 200 feet. The average flow during spring runoff at USGS 09134100 North Fork Gunnison River Below Paonia is approximately 2,000 cubic feet per second (cfs); irrigation diversions can reduce late summer flows to less than 20 cfs at this location. The predominant alluvial landforms can produce high bed load and sediment concentrations, especially during spring runoff. The primary tributaries include Muddy Creek, Anthracite Creek, Coal Creek, Hubbard Creek, Terror Creek, Minnesota Creek, and Leroux Creek. There are over 80 smaller creeks that flow into these major tributaries or into the North Fork River itself. The USGS hydrologic code is 14020004. Major flooding can occur during spring runoff months from rapid snowmelt that is sometimes augmented by rain. The U.S. Geological Survey (USGS) and Colorado Division of Water Resources (DWR) both manage gaging stations along the North Fork of the Gunnison River and its tributaries. The gages provide real-time flow data that is electronically available[4].

Bromide and Disinfection Byproducts (DBPs)

What is bromide?

Bromide is a fairly rare and naturally occurring halide, released into the environment through both natural processes and human activities. It occurs naturally in various forms, though it is found primarily as dissolved bromide ions in water bodies. Its terrestrial form typically occurs in evaporite deposits and its natural presence is attributed to weathering of rocks, volcanic emissions, and marine aerosols[8]. Anthropogenic sources of bromide include industrial discharges, agricultural runoff, and the use of brominated flame retardants. Bromide is commonly found in discharge from coal-fired power plants, and may also be released from water produced from coal bed methane wells. Bromide can also be associated with water discharges from other fossil fuels such as coal and oil and gas production.[5] Additionally, bromide can enter water bodies through domestic wastewater effluents and treated drinking water discharges. These diverse sources contribute to elevated bromide concentrations in

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[4] North Fork River Improvement Association. 2010. North Fork of the Gunnison River Watershed Plan UPDATE.

[5] "Challenges in Reusing Produced Water." Society of Petroleum Engineers, www.spe.org/en/industry/challenges-in-reusing-produced-water/. Accessed 7 April 2023.

watersheds, necessitating a comprehensive understanding of its chemistry[6]. Bromide is typically unreactive and therefore resists removal by environmental conditions. Therefore bromide tends to remain in natural systems for a long period of time. Bromide has a relatively high human and ecological toxicity threshold and therefore is largely unregulated within river systems by water quality standards[5].

Once introduced into watersheds, bromide exhibits unique behavior due to its physicochemical properties. It is highly soluble and does not readily adsorb to sediment particles, making it highly mobile in aquatic systems. Furthermore, bromide can undergo various transformations, including oxidation and reduction reactions, which influence its speciation and mobility. For example, bromide ions can react with natural organic matter and disinfectants (e.g., chlorine) used in water treatment processes to form potentially harmful disinfection byproducts, such as brominated trihalomethanes. Understanding the fate and transport mechanisms of bromide is critical for assessing its impacts on both aquatic ecosystems and human health[7].

What are Disinfection Byproducts?

Bromide entering domestic water sources can react with chlorine-based disinfectants used in water treatment facilities which leads to the formation of disinfection byproducts with potential health risks. Some brominated disinfection byproducts have been associated with adverse health effects, including cancer and endocrine system problems[8]. Therefore, the monitoring and management of bromide levels in watersheds are crucial for safeguarding both aquatic ecosystems and human well-being.

Disinfection Byproducts (DBPs), including total trihalomethanes (TTHMs) and haloacetic acids (HAA5s), are carcinogens. These chemicals form when source waters are disinfected with chemical oxidants such as chlorine and bromide[9]. SDWD diverts surface water from the North Fork of the Gunnison and treats it with chlorine at the SDWD water treatment plant. The presence of high concentrations of bromide in the raw water has caused DBP concentrations to exceed Colorado State drinking water standards[10]. The State requires a certain concentration of residual chlorine to be detected at the end of the domestic water distribution system, so

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[6] VanBriesen, Jeanne M. US Environmental Protection Agency, *Potential Drinking Water Effects on Bromide Discharges from Coal-Fired Electric Power Plants*.

[7] Richard J. Weisman, Kirin E. Furst, and Celso M. Ferreira. Variations in Disinfection By-Product Precursors Bromide and Total Organic Carbon Among U.S. Watersheds. Environmental Engineering Science.Mar 2023.85-94. http://doi.org/10.1089/ees.2022.0256

[8] VanBriesen, Jeanne M. US Environmental Protection Agency, *Potential Drinking Water Effects on Bromide Discharges from Coal-Fired Electric Power Plants*.

[9] “Stage 1 and Stage 2 Disinfectants and Disinfection Byproducts Rules.” EPA, www.epa.gov/dwreginfo/stage-1-and-stage-2-disinfectants-and-disinfection-byproducts-rules. Accessed 7 Apr. 2023.

[10] Marston, Dave. “Billionaire Mine Owner Leaves a Tiny Town in the Lurch: Writers on the Range.” Colorado Springs Gazette, 23 Feb. 2021, gazette.com/pikespeakcourier/billionaire-mine-owner-leaves-a-tiny-town-in-the-lurch-writers-on-the-range/article_da61875a-7160-11eb-afee-67999c616072.html.

Somerset cannot reduce DPB concentrations by decreasing how much chlorine they add to their drinking water[11].

DBPs and Human Health
DBPs generated during water treatment processes have raised concerns due to their potential adverse health effects on humans. Research has consistently demonstrated the negative impact of DBPs on human health. TTHMs and HAA5s are common DBPs formed when disinfectants like chlorine and bromide react with natural organic matter present in water sources[12]. Prolonged exposure to elevated levels of DBPs has been associated with an increased risk of various health problems, including bladder and colorectal cancers, reproductive issues, and adverse birth outcomes. DBPs can also cause skin and eye irritation when present in high concentrations. Furthermore, some studies suggest a possible link between DBP exposure and an elevated risk of certain systemic health conditions, such as kidney and liver damage[13]. These findings emphasize the importance of implementing effective water treatment strategies to minimize DBP formation and ensure the provision of safe drinking water to safeguard public health.

Understanding the impacts of bromide on the Town of Somerset's domestic water system is crucial for maintaining the quality and safety of the drinking water supply. This scientific report aims to provide a comprehensive assessment of bromide's occurrence in the watershed. The findings of this study will inform water treatment strategies and contribute to the development of mitigation measures to ensure the provision of safe and reliable drinking water.

Background on the Town of Somerset and its Drinking Water
History
Originally established in the early 20th century, the town of Somerset was created to support the local coal mines, and the water treatment system was built as the town was born. This involved the construction of a water treatment plant, storage reservoirs, and a distribution network to provide potable water to the town's residents[14]. Originally owned and operated by the Oxbow Mine, in 2019 management of the water plant transitioned to the Town of Somerset. Over the years, the water system underwent upgrades and improvements to meet changing regulatory standards and accommodate increasing water demand. Today, the Town of Somerset's drinking water system is crucial in providing safe and reliable water to approximately 100 people in the community, supported by ongoing maintenance and modernization efforts.

Over the summer of 2018, the Western Slope Conservation Center (WSCC) staff and volunteers met with the Oxbow Mining, Inc. staff (who managed the raw water treatment operations for

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[11] “Disinfectant and Disinfection Byproduct Rules.” Department of Public Health & Environment, cdphe.colorado.gov/dbps. Accessed 7 Apr. 2023.
[12] Fact Sheet: Stage 2 Disinfectants and Disinfection Byproducts Rule, US Environmental Protection Agency, Washington DC, 2005.
[13] “Disinfection By-Products (Dbps) Factsheet.” Centers for Disease Control and Prevention, 18 July 2022, www.cdc.gov/biomonitoring/THM-DBP_FactSheet.html.
[14] Biddle, Christopher. “Colorado Town Spars with Koch-Owned Mine over Water.” KHOL 89.1 FM, 27 Jan. 2021, 891khol.org/colorado-town-spars-koch-owned-mine-over-water/.

Somerset Domestic Water District up until 2019) to gain an understanding of the possible impacts associated with high sediment loads from Paonia Reservoir drawdown/flushing to the domestic water treatment process. Although sediment loads proved to be inconsequential to the domestic treatment process, Oxbow staff informed WSCC that unusually high concentrations of bromide in the raw water supply were creating major problems in meeting state standards for Disinfection Byproducts (DBPs). The Colorado Water Quality Control Division (State) does not have a standard for bromide in drinking water; bromide is typically found at very low concentrations in natural waters (0.2 mg/L or less).

Description of the Town of Somerset's Water Treatment Facility and Operations

Figure 1: Oxbow's water treatment intake facility on the North Fork of the Gunnison River. Map Image: Google Earth, 2023.

Figure 2: A depiction of where Somerset's Water Treatment Facility is in relation to the River Intake Pit Map image: Google Earth, 2023

The Town of Somerset's water treatment facility is based around pulling water directly from the North Fork of the Gunnison River. Figure 1 shows where the river intake, the river intake pit, and the unlined pond are located off of Highway 133 just east of Somerset. In normal conditions, operators from Oxbow Mining LLC use a pump and pipelines to move water from the North Fork at the river intake to the unlined pond for storage. Water is then transferred to a small pit via a buried perforated pipe under the pond, to a pump house building located just west of the unlined pond. From there, water is sent to the water treatment plant just north of the town through a series of pipelines.

When stream flows are high, as what happens during the runoff season from April through July, the pumping of water from the North Fork at the river intake to the unlined pond is not needed, as the water table is naturally high enough to fill the pond through groundwater and reach the elevation of the pump house intake on its own. Additionally, operators at Oxbow Mining LLC often remove the pump entirely from the river at this point as high sediment loads can clog the river pump and cause damage.

During the entirety of the Upper North Fork Bromide study conducted by WSCC in 2022-2023, samples were collected from the North Fork directly at the River Intake, and from the River Intake Pit in the building just east of the unlined pond with the help of employees at Oxbow Mining LLC. Samples were also collected directly from the Somerset Water Treatment Facility just north of the town of Somerset with the help of employees of the Somerset Domestic Water District (see Figures 7-8).

Sampling Efforts Previously Conducted

Oxbow Mining's Prior Sampling Efforts

Oxbow staff informed WSCC that when they realized bromide was the cause of their DBP standard exceedances, they began taking raw water samples to determine a possible source. Oxbow staff collected four raw water samples. Locations were on the North Fork of the

Gunnison River adjacent to the intake near Somerset, on the North Fork just above West Elk Mine, at Anthracite Creek above Kebler corner, and on Muddy Creek below the Paonia Reservoir dam. Results in the North Fork and Muddy Creek showed elevated bromide concentrations at those three locations. The sample from Anthracite Creek had a bromide concentration that was below the laboratory detection limit. This led Oxbow staff to believe that the source of bromide was the sediment in Paonia Reservoir or the Muddy Creek drainage. WSCC was not able to replicate these results in our sampling protocols. Additionally, scattered sampling happened throughout the next several years, including a more regimented sampling protocol in 2020 which is discussed in a later section.

WSCC Sampling Beginning in 2018

The WSCC has managed a robust water quality sampling program for the North Fork River and tributaries through Colorado Park and Wildlife's River Watch program since 2001. WSCC has the 2nd longest-running River Watch water quality data set in the state of Colorado and has completed two comprehensive water quality reports for the North Fork River and its tributaries[15]. To expand upon Oxbow's sampling, the WSCC River Watch team completed four raw water sampling events; September 2018, February 2019, August 2021, and November 2021 from the North Fork and Muddy Creek drainages to test for bromide levels in the watershed. Fourteen total sites were sampled throughout this period. Lab results were inconclusive and showed bromide concentrations near or below lab detection limits at all locations. However, a sample collected at Somerset's raw water tank in November 2021 showed a concentration of 0.3 mg/L for bromide, above the detection limit.

Despite inconclusive results by WSCC and Oxbow, Somerset Domestic Water District (SDWD) continued to have problems meeting TTHM standards due to elevated concentrations of bromide in between these sampling events. It was determined that in order to discover the source of bromide a more comprehensive and coordinated sampling program needed to be implemented.

Somerset Source Water Protection Plan

The Colorado Department of Public Health and Environment (CDPHE) has maintained its enforcement order on SDWD until the district shows that it can meet compliance standards. To work towards meeting those standards, Somerset began steps to establish a Source Water Protection Plan in the fall of 2020, made possible through Colorado Rural Water Association (CRWA) and CDPHE. CRWA facilitated several monthly stakeholder meetings through July 2021 and a final plan was created in September 2021. The plan provides a tool for risk assessment and identifies "bromides during treatment" as a very high risk for domestic water contamination.

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[15] Hartter, Jake. "Watershed Assessments and Plans." Western Slope Conservation Center, 3 June 2021, westernslopeconservation.org/watershed-assessments-and-plans/.

WSCC’s 2023 Upper North Fork Bromide Study

Introduction

The Upper North Fork Bromide Study conducted by the WSCC from March 2023 through February 2024 focused on investigating the presence and behavior of bromide in the Upper North Fork watershed. Through comprehensive sampling and analysis, the WSCC sought to provide insights into the occurrence and behavior of bromide in the upper North Fork watershed, aiding in the development of effective management strategies for maintaining the quality and safety of the water supply in the region.

Strategies

To complete our study, we focused on three main strategies. First, we set out to analyze all pre-existing water quality data, oil and gas spill data, and any other relevant metrics to identify possible correlations and causations. We pulled previously analyzed sample results from WSCC and Oxbow, USGS data, WSCC River Watch data, and other relevant information . Second, we developed and implemented a year-long sampling protocol for the source water protection area of the town of Somerset. We utilized several River Watch sampling locations which already existed in the upper North Fork watershed and added several other stream segments to get a localized idea of if and where bromide was entering the system. Lastly, we set out to complete a detailed report with our findings.

2020 Oxbow Bromide Sampling Analysis - Case Study

Background and Methods

The beginning of our in-depth reporting of bromide in the North Fork of the Gunnison River watershed began with an analysis of pre-existing data that had already been collected through sampling from WSCC, Oxbow, and other sources. Through that analysis, we learned that between February and December of 2020, several sites had been routinely sampled by Chuck Sheldon with Oxbow Mining.

Throughout 2020, Mr. Sheldon sampled three sites twice a month from February through November. He took grab samples from the North Fork of the Gunnison River adjacent to the intake near Somerset, from the river intake pit where the river water is stored before treatment, and from the raw water tank at the treatment plant in Somerset. Keeping these three sampling locations consistent throughout the 10 months of sampling proved critical in determining trends of bromide over time within the Somerset Water Treatment system.

Results

Throughout the 2020 sampling period, bromide concentrations in the sample taken directly from the river were all below the lab detection limit and yielded no results from the laboratory, so we removed them from our analysis. Samples from the river intake pit and the raw water tank are seen in Figure 1 below.

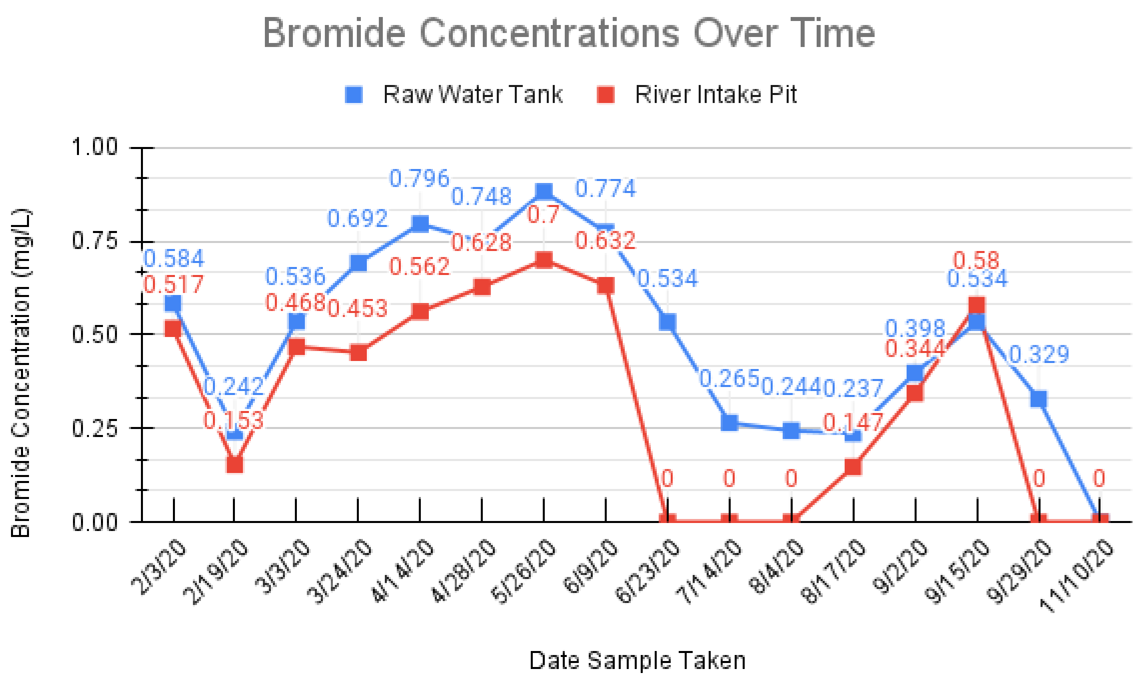

Figure 3: Bromide concentrations from February through November 2020. Sampled by Chuck Sheldon with Oxbow Inc. throughout 2020. Samples were sent to Green Analytical Labs for analysis

We can compare this data with flow data from the North Fork of the Gunnison River taken by the USGS just above Somerset, precipitation data collected from a CoCoRaHS) weather station just west of Hotchkiss, and water elevation data from the Paonia Reservoir taken by the USGS, all within the same time frame.

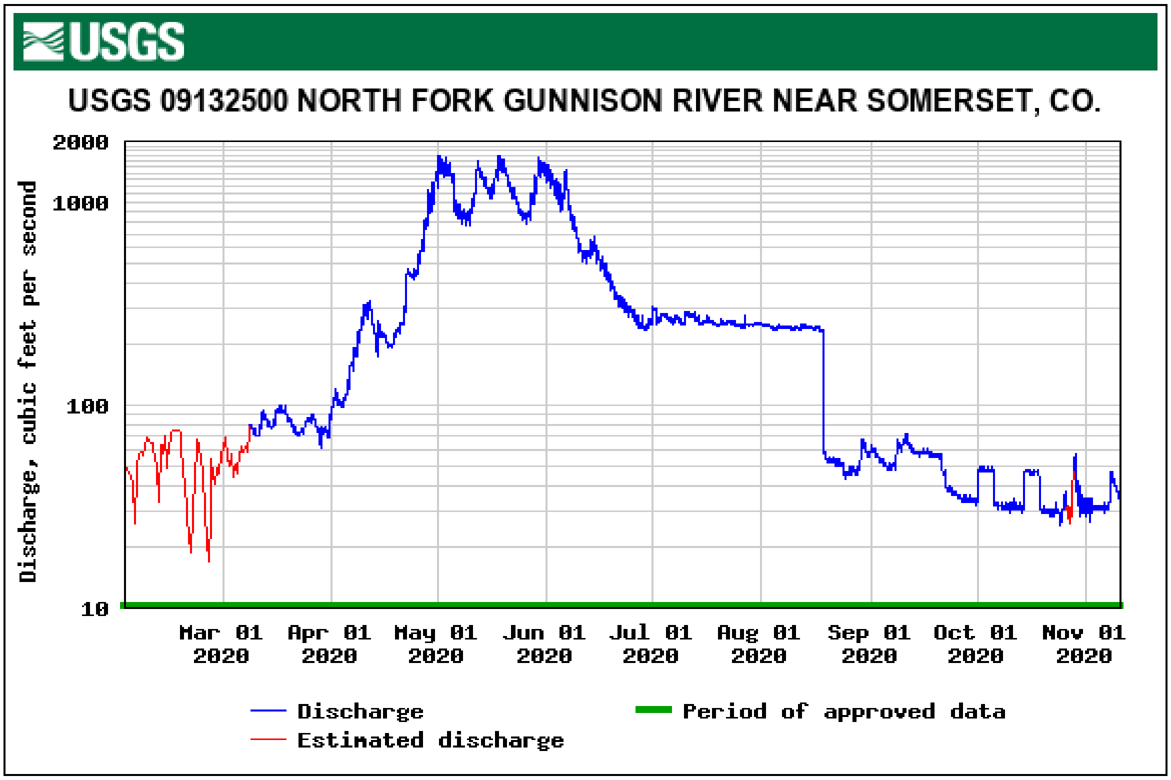

Figure 4: USGS flow rate discharge data taken from the North Fork of the Gunnison River near Somerset, CO, February through November 2020

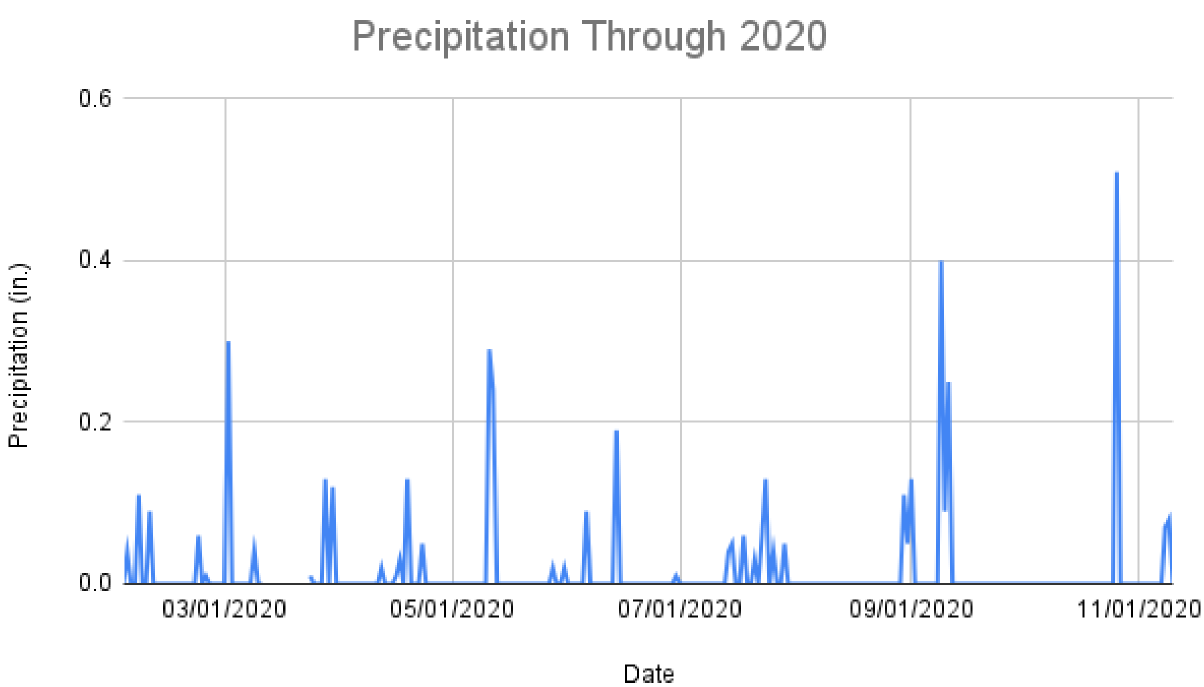

Figure 5: Precipitation data from Community Collaborative Rain, Hail, and Snow Network (CoCoRaHS), site CO-DL-26 outside of Hotchkiss, CO, February through November 2020

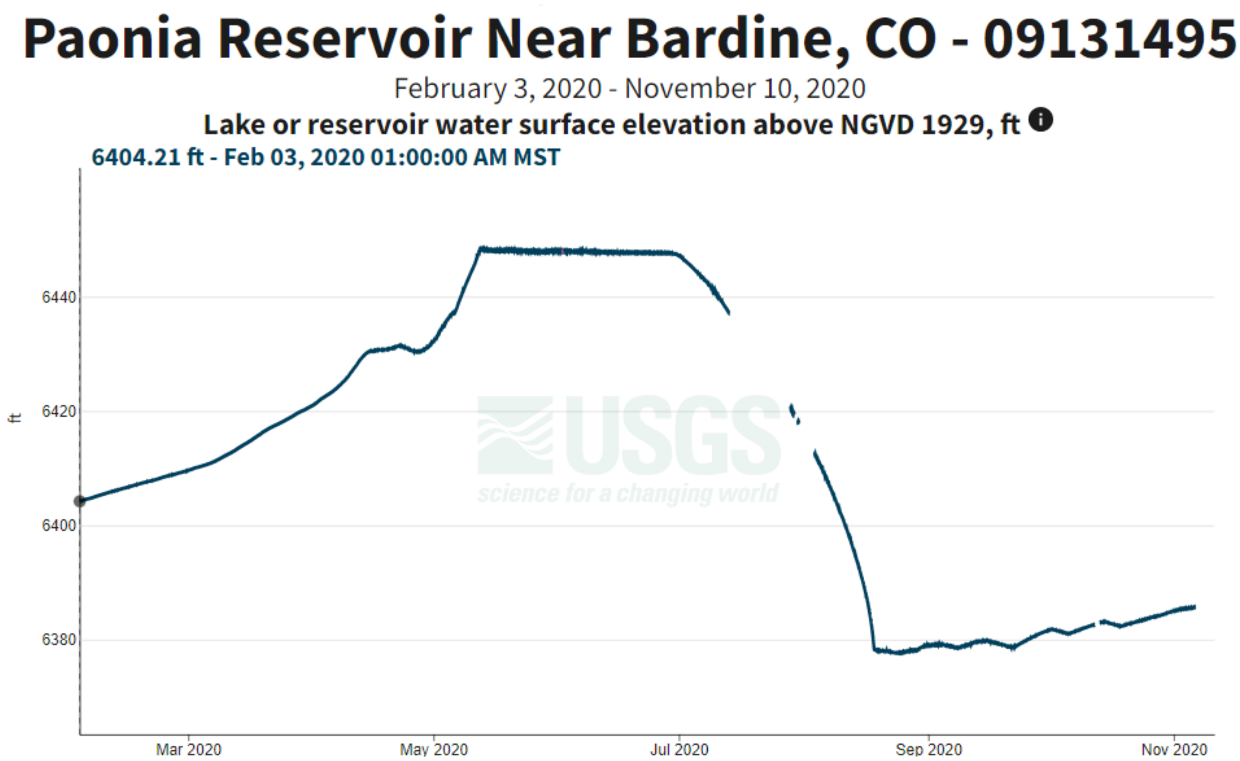

Figure 6: Reservoir surface level data from the Paonia Reservoir, taken by the USGS, Feb through December 2020

Bromide concentrations rise through late February and early March and fall through early July, similar to runoff rates in the North Fork and water levels in Paonia Reservoir over the same time frame. With knowledge of the Somerset water system, we know that water is generally only pumped from the river to the river intake pit outside of high runoff levels in the river, due to the silt levels. Furthermore, we can assume based on Figures 4 and 6 that the Paonia Reservoir began to release water from the dam in early July until about mid-August, however, this water likely has a lower turbidity level than normal runoff due to the ability for sediment to fall out of solution as it sits behind the dam walls prior to release.

With a general correlation between river flows and bromide concentrations, it appears that as the river gets higher, bromide concentrations increase in the Somerset water treatment system. This could indicate that a source of bromide exists in the upper watershed and that as snow melts and runoff begins, bromide is flushed downstream and pumped into Somerset's water treatment facility. Sampling from the river could be non-detect due to a high dilution level within the river. This trend may also suggest that a source of bromide is up the Anthracite Creek drainage, as river flows at Somerset are primarily from this drainage until the Paonia Dam releases, which from Figure 6 suggests that was early July 2020, as bromide concentrations decrease.

With some knowledge of the Somerset water treatment system, we know that as runoff occurs in the spring, operators will stop pumping water directly from the river and let the river intake pit fill from the aquifer to mitigate their water filter becoming filled with silt. This could then represent an idea that the source of bromide exists within the groundwater which feeds the intake pit and that when operators pump water directly from the river into the water treatment facility, bromide is diluted to manageable levels. However, Figure 3 indicates a spike in bromide concentrations from August through October 2020, which may rebuke this theory as well.

Finally, higher concentrations in the raw water tank than in the river intake pit may indicate a source of bromide within the water treatment system itself, somewhere in between the river intake pit and the raw water tank at the Somerset Water Treatment Facility. The raw water tank at the treatment plant is never completely emptied and is not usually flushed out by the river as the unlined pond is. Therefore, bromide concentrations will fluctuate differently from the pit as more contamination is added periodically.

2023 WSCC Sampling Results and Discussion

Methods

WSCC worked with Terra Firma Land Stewardship, LLC to collect grab samples for a calendar year beginning in March 2022 through February 2023. Working with Oxbow Mining and the Town of Somerset, samples were collected at the Somerset Water Treatment plant from the raw water tank, at the intake pit inside the pump house building just west of the unlined pond, and in the North Fork of the Gunnison River adjacent to the river intake near Somerset. Additionally, samples were collected throughout the North Fork watershed (see Figures 7-8)

In March 2022, a sample was not able to be collected at the river intake pit due to the unavailability of access to the Oxbow Mining LLC pump house building. Due to weather, samples were not able to be collected from locations along the North Fork River in April 2022. In May of 2022, no samples were taken due to an illness among staff.

Figure 7: 2022/20203 Sampling locations near Somerset. Map image: Google Earth, 2023

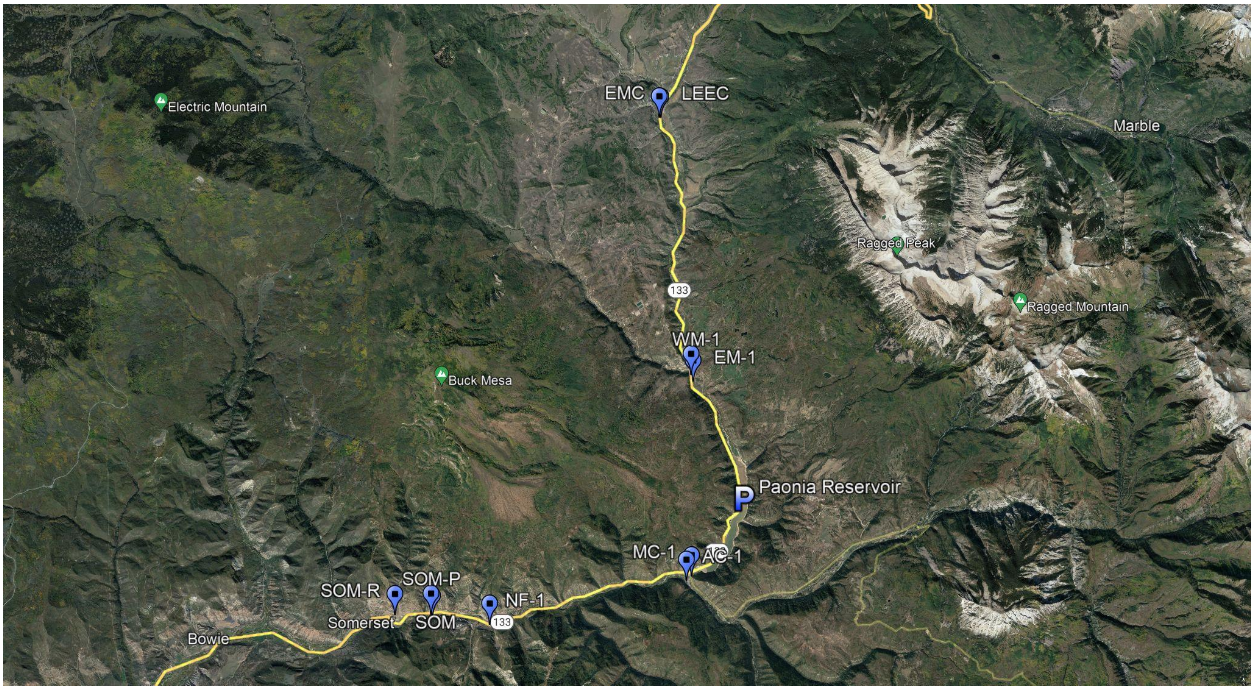

Figure 8: 2022/2023 Sampling Locations throughout the North Fork watershed, Map Image: Google Earth 2023

Results

Throughout the entire course of WSCC's study, no bromide was detected at any of the seven sites on the North Fork of the Gunnison River (see Figure 8: NF-1, MC-1, AC-1, EM-1, WM-1, EMC, or LEEC). Additionally, no bromide was detected at the site on the North Fork adjacent to the intake near Somerset (SOM in Figure 7). Bromide was detected at the intake pit (SOM-P) inside the pumphouse during April, June, and July 2022 and at the raw water tank (SOM-R) March, April, June, and July of 2022 (Figure 7). Bromide values at both locations show an increasing curve of concentrations over the detection window before tapering off slightly in July, then disappearing altogether in August for the remainder of the sampling study. Bromide concentrations at SOM-P ranged from a low of .3 mg/L in April to a high concentration of .6 mg/L in June. Bromide values at SOM-R show concentrations ranging from a low of .27 mg/L in April to a high concentration of .76 mg/L in June, 2022. As was mentioned earlier, no samples were collected in May. However, bromoform concentrations analyzed in SDWD's May TTHM report indicate that bromide was present in the raw water in similar concentrations as was found in June, 2022.

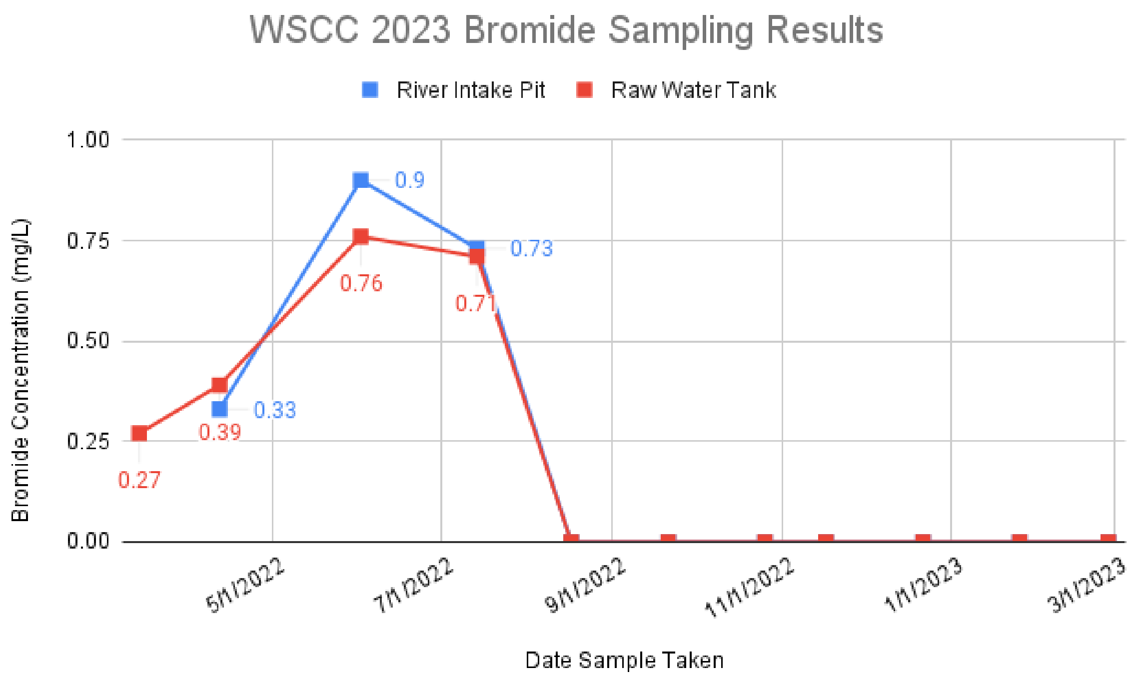

Figure 7: Bromide concentrations from March 2022 through February 2023. Sampled by Jake Hartter with Terra Firma LLC and Ben Katz with WSCC. Samples were analyzed by Colorado Analytical Laboratories LLC

We can compare this data with flow data from the North Fork of the Gunnison River taken by the USGS just above Somerset, flow data from the North Fork of the Gunnison River taken by the USGS just below Hotchkiss, CO at the Lazear gauge, precipitation data collected from a CoCoRaHS) weather station just west of Hotchkiss, and water elevation data from the Paonia Reservoir taken by the USGS, all within the same time frame.

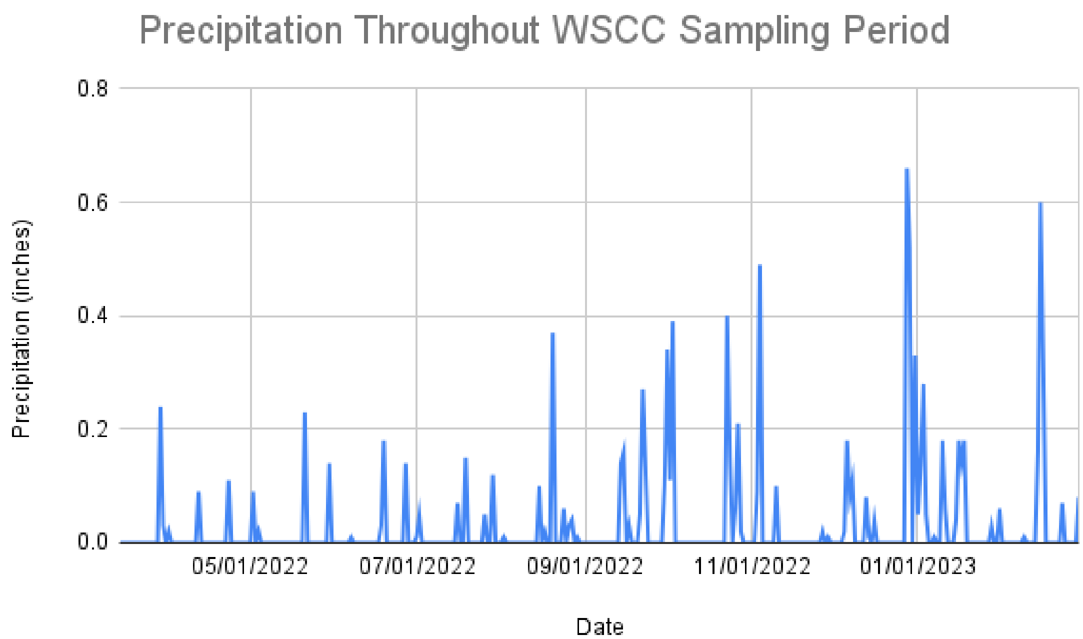

Figure 8: Precipitation data from Community Collaborative Rain, Hail, and Snow Network (CoCoRaHS), site CO-DL-26 outside of Hotchkiss, CO, February 2022 through March 2023

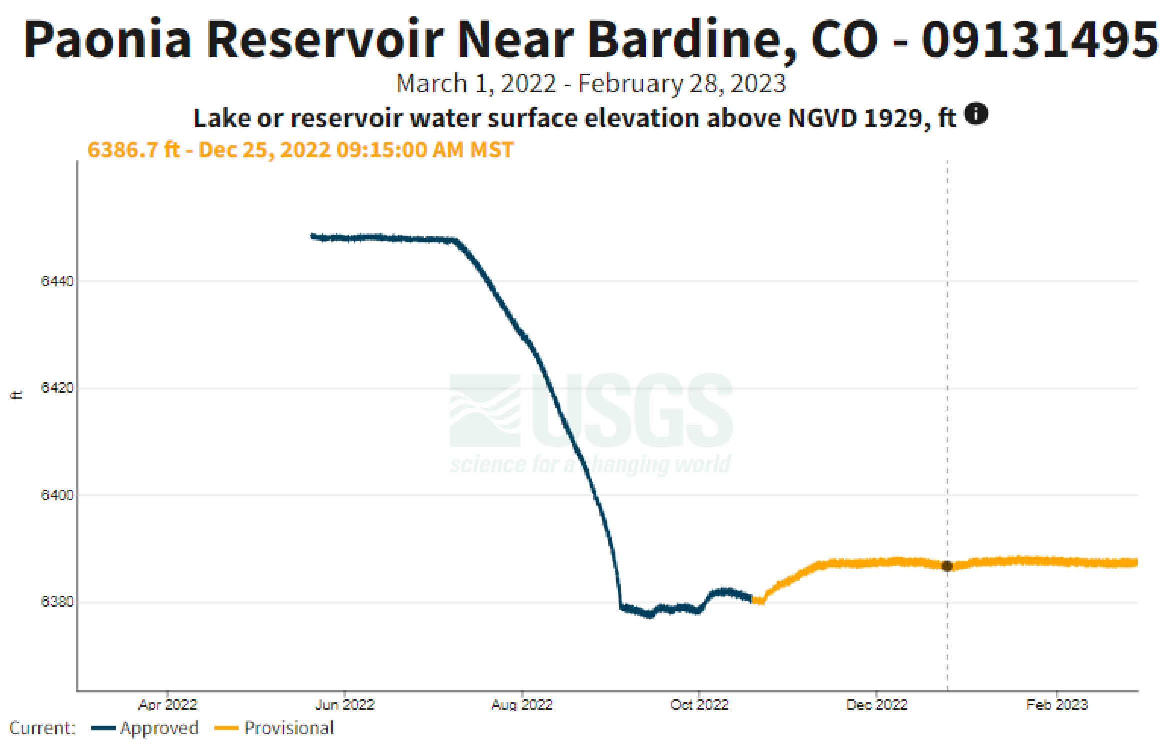

Figure 9: Reservoir surface level data from the Paonia Reservoir, taken by the USGS, February 2022 through March 2023. Data was absent from February through May 20, 2022. Note - Data are provisional and subject to revision until they have been thoroughly reviewed and received final approval. Current condition data relayed by satellite or other telemetry are automatically screened to not display improbable values until they can be verified.

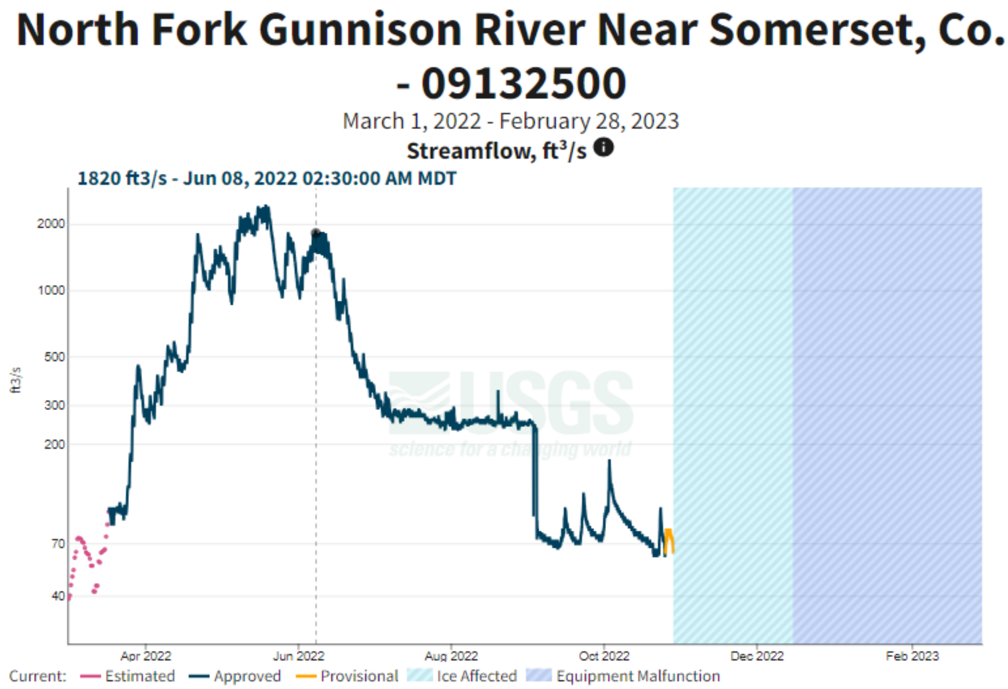

Figure 10: USGS flow rate discharge data taken from the North Fork of the Gunnison River near Somerset, CO, March 2022 through February 2023

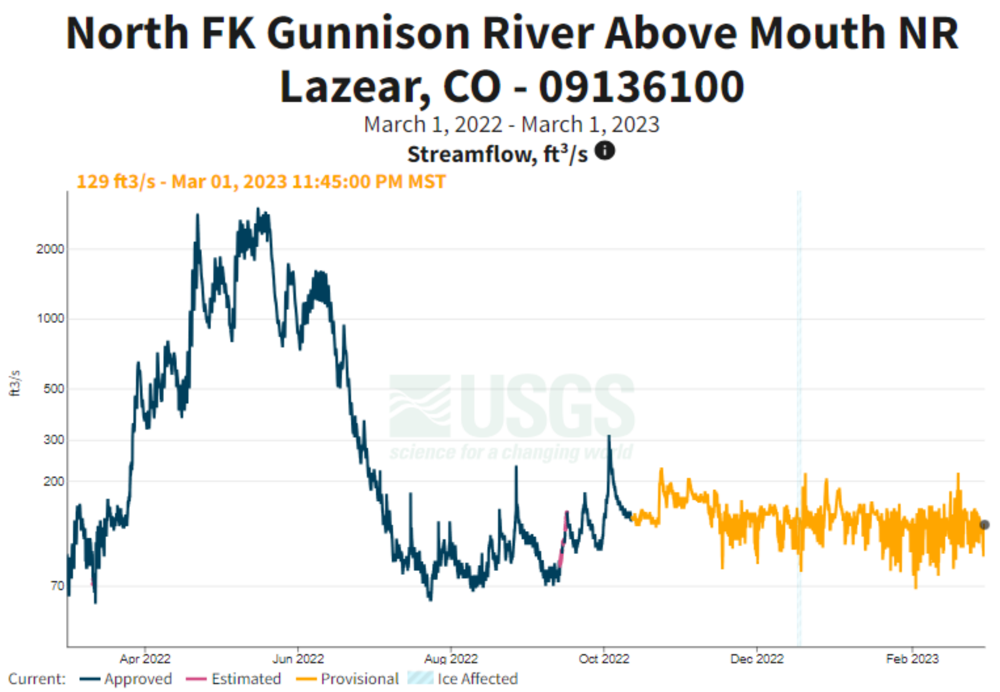

Figure 11: USGS flow rate discharge data taken from the North Fork of the Gunnison River near Lazear, CO, March 2022 through March 2023. Note - Data are provisional and subject to revision until they have been thoroughly reviewed and received final approval. Current condition data relayed by satellite or other telemetry are automatically screened to not display improbable values until they can be verified.

Discussion

In our 2023 sampling analysis, similar trends were observed to the 2020 sampling analysis, except for a fall spike in bromide levels observed in the 2020 sampling analysis in both the river intake pit and the raw water tank. Due to the loss of streamflow data at the Somerset gauge caused by ice and an equipment malfunction, we include streamflow data from the North Fork of the Gunnison just above the confluence with the Gunnison River in Gunnison Gorge National Conservation Area. Note that the Somerset gauge depicts when the Paonia Dam releases water, as there is a clear indication of regulated flow beginning mid July 2022 and continuing until flows decreased on Sept. 4, 2022. After this time, the majority of flows in the North Fork are being contributed by Anthracite Creek as the Paonia Dam is mostly closed. The Lazear gauge operates year round and provides some flow data for analysis, however, its location nearly 30 miles downstream of Somerset makes it difficult to draw accurate comparisons for river operations in the upper reach of the North Fork. Note that releases from Paonia Dam are not present on the Lazear gauge because these flows are being diverted to meet Fire Mountain Canal decrees.

As was the case in the 2020 study, it appears that as the river gets higher, bromide concentrations increase in the Somerset water treatment system. It also appears that as river flows recede, bromide concentrations decrease, or as in the case of the 2022/23 study, are reduced to levels that are below lab detection limits. This could again indicate that a source of bromide exists in the upper watershed and that as snow melts and runoff begins, bromide is flushed downstream and pumped into Somerset's water treatment facility. However, our results did not show any measurable bromide concentrations at any of the river sampling locations during the 2022/23 study.

Though our analysis of the 2020 study suggested that a source of bromide could be up the Anthracite Creek drainage (as river flows at Somerset are primarily from this drainage until the Paonia Dam releases), no bromide was detected within Anthracite Creek or the river sites downstream during the duration of the 2022/23 study.

In analyzing these results it is useful to revisit the operation methods of the Somerset water treatment system. We know that as runoff occurs in the spring, operators will stop pumping water directly from the river and let the river intake pit fill from the underground aquifer adjacent to the river and under the unlined pond. This reduces river sediment which is damaging to pumping units and clogs filters. This suggests that the source of bromide exists within the groundwater which surrounds the intake pit, and that when operators pump water directly from the river into the water treatment facility, bromide is diluted to manageable levels.

Supporting this theory, higher concentrations in the raw water tank than in the river intake pit may indicate that bromide levels are not being diluted as regularly as those of the aquifer surrounding the intake pit. The raw water tank at the treatment plant is never completely emptied and does not get flushed out by the river as the unlined pond often does. Therefore, bromide concentrations will fluctuate differently from the pit as more contamination is added periodically.

Conclusions
Our analysis concludes that if there are sources of bromide in sub-watersheds above the Paonia Dam or the Anthracite range, they were not present during the time our study took place. In analyzing Colorado Oil and Gas Conservation Commission (COGCC) spill data, we found that there were 16 recorded spills between 2014-2023. Many of these spills involved produced water leaks. However, the COGCC reports that these spills were largely confined to the area of impact. Soil tests were conducted at all spill sites. Bromide was not analyzed in the soil tests, but high levels of sodium were found in a few spill records. During the time of our study there was one produced water spill in December 2022, but it did not appear to have an impact on our analysis.

With more specific knowledge of water treatment systems operations during our study period, we know that as water levels rose through early April, water was not pumped from the river into the river intake pit. Instead, treatment operators allowed the pit to fill from the aquifer and the river, as the water table was high enough to reach pumping infrastructure. This additionally mitigated the clogging of filters near the river intake pit due to high sediment loads in the river. With this knowledge, we think that bromide is most likely originating in the aquifer surrounding the intake pit and that when river flows decrease and water is pumped from the river into the treatment system, this process dilutes the bromide levels down to a manageable level.

High levels of suspended solids in the river during spring runoff have a greater weight and viscosity than the surrounding groundwater. This may inhibit the sufficient mixing of river water within the aquifer and groundwater sources during spring runoff. Thus, the majority of water being pumped into the Somerset domestic water treatment facility during this time would originate from groundwater sources adjacent to the river.

Recommendations
Moving forward, more sampling and analysis are likely needed to determine more specifically where bromide is originating in the North Fork of the Gunnison River watershed. This process may include groundwater sampling from the area immediately above the unlined pond and other areas around the town of Somerset. Monitoring of surface water should also be continued, particularly within adjacent tributaries and drainages around the town of Somerset. While bromide levels were not detected in the main stem of the North Fork of the Gunnison during our study, it is recommended that river sampling continues in order to maintain a baseline of data and to capture any future increases in bromide concentrations that may be present.

Our study suggests that by-passing the groundwater aquifer and intake pit pump house would reduce levels of bromide. However, the infrastructure needed for this does not exist and could be quite expensive to obtain. Understanding where bromide is originating and the seasonal timing of bromide levels will help Oxbow operators and SDWD managers in avoiding pumping water when high concentrations of bromide exist in the raw water. It is our hope that this study provides Oxbow operators and SDWD managers with additional information to help make appropriate water management decisions.

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