Final Project: Navajo Nation Water Quantity (2019-2024) and Quality Analysis (2018-2023)

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Rationale and Research Questions

The Navajo Nation has severe water infrastructure deficiencies that impact the health, economy, and welfare of the Navajo people. Inadequate domestic and municipal water is the greatest water resource problem facing the Navajo Nation. Approximately 30-40% of the Navajo Nation population does not have access to clean, reliable drinking water (Navajo Nation Department of Water Resources, 2024). Also, 173 thousand people are affected because drinking water sources are limited, and abandoned uranium mines have caused groundwater contamination (Ibid.). In addition, many improvements are needed for other areas of water use, including water for irrigation, livestock, commercial, businesses, health care, schools, and other facilities (Ibid.).

In terms of water quantity, climate change in the Southwest has adversely impacted water availability and is projected to continue doing so. The USGS Disaster Risk Assessment Study concluded that a long-term drying trend and decreasing snowpack, superimposed on the regional drought cycles, will magnify water-related impacts in the Navajo Nation and leave the Navajo people increasingly vulnerable (Navajo Nation Department of Water Resources, 2024).

The Navajo Nation's water sources are mainly the interstate rivers (Colorado and San Juan Rivers) and groundwater, but unfortunately it faces legal difficulties in getting its interests met within inter-state negotiations on water rights. The Colorado River Compact set in 1922 gives seven states the right to draw water, and are grouped into two, the Upper Basin States (namely Colorado, New Mexico, Utah and Wyoming) and Lower Basin States (namely Arizona, Nevada and California) (Anastasia Hufham, 2024), but the Navajo Nation is not formally included in these agreements. As the post-2026 operations of the river are being negotiated, the Navajo Nation is engaging in persistent legal efforts to be part of the negotiations and acquire the water rights that would allocate more water for its people.

This project comprises of two sections: 1) water quantity, 2) water quality. The five-year periods selected provide a more current evaluation of the water conditions faced by the Navajo Nation. The water quantity of the Colorado River and the San Juan River over the last 5 years (2019-2024) were assessed for trends. Given prolonged drought and climate change, we establish the following research question and hypothesis.

RQ 1: What are the trends in water availability for the Navajo Nation in the last 5 years?

Hypothesis 1: Water availability decreased in the last 5 years for the Navajo Nation.

The water quality section focuses on analyzing the concentrations of 3 components (Uranium, Magnesium, and Boron) in the main Colorado River before and after it flows through the reservation over 5 years (2018-2023). Those components were chosen as they pose a high risk for human health and the environment at high levels. Uranium is radioactive , and high and prolonged exposure increases risks of kidney diseases (Vengosh, 2024). High concentrations of boron in humans can cause nausea, vomiting, redness of the skin, difficulty swallowing due to ulcers in the throat, and non-bloody diarrhea (U.S. EPA, et al., 2008). Moreover, these components were selected since the data was available for both stations, enabling a comparative analysis. The period of analysis differs between water quantity and quality analysis due to data availability. Taking into account the tribe's persistent efforts to compel the federal government to meet its obligations, aiding in the quantification of the tribe's water rights on the Colorado River and ensuring access to high-quality water, we have chosen to focus our quality analysis on the Colorado River. This decision stems from the river's current water rights litigation and data availability. This analysis aims to answer these questions and test the following hypotheses:

RQ 2: Does water quality change in the Colorado River as it passes through the Navajo Nation, and if so, in what ways?

Hypothesis 2: The water quality in the Colorado River before and after passing through the Navajo Nation is significantly different.

RQ 3: How has the water quality changed in the Colorado River in the last 5 years?

Hypothesis 3: The water quality in the Colorado River before and after passing through the Navajo Nation has changed significantly in the last 5 years.

Table 1: Summary Table of Water Quantity Dataset

	Class
agency_cd	character
site_no	character
Date	Date
X_00060_00003	numeric
X_00060_00003_cd	character

Dataset Information and Methods

The dataset was taken from the USGS Monitoring the rivers of the Nation (U.S. Geological Survey, n.d.).

For water quantity, the data was extracted from years 2019 to 2024 for Colorado River and San Juan. Our chosen proxy for water quantity is water discharge in cubic feet per second. Data for the Colorado River was taken from the same gage as site 1 in water quality (see next paragraph). For the San Juan river, the data was extracted from the gage on San Juan River near Bluff, UT - FF09379500.

Two sites were selected to assess how water quality changes as the river passes through the Navajo Nation. Site 1 referred to Colorado River at Lees Ferry, AZ - 09380000, while Site 2 referred to Colorado River Near Grand Canyon, AZ - 09402500. Site 1 represented the Colorado River water condition before entering the Navajo Nation, while site 2 was upon exiting the nation.

Data wrangling was conducted for each dataset as follows. For water quantity, the data was wrangled to have more understandable column names for the discharge. The data was parsed to include only relevant variables, namely, discharge and date. No additional wrangling was needed since the dates and discharge were already in the correct format (year-mm-dd) and class (Date and number respectively), and the dataset contained no missing data. For water quality, the datasets were converted and filtered such that the dates had the correct format and the time period across the two sites were consistent (starting from January 1, 2018 and ending on December 31, 2023). For each contaminant, the datasets for sites 1 and 2 were merged to examine and compare their annual average concentrations over time.

Table 2: Summary Table of Water Quality Dataset

	Class
Org_Identifier	factor
Org_FormalName	factor
Project_Identifier	factor
Location_Identifier	factor
Location_Name	factor
Location_Type	factor
Location_State	factor
Location_HUCEightDigitCode	integer
Location_HUCTwelveDigitCode	numeric
Location_TribalLand	logical
Location_Latitude	numeric
Location_Longitude	numeric
Activity_ActivityIdentifier	factor
Activity_TypeCode	factor
Activity_Media	factor
Activity_MediaSubdivision	factor
ActivityBiological_AssemblageSampled	logical
Activity_StartDate	factor
Activity_StartTime	factor
Activity_StartTimeZone	factor
Activity_DepthHeightMeasure	numeric
Activity_DepthHeightMeasureUnit	factor
SampleCollectionMethod_Name	factor
Result_ResultDetectionCondition	logical
Result_Characteristic	factor
Result_MethodSpeciation	logical
Result_SampleFraction	factor
ResultBiological_Intent	logical
ResultBiological_Taxon	logical
ResultDepthHeight_MeasureValue	logical
ResultDepthHeight_MeasureUnit	logical
Result_MeasureIdentifier	factor
Result_MeasureValue	integer
Result_MeasureUnit	factor
Result_MeasureQualifierCode	logical
Result_MeasureStatusIdentifier	factor
Result_StatisticalBase	logical
Result_MeasureValueType	factor
DataQuality_ResultCommentText	logical
DetectionLimit_TypeA	logical
DetectionLimit_MeasureValueA	logical
DetectionLimit_MeasureUnitA	logical
DetectionLimit_CommentTextA	logical
DetectionLimit_TypeB	factor
DetectionLimit_MeasureValueB	integer
DetectionLimit_MeasureUnitB	factor
DetectionLimit_CommentTextB	factor
ResultAnalyticalMethod_Identifier	factor
ResultAnalyticalMethod_IdentifierContext	factor
ResultAnalyticalMethod_Name	factor
ResultAnalyticalMethod_Url	logical
LabInfo_AnalysisStartDate	factor
LabInfo_AnalysisStartTime	logical
LabInfo_AnalysisStartTimeZone	logical
Result_DetectionLimitProfileDownload	logical

Analysis

Water Quantity

Question 1: How have water discharge levels changed in the last 5 years at San Juan and Colorado rivers?

Data Visualization

The downward slope measured at both gages shows that the discharge volume for both San Juan and Colorado Rivers have declined in the last five years (Figures 1 and 2). This corroborates with previous years where drought conditions have affected water quantity, posing a continued challenge to water availability for the people in the Navajo Nation and impacting aquatic ecosystems. While both rivers experience seasonal variability, the San Juan River has more frequent periods of high discharge (eg. mid-2023 and mid-2019) compared to the Colorado River.

In Colorado river, the median discharge in 2024 was 11400 cf/s, which was 6.938776% lower than that of 2019 (12250 cf/s). In San Juan River, the median discharge in 2024 was 635 cf/s, which was 54.48029% lower than that of 2019 (1395 cf/s). Assessing the slope of decline over time, the Colorado River had an average decrease of 0.6946 cf/s per day over the five-year period while San Juan River had an average decrease 0.1454 cf/s per day.

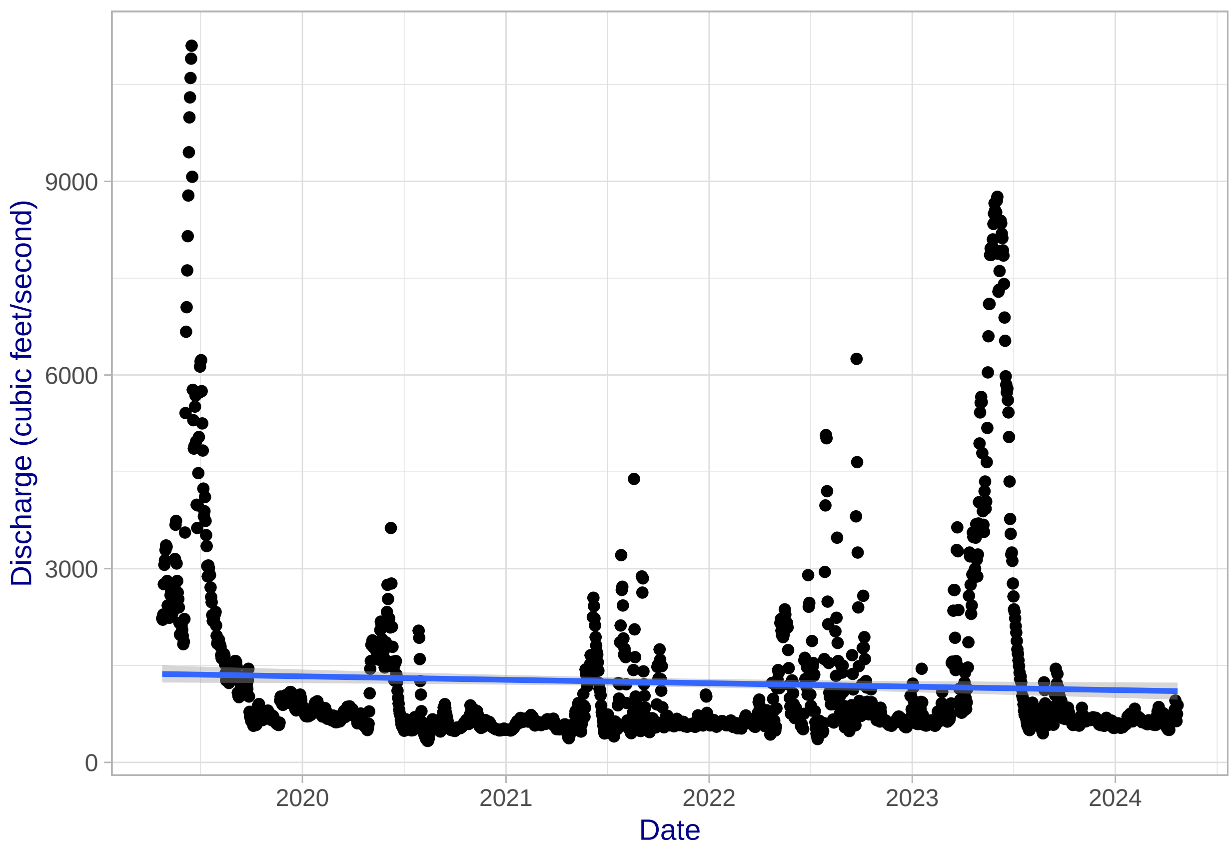

Figure 1: Water Discharge in San Juan River from 2019-2024

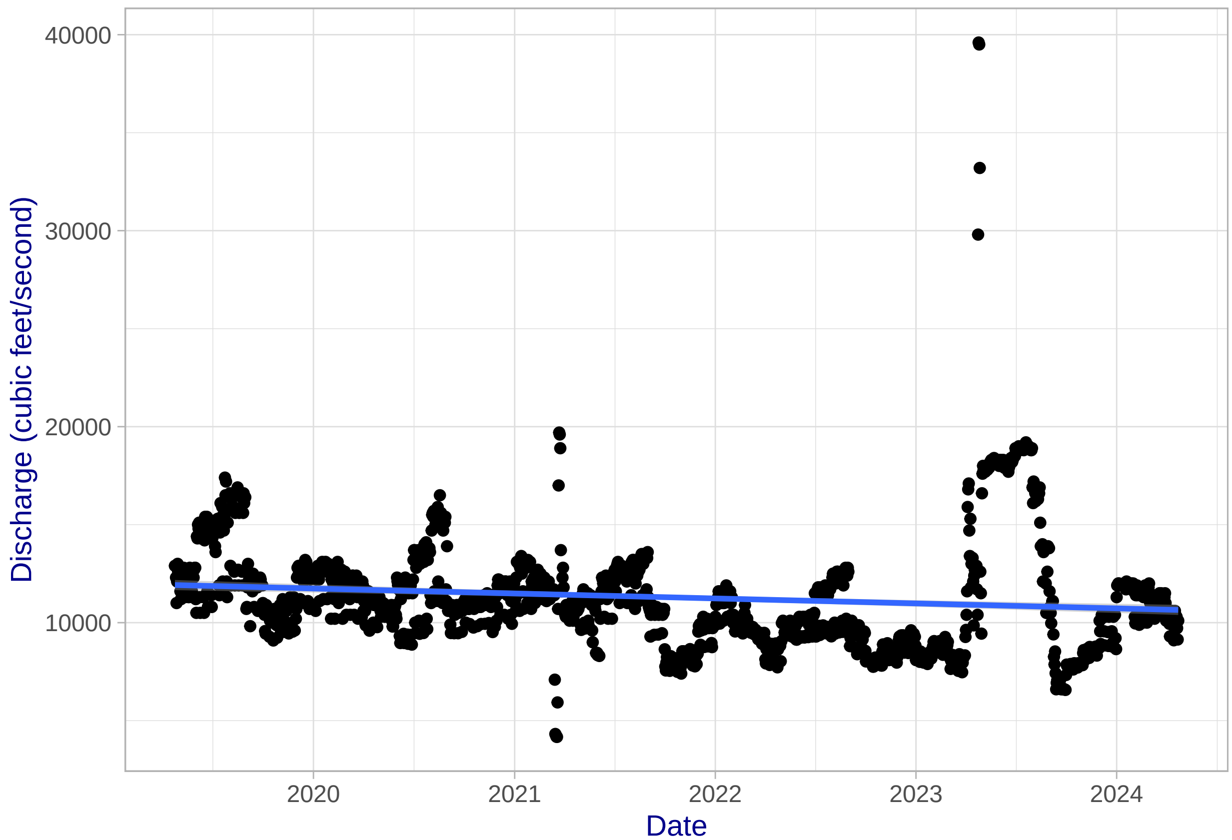

Figure 2: Water Discharge in Colorado River from 2019-2024

Time Series Analysis

For Colorado River, water levels have declined from 2019 to mid-2022 and then increased to peak at early 2023 (Figure 3). For San Juan River, water levels have declined from 2019 to 2020 and remained steady (at a low level) up till mid-2022. Suddenly, water levels increased to peak at early 2023, and declined since then (Figure 4).

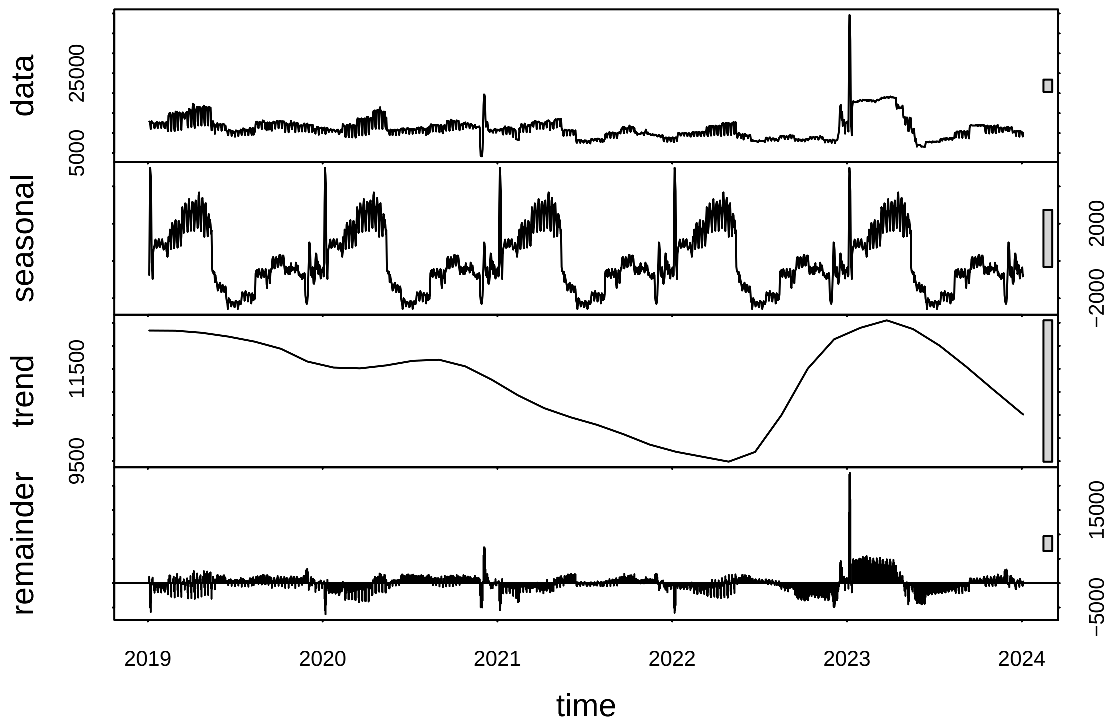

Figure 3: Time Series Analysis of Discharge by the Colorado River, 2019-2024

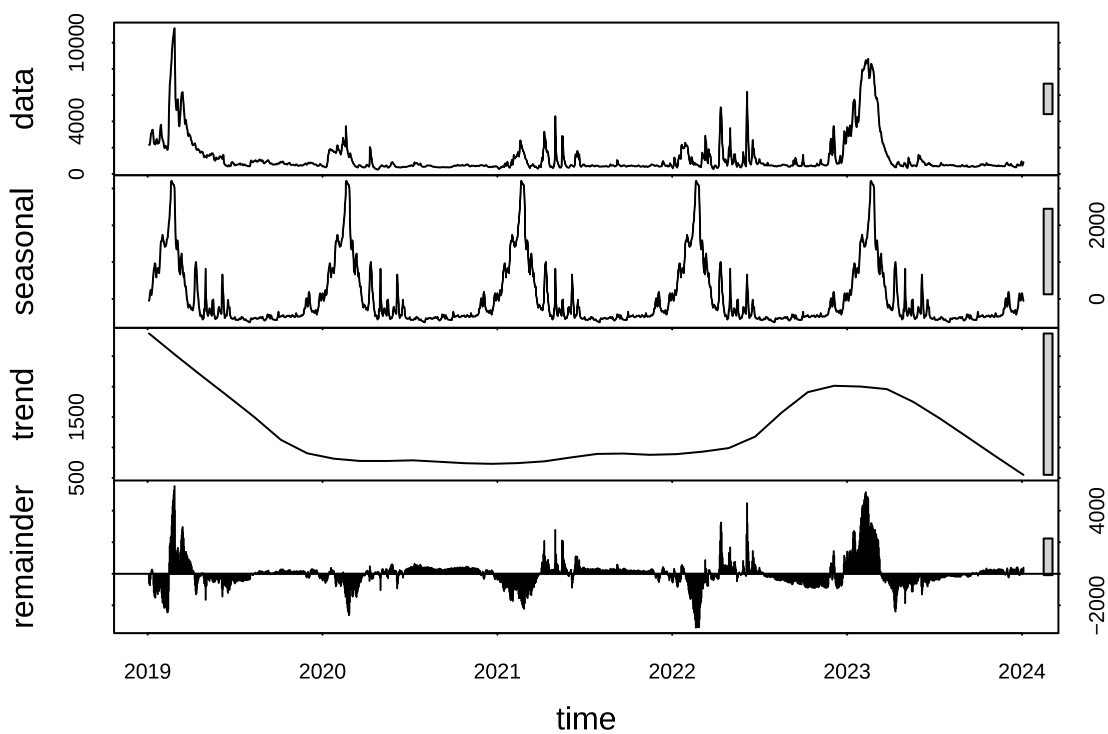

Figure 4: Time Series Analysis of Discharge by the San Juan River, 2019-2024

Population Drawing Directly From the Rivers

We examined each of the chapters under the Western and Northern Agency on whether the San Juan and Colorado River passes through their territory (Navajo Nation Division of Community Development, n.d.). This would allows us to determine how much of the Navajo population drew water directly from each river.

For Colorado River, the following chapters met this criteria: Bodaway-Gap, Coppermine, LeChee, and Navajo Mountain. For San Juan, the following chapters met this criteria: Kayenta, Oljato, Shonto, Beclabito, Upper Fruitland, Gadii Ahi/to'koi, Mexican Water, Red Mesa, Teec Nos Pos, Tse Daa Kaan.

The total Indian population in the Navajo Nation estimated to live in the chapters bordering the Colorado River is about 4516 (Navajo Nation Division of Community Development, n.d.). San Juan River has about 18728 people living close-by (Ibid.).

Note: We intended to use scrape data from the website but it generated empty values. Hence, copy pasting the data was done instead. See appendix 1.

Navajo people are estimated to use only 7 gallons of water per day (Supreme Court of the United States, 2022). Based on this estimate, and the estimate of population drawing water directly from the rivers, we can estimate the gallons of annual water withdrawal by the Navajo Nation. About 11538380 gallons in total are directly withdrawn from the Colorado River by the Navajo Nation, while about 47850040 gallons in total are directly withdrawn by the Navajo Nation from the San Juan River.

This is a minuscule quantity compared to the water drawn by states in the Lower Basin (Arizona, Nevada and California) for agricultural irrigation, the activity responsible for the largest water use from the Colorado River (Richter et al., 2024). The average water used for agriculture by the Lower Basin from 2000 to 2019 is 6610.06 million cubic meters, which is 1746193109029.7864 gallons (Ibid.).

As a caveat, we are counting only populations right beside the river, even though with water transport infrastructure, people in chapters far from the river will also be withdrawing, so this estimate of water withdrawing is an underestimate. This estimate applies only for domestic use but since they use water for other activities such as agriculture, the water availability of both rivers is a limiting factor.

Water Quality

Question 2: How has been the water quality of Colorado River before, and after it pass through the reservation in the past 5 years?

Boron

Mean annual boron concentrations increased on the Colorado River (Figure 5) from 2019 to 2024; nevertheless, the concentrations have not yet exceeded a concerning level for human health according to the recommended maximum levels for drinking water by Canada and The World Health Organization (World Health Organization, 2009; Health Canada, 2020). The US has not set any regulations limiting boron concentrations in water.

Throughout this 5-year period, boron concentration is lower when entering the tribal territory than when it exits. It reached a maximum concentration of >120 ug/L, which is still considered low, with a general mean concentration along the river of 74.81 ug/L. The statistically significant difference (p-value = 0.002834 < 0.05, df = 8.9481, t = -4.0699) found through a t-test indicates that the Navajo Nation engages in activities that result in boron discharge in the Colorado River.

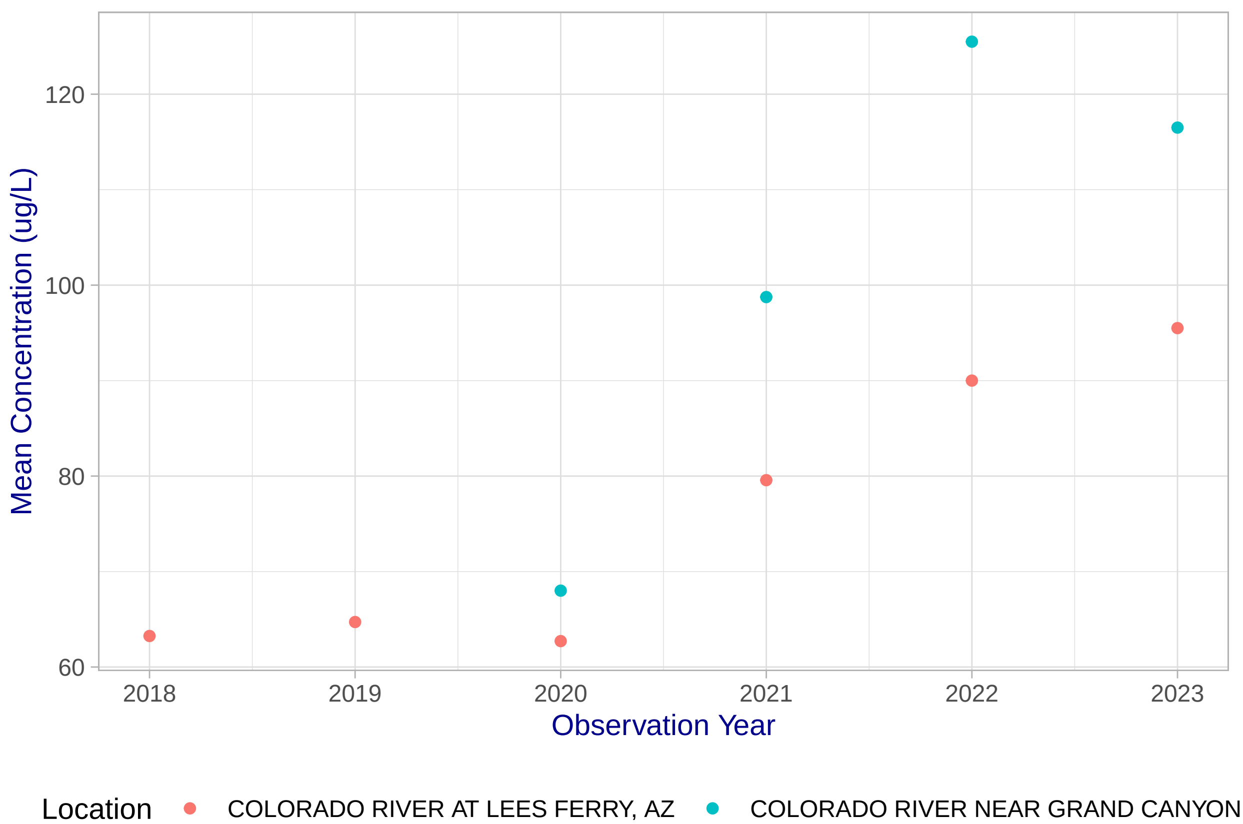

Figure 5: Boron Concentrations Before and After Passing Through the Navajo Nation

Magnesium

Mean annual magnesium concentrations increased on the Colorado River (Figure 6) from 2020 to 2023, with a low concentration in 2018 and a significant increase in 2019, reaching up to 22.9 mg/L. Throughout this 5-year period, magnesium concentration is lower upon entering the tribal territory than when it exits, with a significant difference of 93.61% between both sides, resulting in a mean concentration along the river of 21.55 mg/L. This element is one of the most common elements in natural resources and is essential for human nutrition. The levels found in the water source are typical in water bodies and do not represent a risk to human and natural health (U.S. EPA, 1984).

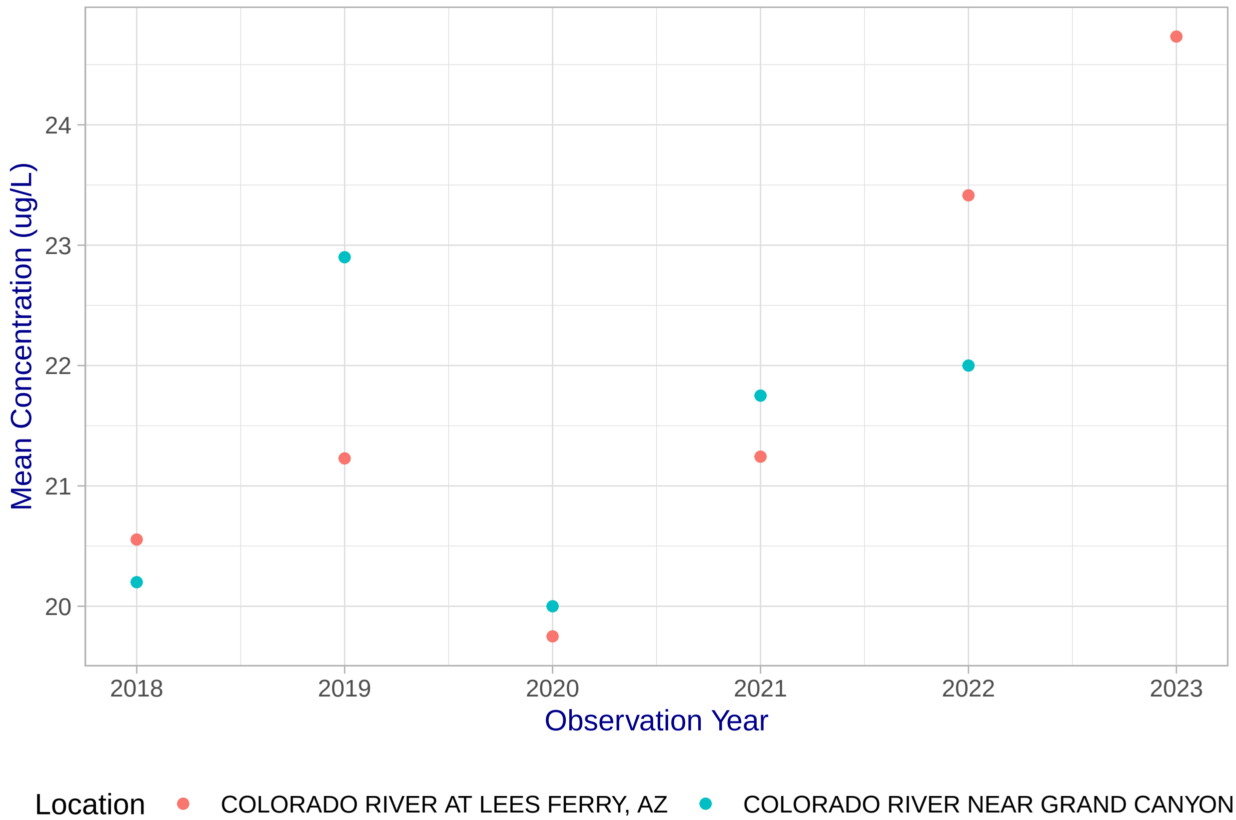

Figure 6: Magnesium Concentrations Before and After Passing Through the Navajo Nation

Uranium

Mean annual uranium concentrations have increased on the Colorado River (Figure 7) from 2019 to 2024. Nevertheless, the concentrations have not yet exceeded concerning levels for human health according to the recommended maximum levels for drinking water by The World Health Organization and the EPA. However, the goal concentrations are zero (World Health Organization, 2009; US EPA, 2024). Considering that the water used from the Colorado River is for direct human consumption and other activities, accumulation of this element can potentially generate radiological toxicity. The low concentrations of this component at this location indicate a positive environmental stage considering the historical mining in the Navajo territories (Doug Brugge, Rob Goble, 2002).

Throughout this 5-year period, uranium concentration is lower when entering the tribe territory than when it exits (except in 2021 and 2023), reaching a maximum concentration of 5.80 ug/L, with a general mean concentration along the river of 3.47 ug/L. The statistically significant difference (p-value = 8.993e-5) indicates a difference in uranium measurements between the entrance to the reservation and the exit of the water concentrations of the Colorado River, suggesting that there are activities or naturally occurring uranium discharges.

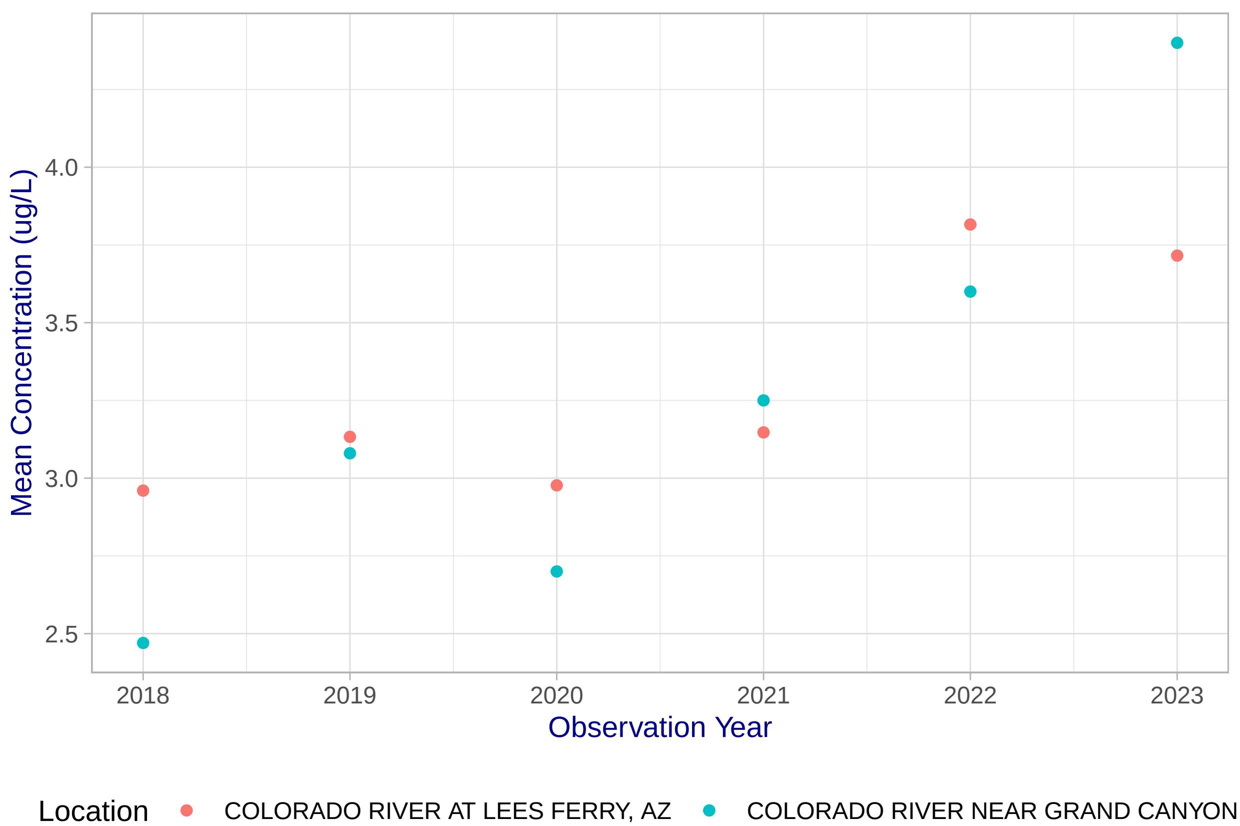

Figure 7: Uranium Concentrations Before and After Passing Through the Navajo Nation

Summary and Conclusions

In terms of water availability, the discharge for both the San Juan and Colorado Rivers has declined over the last five years. In Colorado river, the median discharge in 2024 was 11400 cf/s, which was 6.938776% lower than that of 2019 (12250 cf/s). In San Juan River, the median discharge in 2024 was 635 cf/s, which was 54.48029% lower than that of 2019 (1395 cf/s). Assessing the decline over time, the Colorado River had an average decrease of 0.6946 cf/s per day over the five-year period while San Juan River had an average decrease 0.1454 cf/s per day. This result is corroborated by previous years' droughts that have affected the water quantity in the reservation.

The Indian populations within the Navajo Nation use very limited water. We estimate that the Indian population living in chapters where the both rivers pass through are using only 11,538,380 gallons/year from the Colorado River and 47,850,040 gallons/year from the San Juan River for domestic use, which is 7 gallons per day per capita. 7 gallons per day is not enough to meet basic needs. At least 50 liters per day per person is needed (UN-Water), which is about 13.2 gallons. The water availability by both rivers would be sufficient if they were only used for household consumption in the states they pass through. However, since most of the water is extracted for water-intensive agricultural practices, it ends up being limited. As mentioned before, the average water used for agriculture by the Lower Basin from 2000 to 2019 is 6,610.06 million cubic meters, which is 1,746,193,109,029.7864 gallons. This suggests that agricultural practices need to be regulated such that they improve water use efficiency and reduce overall water withdrawals from both Colorado and San Juan Rivers.

Based on the analysis of element concentrations, the water quality of the Colorado River meets good standards for human use. The concentrations of Magnesium, Boron and Uranium when entering the tribal territory is relatively low compared to maximum human health standards. However, it is necessary to conduct a broader evaluation of other elements and contaminant concentrations in the water to identify if there are additional components that could deteriorate the water quality for Navajo activities such as agriculture, consumption, and others. Data availability was limited for the present document analysis in terms of the time period and the station's measurements. On the other hand, the contaminant concentrations of the water leaving the reserve for Boron and Uranium is significantly higher than when entering, indicating that there are activities in the territory that contribute to the concentration of those elements in the water.

The concentrations of those elements over the past 5 years have increased when entering and leaving the territory. Although these concentrations do not exceed regulatory/international guidelines, their continued increase over time would suggest a deterioration in the water quality of the river, posing health risks for people in the Navajo Nation and its neighboring states.

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Appendix

Appendix 1

```
#set scraping website
Water_URL<- read_html('https://navajoprofile.wind.enavajo.org/')
Water_URL
```

```
## {html_document}
## <html>
## [1] <head>\n<meta http-equiv="Content-Type" content="text/html; charset=UTF-8 ...
## [2] <body>\r\n        <form id="form1">\r\n            <div class="outerNavCo ...
```

```
#scrape the data
navajo_nation_chapter<-Water_URL%>%
  html_nodes("td:nth-child(3)")%>%
  html_text()
navajo_nation_chapter
```

```
## character(0)
```

```
indian_population<-Water_URL%>%
  html_nodes("td:nth-child(4)")%>%
  html_text()
indian_population
```

```
## character(0)
```

```
table<-Water_URL%>%
  html_nodes("tabContent001")%>%
  html_text()
table
```

```
## character(0)
```