Impacts of Dam Removal on the Shenandoah River

https://github.com/lydiecos/WDA-Dam-Removal

Lydie Costes

1 Rationale and Research Questions

Over the past century, perceptions of dams have gradually changed, as understanding of their serious ecological issues has increased and as existing dams have aged, creating safety concerns and the need for expensive repairs. Dams block the passage of fish and other aquatic species, seriously disrupting life cycles for some species. They also impact water quality and alter natural flow. Increasingly, dam removal is pursued as an option to deal with aging dams and restore rivers.

In this study, we seek to understand how dam removal has impacted the physical and chemical processes of one river, the Neuse River in North Carolina. From 2004-2005, three dams were removed from the Southern Fork of the Shenandoah River (see map below). The gage we are using for these analyses is downstream from these dams and should thus reflect some of the changes in flow and water quality that occurred after these removals.

Below: The red X marks the spot of the McGaheysville Dam, which were removed along with the Knightly Dam and Rockland Dam upstream in 2004-2005. All three dams were located along the south fork of the Shenandoah River, which feeds into the Potomac.

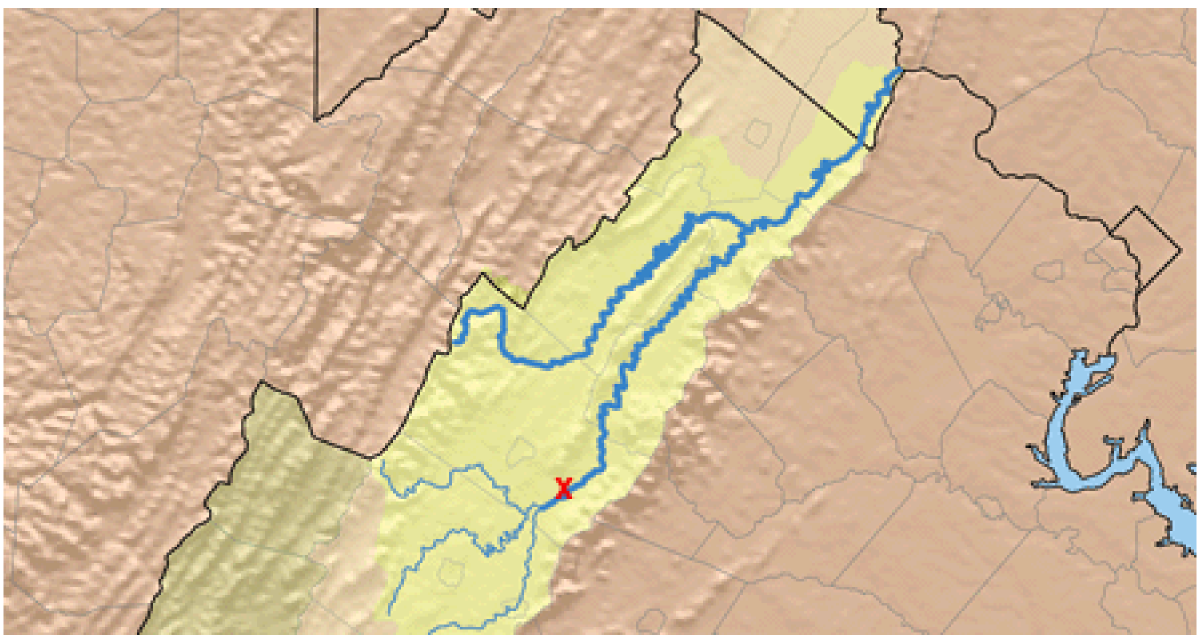


Figure 1: map of Neuse River

We are interested in both changes in physical process and changes in chemical processes, which can vary widely according to the specific river, its history, and the dam removal process (Foley et al 2017). Dams allow for moderation of flow, often eliminating extreme flooding events. Therefore, dam removal in combination with increasing extreme weather events due to climate change could lead to more extreme and more frequent high flow events. On the other hand, natural river systems and riparian areas can be more resilient to flood events than artificially constructed channels, so true restoration could help mitigate high flow events to some extent.

Changes in water quality are also an area of interest. Large amounts of sediment and minerals built up behind the dam may release quickly after removal, especially if the removal was sudden rather than gradual (Foley et al 2017). Over longer time, water quality is expected to improve because of restored ecological processes.

1. Question 1: Have discharge levels become more extreme since dam removal?
2. Question 2: Has there been a change in release of sediment and nutrients since the dam removal?

2 Dataset Information

The dataset consists of discharge and water quality data from stream gage #01631000, which is located on the South Fork of the Shenandoah River downstream from the three dam removal sites. These data were obtained from USGS StreamStats: https://streamstats.usgs.gov/ss/.

The dataset includes 183 parameters, but these parameters vary widely in terms of how many datapoints were collected. To choose water quality variables, I made a list of the top ten water quality parameters according to the number of observations, and then selected three that I thought would be particularly interesting and informative in light of dam removal. These three were: suspended sediments, nitrogen, and phosphate. Temperature is also included in the exploratory analyses. All of these variables could be expected to change after dam removal.

2.1 Data Wrangling

The data were downloaded as two separate datasets: discharge ('ShenaFlow') and water quality ('ShenaWQ'). Column names were changed from defaults to be more comprehensible. Month and Year columns were added to each dataset.

The discharge dataset was summarized into two dataframes, one by month and the other by year. In both cases, discharge minimum, mean, and maximum were calculated according to the summary unit.

The water quality dataset was transformed into a wider dataset with the four parameters of interest divided into separate columns, instead of being compiled in two columns by characteristic and value. The resulting dataframe was also summarized by month, with minimum, mean, and maximum calculated for each of the four parameters.

	vars	n	mean	sd	min	max	range	se
Discharge	1	33451	1602.889	2563.372	103	114000	113897	14.01545

	vars	n	mean	sd	min	max	range	se
Nitrogen_mg.L	1	589	0.9908829	0.4492672	0.01	2.69	2.68	0.0185117
Temp_C	2	767	14.2938722	8.2711759	-0.10	30.50	30.60	0.2986549
Phosphate_mg.L	3	582	0.2240997	0.2547145	0.00	1.93	1.93	0.0105583
Sediments_mg.L	4	471	54.7594055	150.6138832	0.00	2020.00	2020.00	6.9399214

3 Exploratory Analysis

Below are exploratory plots showing each parameter over time.

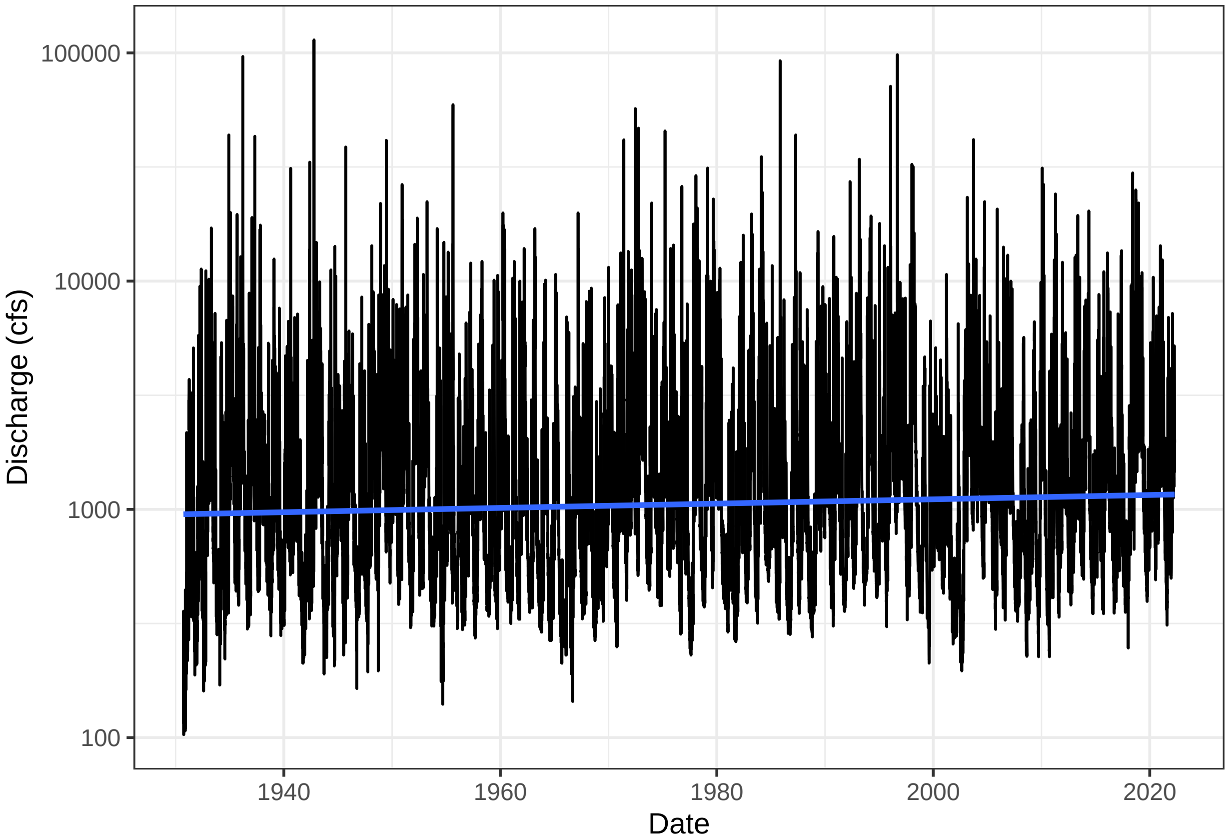


Figure 2: Discharge over time

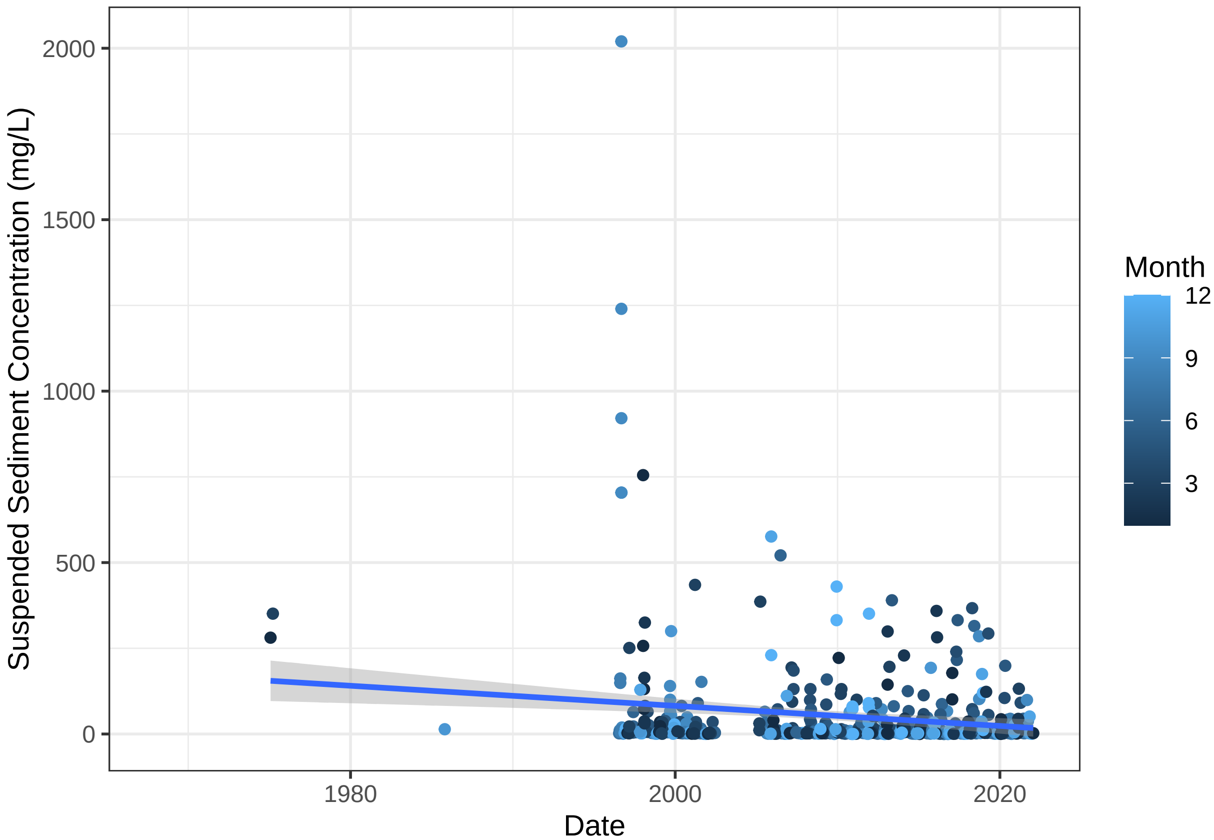


Figure 3: Sediment over time

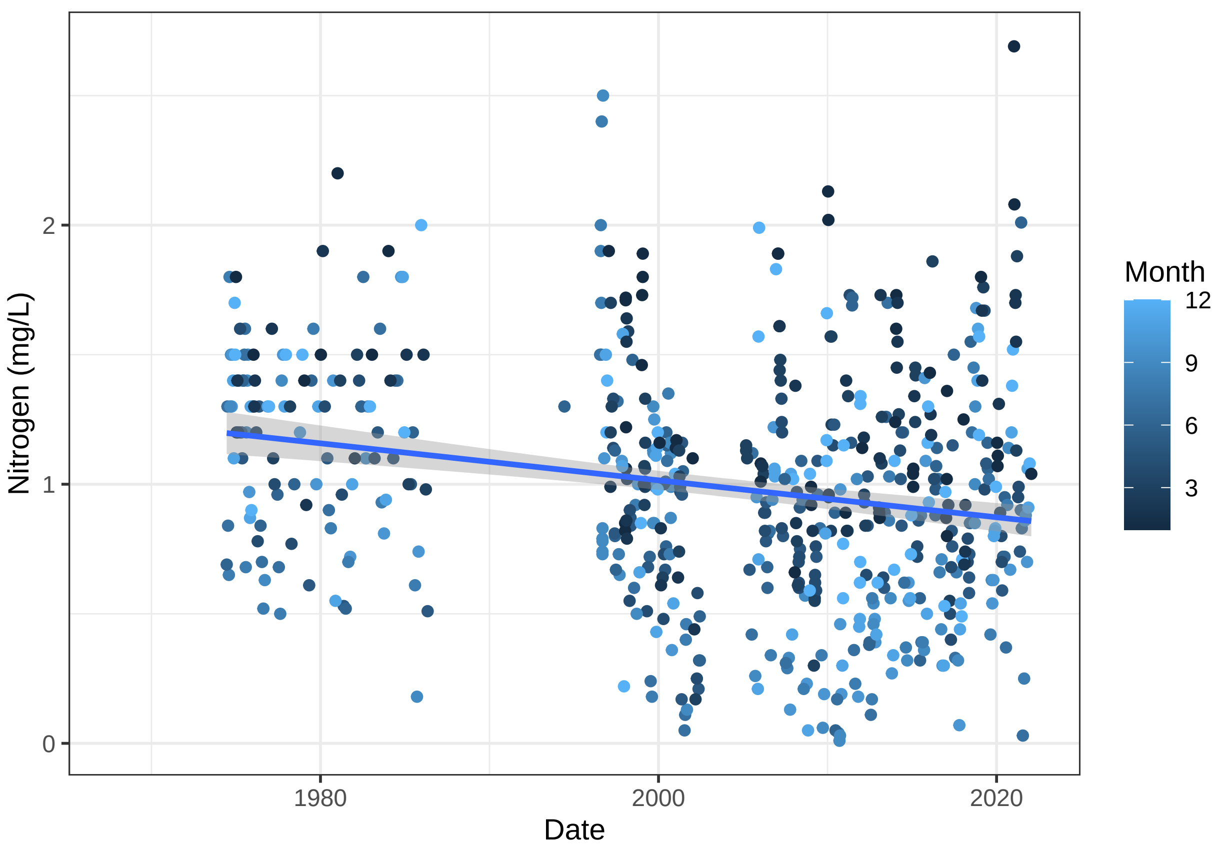


Figure 4: Nitrogen over time

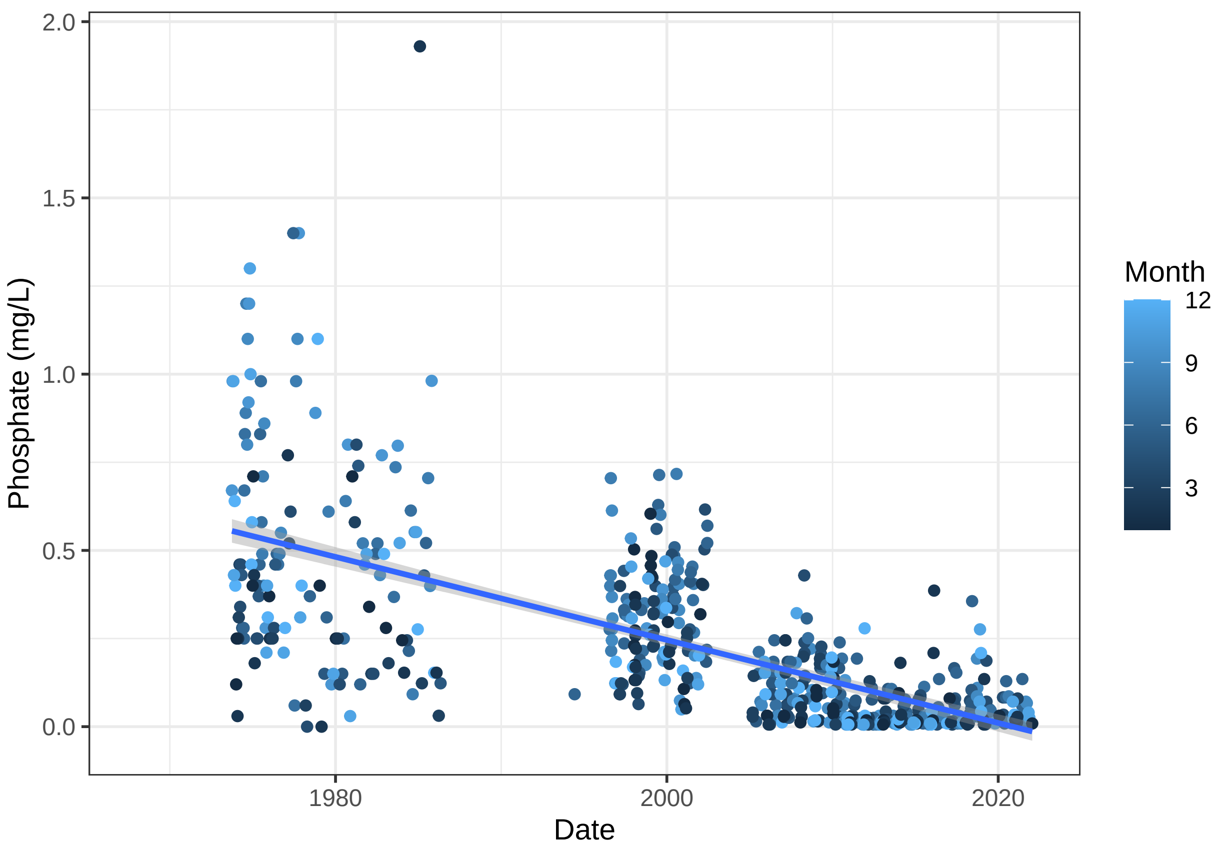


Figure 5: Phosphate over time

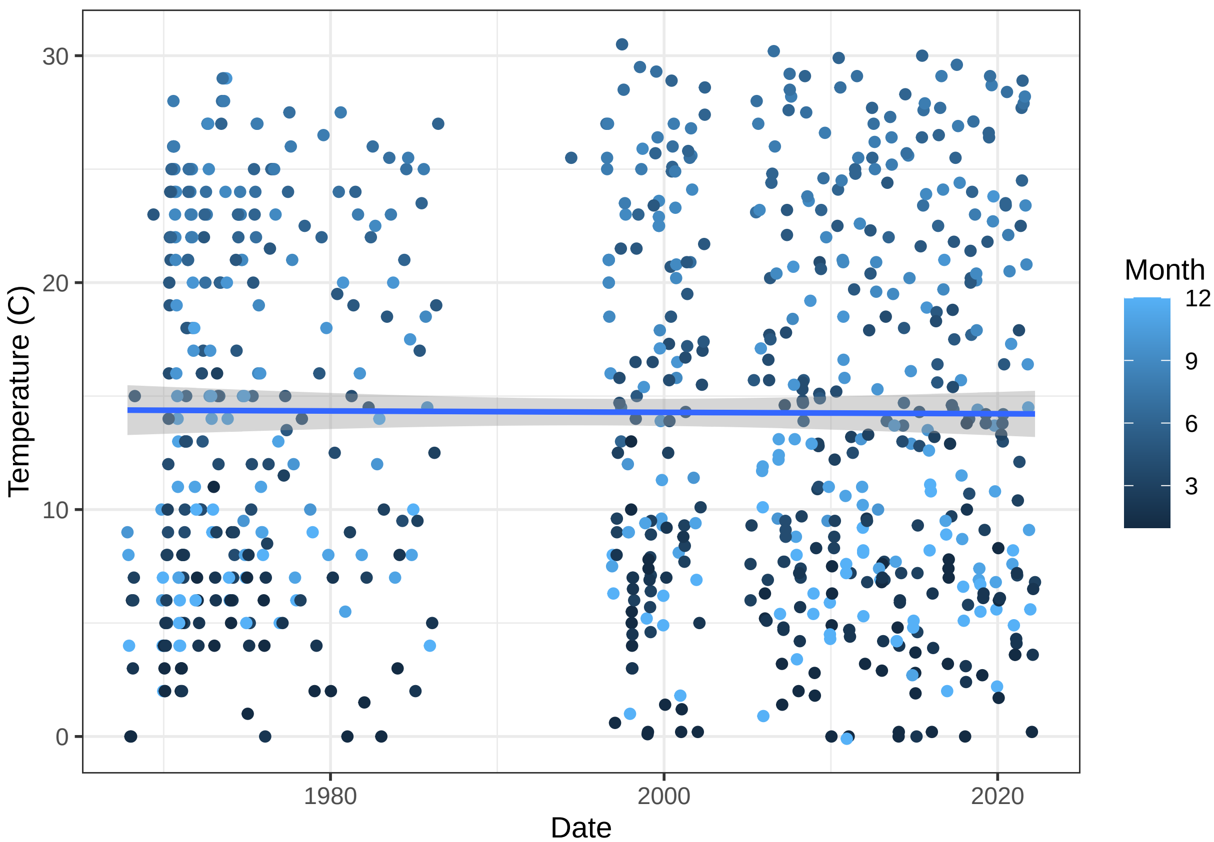
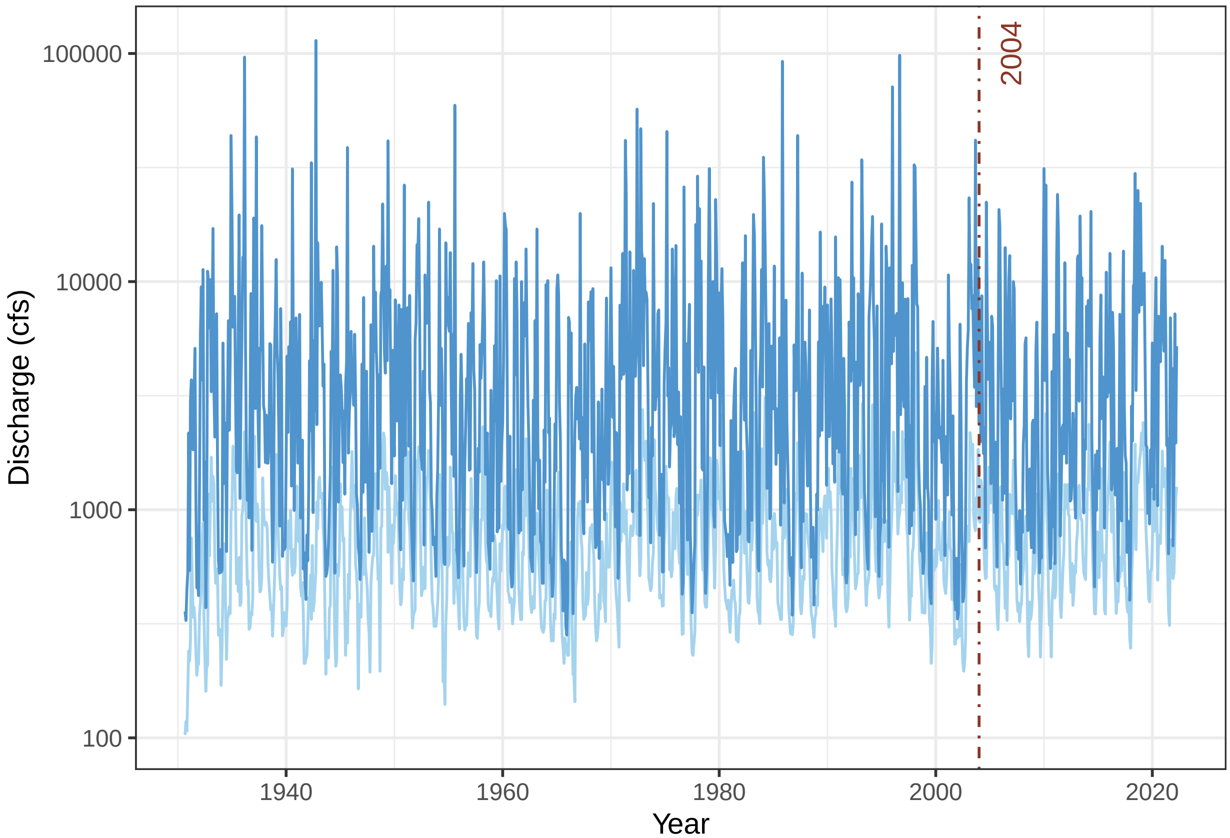


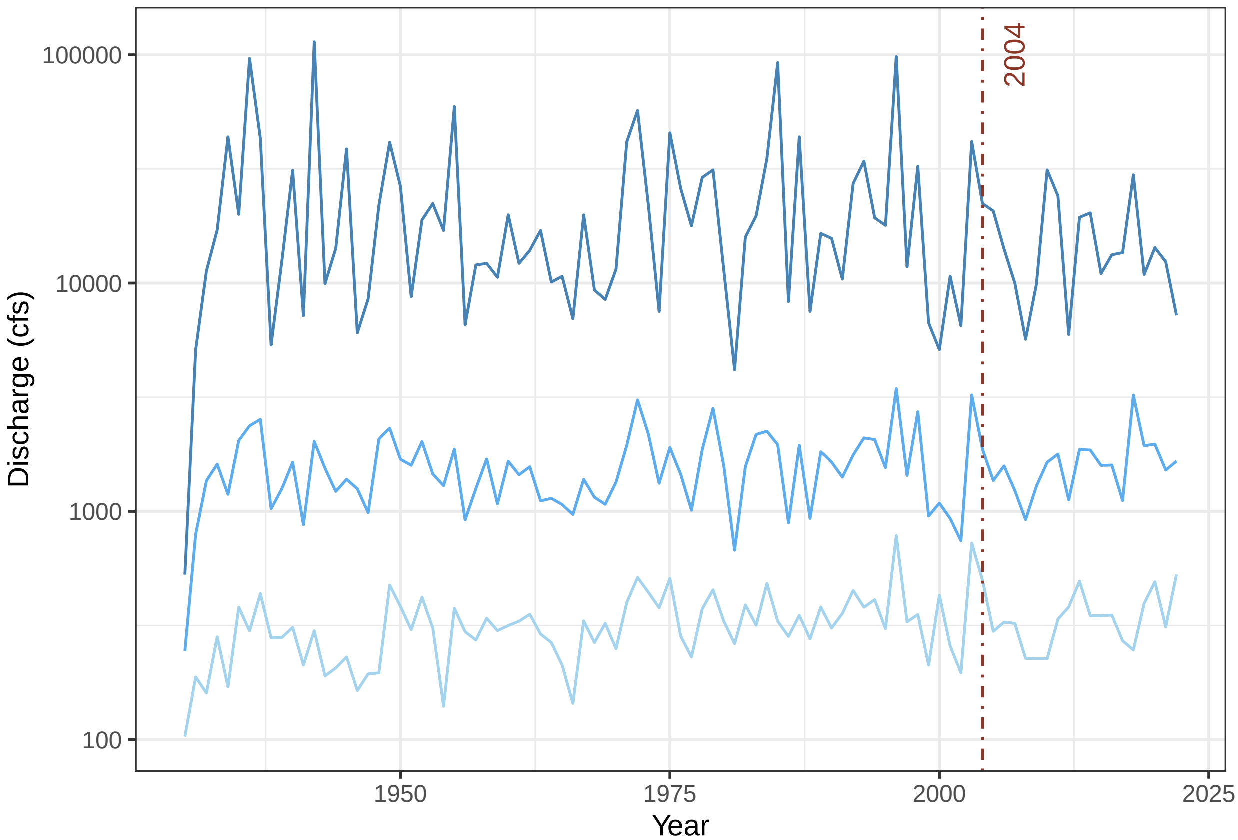
Figure 6: Temperature over time

4 Analysis

4.1 Question 1: Flow

Question #1: Have discharge extremes increased since the removal of the dams? Has average discharge increased since dam removal?





Maximum and minimum flows have not gotten more extreme since dam removal.

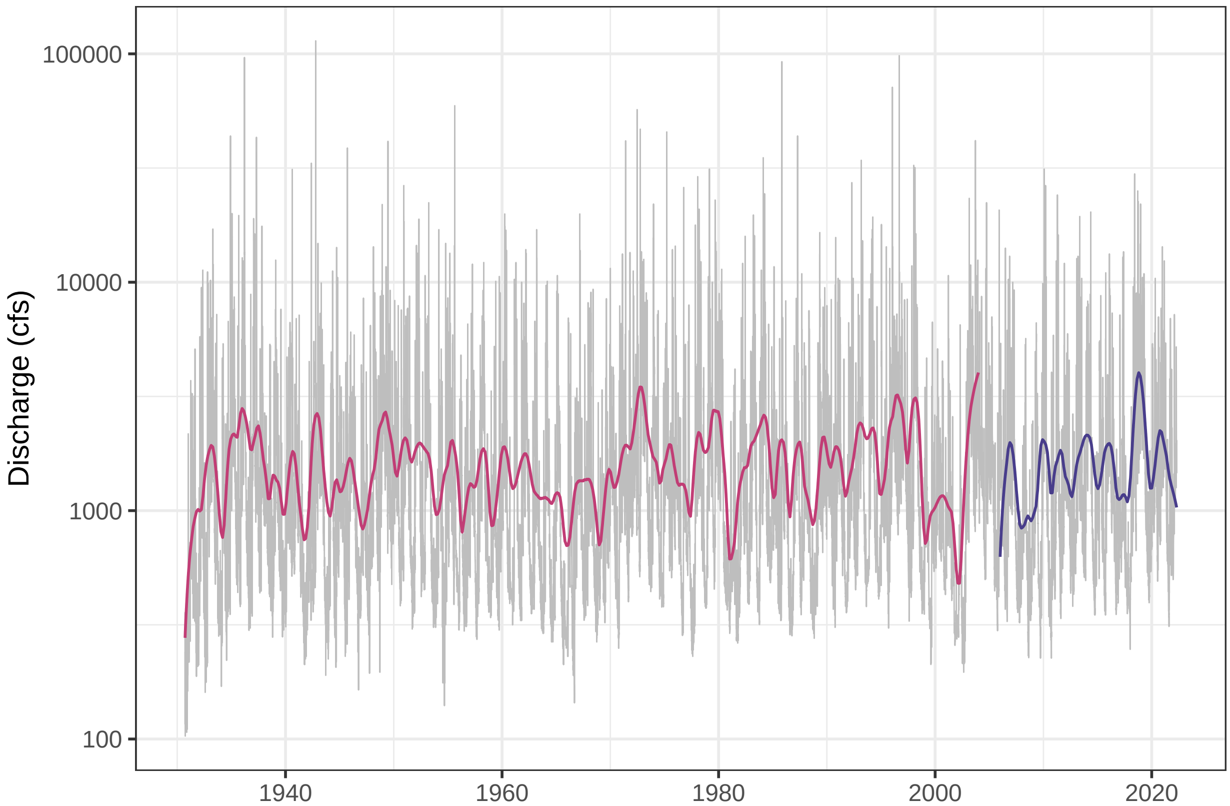
Table 3: Summary Statistics for Discharge

	Timeframe	n	mean	sd	min	max	range	se
X1	Before	26764	1594.155	2687.319	103	114000	113897	16.42645
X11	After	5956	1640.279	2009.455	226	31300	31074	26.03760

Average flow appears to be higher since dam removal. Verify with a t-test:

```
##
##  Welch Two Sample t-test
##
## data:  ShenaFlow.before$Discharge and ShenaFlow.after$Discharge
## t = -1.4982, df = 11242, p-value = 0.1341
## alternative hypothesis: true difference in means is not equal to 0
## 95 percent confidence interval:
##  -106.47011   14.22224
## sample estimates:
## mean of x mean of y
##  1594.155  1640.279
```

Flow levels have not been significantly different before versus after the dam removal (p = 0.140, df = 11202).



4.2 Question 2

Question #2: Has there been a change in release of sediment and nutrients since the dam removal?

4.2.1 Sediment

Have sediment levels changed since dam removal?

View summary statistics comparing sediment levels before versus after dam removal:

Table 4: Summary Statistics for Sediment

	Timeframe	n	mean	sd	min	max	range	se
Sediments_mg.L	Before	137	83.15474	242.94443	0.3	2020	2019.7	20.756144
Sediments_mg.L1	After	321	40.64324	79.63389	0.0	521	521.0	4.444731

Test whether average sediment has been different before versus after dam removal:

```
##
##  Welch Two Sample t-test
##
## data:  ShenaWQ.before$Sediments_mg.L and ShenaWQ.after$Sediments_mg.L
## t = 2.0027, df = 148.63, p-value = 0.04702
## alternative hypothesis: true difference in means is not equal to 0
## 95 percent confidence interval:
##   0.5663858 84.4566235
## sample estimates:
## mean of x mean of y
##  83.15474  40.64324
```

4.2.2 Nitrogen

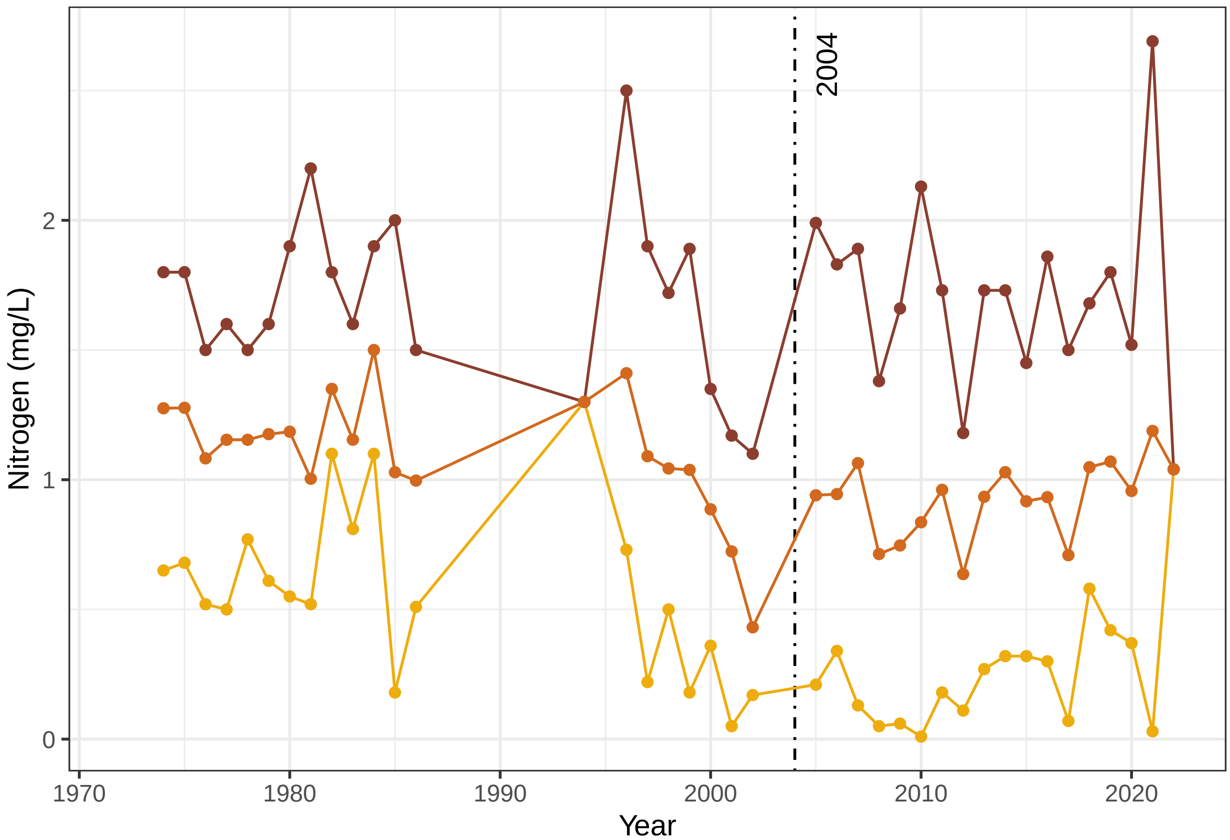
Have nitrogen levels changed since dam removal?

View summary statistics comparing nitrogen levels before versus after dam removal:

Table 5: Summary Statistics for Nitrogen

	Timeframe	n	mean	sd	min	max	range	se
Nitrogen_mg.L	Before	254	1.0861811	0.4326022	0.05	2.50	2.45	0.0271439
Nitrogen_mg.L1	After	323	0.9178328	0.4466726	0.01	2.69	2.68	0.0248535

Visualize yearly minimum, mean, and maximum nitrogen levels:



Check whether average nitrogen levels have changed since dam removal:

```
##
##  Welch Two Sample t-test
##
## data:  ShenaWQ.before$Nitrogen_mg.L and ShenaWQ.after$Nitrogen_mg.L
## t = 4.5743, df = 550.84, p-value = 0.000005908
## alternative hypothesis: true difference in means is not equal to 0
## 95 percent confidence interval:
```

```
##  0.09605617 0.24064040
## sample estimates:
## mean of x mean of y
## 1.0861811 0.9178328
```

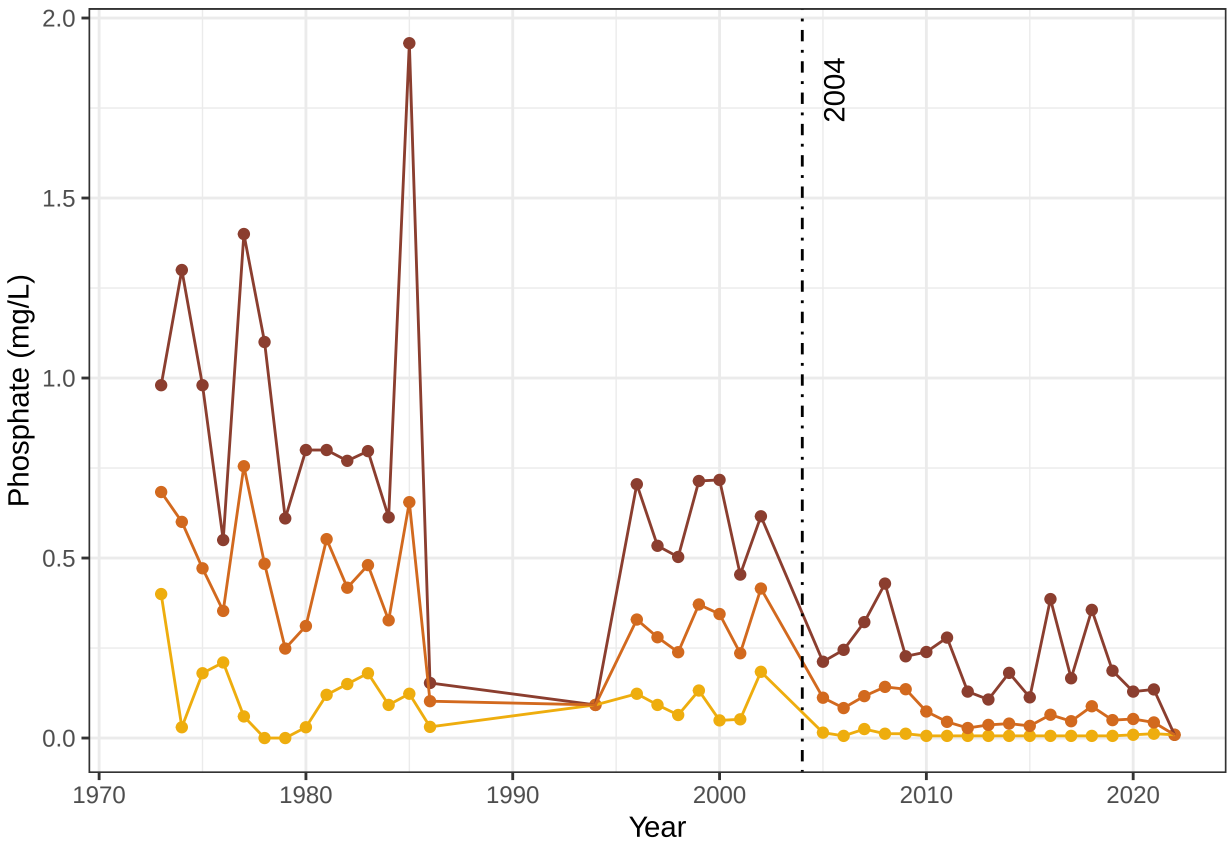
Yes, nitrogen levels since dam removal (M = 0.92, SD = 0.45) have been significantly lower ($t(550.8) = 4.56$, $p < 0.001$) compared with nitrogen levels before dam removal (M = 1.09, sd = 0.43).

4.2.3 Phosphate

View summary statistics comparing sediment levels before versus after dam removal:

Table 6: Summary Statistics for Phosphate

	Timeframe	n	mean	sd	min	max	range	se
Phosphate_mg.L	Before	272	0.3984853	0.2743858	0.000	1.930	1.930	0.0166371
Phosphate_mg.L1	After	297	0.0692997	0.0755835	0.006	0.429	0.423	0.0043858



Test whether phosphate levels were different before versus after dam removal:

```
##
##  Welch Two Sample t-test
##
## data:  ShenaWQ.before$Phosphate_mg.L and ShenaWQ.after$Phosphate_mg.L
## t = 19.133, df = 308.61, p-value < 2.2e-16
## alternative hypothesis: true difference in means is not equal to 0
## 95 percent confidence interval:
##  0.2953308 0.3630405
## sample estimates:
##  mean of x  mean of y
## 0.39848529 0.06929966
```

Phosphate levels have been significantly lower ($t(309.22) = 19.10$, $p < 0.001$) since dam removal ($M = 0.07$, $SD = 0.08$) compared with during the dammed years ($M = 0.40$, $SD = 0.27$).

5 Summary and Conclusions

- Flow:
- Sediment:
- Both Nitrogen and Phosphate levels were significantly lower after dam removal.

6 References

- Foley, M. M., J. R. Bellmore, J. E. O'Connor, J. J. Duda, A. E. East, G. E. Grant, C. W. Anderson, J. A. Bountry, M. J. Collins, P. J. Connolly, L. S. Craig, J. E. Evans, S. L. Greene,F. J. Magilligan, C. S. Magirl, J. J. Major, G. R. Pess,T. J. Randle, P. B. Shafroth, C. E. Torgersen, D. Tullos, A. C. Wilcox. 2017. Dam removal: Listening in. Water Resources Research. 53(7):5229-5246. https://doi-org.proxy.lib.duke.edu/10.1002/2017WR020457

Map source: http://www.virginiaplaces.org/watersheds/fishpassage.html

Sediment deposits alter downstream tidal communities https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0187742#references

info: https://dwr.virginia.gov/fishing/fish-passage/#orange