UNIVERSITY OF MICHIGAN

The Effects of Dam Removal on River Ecosystems:

A Study of Succession in the Maple River

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Abstract

Policy and environmental decisions rely on a thorough understanding of the impacts of human action on the natural world. Such action, in the form of river reconnection movements, has highlighted an area of environmental manipulation in need of further research. As part of a larger before-and-after study of the limnological conditions and species abundances in the Maple River (Boehm, 2015), this study investigated the effects of dam removal on the macroinvertebrate Functional Feeding Group (FFG) richness and distribution, discharge, and concentrations of nitrogen and phosphorus in the Maple River. This study found notable differences between the state of the Maple River prior to dam removal and its current state, post dam removal. These differences primarily pertain to discharge, water chemistry, and P/R ratios, and are most prominent at sites downstream nearest to the former dam site, in accordance with the river continuum concept.

Introduction

Understanding the impacts of human intervention on the natural world is paramount to advising policy and environmental management decisions, particularly in the era of climate change. One of the foremost ways humans have impacted the biosphere is through severe habitat fragmentation. Dams are notorious for creating impassible reaches of habitat and changing the natural state of freshwater environments (Doyle et al, 2005). This has cascading effects on the ecological health of an ecosystem, both through its biotic and abiotic factors. While dams have long been an effective means of flood control, river flow, and river restoration (Bednarek, 2001), there are compelling arguments for dam removal (Burroughs, 2010, Thompson, 2004). These arguments, along with advances in ecological thinking and the emergence of the "Reconnecting Rivers" movement (Burroughs, 2010), led to the removal of the Maple River Dam in Pellston, Michigan in 2018. There has been increased interest in dam removal as a method for promoting more connected, biodiverse ecosystems. Comparison of data from before and after a major dam removal allows for the examination of the ecological consequences of such human ecosystem manipulation.

As part of a larger before-and-after study of the limnological conditions and species abundances in the Maple River (Boehm, 2015), the data collected has been compared to East, West, and Main Branch data from before the dam was removed. Quantifying the effects of ecosystem disturbance related to dam removal may be useful in establishing expectations for ecosystem recovery and succession elsewhere. Therefore, it is important to understand the effects of dam removal on various species, specifically macroinvertebrate populations, which are often used as indicators of the health and status of lotic ecosystems (Monaghan, 2012), as well as any changes in physical or chemical characteristics related to human intervention. This study investigated the effects of dam removal on the macroinvertebrate Functional Feeding Group (FFG) richness and distribution, discharge, and concentrations of nitrogen and phosphorus in the Maple River.

Methods

Samples were collected over the course of several days in late spring. On May 25th, 2019, sites MB 7 and MB 14 (Figure 1) on the Main Branch of the Maple River were visited. The Maple River was entered in canoes downstream of Lake Kathleen's former dam site, near a road crossing. Site locations were tracked via GPS coordinates on an iPad loaded with ArcGIS GPS software (Table 1). Upon arrival, macroinvertebrate richness was sampled first to avoid disruption of substrate habitats. Discharge samples were measured using a Marsh McBirney flow meter.

Sites WB 100, EB 200, and MB 31 were sampled on May 29, 2019. Physical and chemical properties such as Turbidity (NTU), pH, Dissolved-oxygen content (mg/L), temperature in Celsius, and conductivity (µS/cm) were collected on site using a Hydrolab, which was not done on the first day due to instrumental error. Velocity and discharge were not recorded at sites EB 200 and MB 31 on the 29th due to technical difficulties. Missing data was later sampled on June 2, 2019. Data was recorded on an iPad, and the operator stood downstream of the instrument to avoid disrupting the reading.

The sampling protocols used are as follows:

Macroinvertebrate Collection Protocol (as adapted from CABIN Stream Sampling Protocol pages 24-29 (2017) used by previous collectors)

Macroinvertebrate sampling is conducted across four sample habitats in a given site: cobble, sand, macrophytes, and woody substrates. Cobble refers to any small rocks available at the site. Sand refers to the fine substrate present at the site. Macrophytes are live aquatic plants, and woody habitats refer to any loose deadwood that could reasonably fit in our enamel pan to collect. Surber sampling bags of area 0.25 m^2 were used to collect from each of the four sample areas. The operator stood downstream of the sampler so as to not disrupt the substrate, and used the current and their hands to collect and dislodge any material. Samples were transferred to enamel pans and searched for macroinvertebrates for ten minutes with three people searching each pan using forceps and hands. Macroinvertebrates from each microenvironment were placed in labeled bottles containing 100% ethanol, with a total of 20 bottles (5 sites x 4 habitats per site). Once back from the field, each macroinvertebrate was identified under a microscope and sorted into the five functional feeding groups (FFGs): shredders, grazers, gathering collectors, filtering collectors, and predators. These FFGs were analyzed using previously established methods (Merritt & Cummins, 1996)**.**

Water Chemistry Sampling and Analysis Protocol

A water sample was collected to analyze the nutrient content of the water flowing in the Maple River. Acid-washed collection bottles were used to minimize contamination. Bottles were 150 mL and filled using a sampling syringe with filter attachment featuring 45-micron filters. The filter papers were not touched so as to avoid possible contamination. During sampling, filter papers were separated using forceps. Next, the 45-micron filter paper was carefully inserted into the attachment. The first 15 mL of water was expelled from syringe and the filter cartridge was attached. The contents of the syringe were then discharged into the collection bottle. This process was repeated until the collection bottle was full--approximately three times. The water filter was promptly removed from the syringe attachment and placed into a clean tin foil pack using forceps. Once collection was complete, the water samples were placed in a refrigerator for preservation and were analyzed in a lab at a later date.

Results

Physical and Chemical Properties of Water

The abiotic conditions of the stream changed upon dam removal. Discharge more than doubled at all five sampling sites when compared to data collected within the past four years. East Branch experienced the lowest discharge increases when compared to other sampling sites with a rate increase of 71 L/s to 1934 L/s (Figure 2).

Dissolved oxygen increased at the East and West Branches, while the Main Branch sites matched historical data of the past five years (Figure 3). Conductivity increased at sites MB 7 and MB 14—the closest downstream sites from the former dam site—with less notable changes in sites WB 100, MB 31 and, EB 200 (Figure 4). Every sampling site rose in turbidity over time, with the Main Branches experiencing the largest increases (Figure 5).

Nitrate concentrations decreased by multiple orders of magnitude (Figure 12 & Table 4) in all sites, whereas nitrogen increased overall in the West Branch and decreased in all other sites (Figure 15). The concentration of phosphate increased upstream of the dam site and decreased downstream relative to pre-removal conditions (Figure 13 & Table 5). However, the concentration of phosphorus in all forms within the stream increased greatly at each site, with the magnitude of the East Branch increase being highest (Figure 14). Ratios of N:P exhibit a shift from pre-dam removal values much greater than 15 to post-removal values much less than 15 (Table 6). Chlorophyll *a* concentration at each site also decreased further downstream (Figure 16 & Table 3).

Macroinvertebrates

The ratio of P/R at sites MB 14, MB 31, and MB 7 increased post-dam removal to greater than 0.75, changing their classification from heterotrophic to autotrophic. EB 200 also increased from about 0.085 to 0.349, and while WB 100 experienced no changes in its P/R ratio overall (Figure 6). The CPOM/FPOM ratio decreased most in sites MB 7, MB 14, and EB 200 (Figure 7). Sites MB 14 and MB 7 experienced stark increases in TFPOM/BFPOM ratios while the remaining three sites experienced a decrease (Figure 8). The measures of channel stability increased in sites MB 14, MB 7, and EB 200. MB 31 and WB 100 both experienced marginal decreases (Figure 9). Top-down control had a sharp increase in WB 100 and a small increase in MB 7, while all other sites had marginal decreases (Figure 10).

Discussion

It is clear that dam removal affects river environments differently across varying stream orders. The macroinvertebrate P/R ratios and discharge are most prominent at sites downstream of the dam, whereas phosphorus and Chlorophyll *a* increased most in the branches upstream of the dam. The strongest differences in discharge and P/R were present at site MB 7, immediately downstream of the dam removal area, highlighting spatial differences in river ecosystems. The greater impact of dam removal on the areas closest to the former dam may be explained by the larger intensity of disturbance caused by the increased discharge and turbidity that results from the uninhibited flow of the river. The results show that dam removal has substantial impacts on erosive capacity of the stream by way of increased discharge—especially downstream nearest to the dam removal. The resulting increase in turbidity and nutrient content allows for heightened primary production, demonstrated by the P/R ratio results. As the East and West Branches converge and the river increases in stream order, the river shifts from allochthonous to autochthonous. This observation is in alignment with the river continuum concept (Vannote et al., 1980), as the ecosystem's response to dam removal has varied across spatial conditions.

The P/R macroinvertebrate ratio interpretations provided by Table 2 show that all of the downstream sites went from heterotrophic designations to autotrophic after the dam was removed. This could be aided by the increased sediment deposits which were released with dam removal. Notably, the autochthonous character is greatest immediately after the former dam site, implying that the downstream ecosystem does not require external supplies of organic matter for nutrients. The P/R ratio remains autotrophic but approaches heterotrophic dominance with further downstream movement, potentially because the downstream ecosystem relies more on macrophytes from the riparian zones than upstream ecosystems. More vegetation may have been stripped away from sites closer to the dam during the initial influx of water than at sites further from the dam, meaning that there was relatively less allochthonous carbon available at sites closer to the dam and the ecosystem is supported by greater relative autotrophy.. Further analysis of riparian cover at each site may be useful in testing this hypothesis.

The decrease in nitrogen levels is consistent with established expectations for early stages of primary succession (Schindler et al, 2008), and when compared to phosphorus concentration there is a clear shift in the limiting resource from phosphorus (pre-removal) to nitrogen (post-removal) (Table 6). This result is supported by previous terrestrial experimentation (Chapin et al. 1994). Nitrogen appears to be the limiting nutrient in the Maple River, based on its low bioavailability and the deviation of post-removal N:P ratios below the standard of 15:1, while pre-removal conditions were all greater than 15 (Tables 4 & 5). The increased concentration of both phosphorus and phosphate across all sites can be explained by it no longer acting as a limiting agent of primary production—the organisms cannot uptake the excess phosphate because they are limited by nitrogen. The increase of phosphorus in its bioavailable form (phosphate) indicates that it is most likely not limiting in the river's current state, thereby demonstrating that the river is in the early stages of primary succession.

Another potential explanation for the increase of phosphorus is erosion due to increased discharge post-removal. Phosphorus primarily enters ecosystems through physical weathering of sediment. Greater erosive activity can be justified by increased turbidity and discharge post-removal (Figures 2 & 5). As increased velocity weathers sediment more rapidly, greater amounts of erosion occurs which results in an increase of sediment and phosphorus in the water.

As this analysis has found, the Maple River ecosystems appear to have changed as a result of dam removal and spatial orientation. Some physical properties were altered in similar magnitudes over the course of all sites (figures 2, 5), while other variables such as Chlorophyll *a* and P/R ratios (which are both proxy measures for primary production) varied across the geography of the river. The spatial factors that appear to alter succession can be explained using the river continuum concept; stream order is higher in downstream sites, which may explain the difference in responses between up and downstream. Further, the river's successional response changes among downstream sites, in a progression that aligns with the river continuum concept, indicating that both dam removal and spatial orientation influence the variance of ecosystem response.

Conclusion

Spatial shifts in biotic communities and abiotic features of the Maple River may occur due to differences in the Maple River ecosystems and might be observed and measured in future studies and placed within a temporal frame. As noted in this study, changes were different in sampling locations downstream of dam removal and less pronounced upstream in the East and West Branches.

This study would be most accurate and meaningful if post-removal sampling had equal or greater frequency of site visits as pre-removal data collection. A possible alternative explanation for differences in data is the time of collection and weather patterns. The four pre-removal sites were visited in mid-to-late July, while the post-removal sites were visited in late spring. Varying levels of snowfall, temperature differences, and spring precipitation levels also were not controlled for, which may have impacted the results.

Previous dam removal studies such as Thomson et al., 2005 have looked at smaller dams over a period of months, but this study looks at a variety of measures over a longer period of time. Follow up data will be collected in future months to continue the study of succession following dam removal with increased scrutiny. Examinations of other factors that may be indicative of a greater top-down view of ecology, such as a study of changing Teleost species distribution, could also be explored to provide a more comprehensive characterization of stream ecology.

Appendix

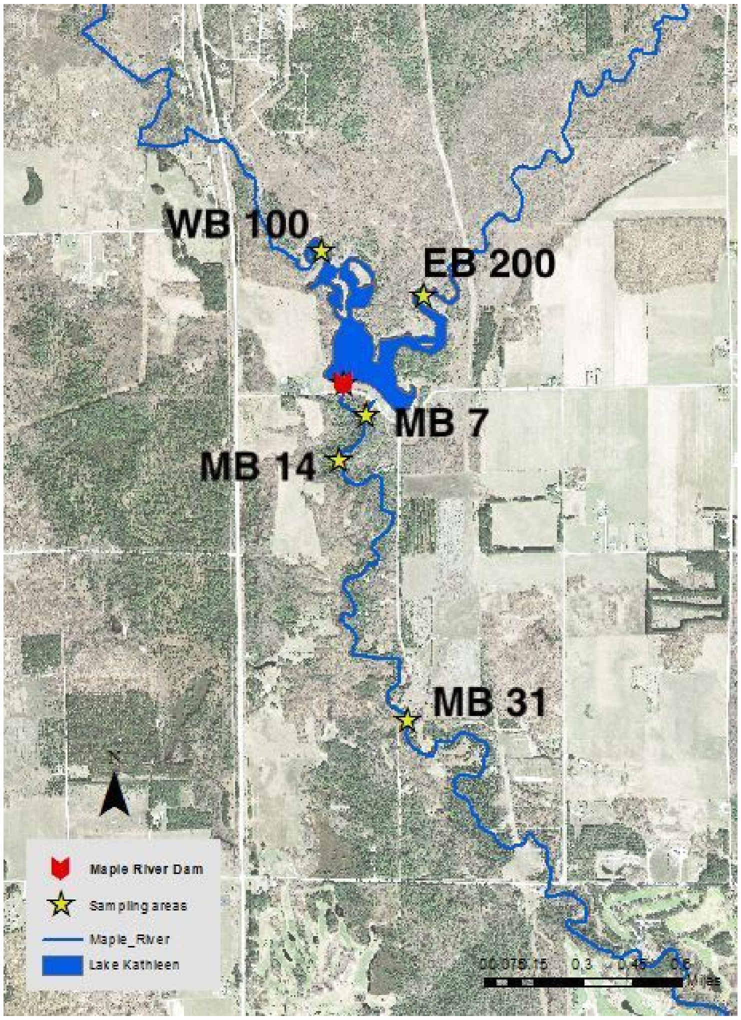

Figure 1: Map of sampling sites used in this study; the East Branch is fed primarily by surface water from Douglas Lake, and the West Branch is fed from a swamp and is primarily a ground water stream

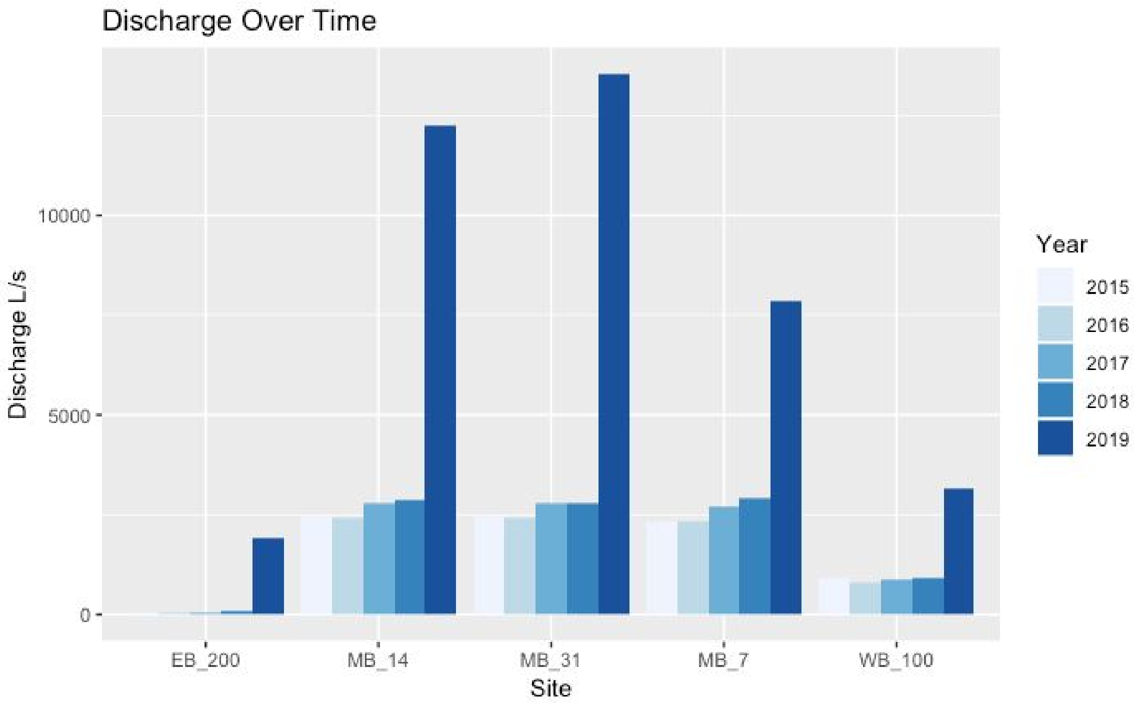

Figure 2: Discharge rates along three sites on the Main Branch of the Maple River (MB_14, MB_31, MB_7) as well as the East (EB_200) and West Branches (WB_100) measured from 2015-2019.

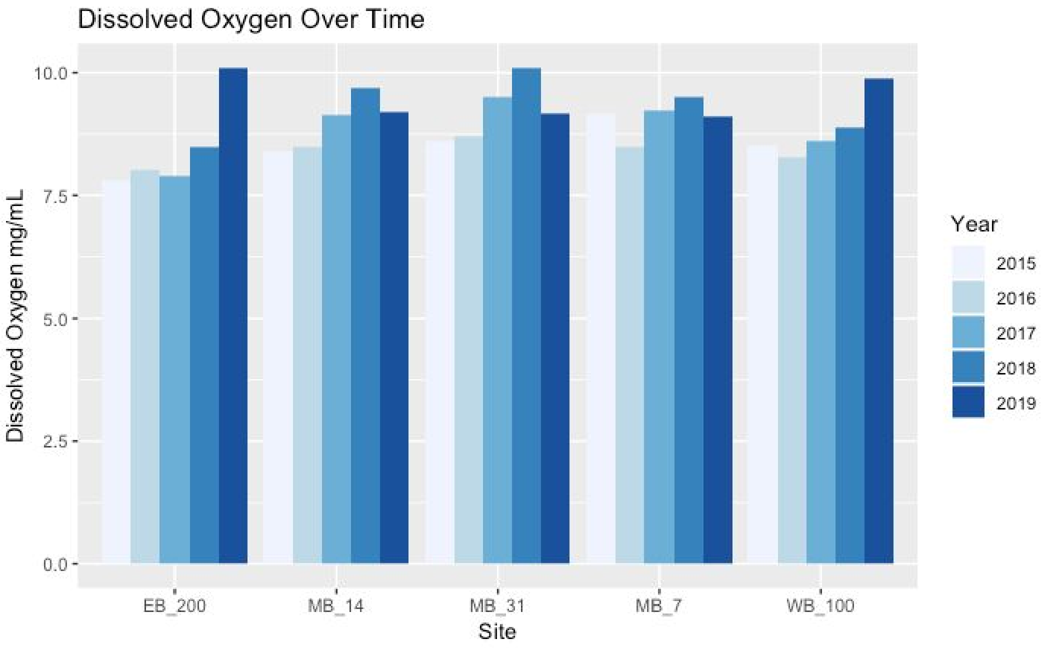

Figure 3: Dissolved oxygen (mg/mL) measured from 2015-2019 along the Main (MB_14, MB_31, MB_7), East (EB_200), and West (WB_100) Branches of the Maple River.

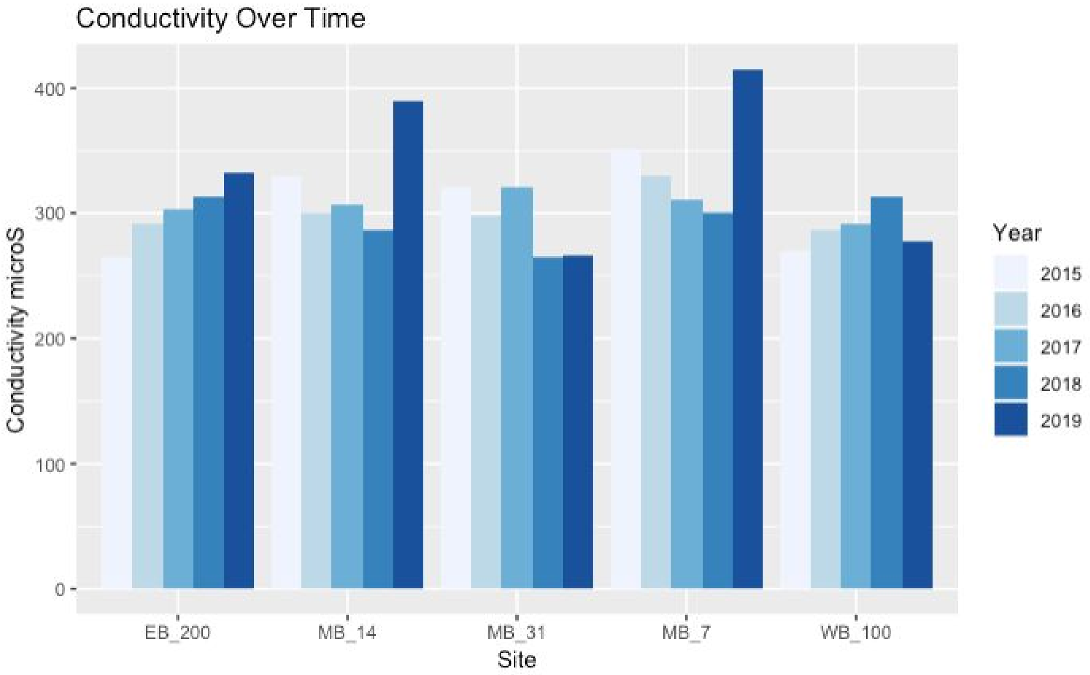

Figure 4: Conductivity (µ per meter) measured from 2015-2019 along the Main (MB_14, MB_31, MB_7), East (EB_200), and West (WB_100) Branches of Maple River.

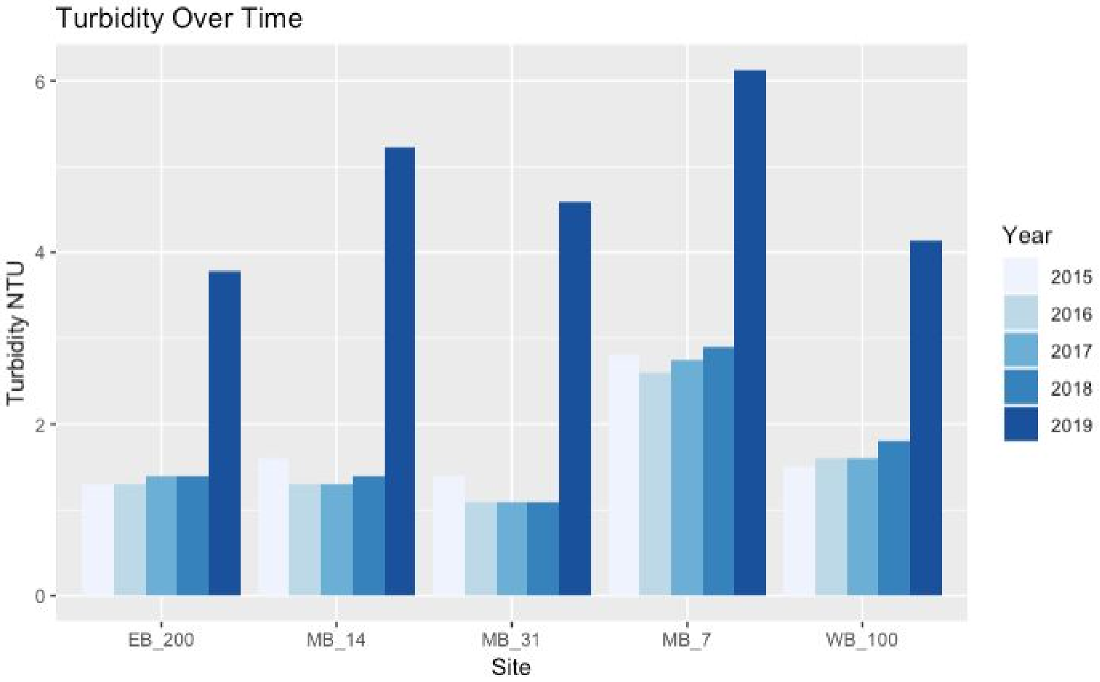

Figure 5: Turbidity (NTU) measured from 2015-2019 along the Main (MB_14, MB_31, MB_7), East (EB_200), and West (WB_100) Branches of the Maple River measured from 2015- 2019.

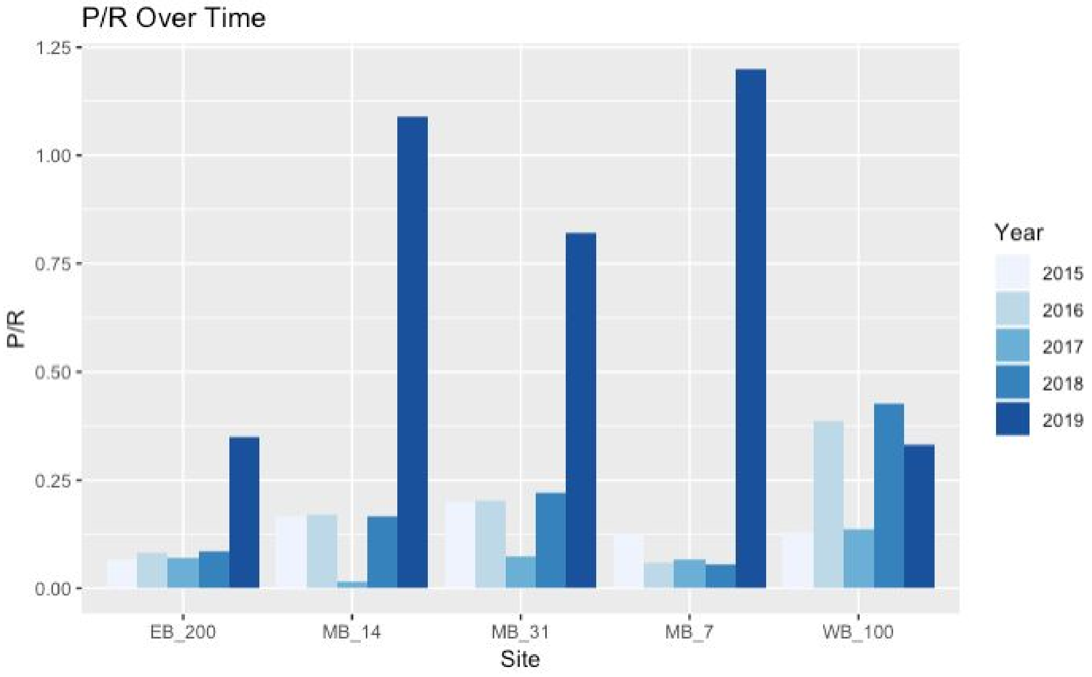

Figure 6: P/R (Scrapers / Shredders + Total Collectors) collected from 2015-2019 on the Main (MB_14, MB_31, MB_7), East (EB_200), and West (WB_100) Branches of the Maple River.

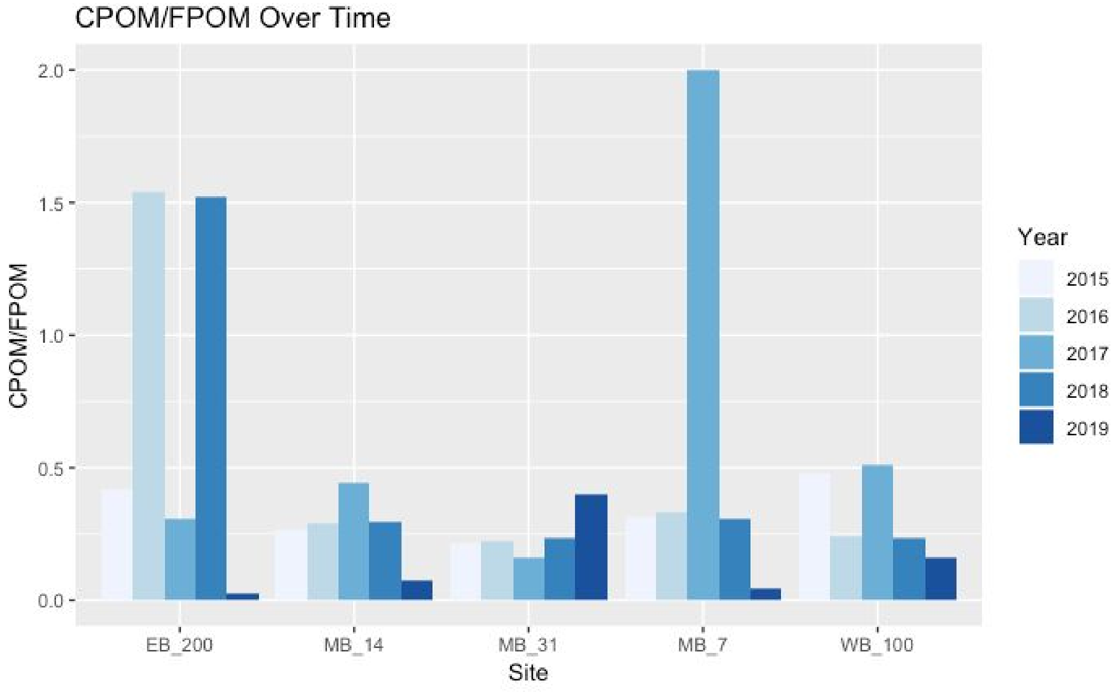

Figure 7: CPOM/FPOM (Coarse Particulate Organic Matter / Fine Particulate Organic Matter) measured from 2015-2019 along the Main (MB_14, MB_31, MB_7), East (EB_200), and West (WB_100) Branches of Maple River.

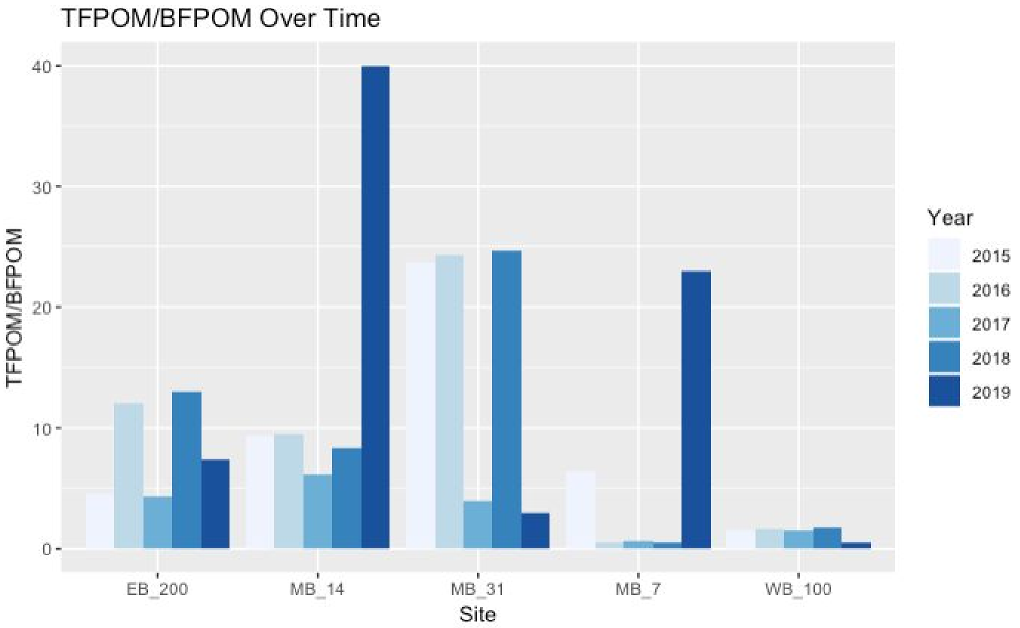

Figure 8: TFPOM/BFPOM (fine particulate organic matter suspended / fine particulate organic matter deposited) measured from 2015-2019 along the Main (MB_14, MB_31, MB_7), East (EB_200), and West (WB_100) Branches of Maple River.

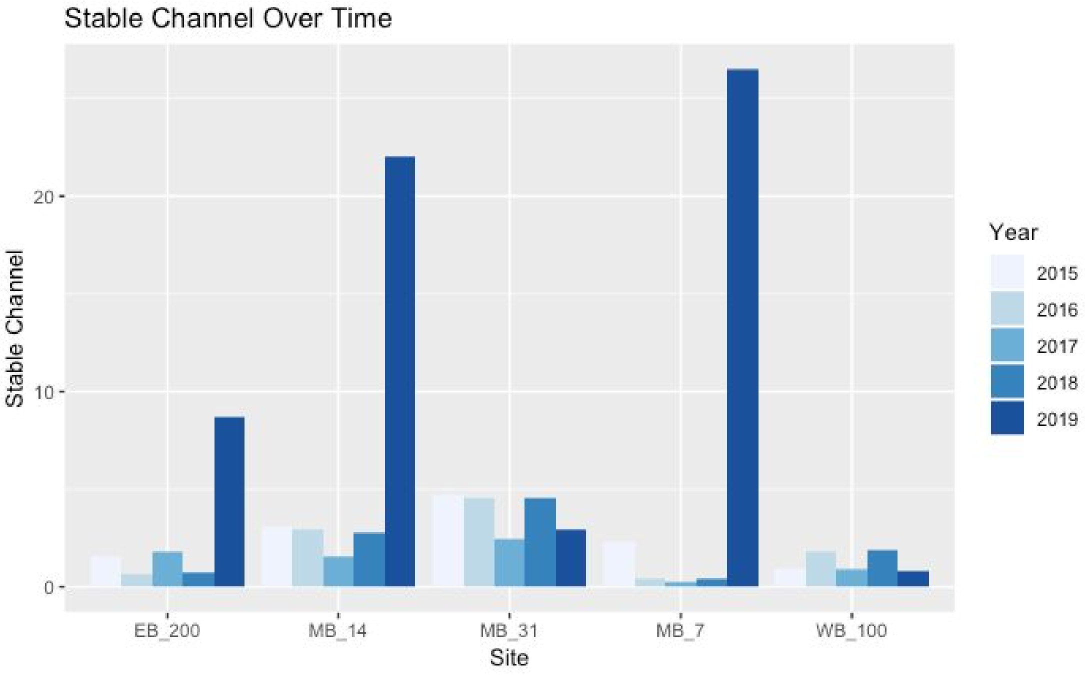

Figure 9: Substrate Stability (scrapers and filterers / gatherers and shredders) measured from 2015-2019 along the Main (MB_14, MB_31, MB_7), East (EB_200), and West (WB_100) Branches of Maple River.

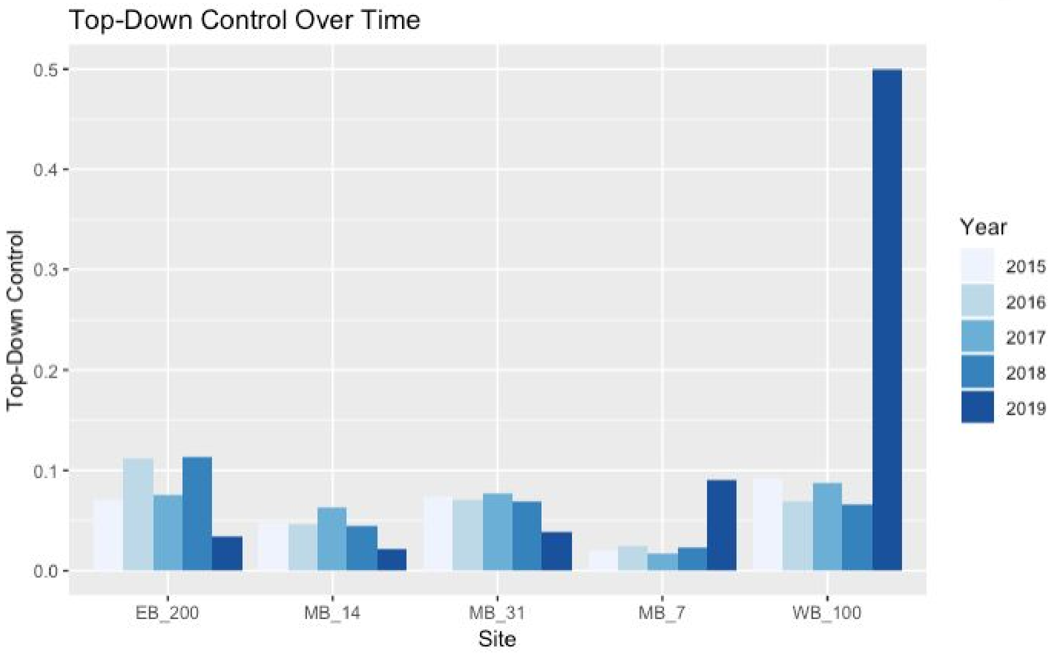

Figure 10: Top-down control (predator to prey balance) measured from 2015-2019 along the Main (MB_14, MB_31, MB_7), East (EB_200), and West (WB_100) Branches of Maple River.

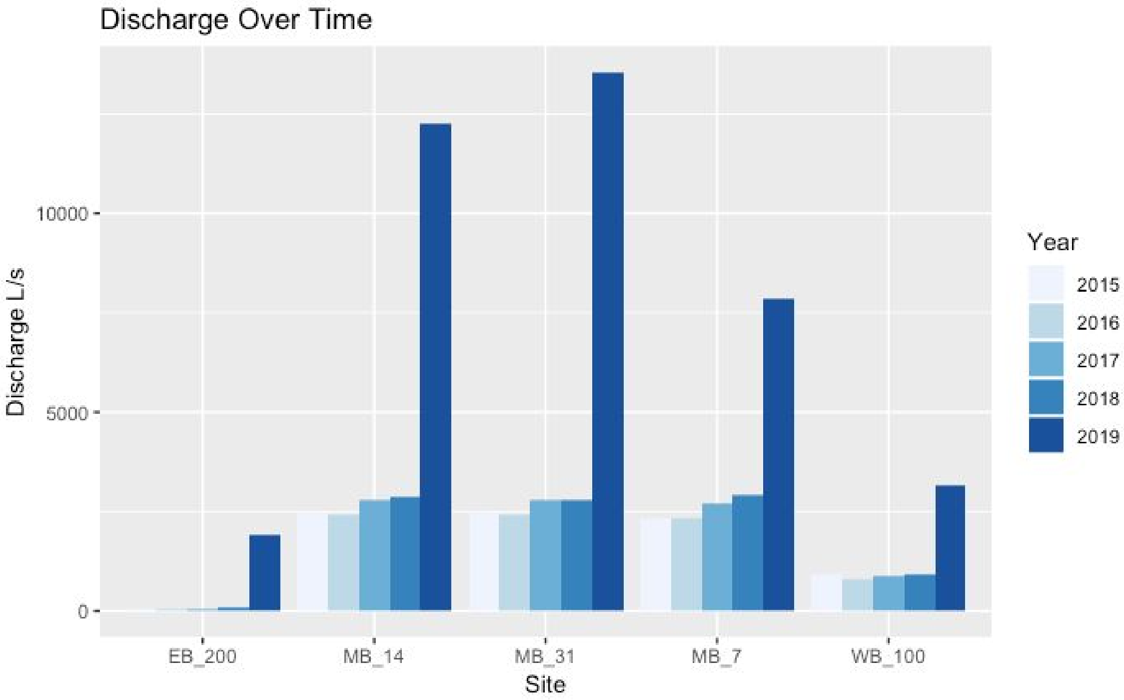

Figure 11: Discharge rates along three sites on the Main Branch of the Maple River (MB_14, MB_31, MB_7) as well as the East (EB_200) and West Branches (WB_100) measured from 2015-2019.

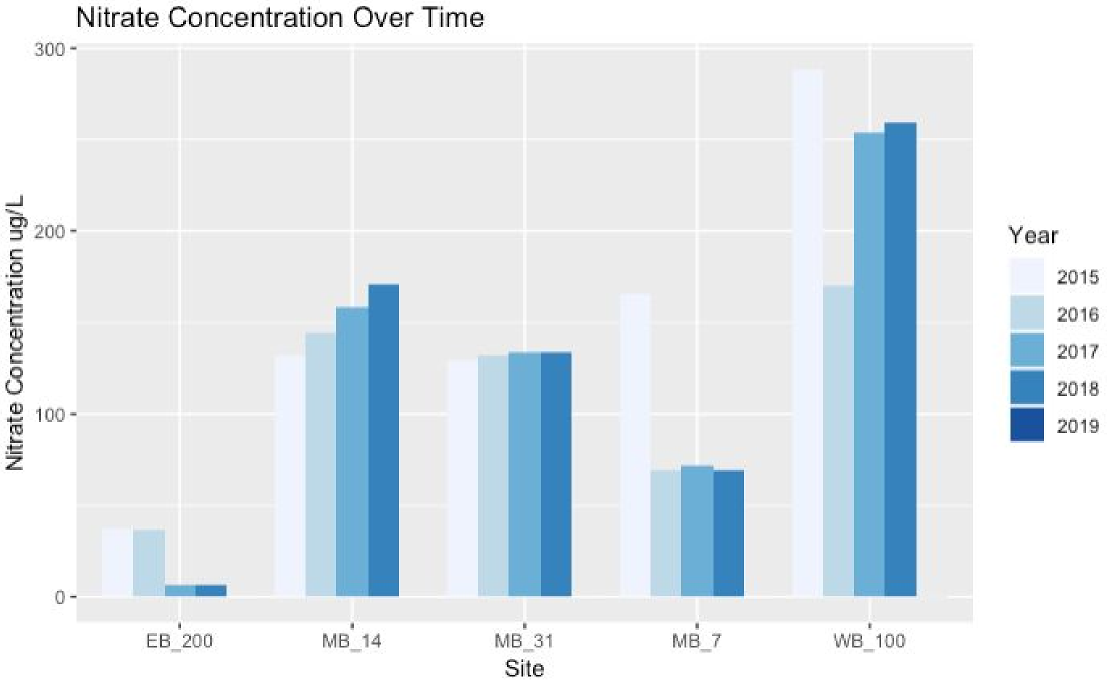

Figure 12: Nitrate Concentration (ug/L) along three sites on the Main Branch of the Maple River (MB_14, MB_31, MB_7) as well as the East (EB_200) and West Branches (WB_100) measured from 2015-2019.

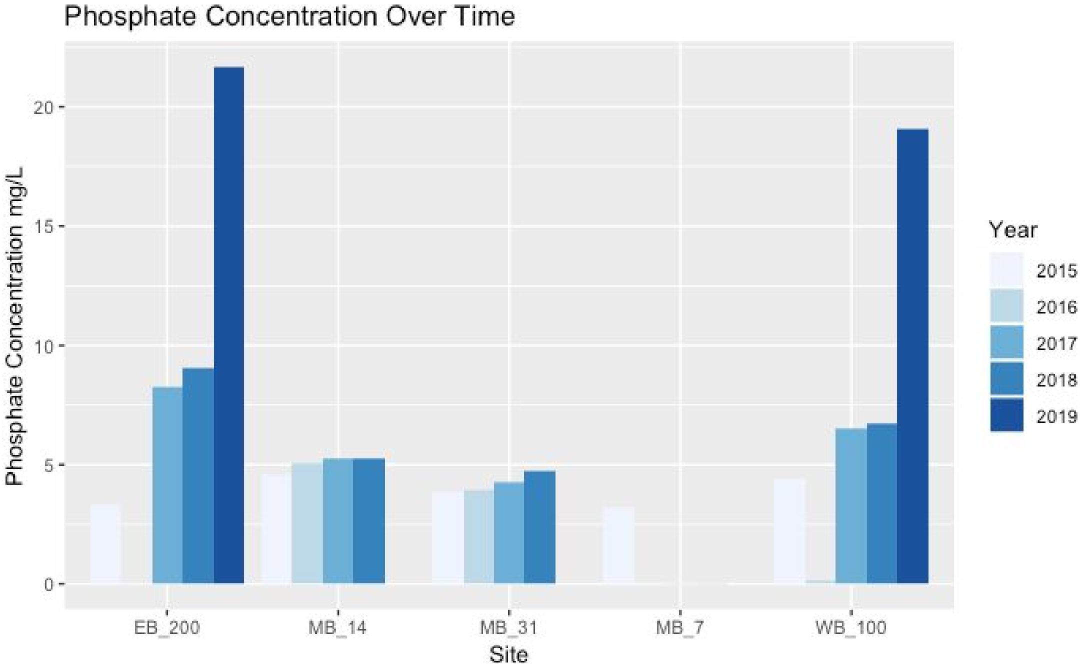

Figure 13: Phosphate Concentration (mg/L) along three sites on the Main Branch of the Maple River (MB_14, MB_31, MB_7) as well as the East (EB_200) and West Branches (WB_100) measured from 2015-2019.

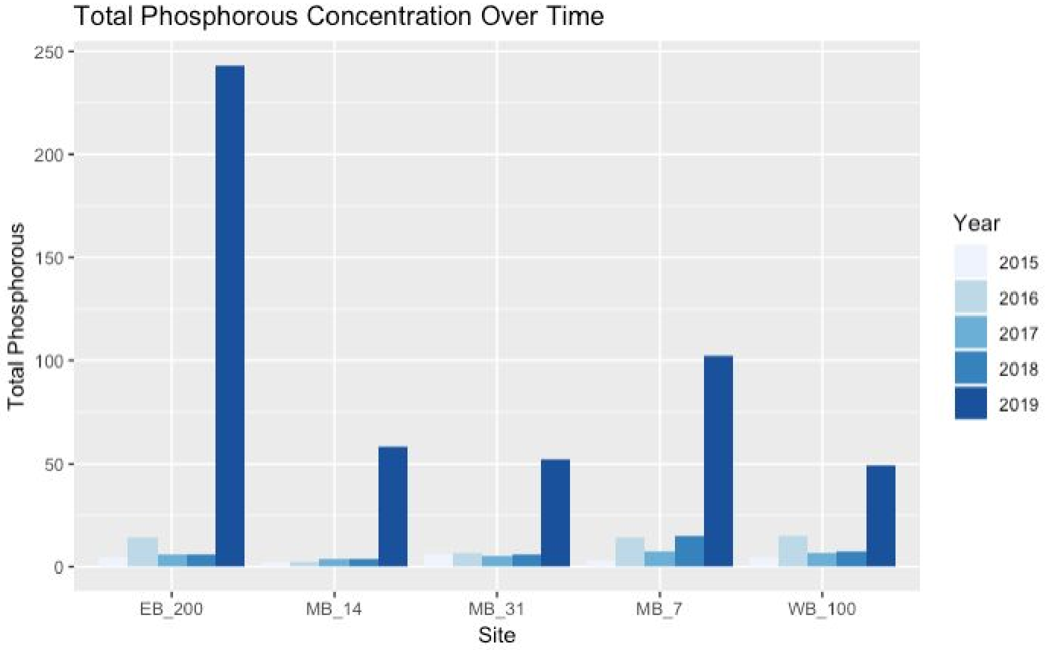

Figure 14: Total Phosphorus Concentration (ug/L) along three sites on the Main Branch of the Maple River (MB_14, MB_31, MB_7) as well as the East (EB_200) and West Branches (WB_100) measured from 2015-2019.

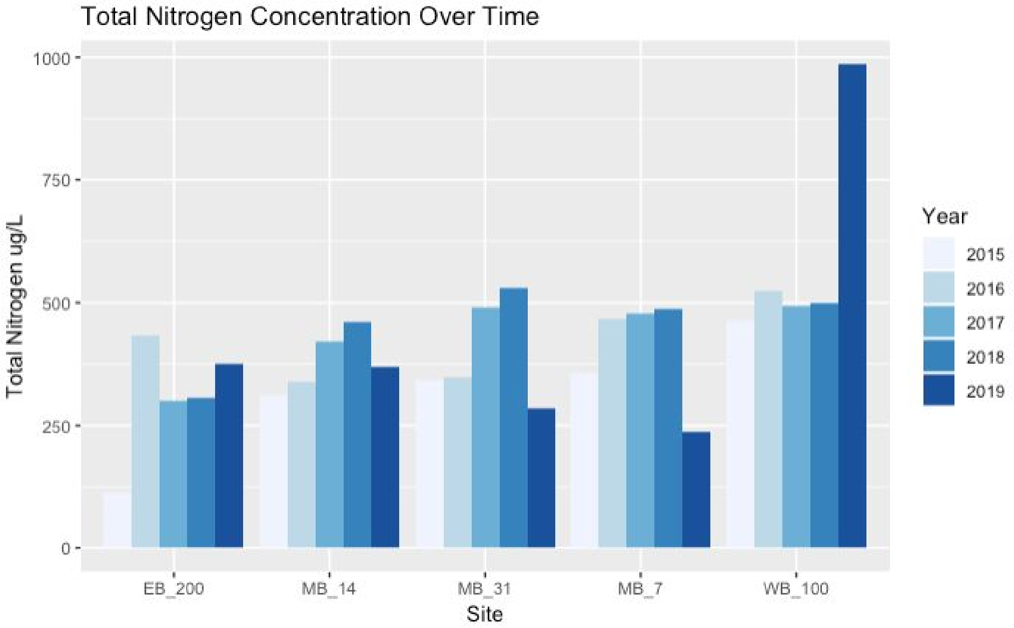

Figure 15: Total Nitrogen Concentration (ug/L) along three sites on the Main Branch of the Maple River (MB_14, MB_31, MB_7) as well as the East (EB_200) and West Branches (WB_100) measured from 2015-2019.

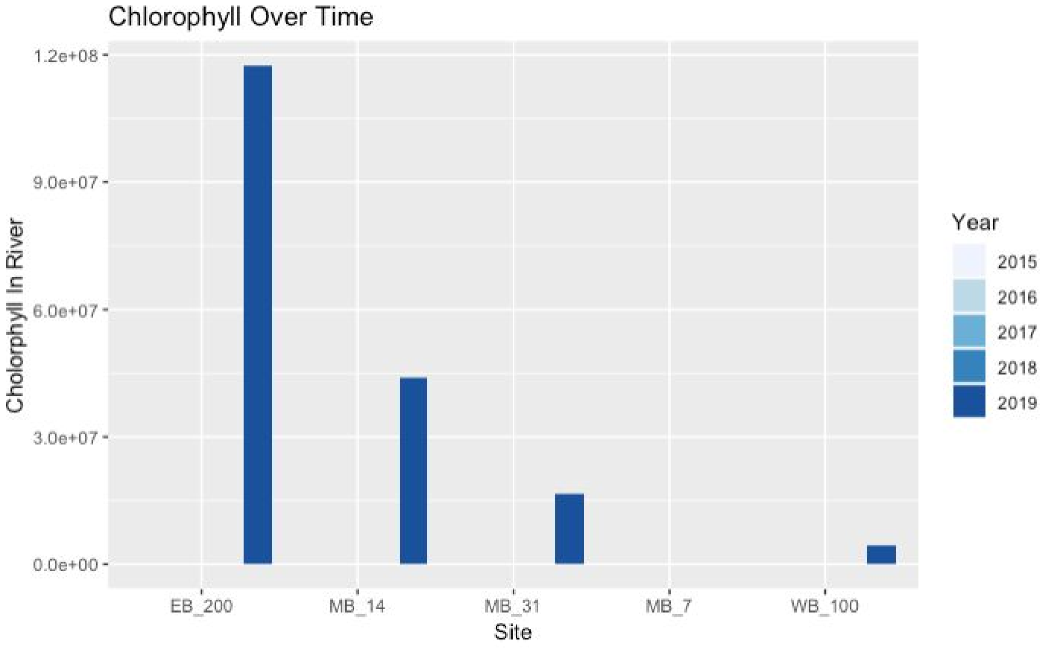

Figure 16: Chlorophyll *a* Concentration (ug/L) along three sites on the Main Branch of the Maple River (MB_14, MB_31, MB_7) as well as the East (EB_200) and West Branches (WB_100) measured from 2015-2019.

Table 1: GPS coordinates of each sampling site

Site Location	West Branch 100	East branch 200	Main branch 7	Main branch 14	Main Branch 31
GPS coordinates	-84.77857 45.534475	-84.770669 45.533227	-84.774381 45.528211	-84.775476 45.526415	-84.771517 45.517153

Table 2: Table of macroinvertebrate ratio interpretations based on Merritt and Cummins, 1996

Site Code, time period	P/R >.75	CPOM/ FPOM >.25	TFPOM/ BFPOM>.5	Stable Channel>.5	Top-Down Control .1-.2
EB 200, Pre-removal 4yr avg.	**Heterotrophic** 0.076253	**Normal** shredder association to functioning riparian system 0.946205	**Greater than normal** suspended FPOM 8.478125	**Stable substrates plentiful** (bedrock, boulders, cobble, large woody debris) 1.197041	**Approximately typical** predator to prey balance 0.092922
EB 200, Post-removal (2019)	**Heterotrophic** 0.348837209	**Below normal** shredder association to functioning riparian system 0.023809524	**Greater than normal** suspended FPOM 7.4	**Stable substrates plentiful** (bedrock, boulders, cobble, large woody debris) 8.666666667	**Atypical** predator to prey balance 0.034482759
WB 100, Pre-removal 4yr avg.	**Heterotrophic** 0.27076	**Normal** shredder association to functioning riparian system 0.366374	**Greater than normal** suspended FPOM 1.578947	**Stable substrates plentiful** (bedrock, boulders, cobble, large woody debris) 1.366139	**Atypical** predator to prey balance 0.079075
WB 100, Post-removal (2019)	**Heterotrophic** 0.333333333	**Below normal** shredder association to functioning riparian system 0.161290323	**Normal** suspended FPOM 0.476190476	**Stable substrates plentiful** (bedrock, boulders, cobble, large woody debris) 0.846153846	**Atypical** predator to prey balance .5
MB 7,	**Heterotrophic**	**Normal**	**Greater**	**Stable**	**Approximately**

Pre-removal 4yr avg.	0.077116	shredder association to functioning riparian system 0.738007	**than normal** suspended FPOM 1.986723	**substrates plentiful** (bedrock, boulders, cobble, large woody debris) 0.823258	**typical** predator to prey balance 0.21338
MB 7, Post-removal (2019)	**Autotrophic** 1.2	**Below normal** shredder association to functioning riparian system 0.041666667	**Greater than normal** suspended FPOM 23	**Stable substrates plentiful** (bedrock, boulders, cobble, large woody debris) 26.5	**Approximately typical** predator to prey balance 0.090909091
MB 14, Pre-removal 4yr avg.	**Heterotrophic** 0.12903135	**Normal** shredder association to functioning riparian system 0.32168848	**Greater than normal** suspended FPOM 8.3139881	**Stable substrates plentiful** (bedrock, boulders, cobble, large woody debris) 2.57304029	**Atypical** predator to prey balance 0.05009105
MB 14, Post-removal (2019)	**Autotrophic** 1.090909091	**Below normal** shredder association to functioning riparian system 0.073170732	**Greater than normal** suspended FPOM 40	**Stable substrates plentiful** (bedrock, boulders, cobble, large woody debris) 22	**Atypical** predator to prey balance 0.02173913
MB 31, Pre-removal 4yr avg.	**Heterotrophic** 0.174857	**Below normal** shredder association to functioning riparian	**Greater than normal** suspended FPOM 19.14035	**Stable substrates plentiful** (bedrock, boulders, cobble, large	**Atypical** predator to prey balance 0.073014

		system 0.208739		woody debris) 4.054956	
MB 31, Post-removal (2019)	**Autotrophic** 0.821428571	**Normal** shredder association to functioning riparian system 0.4	**Greater than normal** suspended FPOM 3	**Stable substrates plentiful** (bedrock, boulders, cobble, large woody debris) 2.923076923	**Atypical** predator to prey balance 0.039215686

Table 3: Chlorophyll *a* (ug/L)

	WB_100	**EB_200**	**MB_7**	**MB_14**	**MB_ 31**
2015	0.294	0.194	0.698758457	0.517	0.489
2016	1.83	4.685	3.45	0.54802	0.53301
2017	1.352227014	0.207039543	0.487692192	0.425535344	0.207986376
2018	1.473927446	0.209109938	3.6225	0.468088878	0.207986376
2019	4282656.681	117451595.7	NA	43979187.66	16776781.54

Table 4: Nitrate (ug/L)

	WB_100	**EB_200**	**MB_7**	**MB_14**	**MB_ 31**
2015	288.4	37.1	165	132	129.3
2016	169.6	36.6	69.4	143.88	131.886
2017	254	6.4	72.176	158.268	133.20486
2018	259.08	6.4	69.4	170.92944	133.20486
2019	0.5	0.034482759	0.02173913	0.02173913	0.039215686

Table 5: Phosphate (ug/L)

	WB_100	**EB_200**	**MB_7**	**MB_14**	**MB_ 31**
2015	4.38	3.3	3.23	4.57	3.86
2016	0.1607	0.102	0.0102	5.027	3.9372
2017	6.51	8.28	0.0102	5.228	4.292
2018	6.705	9.025	0.0106	5.28	4.721
2019	19.056	21.675	N/A	N/A	N/A

Table 6: N : P Ratios, compared to 15:1 for classification of limiting nutrient (ug/L). 15 signifies the threshold to distinguish between Phosphorus or Nitrogen limitation. If the ratio is above 15, it indicates a Phosphorus limitation. If it is below 15 it indicates a Nitrogen limitation.

Site	**Year**	**Total P (ug/L)**	**Total N (ug/L)**	**ratio (N/P)**	**Limiting Nutrient**
MB_7	2015	3.09	356.4	**115.339806**	**Phosphorus**
MB_14	2015	2.65	313	**118.113208**	**Phosphorus**
MB_31	2015	6.1	341.8	**56.0327869**	**Phosphorus**
WB_100	2015	4.7	463.5	**98.6170213**	**Phosphorus**
EB_200	2015	4.6	112.4	**24.4347826**	**Phosphorus**
MB_7	2016	14.5	464.9	**32.062069**	**Phosphorus**
MB_14	2016	2.65	338.04	**127.562264**	**Phosphorus**
MB_31	2016	6.588	348.636	**52.9198543**	**Phosphorus**
WB_100	2016	15	524.2	**34.9466667**	**Phosphorus**
EB_200	2016	14.5	432.6	**29.8344828**	**Phosphorus**
MB_7	2017	7.929	477.144	**60.1770715**	**Phosphorus**

MB_14	2017	3.549	419.33	**118.15441**	**Phosphorus**
MB_31	2017	5.652	489.512	**86.6086341**	**Phosphorus**
WB_100	2017	7.12	494.4	**69.4382022**	**Phosphorus**
EB_200	2017	5.88	301.3	**51.2414966**	**Phosphorus**
MB_7	2018	14.935	488.145	**32.6846334**	**Phosphorus**
MB_14	2018	3.549	461.263	**129.969851**	**Phosphorus**
MB_31	2018	5.99112	528.67296	**88.2427593**	**Phosphorus**
WB_100	2018	7.7608	499.344	**64.3418204**	**Phosphorus**
EB_200	2018	6.0564	307.326	**50.7440063**	**Phosphorus**
MB_7	2019	101.9691	236.8085	**2.3223555**	**Nitrogen**
MB_14	2019	58.2844	370.5555	**6.35771321**	**Nitrogen**
MB_31	2019	52.1382	285.055	**5.46729653**	**Nitrogen**
WB_100	2019	49.0262	986.6685	**20.1253309**	**Phosphorus**
EB_200	2019	243.2928	376.052	**1.54567665**	**Nitrogen**

Table 7: N:P ratio averages before compared to data after dam removal (ug/L).

	WB_100	**EB_200**	**MB_7**	**MB_14**	**MB_ 31**
Pre-Removal Average	66.839276	39.0636920	60.0658949	123.449933	70.9510086
Post- dam removal	20.1253309	1.54567665	2.3223555	6.35771321	5.46729653

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