10-2017

# Quantity and Quality of Suspended Particulate Organic Matter Upstream and Downstream of a Series of Surface-Release Impoundments on the Upper Mississippi River

Joshua Mankowski
*St. Cloud State University*, josh312583@msn.com

**Quantity and Quality of Suspended Particulate Organic Matter Upstream and Downstream of a Series of Surface-Release Impoundments on the Upper Mississippi River**

by

Joshua J. Mankowski

A Thesis

Submitted to the Graduate Faculty of

St. Cloud State University

in Partial Fulfilment of the Requirements

for the Degree of

Master of Science

in Ecology and Natural Science

October, 2017

Thesis Committee:
Dr. Neal J. Voelz, Chairperson
Dr. William M. Cook
Dr. Charles L. Rose

## Abstract

Through the continual flow of water in lotic systems, upstream impacts may be observed in downstream reaches. The River Continuum Concept classifies and describes abiotic and biotic processes as a river flows from headwaters to mouth. Disruptions of the theoretical system by impoundments are described by the Serial Discontinuity Concept that predicts, among other things, changes in biotic and abiotic stream processes. This study observed four surface-release impoundments on the Upper Mississippi River and documented impacts on the quantity and quality of fine particulate organic matter (FPOM) and looked for evidence of the Serial Discontinuity Concept. It was hypothesized that there would be an increase in the FPOM downstream of the impoundments, that there would be an impact on the quality of the FPOM, and that there would be evidence to support the Serial Discontinuity Concept. Three scenarios were observed in the quantity of the FPOM. 1) No difference between above and below sampling sites, 2) higher amounts of FPOM above the impoundments, and 3) higher amounts of FPOM below the impoundments. The hypothesis that there would be an increased amount of FPOM was supported by the third scenario. The results did not support the hypothesis that there would be an impact on the quantity of FPOM, there were no significant differences in phosphorus content between sampling sites. Disconnected sections of the river were found in support of the Serial Discontinuity Concept.

## Acknowledgment

For my wife, Erin Mulvany-Mankowski, thank you for your support and pushing me to complete this project. Even when I gave up on it, you didn't.

For my mom, Pauline Lambrecht, thank you for instilling within me the importance of education and for supporting me these many years.

For my advisor, Dr. Neal Voelz, thank you for sticking with me through this long process and all you have done to get me to the end.

For Dr. Adam Kay, University of St. Thomas, thank you for the use of your laboratory and your help analyzing samples.

# Table of Contents

Page

## List of Figures

Figure Page

**List of Tables**

## Introduction

Water in streams is always moving, flowing downstream. Through the flow of the water, upstream impacts (e.g. agriculture, clearing of trees, impoundments, etc.) can be observed in physical and chemical properties for some distance downstream. Through this continual current it is observed that the downstream stretch of a river is heavily dependent on upstream processes (Vannote et al. 1980). Vannote et al (1980) also reasoned that producer and consumer communities become established in given reaches of a river in harmony with dynamic physical conditions within the waterway. One of the processes that is important to lotic organisms that may be impacted by modifications to a lotic system is the flow and breakdown of particulate organic matter (POM). At the headwaters of streams that originate in deciduous forests, allochthonous coarse particulate organic matter (CPOM; ≥ 1 mm) forms the basis of the food web. At this point, the stream is small and greatly shaded by trees, and there may not be enough sun to support adequate primary productions. In these situations, the food web of the stream depends primarily on terrestrial sources for nutrient input (Wang et al. 2014, Brett 2017).

The nutrients enter the stream mainly in the form of deciduous leaf material or CPOM. This material supports the primary consumers of the stream ecosystem, the shredder and collector invertebrates (Finlay 2001). Through their actions, the CPOM is broken down into smaller pieces while it is simultaneously washed downstream by the flow of the water. As the POM becomes smaller, its surface area to volume ratio becomes larger. This increase in surface area supports growing communities of microbes that feed on the organic components. These large communities of microbes increase the quality of the now fine particulate organic matter (FPOM; 0.45 µm-1mm) (Vannote et al. 1980, Graca and Canhoto 2006). As the water continues to flow, the river becomes larger and more sunlight can reach the water's surface. As more light reaches the surface of the river, primary production begins to increase. At this point, the food web switches from being supported by CPOM to being supported by FPOM and increasingly by autochthonous primary production (Vannote et al. 1980). There is also a change in the micro and macroorganism populations, shifting from being dominated by shredder species to assemblages of species that feed on algae (Patrick 2013).

The natural flow of water down a stream can be disturbed by impoundments. An impoundment is any structure that collects and confines water and creates a reservoir. The result of constructing these structures is to impede the natural flow of water in a system, greatly disrupting the River Continuum Concept (Vannote et al. 1980, Ward and Stanford 1983). Humans have been creating impoundments for centuries to store drinking water, power equipment, produce electricity, increase navigability and to supply water to agriculture. According to the Army Corps of Engineers' National Inventory of Dams (2017), 90,580 dams are currently in the United States, 1097 of those are in Minnesota. Besides holding back water, impoundments affect flow regimes, sedimentation rates, impede the movement of species up and downstream, and various other impacts. Impoundments ultimately divide up these continually moving systems into definite fragments.

Impoundments can be divided into various categories based on many various factors, including construction material, design, purpose, or water release. For this study, impoundments are divided into two categories depending on their designed release of water: deep-release and surface-release.

A deep-release impoundment is a dam that is capable of releasing water from the deepest part of the reservoir. This style of impoundment tends to be taller, storing copious amounts of water. Deep-release impoundments are, thus, capable of releasing water from deeper depths, creating a different temperature regime than a free-flowing river. This usually results in colder temperatures in the summer months and warmer temperatures in the winter months, altering the regime. These impacts will then be reflected in the different populations of species downstream.

A surface-release impoundment allows water to flow over a weir. Surface-release impoundments lack the height needed to create cold water storage and, during the hot months, may have an opposite impact, allowing warmer surface water to more easily flow over the impoundment.

Impoundments help stabilize a seemingly chaotic lotic system (e.g. reducing or eliminating flood events, provide a constant flow throughout the year). Impoundments can be installed in a stream or river for many reasons—flow control and water storage are two of the biggest. Lotic systems and the species that make them their home have adapted to variability offered by this environment. By artificially adding stability, species that have adapted to these areas may be out competed by other species (Ziger 1985). Over time, species that are favored by this type of habitat will increase in number and replace other species, reducing diversity. With this loss of diversity, the system becomes less stable (MacArthur 1955, Goodman 1975). These different organisms will also impact food web dynamics (Patrick 2013). The varied species present will impose different pressures on the food web by modifying predator-prey relationships and by altering the food quality available to species higher in the food web (Conde-Porcuna 2000, Bonsall and Hastings 2004).

The impacts an impoundment can have on a river system are profound. The areas both downstream and upstream from the impoundment are far different from the natural river system that existed pre-impoundment. The water above the impoundment begins to backup, creating a reservoir, flooding over the natural banks of the channel. The water in this area has a slower velocity, decreasing its ability to carry particulate matter. This area begins to act more like a lentic system (Bott et al. 2006, Okuku et al. 2016). The impacts caused by this change then can impact organisms for kilometers downstream. Eventually, after flowing downstream, the system begins to return to a more natural condition, acting again like a riverine system (Ward and Stanford 1983, Yount and Niemi 1990). If a river has multiple impoundments, forming a series of disturbances to the system, these impacts may become cumulative, creating a condition where it takes longer and longer for the system to revert to a more natural state (Ward and Stanford 1983, Matzinger et al. 2007).

Changes in the quantity and quality of the particulate organic matter flowing downstream can impact the growth rate of the organisms that reside in the stream. Not only is the quantity of food important, but also the overall quality for providing the needed nutrients. One way to measure the quality of food in an aquatic environment is the ratio of carbon to phosphorus (C:P). If a food source has a higher C:P ratio, more food will need to be consumed to obtain the needed amount of phosphorus; there is also an increased energy cost for obtaining, consuming and breaking down this food to acquire the needed nutrients. All organisms need phosphorus to perform many of their internal processes, from protein synthesis to energy storage in the form of Adenosine Triphosphate. According to the Growth Rate Hypothesis, the amount of phosphorus in an organism's tissues is directly related to its growth rate (Urbe et al. 1997). This is believed to be true because a higher level of phosphorus can be translated into a higher level of RNA. Higher levels of RNA can support higher levels of protein synthesis (Main et al. 1997; Hessen et al. 2007).

An impoundment can alter the phosphorus concentration of POM flowing downstream, thus changing the quality of the food available at the basis of the food web (Liu et al. 2016). This can be done by altering the composition of the microorganism community or by altering how particulate autochthonous material flows downstream. If an organism's food sources are of a lower quality, it will need to take in more food to get the needed nutrients (Kilham el al. 1997). This need to exert more energy to obtain the needed nutrients leaves fewer resources for reproduction, reducing fecundity (Kilham el al. 1997) and possibly reducing generational recruitment (Korpinen and Jormalainen 2008).

A shift in resource quantity and quality can have a compounding impact on food web dynamics. If food sources are of lower quality, then more needs to be consumed to gain the same amount of a limited nutrient (Kilham el al. 1997). By impacting the base of a food web, these impacts can reverberate up into consumer species, with consumers needing to expend more energy to obtain more food to gain the needed nutrients to have higher fecundity (Kilham el al. 1997). A similar impact can be seen with the quantity of food. Low amounts of food can have a similar impact as low quality food (Kilham el al. 1997). Even if food sources are of high quality, if there isn't enough in the environment, then fecundity will be impacted. These effects can be compounding, with low amounts of low quality food resources have an even more negative impact on the different species in the system. Impacts can also be felt on species dynamics with high amounts of high quality food. With this no longer being a limiting resource, species that are better at competing for other resources such as space may be favored in the alternate dynamic (Conde-Porcuna 2000).

The organisms that populate lotic systems have adapted over time to handle the flow variability of moving water. The organisms have adapted to changes in flow regime brought on by seasonal variation. By installing impoundments in these systems, artificial stability has been introduced in a system adapted to change (Ziser 1985). Not only do impoundments impact the variability in a steam, but they create a reservoir. This reservoir can introduce an artificial lentic environment within the stream (Okuku el al. 2016); a lake within a river. This provides a habitat more suited to species that have evolved in a lentic environment. These organisms are better adapted to more stagnant water and may outcompete organisms that would naturally habitat this area if it were not for the impoundment.

Impoundments have a substantial impact on our river systems and, even though work has been done to look at these impacts, much more work is needed. This study intends to look at the impacts impoundments on a limited stretch of the Upper Mississippi River may have on the quantity and quality of fine particulate organic matter in the water column. It is hypothesized that, because of increased primary production of plankton in the reservoir, there will be an increase in FPOM downstream of the impoundments. Adams et al. (1983) stated that an increase in primary production in the reservoir, may support higher levels of FPOM flowing over the impoundment. It is also hypothesized that there will be an impact on the quality of FPOM as it relates to its phosphorus content. This is hypothesized because of a shift from allochthonous material to zooplankton and phytoplankton caused by the widened channel that is the reservoir. This study will also look for evidence of the Serial Discontinuity Concept as described by Ward and Stanford (1983) as it pertains to samples collected going downstream in this stretch of river. Support for the Serial Discontinuity Concept will be shown by finding significant disconnects between upstream and downstream sample sites. A significant difference between these sample locations would demonstrate that the system is attempting to normalize as it moves downstream.

## Study Sites

This study was conducted on the Upper Mississippi River between river kilometer 1,556.5 and 1491. This stretch of the Mississippi River flows through five communities in Minnesota: Little Falls, Royalton, Rice, Sartell, and St. Cloud. There are four impoundments on this section of the river. The impoundments' impacts will be observed in this study. The location of the impoundments and their relation to each other can be seen in Figure 1.

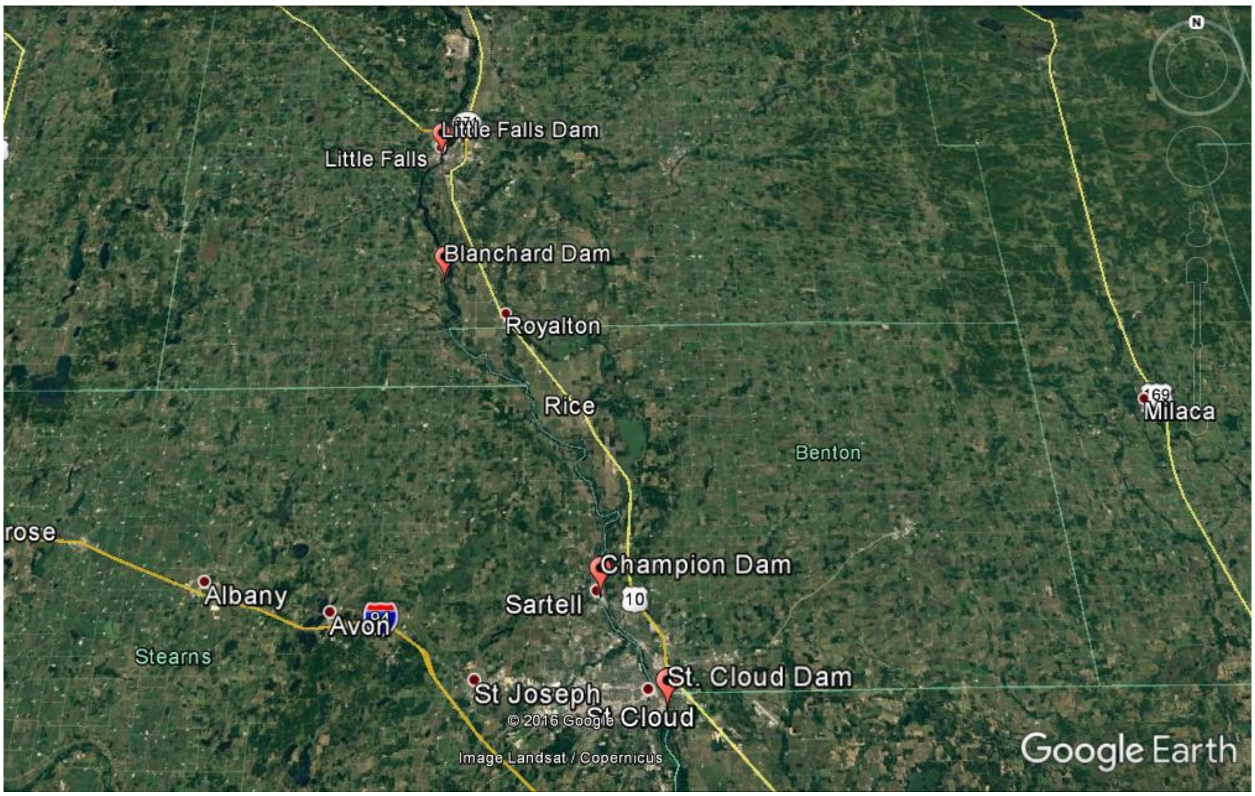


Figure 1: This map shows the four impoundment locations utilized in this study and their relation to area cities.

Little Falls Dam

Located at river kilometer 1,553.3 (45.975897, -94.367664) in Morrison County (Figure 2), the Little Falls Dam was first constructed in 1887. The current surface release impoundment (Figure 3) was constructed from 1918 to 1920. The impoundment currently supplies 4.9 megawatts of hydroelectric power to the area. The impoundment height is 7.3 meters and has a crest length of 375 meters. The reservoir is estimated to extend 2.9 kilometers upstream.

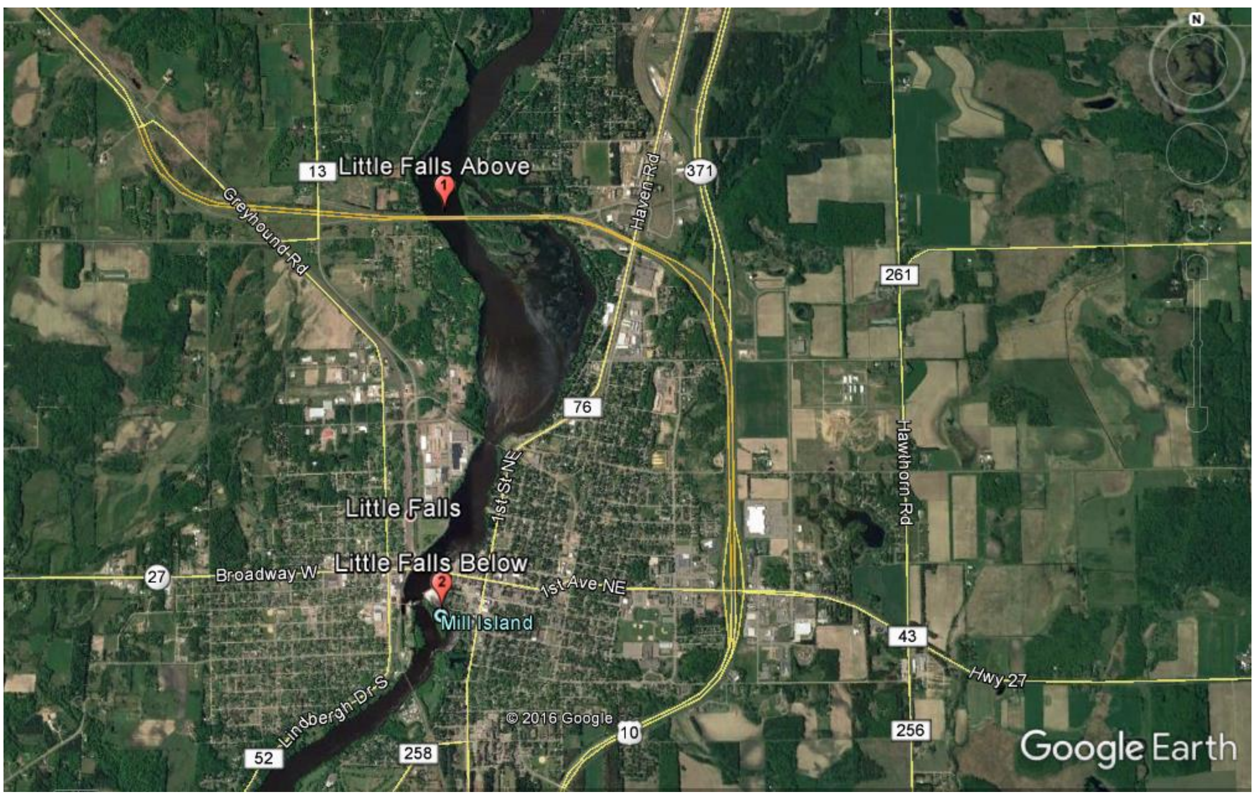


Figure 2: Little Falls Dam above and below impoundment sampling locations.

Figure 3: Little Falls dam as seen from downstream.

<u>Blanchard Dam</u>

Blanchard Dam is a surface release impoundment located at river kilometer 1539.5 (45.975897, -94.367664) in Morrison County (Figure 4). Construction of the impoundment was completed and the power plant was first used in 1925. The impoundment is currently owned by Minnesota Power and has the capacity to supply 18.0 megawatts of electricity. Blanchard Dam (Figure 5) was constructed to a height of 14 meters and is 228.6 meters long. To the east is the powerhouse which is 37.8 meters long and a 737.6 meter long earthen dike. A 341.4 meter earthen dike is located on the west side of the impoundment. It has a drainage area of approximately 30,043.9 sq. km. The reservoir is measured to extend approximately 4.2 kilometers upstream.

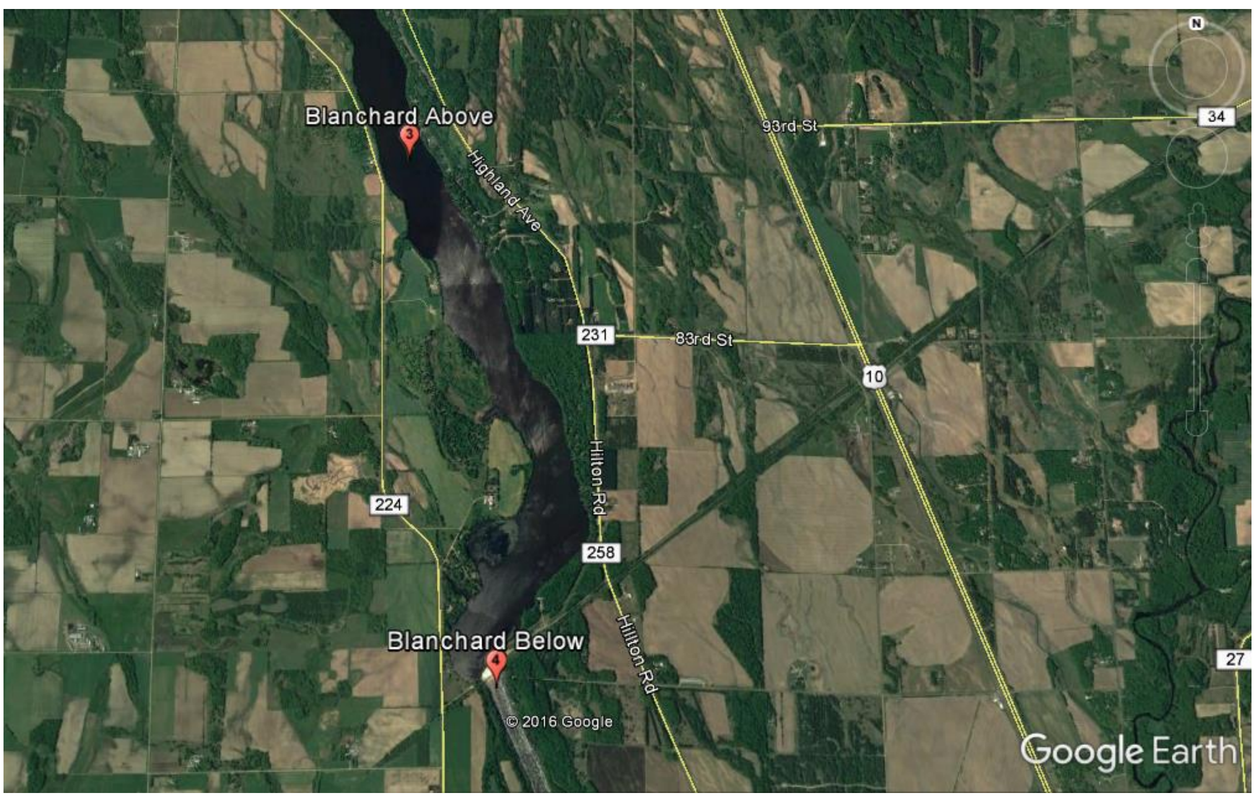


Figure 4: Blanchard Dam above and below impoundment sampling locations.

Figure 5: Blanchard Dam as seen from downstream.

<u>Champion Dam</u>

Champion Dam is a surface release impoundment located at river kilometer 1,500.7 (45.975897, -94.367664) in Stearns County (Figure 6). It was originally construction between 1905 and 1907 for producing electricity and to grind wood into pulp. The impoundment was rebuilt in 1964 and can produce 9.5 megawatts of power (Figure 7). Champion Dam was constructed to a height of 14 meters and 118.3 meters long, not including the power house. The reservoir extends 14.4 kilometers upstream.

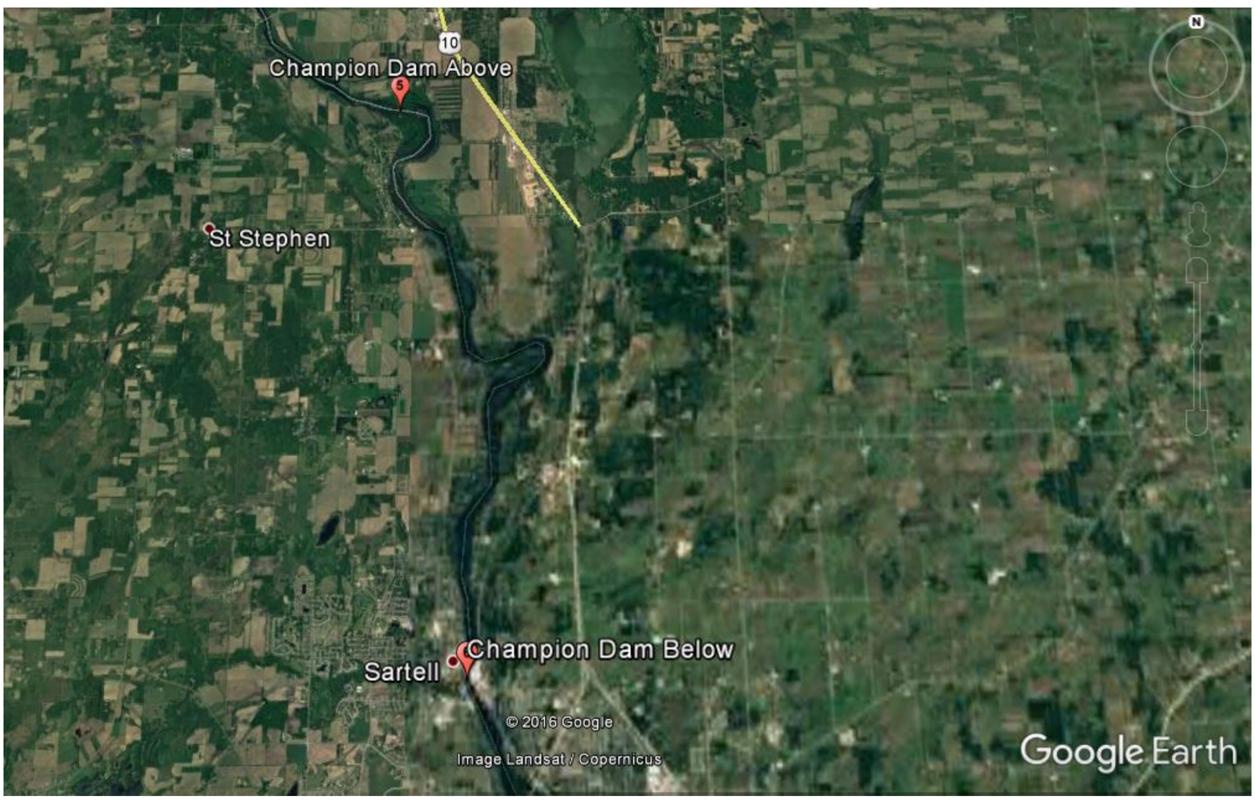


Figure 6: Champion Dam above and below impoundment sampling locations.

Figure 7: Champion Dam as seen from downstream.

St. Cloud Dam

The St Cloud Dam is a surface release impoundment located on river kilometer 1,491.1 (45.975897, -94.367664) in Sterns County (Figure 8). The first hydroelectric dam was constructed in 1888. The dam stood at the west end of the cities wooden dam that was constructed two years earlier. The construction of the current concrete impoundment was completed in May of 1988 and the plant went into commercial operation June 1st of that year (Figure 9). It reaches a height of 7.1 meters and is 205.7 meters long. It has a drainage area of 34,398.7 sq. km and can provide 8.8 megawatts of power to the Northern States Power Company. The reservoir extends 5.1 kilometers upstream.

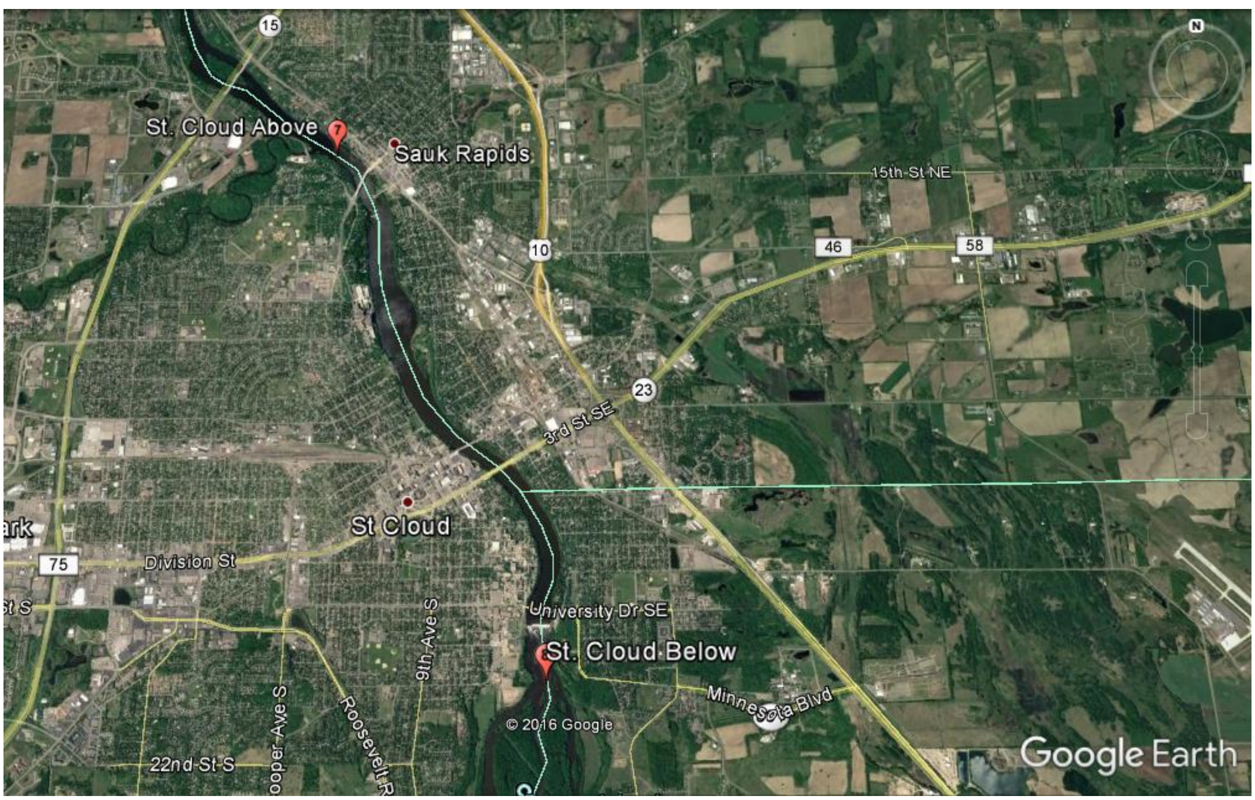


Figure 8: St. Cloud Dam above and below impoundment sampling locations.

Figure 9:  St. Cloud Dam as seen from downstream.

Water samples were taken before each reservoir and after the impoundment at each sample location.

## Materials and Methods

Nine, one liter, water samples were collected during each sampling period from the middle of the channel and at a depth of approximately 15 cm to avoid contamination from floating particulate matter at each site. Sampled impoundments can be seen in Figure 1. Sample locations for Little Falls Dam can be seen in Figure 2, for Blanchard Dam in Figure 4, for Champion Dam in Figure 6, and for St. Cloud Dam in Figure 8. Three samples were collected to determine the phosphorus concentration of the FPOM, three to determine the carbon concentration of the FPOM, and three to determine the inorganic to organic composition of the FPOM. All nine sample weights were used to determine the amount of FPOM. Samples were collected at each site on August 14, September 25, and November 6, 2007. Samples were put on ice and brought back to the laboratory. On the same day samples were collected, they were first put through a 1 mm sieve to remove any course particulate matter (>1 mm). The water samples were then filtered through a 3 µm glass fiber filter (Whatman Schleicher & Schuell Cat. No 1823 047) to separate the fine particulate matter (<1 mm and > 2.7 µm) from dissolved (<2.7 µm). The filters were then placed in a drying oven at 60ºC for 48 hours. Dry weights were then recorded. To analyze the amount of Carbon, a Costech Analytical Elemental Combustion System 4010 (Costech Analytical, Valencia, California, USA) was used. The total phosphorus and carbon contained in the FPOM samples were calculated using standardization curves based of National Institute of Standards and Technology (NIST) samples (Kay et al. 2008). Due to technical difficulties, the carbon data obtained from these samples were unusable. Phosphorus was measured using persulfate acid digestion and ascorbate-molybdate colorimetry on an Alpkem autoanalyzer (OI Analytical, College Station, Texas, USA). To determine the ratio of organic to inorganic matter in the samples, samples were combusted in a 550° Celsius muffle furnace.

Statistical analyses were done utilizing Minitab 18, 2017. Above versus below impoundment comparisons were done via a Mann-Whitney U test, Bonferroni corrections were done for means that were used twice. Comparison of differences between sampling periods and overall difference of samples as they progress downstream were done using a one-way ANOVA.

## Results

Sample Weights

The FPOM (Figure 10) samples collected at each sample location during the 08/14/07 sampling period demonstrated a significant difference when comparing Champion Dam Above and Champion Dam Below ($p<0.001$), Champion Dam Below and St. Cloud Dam Above ($p<0.001$), and St. Cloud Dam Above and St. Cloud Dam Below ($p<0.001$). Significant differences were observed between sample locations during the 09/25/17 sampling period between Little Falls Dam Above and Little Falls Dam Below ($p=0.027$) and Blanchard Dam Below and Champion Dam Above ($p=0.006$). During the 11/06/07 sampling period, significant differences were observed between samples collected between Little Falls Dam Below and Blanchard Dam Above ($p=0.013$), Blanchard Dam Above and Blanchard Dam Below ($p=0.008$), and St. Cloud Dam Above and St. Cloud Dam Below ($p<0.001$). The p-values for each individual test can be seen in Table 1.

When comparing sample collected at each sample location between sampling periods, there was a significant difference in FPOM sample weights at Little Falls Dam Above ($p=0.027$), Blanchard Dam Above ($p<0.001$), Blanchard Dam Below ($p=0.021$), Champion Dam Above ($p=0.003$), Champion Dam Below ($p<0.001$), St. Cloud Dam Above ($p<0.001$), and St. Cloud Dam Below ($p<0.001$). All p-values for each statistical test can be seen in Table 2.

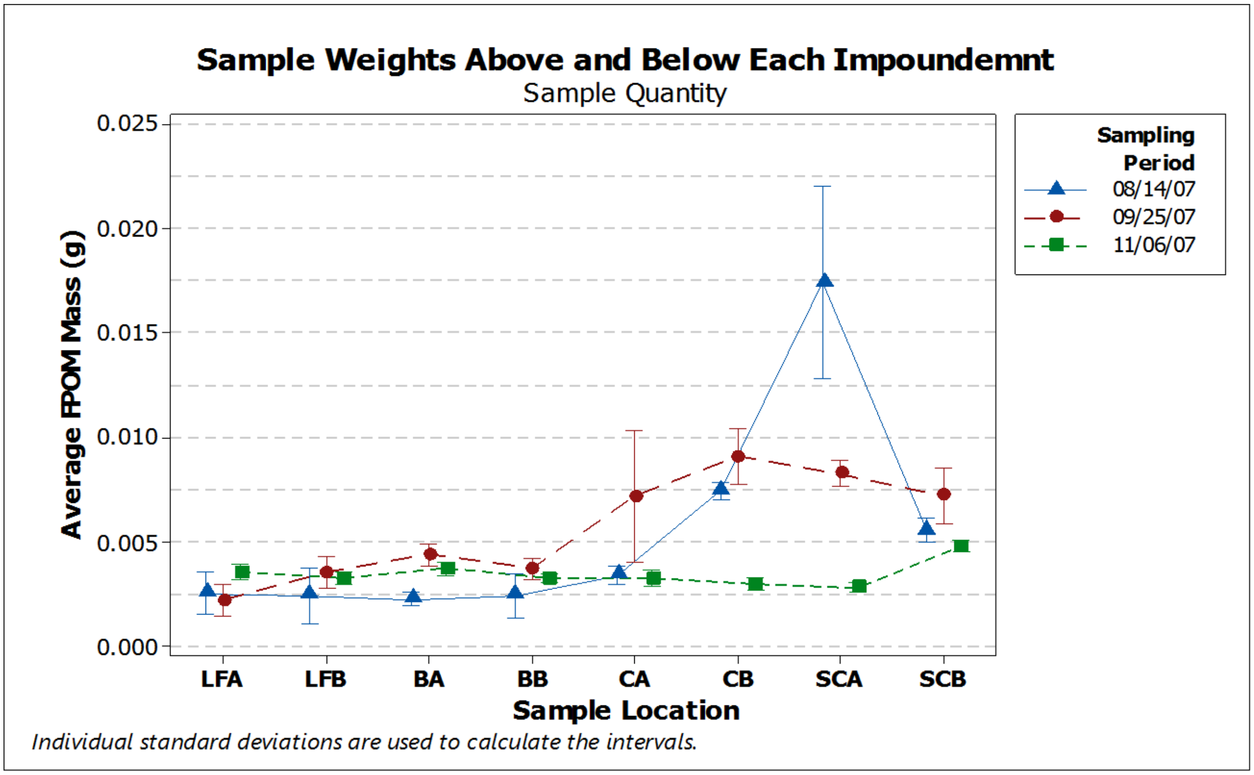


Figure 10: Total mean ± 1 SD FPOM weights at each sample site during the three sample periods. Codes for each sample location: Little Falls Above (LFA), Little Falls Below (LFB), Blanchard Above (BA), Blanchard Below (BB), Champion Above (CA), Champion Below (CB), St. Cloud Above (SCA), and St. Cloud Below (SCB).

Table 1: This table shows the p-values comparing the sample weights for samples collected at each sample locations as water progresses downstream for each sampling period. Codes for each sample location: Little Falls Above (LFA), Little Falls Below (LFB), Blanchard Above (BA), Blanchard Below (BB), Champion Above (CA), Champion Below (CB), St. Cloud Above (SCA), and St. Cloud Below (SCB).

| P-values for FPOM Weights | | | |
|---|---|---|---|
| Sample Site | 08/14/07 | 09/25/07 | 11/06/07 |
| LFA<br>LFB | p=0.724 | p=0.027 | p=0.216 |
| LFB<br>BA | p=0.965 | p=0.042 | p=0.013 |
| BA<br>BB | p=0.158 | p=0.077 | p=0.008 |
| BB<br>CA | p=0.158 | p=0.006 | p=0.930 |
| CA<br>CB | p<0.001 | p=0.052 | p=0.310 |
| CB<br>SCA | p<0.001 | p=0.566 | p=0.251 |
| SCA<br>SCB | p<0.001 | p=0.077 | p<0.001 |

Table 2: This table shows the p-values comparing sample weights at each sample location over each sample period. Codes for each sample location: Little Falls Above (LFA), Little Falls Below (LFB), Blanchard Above (BA), Blanchard Below (BB), Champion Above (CA), Champion Below (CB), St. Cloud Above (SCA), and St. Cloud Below (SCB).

| P-values for FPOM Weight Change Among Sampling Periods | |
|---|---|
| Sample Site | |
| LFA | p=0.027 |
| LFB | p=0.143 |
| BA | p<0.001 |
| BB | p=0.021 |
| CA | p=0.003 |
| CB | p<0.001 |
| SCA | p<0.001 |
| SCB | p<0.001 |

Phosphorus

Average Phosphorus composition for samples collected at each sample location can be seen in Figure 11. When comparing sample locations following the water downstream, there was no significant difference between any of the sample locations during each of the three sample periods. P-values for statistical analysis can be seen in Table 3.

Significant differences at each sample locations were observed at Little Falls Dam Below, Champion Dam Above, St. Cloud Dam Above, and St. Cloud Dam Below when comparisons were made between sampling periods at each sample site. The results of the statistical analysis can be seen in Table 4.

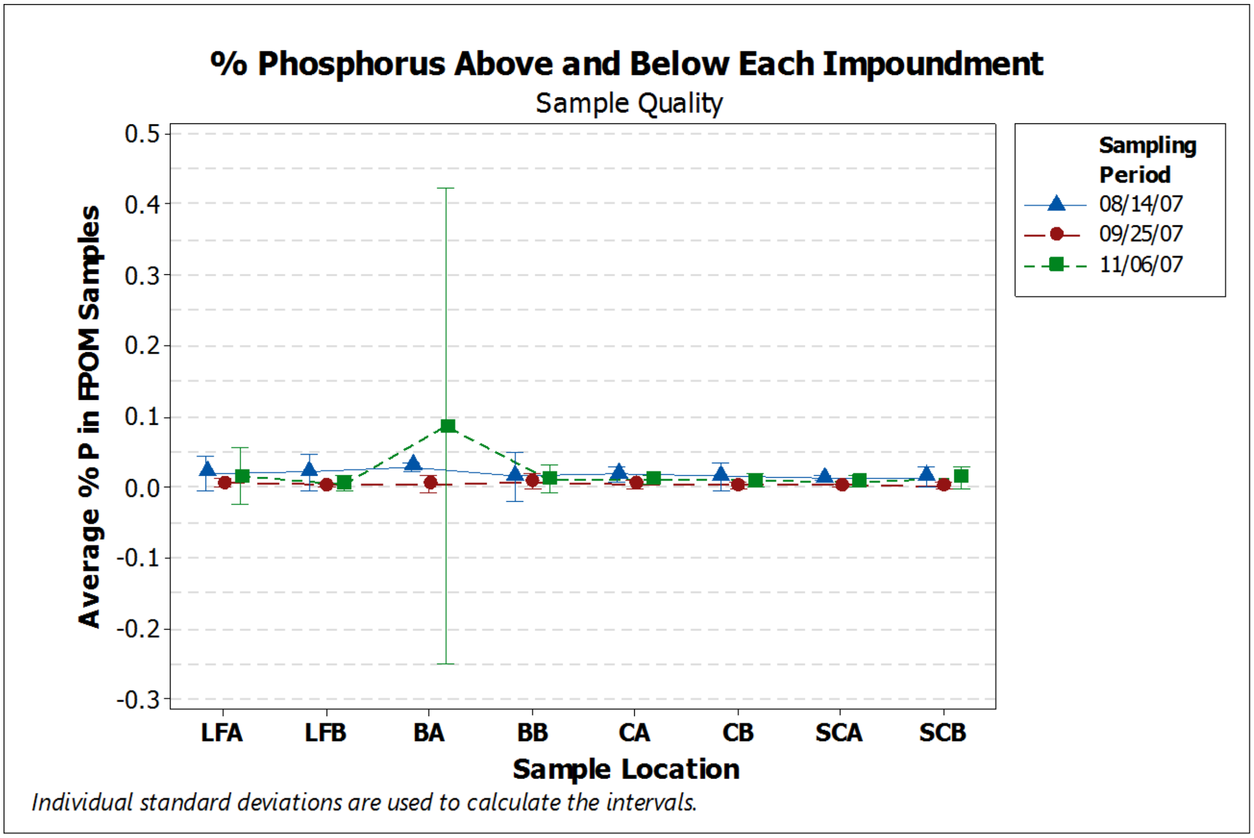


Figure 11: This figure depicts the mean percentage of Phosphorus in samples collected at each sample location. Symbols represent means ± 1 SD. Codes for each sample location: Little Falls Above (LFA), Little Falls Below (LFB), Blanchard Above (BA), Blanchard Below (BB), Champion Above (CA), Champion Below (CB), St. Cloud Above (SCA), and St. Cloud Below (SCB).

Table 3: This table shows the p-value comparing the phosphorus composition for samples collected at each sample locations as water progresses downstream for each sampling period. Codes for each sample location: Little Falls Above (LFA), Little Falls Below (LFB), Blanchard Above (BA), Blanchard Below (BB), Champion Above (CA), Champion Below (CB), St. Cloud Above (SCA), and St. Cloud Below (SCB).

| P-values for FPOM Phosphorus Content | | | |
|---|---|---|---|
| Sample Site | 08/14/07 | 09/25/07 | 11/06/07 |
| LFA<br>LFB | p=1.000 | p=0.081 | p=0.663 |
| LFB<br>BA | p=0.663 | p=0.663 | p=0.383 |
| BA<br>BB | p=0.190 | p=0.383 | p=1.000 |
| BB<br>CA | p=1.000 | p=0.383 | p=1.000 |
| CA<br>CB | p=0.663 | p=0.383 | p=1.000 |
| CB<br>SCA | p=0.663 | p=0.663 | p=1.000 |
| SCA<br>SCB | p=0.663 | p=0.663 | p=0.383 |

Table 4: This table shows the p-values comparing phosphorus composition at each sample location over each sample period. Codes for each sample location: Little Falls Above (LFA), Little Falls Below (LFB), Blanchard Above (BA), Blanchard Below (BB), Champion Above (CA), Champion Below (CB), St. Cloud Above (SCA), and St. Cloud Below (SCB).

| P-values for FPOM Phosphorus Content Change Among Sampling Periods | |
|---|---|
| Sample Site | |
| LFA | p=0.394 |
| LFB | p=0.031 |
| BA | p=0.476 |
| BB | p=0.671 |
| CA | p=0.008 |
| CB | p=0.063 |
| SCA | p=0.003 |
| SCB | p=0.039 |

<u>Inorganic and Organic Composition</u>

The inorganic and organic composition of samples collected at each sample location during each sample period can be seen in Figure 12. When comparing the total sample weight to the total organic weight of the FPOM, none of the samples contained a significant amount of inorganic material (Figure 12).

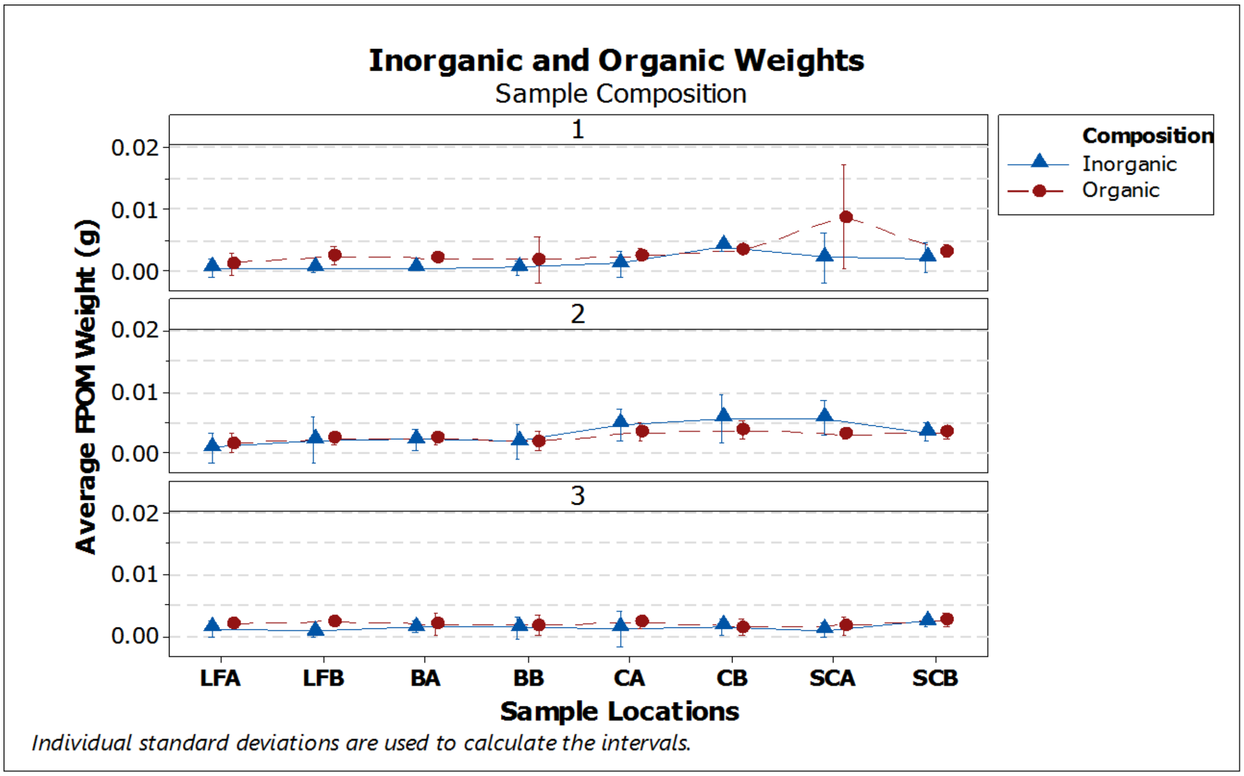


Figure 12: The above graph shows the changes in inorganic and organic composition of samples collected at each sample location during the three sample periods. Sample period 1 was 08/14/07, sample period 2 was 09/25/07, and sample period 3 was 11/06/07. Symbols represent means ± 1 SD. Codes for each sample location: Little Falls Above (LFA), Little Falls Below (LFB), Blanchard Above (BA), Blanchard Below (BB), Champion Above (CA), Champion Below (CB), St. Cloud Above (SCA), and St. Cloud Below (SCB).

Table 5: This table shows the p-value comparing the inorganic and organic composition for samples collected at each sample locations as water progresses downstream for each sampling period. Codes for each sample location: Little Falls Above (LFA), Little Falls Below (LFB), Blanchard Above (BA), Blanchard Below (BB), Champion Above (CA), Champion Below (CB), St. Cloud Above (SCA), and St. Cloud Below (SCB).

| P-values for Sample Inorganic and Organic Composition | | | |
|---|---|---|---|
| Sample Site | 08/14/07 | 09/25/07 | 11/06/07 |
| LFA | p=0.663 | p=0.827 | p=0.081 |
| LFB | p=0.827 | p=0.081 | p=0.081 |
| BA | p=0.081 | p=0.081 | p=0.081 |
| BB | p=0.513 | p=0.081 | p=0.081 |
| CA | p=0.081 | p=0.081 | p=0.127 |
| CB | p=0.081 | p=0.081 | p=0.081 |
| SCA | p=0.383 | p=0.081 | p=0.081 |
| SCB | p=0.081 | p=0.081 | p=0.081 |

## Discussion

Many studies have focused on the impacts of large, deep release impoundments on riverine systems (Matzinger et al. 2007). The impacts on temperature regimes (Hamblin and McAdam 2003), fish (Zhong and Power 1996), and sediment transport (Conley et al. 2000) have all been examined. Much less research has been done on surface release impoundments and their impacts (Mbaka and Mwaniki 2015). This study examined the impact of four surface=release impoundments on the Upper Mississippi River, and their impacts on the quantity and quality of FPOM, as well as impacts on its inorganic and organic composition.

Quantity

There appears to be three distinct scenarios being displayed by the impoundments regarding FPOM quantity. The first scenario is no significant difference between upstream and downstream sampling sites. This was displayed by Little Falls and Blanchard Dams during the 08/14/07 sampling period; Blanchard, Champion, and St. Cloud Dams during the 09/25/07 sampling period; and Little Falls and Champion Dams during the last sampling period on 11/06/07. At these impoundments, during these sampling periods, no detectable impact on the amount of FPOM caused by the impoundment was observed. The stream flowed through these sites without being notably impacted. This scenario was also found in larger impoundments by Finger et al. (2006), where they noted no impact on the quantity of fine particulate matter was caused by damming. The second scenario, supported by the data form St. Cloud Dam during the 08/14/07 sampling period and Blanchard Dam during the 11/06/07 sampling period, was that the reservoir was acting like a sink for FPOM. The impoundment is slowing the flow of water to the point that suspended material settles out before flowing over the impoundment, depositing sediments in the reservoir (Conley et al. 2000). The third observed scenario was higher FPOM weights below the impoundments. This was seen during the 08/14/07 sampling period at Champion Dam, the 09/25/07 sampling period at Little Falls Dam, and during the 11/06/07 sampling period at St. Cloud Dam. This scenario supports the hypothesis that there would be an increase in FPOM downstream of the impoundments due to higher primary (phytoplankton) and secondary (zooplankton) production (Adam et al. 1983). Lamberti and Steinman (1997) state that wider stretches of slower moving streams would have higher amounts of primary production when compared to the narrower, quicker moving waters that would be more natural to these locations. The observation that some of the impoundments switching back and forth between acting as a sink or as a source for FPOM was documented by Thomson et al. (2005) on a small run-of-river dam. While the data supports the hypothesis at some of the sites during the different sampling periods, the true answer is much more complicated.

Quality

There were no significant differences in the phosphorus content of the FPOM samples collected above to those collected below any of the impoundments during any of the sampling periods (Figure 11). The hypothesis that the impoundments would influence the quality of FPOM as measured by phosphorus content was not supported. Matzinger et al. (2007) found that the total nutrients entering a reservoir were not affected by the hydrological changes, but the internal nutrient supply was significantly modified. The impoundments have not impacted the nutrient formation of FPOM and thus not changed the composition of FPOM found at these locations. It was also noted by Matzinger et al. (2007) that algae abundance did not change significantly for various levels of primary production; however, reduced production transferred into reduced zooplankton production. This is interesting considering the potential change in plankton communities between the lotic habitat if a reservoir and the lentic habitat of a stream (Okuku et al. 2016).

Serial Discontinuity Concept

The Serial Discontinuity Concept describes how impacts on a lotic system can disrupt the River Continuum Concept. If a lotic system flows from headwaters to mouth without any major disturbance, the system would progress as described by the River Continuum Concept. Natural disturbances such as flooding, natural blockages, and impacts posed by lower order stream tributaries and water management by humans have disturbed this theoretical system. This study did find disconnects imposed by the impoundments in relation to the quantity of FPOM (Figure 10). The Serial Discontinuity Concept describes how dams disconnect upstream and downstream sections of the river they impede. If this were a flow-through system, there would be little to no significant difference between sample sites, but disruptions were found in the relatively short section of the river. During the 08/14/07 sampling period, disconnects between sampling sites were observed between Champion Dam above and Champion Dam below, Champion Dam below and St. Cloud Dam above, and St. Cloud Dam above and St. Cloud Dam below; between Little Falls Dam above and Little Falls Dam below, and Blanchard Dam below and Champion Dam above during the 09/25/07 sampling period; and between Little Falls Dam below and Blanchard Dam above, Blanchard Dam above and Blanchard Dam below, and St. Cloud Dam above and St. Cloud Dam below sampling sites during the 11/06/07 sampling period. Each of the sampling sites is disconnected from each other during their pertinent sampling periods.

Change Among Sampling Periods

Seasonality is normal in a lotic system (Mulholland et al. 1985). Under normal conditions, a seasonal difference in nutrients would be detected and carried downstream. This change in resource availability, as well as flow regime, influence the diversity that is found in lotic systems (Paterson et al. 1997). By adding stability into the system, one group of species will be favored; thus, allowing them to increase in population size and outcompete other species, reducing the diversity of the system. As diversity decreases, the overall health of the system decreases and can be pushed to the brink when there is an event that puts pressure on the stabilized system that it may not be able to rebound.

One would expect, in any ecosystem in this climate to show signs of change among sampling periods. With temperature, rainfall, and primary production changing from one season to another, this system has adapted to changes in the time of year. Not only does this mean adjusting to temperature and rainfall regimes, but to sources of nutrients (Lowe and Hauer 1999). According to the results displayed in Table 2, a difference in the amount of FPOM at each sample location between sample periods was noted except below Little Falls Dam. At this sample site, the impoundment provided stability in the amount of FPOM flowing downstream, while one would expect to see seasonal variation in the amount of FPOM flowing downstream (Richter et al. 1997). Even though there is a significant difference in the FPOM above the reservoir, the Little

Falls Dam has stabilized the amount of FPOM during the sampling period. This stability could come about by the sedimentation in the reservoir during times of high FPOM flow and increased primary and secondary production during time of low FPOM input to maintain a more constant flow.

Looking at the results for the phosphorus content of the FPOM (Table 4), there was more variation in the change between sampling periods. It is interesting to note that the incoming flow of FPOM into the Little Falls above sampling location exhibited no variation in phosphorus content. It is unknown why the phosphorus content exhibited no variation, something upstream had added stability. The closest upstream impoundment is in Brainard, approximately 63 river kilometers upstream. Below Little Falls Dam, variation was restored. Impoundments tend to be thought of as stabilizing structures, but in this case, processes within the reservoir have restored variation. Traveling down to the next site, Blanchard Dam above, again the phosphorus variation between sampling periods has been lost. In the case of Blanchard Dam, this stability flows through the reservoir down to Blanchard Dam below sampling site. At Champion Dam above, variation has returned. The stretch of the river between Blanchard Dam and Champion Dam's reservoir has reverted to a more natural condition. Champion Dam then stabilizes the system once again; there were no significant difference between sample periods below Champion Dam. This stability does not last since at St. Cloud Dam above variation was once again restored and then carried down over St. Cloud Dam to the final sampling site. While Little Falls and Champion Dams both have significant impacts on the between sampling period variation, Blanchard and St. Cloud Dams both operate in a more flow-through fashion.

Inorganic and Organic Composition

Inorganic matter in a steam includes fine silt, sand, and clay and inorganic components of living organisms such as diatoms. High concentrations of inorganic matter can decrease transparency and make it more difficult for aquatic organisms to locate food (Henley et al. 2000) and limit primary production to the upper portion of the water column (Diehl 2002). Inorganic material can enter the water through stormwater runoff, streambank erosion, and other natural processes. Diatoms are microscopic plankton that have shells consisting of silica, an inorganic compound. While the purpose of determining the inorganic and organic content of the FPOM was to demonstrate that there was indeed organic matter in the samples, higher levels of inorganic matter can point towards there being increased silt, sand and clay suspended in the water column and/or increase in the production in the diatom community. This study did not look at the source of the inorganic matter or try to determine the physical makeup of the FPOM.

## Conclusion

Riverine systems are very complex.  Different orders of streams flow into one another carrying different substances they have picked up from their individual watersheds.  It can be very difficult looking to apply different theories to how these systems are governed when so many different influential forces are at play through the many different sections of the stream.  One may find locations that provide support for different hypotheses and then move downstream to find data that show different results.  Riverine systems are also influenced by of the weather.  Drought and flooding can have massively different impacts on the dynamics within a river.  Trying to look for data to either support or rebut a hypothesis can be complicated.   What are standard conditions for a system that is driven by change? These are also massive systems, taking water cross country in a continuous cycle with no apparent end.  While conducting this study, there are locations that offer support for the hypotheses made at the beginning of this study, but then there are other locations that invalidate the hypotheses.

While this study only looked at a selection of surface release impoundments, the assumption was that they would each impact the lotic system in similar ways.  It is possible that, due to differences in construction, the impacts caused by these structures vary.  The impoundments were installed at varying lengths and heights, but they all obstruct the river in an analogous way.

Another factor that is impossible to control in a complex system like this one is the input from tributary streams and rivers.  In the stretch of the Mississippi River that was observed, there are 17 named and unnamed tributaries, not including the many different storm drains and tile lines directed to the river for drainage purposes.  Each of these tributaries contribute their own unique deposits into the Mississippi River. It is highly possible that, do to this input of variation, results may have been skewed.

Besides the many tributaries flowing into the system, at this point, the river may already be at such a size that it is less dependent on seasonal input of leaf litter as a primary source of nutrients. As a stream increases in size and more light reaches the surface, primary and secondary production increase. It is possible, that the study stretch of river has reached such a size that the input of martial originally related to a terrestrial system is not very significant to the food web. In this study, no distinction was made to the source of FPOM traveling downstream. This would include both material with terrestrial origins and that which is due to production within the aquatic system.

## Future Research

To help gain a better understanding of this system, there are several research projects that need to be conducted. We need to gain a better understanding on the impact on the C:P ratio surface-release impoundments may have on FPOM. Due to issues with sampling and analysis, this study was not able to ascertain if there is such an impact. If there is an impact, there could be impacts that reverberate through the food-web. Work also needs to be done to see how these changes occur year to year. There is no way to know if the results obtained in this study are indicative of the system or were just an anomaly due to unusual conditions. It would also be very interesting to concentrate on the communities of invertebrate populations seen in this system. Were the reservoirs of a sufficient size to begin to promote invertebrate populations that are normally only observed in lentic environments? It would also be interesting to examine the food quality differences these divergent assemblages of organism provide. Another factor that was not taken into consideration in this study would be flow data. It would be very interesting to look at a range of different flow patterns to see how FPOM is impacted. It is highly possible that variations in flow had an impact on this study. Finally, it would also be very interesting to examine the contents of the FPOM sampled and determine what it is composed of; are the samples made up of silt, fine sand and decaying allochthonous materials or are they primarily composed of zooplankton and phytoplankton?

## Literature Cited

Adams, S. M., B. L. Kimmel, and G. R. Ploskey. 1983. Sources of organic matter for reservoir fish production: a trophic-dynamics analysis. Canadian Journal of Fisheries and Aquatic Sciences 40(9):1480-1495.

Bonsall, M. B. and A. Hastings. 2004. Demographic and environmental stochasticity in predator-prey metapopulation dynamics. Journal of Animal Ecology 73:1043-1055.

Bott, T. L., D. S. Montgomery, D. B. Arscott, and C. L. Dow. 2006. Primary productivity in receiving reservoirs: links to influent streams. Journal of the North American Benthological Society 25(4):1045-1061.

Brett, M. 2017. How important are terrestrial organic carbon inputs for secondary production in freshwater ecosystems? Freshwater Biology 62(5):833-853.

Conde-Porcuna, J. M. 2000. Relative importance of competition with Daphnia (Cladocera) and nutrient limitation on Anuraeopsis (Rotifera) population dynamics in a laboratory study. Freshwater Biology 44:423-430.

Conley, D. J., P. Stalnacke, H. Pitkanen, and A. Wilander. 2000. The transport and retention of dissolved silicate by rivers in Sweden and Finland. Limnology and Oceanography 45(8):1850-1853.

Diehl, S. 2002. Phytoplankton, light, and nutrient in a gradient of mixing depths: theory. Ecology 83(2):386-398.

Finger, D., M. Schmid, and A. Wüest. 2006. Effects of upstream hydropower operation on riverine particle transport and turbidity in downstream lakes. Water Resources Research 42(8):1-20.

Finlay, J. C. 2001. Stable-carbon-isotope ratios of river biota: implications for energy flow in lotic food webs. Ecology 82(4):1052-1064.

Goodman, D. 1975. The theory of diversity-stability relationships in ecology. The Quarterly Review of Biology 50(3):237-266.

Graca, MM A. S. and C. Canhoto. 2006. Leaf litter processing in low order streams. Limnetica 25(1-2):1-10.

Hamblin, P. F. and S. O. McAdam. 2003. Impoundment effects on the thermal regimes of Kootenay Lake, the Arrow Lakes Reservoir and Upper Columbia River. Hydrobiologia 504:3-19.

Henley, W. F., M. A. Patterson, R. J. Neves, , and A. D. Lemly. 2000. Effects of sedimentation and turbidity on lotic food webs: a concise review for natural resource managers. Reviews in Fisheries Science 8(2):125-139.

Hessen, D. O., T. C. Kylet, and J. J. Elser. 2007. RNA responses to N- and P-limitation: reciprocal regulation of stoichiometry and growth rate in Brachionus. Functional Ecology 21(5): 956-962.

Kay, Adam, J. Mankowski, and S. Hobbie. 2008. Long-term burning interacts with herbivory to slow decomposition. Ecology 89(5):1188-1194.

Kilham, S. S., D. A. Kreeger, C. E. Goulden, and S. G. Lynn. 1997. Effects of algal food quality on fecundity and population growth rates of Daphnia. Freshwater Biology. 38:639-647.

Korpinen, S. and V. Jormalainen. 2008. Grazing and nutrients reduce recruitment success of *Fucus versiculosus* L. (Facales: Phaeophyceae). Estuarine Coastal and Shelf Science 78:437-444.

Lamberti, G. A. and A. D. Steinman. 1997. A comparison of primary production in stream ecosystems. Journal of The North American Benthological Society 16(1):95-104.

Liu, Su Mei, X. H. Qi, X. Li, H. R. Ye, Y. Wu, J. L. Ren, J. Zhang, and W. Y. Xu. 2016. Nutrient dynamics from the Changjiang (Yangtze River) estuary to the East China Sea. Journal of Marine Systems. 154(A):15-27.

Lowe, W. H. and F. R. Hauer. 1999. Ecology of two large, net-spinning caddisfly species in a mountain stream: distribution, abundance, and metabolic response to a thermal gradient. Canadian Journal of Zoology 77:1637-1644.

MacArthur, R. 1955. Fluctuations of animal populations and a measure of community stability. Ecology 36(3):533-536.

Main, T., D. Dobberfuhl, and J. Elser. 1997. N:P stoichiometry and ontogeny of crustacean zooplankton: a test of the growth rate hypothesis. Limnology and Oceanography 42(6):1474-1478.

Matzinger, A., R. Pieters, K. I. Ashley, G. A. Lawrence, and A. Wüest. 2007. Effects of impoundment on nutrient availability and productivity in lakes. Limnology and Oceanography 52(6):2629-2640.

Mbaka, J. G. and M. W. Mwaniki. 2015. A global review of the downstream effects of small impoundments on stream habitat conditions and macroinvertebrates. Environmental Reviews 23:257-262.

Mulholland, P. J., J. D. Newbold, J. W. Elwood, L. A. Ferren, and J. R. Webster. 1985. Phosphorus spiralling in a woodland stream: seasonal variations. Ecology 66(3):1012-1023.

Okuku, E. O., M. Tole, L. I. Kiteresi, and S. Bouillon. 2016. The response of phytoplankton and zooplankton to river damming in three cascading reservoirs of the Tana River, Kenya. Lakes and Reservoirs: Research and Management 21:114-132.

Paterson, M. J., D. Findlay, K. Beaty, W. Finlay, E. U. Schindler, M. Stainton, and G. McCullough. 1997. Changes in the planktonic food web of a new experimental reservoir. Canadian Journal of Fisheries and Aquatic Sciences 54(5):1088-1102.

Patrick, C. J. 2013. The effect of shredder community composition on the production and quality of fine particulate organic matter. Freshwater Science 32(3):1026-1035.

Richter, B. D., J. V. Baumgartner, T. Wiginigton, and D. P. Braun. 1997. How much water does a river need?. Freshwater Biology 37:231-249.

Thomson, J. R., D. D. Hart, D. F. Charles, T. L. Nightengale, and D. M. Winter. 2005. Effects of removal of a small dam on downstream macroinvertebrate and algal assemblages in a Pennsylvania stream. The American Benthological Society 24(1):192-207.

Urbe, J, J. Chasen, and R. Sterner. 1997. Phosphorus limitation of daphnia growth: is it real?. Limnology and Oceanography 72(6):1436-1443.

Vannote, R. L., G. W. Minshall, K. W. Cummins, W. Kenneth, J. R. Sedell, and C.E. Cushing. 1980. The river continuum concept. Canadian Journal of Fisheries and Aquatic Sciences 37(1):130-137.

Ward, J.V., and J. A. Stanford. 1983. The serial discontinuity concept of lotic ecosystems. Dynamics of Lotic Ecosystems. Edited by T.D. Fontaine III and S.M. Bartell. Ann Arbor Scientific Publishers. Ann Arbor, MI. pp. 29–42.

Wang, J., B. Gu, J. Juan, X. Han, G. Lin, F. Zheng, Y. Li. 2014. Terrestrial contributions to the aquatic food web in the Middle Yangtze River. PLoS One 9(7):e102473.

Yount, J. D. and G. J. Niemi. 1990. Recovery of lotic communities and ecosystems from disturbance – a narrative review of case studies. Environmental Management 14(5):547-569.

Zhong, Y. G., and G. Power. 1996. Environmental impacts of hydroelectric projects on fish resources in China. Regulated Rivers: Research and Management 12:81-98.

Ziser, S. W. 1985. The effects of a small reservoir on the seasonality and stability of physiochemical parameters and macrobenthic community structure in a rocky mountain stream. Freshwater Invertebrate Biology 4(4):160-177.