PONDERING LAKE PERFIDY: AN EXPLORATION OF DRIVING FORCES BEHIND HARMFUL ALGAL BLOOMS

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Ecosystems: Land-Water-Atmosphere Interactions (GEOL3853)

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Preface

This report was prepared as a group project for the class *GEOL3853: Ecosystems: Land-Water-Atmosphere Interactions* taught by Dr. EM Elliott. During the course of the semester, the class read and discussed journal papers related to the pre-Colonial ecological history of northwestern Pennsylvania, the political and other drivers for construction of the Kinzua Dam, legacy and contemporary nitrogen and phosphorous dynamics and their impact to surface waters, stable isotope and sensor-based approaches for evaluating nutrient dynamics, drivers and dynamics of toxin-producing bacterial and algal phytoplankton blooms, and ecological ramifications of the microcystin toxin on aquatic ecosystems. These papers and subsequent discussions provided the background needed for the students to independently undertake the analysis presented here.

Indigenous Land Acknowledgement

The Allegheny Reservoir (colloquially dubbed "Lake Perfidy" by the Seneca people) was created by flooding a large portion of the Allegany Reservation (*Uhì·ya'* in Tuscarora) and the entirety of the Cornplanter Tract - lands of the Seneca Nation of Indians reservation. The lands were flooded by the completion of the Kinzua Dam in September of 1965. The taking of this land represents a violation of the 1794 Treaty of Canandaigua. We would like to respectfully acknowledge the loss of land and cultural heritage faced by the Seneca Nation as a result of the establishment of the reservoir. It is impossible to truly convey the magnitude of the loss faced by the Seneca Nation, and we encourage readers to learn more about the past, present, and future of the Seneca Nation, and other Indigenous peoples who called the lands of what is now the United States home before imperial European colonization, subjugation, and ethnic cleansing.

Abstract

The Allegheny Reservoir is an 85 km2 body of water that runs perpendicular to the Pennsylvania-New York border, located just south-west of the town of Salamanca, NY. The Reservoir was constructed for the stated purpose of preventing dangerous floods from harming the people and property of those living and working in proximity to the Allegheny Reservoir, particularly downtown Pittsburgh. The Allegheny Reservoir hosts unusually intense algal blooms, which occur frequently. However, unlike other aquatic ecosystems, the Allegheny Reservoir is in a relatively pristine setting near the headwaters of the Allegheny River. As such, there is no obvious explanation as to why these blooms started occurring as early as 1972 and have become increasingly prevalent (M. Schellhammer, 2019, U.S. ACE., 2014, NY DEC, 2012-2019, U.S. EPA, 1975). To better understand the underlying cause of this algal activity, our group analyzed existing data regarding land use and water quality trends (nutrient, toxin concentrations), algal dynamics (trophic status index, community dynamics relative to nutrient concentrations), nutrient sources (legacy nitrogen, agricultural nitrogen and phosphorous, atmospheric deposition, point source effluent), reservoir stratification, and climatic and hydrologic drivers (water temperature, lake stratification, precipitation and discharge trends).

1. Introduction

1.1 Water Quality Standards (Sam Cohen)

Question(s)	How do nutrient concentrations in the Allegheny Reservoir compare to EPA standards?
Data Sources	KIN Nutrient Data 2012-2016 KIN Nutrient Data 2016-2018
Results File	1.1Cohen_WQStandards

Rationale

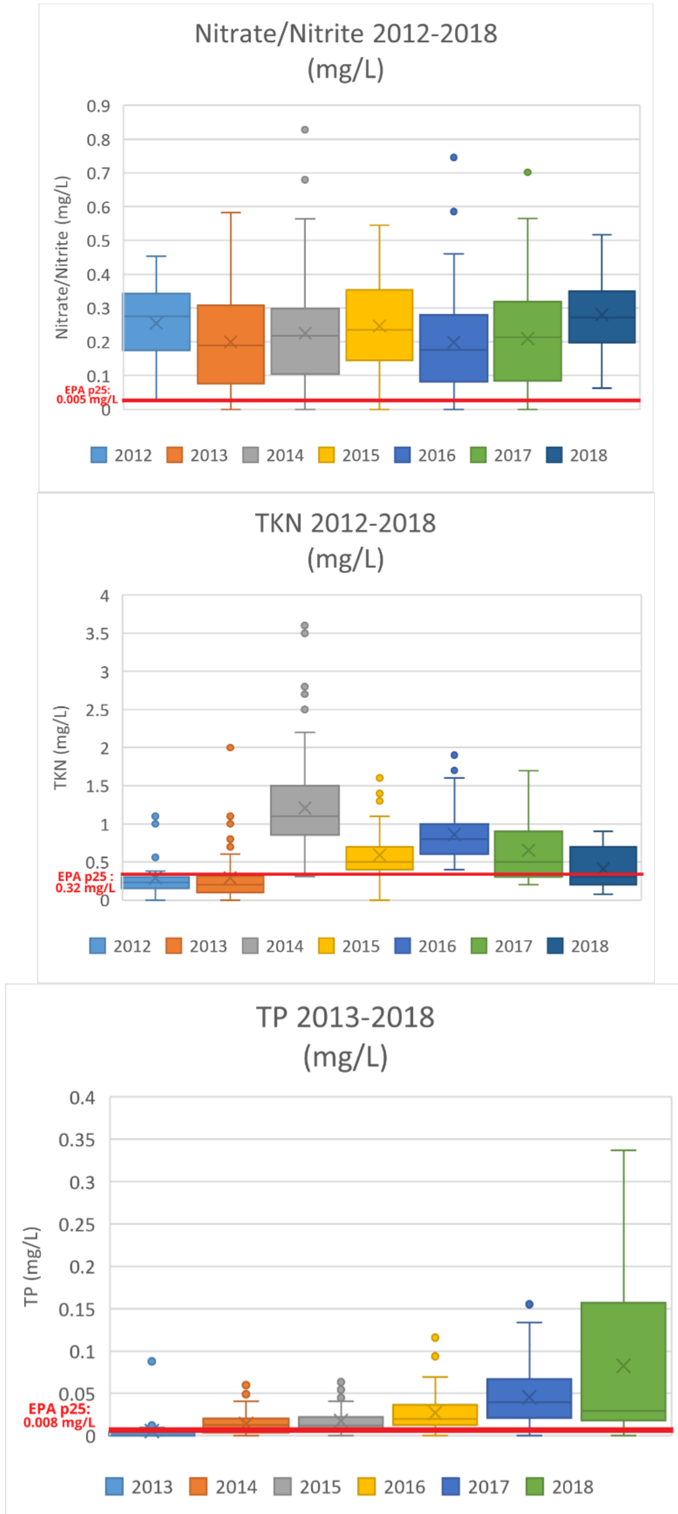
The Allegheny Reservoir and Kinzua Dam area have experienced widespread harmful algae blooms, beginning in 1972 (M. Schellhammer, 2019, U.S. ACE., 2014, NY DEC, 2012-2019, U.S. EPA, 1975). Understanding patterns of the concentration of nutrient pollution found in the Allegheny Reservoir is crucial in determining the drivers and thus management strategies for minimizing threats from harmful algae blooms (HABs) form.

Analyzing the concentrations of nutrients, particularly in relation to established EPA nutrient level recommendations, is crucial, as it allows us to compare the Allegheny Reservoir to similar lakes and reservoirs in Ecoregion VIII.

Methods

To determine the magnitude of measured nutrient concentrations in the Allegheny Reservoir, U.S. ACE data spanning from 2012 to 2018 were consolidated and analyzed by nutrient species. Plots showing the range of concentrations of nitrate/nitrite, total phosphorous, and TKN over the aforementioned time period are shown below.

Due to the wide variety of environments, geological settings, land use, and ecosystems found across the United States, regulations defining appropriate ambient levels of nutrients, other than those set for drinking water, are not clearly defined. The U.S. Environmental Protection Agency released a publication in 2000, that set forth suggested levels of nutrients in lakes and reservoirs, defined as the lower 25th percentile of sampled lake and reservoir systems in Ecoregion VIII, which is home to the Allegheny Reservoir. While this publication was published over 20 years ago, the validity of the guidance was confirmed by a 2020 study by J.W. Clune et al. The aggregated data taken from the EPA's survey of the ecoregion is plotted below, to be compared to measured sample data (U.S. EPA, 2000).



Figures 1.1.1 Data adapted from the U.S. EPA ambient water quality recommendations (2000). Box and whisker plots show sampled nutrient values from the Allegheny Reservoir. Intersecting red lines represent the US EPA's recommended nutrient level. Center line of box plots indicates median. X represents mean values (U.S. EPA., 2000).

Analysis & Results

The data above indicates that the sampled average concentration nutrients found in the waters of the Allegheny Reservoir are significantly higher than the hypothetical reference levels defined by the EPA.

References Cited

P. C. Rosier. “Dam Building and Treaty Breaking: The Kinzua Dam Controversy, 1936-1958.”The PA Magazine of History and Biography. Vol. 119, No. 4. Oct. 1995.

J.W. Clune et al. “Nitrogen and Phosphorous Concentration Thresholds toward EstablishingWater Quality Criteria for Pennsylvania, USA.” Water. Dec. 2020.

M. Schellhammer. “Harmful Algae Blooms Detected in Allegheny Reservoir.” The Bradford Era. Aug. 2019.

U.S. ACE. “Harmful Blue-Green Algal Bloom Detected at Allegheny Reservoir in New York.” Pittsburgh District Website. Aug. 2014.

NY DEC. “Harmful Algal Blooms by County 2012-2019.” Water Qual. Monitoring & Assmt.

U.S. EPA. “Ambient Water Quality Criteria Recommendations.” Office of Water. Dec. 2000.

U.S. EPA. “Report on Allegheny Reservoir, McKean and Warren Counties, Pennsylvania, and Cataragus County, New York.” Working Paper No. 147. June 1975.

1.2 Algal and Toxin Standards (Alex Pizzi)

Question(s)	How do recent algal blooms and toxin concentrations compare to WHO and EPA standards?
	[if more than one, add the other here]
Data Sources	DB COE PITTS 2013-2015 TOTAL with cells per mL.xlsx 2016 algae data Allegheny Reservoir algae 2019.xlsx
Results File	1.2Pizzi_AlgalToxinStandards

Rationale

Cyanobacteria, also known as blue-green algae, are commonly found in freshwater systems and can produce harmful cyanotoxins (EPA, 2019). Exposure to these toxins can have serious health effects on humans and the ecosystem. If ingested, cyanotoxins can cause nausea, diarrhea, liver failure, fever, and pneumonia. Skin contact to toxins can cause blistering and swelling. These reactions will depend on the type of toxin, duration of exposure and the concentration of the toxin (CDC, 2018). Microcystins are recognized as one of the most hazardous groups of cyanotoxins and produce more blooms than any other toxin (EPA, 2019). They can lead to serious health conditions if ingested or exposed for extended periods of time. Specifically, Microcystins attack the liver of animals, including humans, and can be lethal. (Pham, 2018).

The US EPA and World Health Organization (WHO) have differing standards when it comes to exposure to cyanotoxins in water and are compared in Table 1. "Acceptable short-term exposure" concentration thresholds describe the maximum concentrations that people can withstand without any serious long-term damage. This short-term exposure is normally listed as 10-14 days. Differing concentrations are established for drinking water compared to recreational use (EPA, 2019). While states can adopt these health advisory standards set by the EPA and WHO, Pennsylvania and New York (the two states that are home to the Allegheny Reservoir) have not. In terms of cyanobacteria biovolume, the WHO describes 20,000 cells/mL of cyanobacteria as low risk to public health, 100,000 cells/mL of cyanobacteria as a moderate risk, and anything above and the formation of scum on the surface would present as high risk, in which immediate action should be taken and recreational use of the water should be prohibited (WHO, 2018).

Methods

To determine hazards of algal blooms in recent years in the Allegheny Reservoir, U.S. ACE total algae cell counts from 2013- 2016 from multiple sites across the reservoir were compared to WHO standards. Cell counts are measured in mg/L and describe the biovolume of cyanobacteria. More specifically, Microcystis cell counts from those years were analyzed separately as well given that they are the largest producer of microcystin.

Results

In 2019, concentrations of microcystin reached up to 60 ug/l in the Allegheny Reservoir, causing an extreme health advisory and water to be unusable for drinking as well as recreational purposes according to US EPA and WHO guidelines. In recent years, peak bloom time with the highest biovolume of Microcystis cells was from August to October, during which time microcystin cell counts exceeded 100,000 cells/mL. From 2013- 2015, Microcystis alone surpassed 100,000 cells/mL count and on multiple occasions, reached 10,000,000 cells/mL.

Microcystin Exposure	**EPA (ug/L)**	**WHO (ug/L)**	**Highest AR Concentration 2019 (ug/L)**
Short-term drinking water	1.6	1	66.2
recreational	6-20	24	66.2

Table 1: Comparison of Microcystin exposure from EPA, WHO and the concentrations in 2019 in the Allegheny Reservoir.

	Cyanobacteria Biovolume (cells/mL)
Low Risk	<20,000
Moderate Risk	20,000-100,000
High Risk	>100,000

Table 2: Cyanobacteria biovolume, measured in cells/mL and risk levels associated with those cell counts according to the WHO.

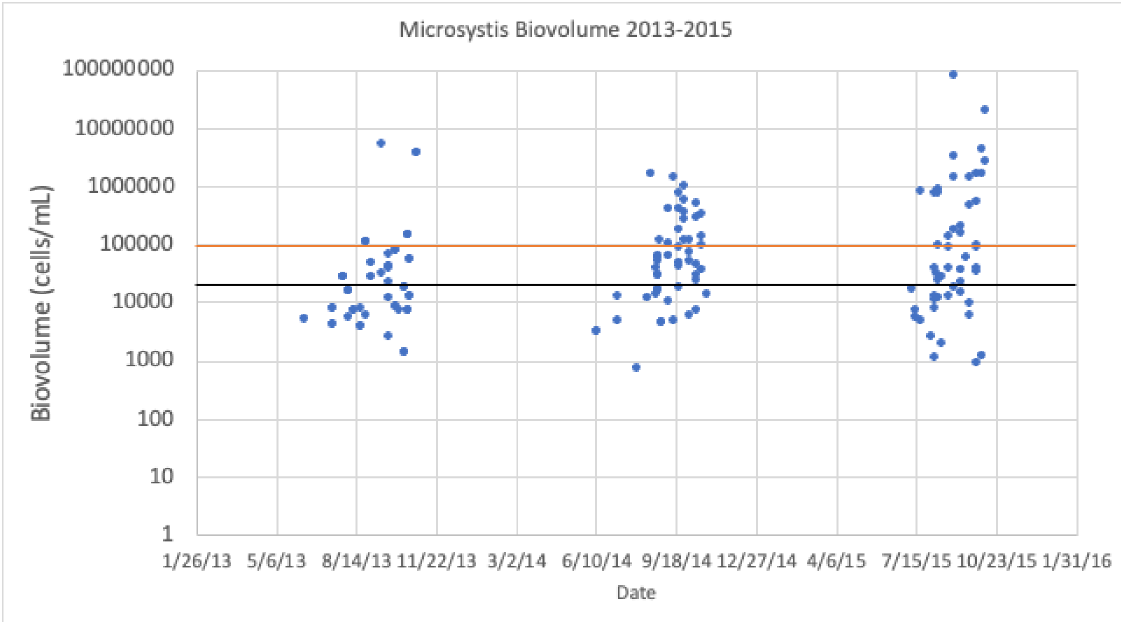


Figure 1.2.1: Yearly Microcystis biovolume from 2013-2015 show seasonality of blooms with reference lines at low risk (20,000 cells/mL) and high risk (100,000 cells/mL).

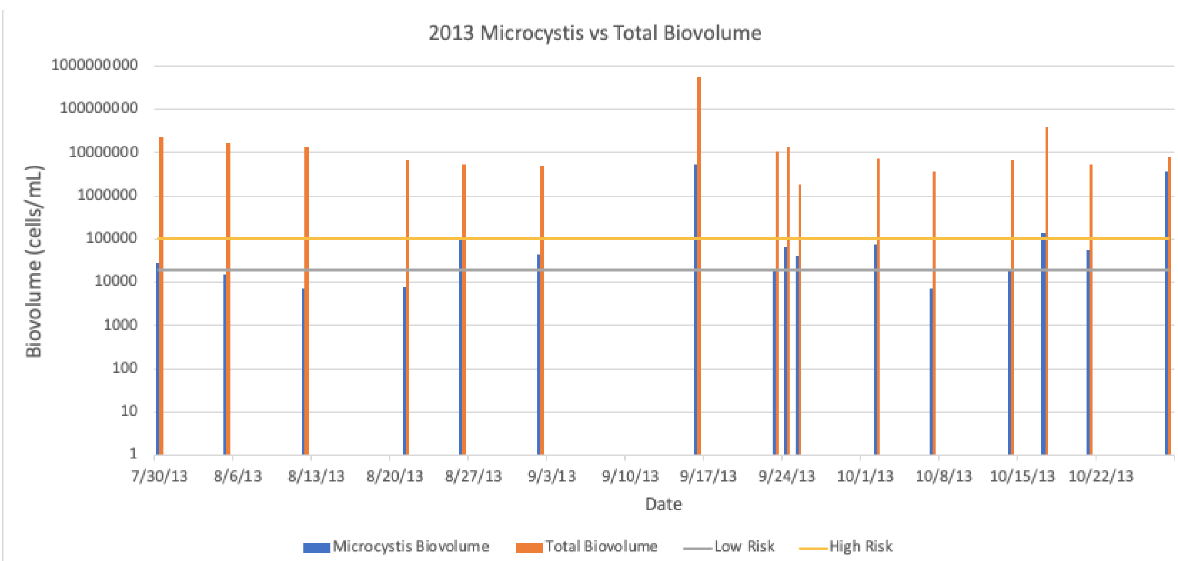


Figure 1.2,2: The total biovolume of Microcystis algae compared to the overall biovolume of algae in cells/mL in 2015. Lines at 20,000 cells and 100,000 cells indicate health advisories from the WHO.

References Cited:

Pham, T. L., & Utsumi, M. (2018). An overview of the accumulation of microcystins in aquatic ecosystems. Journal of environmental management, 213, 520-529.

US EPA "Recommended Human Health Recreational Ambient Water Quality Criteria or Swimming Advisories for Microcystins and Cylindrospermopsin" May 2019.

1.3 Land Use/Change (Kate Zidar)

Question(s)	How has land use changed over time in the Allegheny Reservoir watershed?
Data Sources	NLDC land cover database from 2001-2016 United States Census County Population by Characteristics: 2010-2019 (PA and NY)
Results File	1.3Zidar_LandUseChange 1.3Beck_Population

Rationale

Many ecological disturbances within a watershed can be linked to specific changes in land use and land cover (Beaulac & Reckhow, 1982). Different land covers (namely, forested, agricultural, and urban) yield different forms and amounts of nutrients in runoff to streams, affecting in-stream communities (Lenat & Crawford, 1994). Changes in land cover, particularly conversion of forest to agricultural or developed (urbanized) land, may increase nutrient runoff from chemical fertilizers, animal waste, air pollution, and sewage waste, contributing nutrients that fuel harmful algae blooms (HABs).

Methods

To better understand the potential impacts of land cover to the Allegheny Reservoir, imagery from the National Land Cover Database was obtained for the reservoir's 5641 km^2 watershed area and analyzed in ArcGIS. Data from 2001 and 2016 were compared to quantify the land cover types present and amount/direction of land cover change during that 15-year time span. Nutrient data from the New TREND-Nitrogen Data Set (Byrnes et. al., 2020) were analyzed for sources related to relevant land cover types over the same time period to compare changes in nutrient loading to changes in land cover.

Results

In 2016, the dominant land cover in the Allegheny Reservoir watershed were forested areas, which comprised 80.19% of the total watershed area. Agricultural land cover classifications, including hay/pasture and cultivated crops, comprised a relatively minor fraction (8.72%) of the watershed. Developed land covers (both high and medium intensity) were very minor, comprising less than 0.01% of the watershed (Figure 1.3.1). With regards to changes in land use between 2001 and 2016, forested areas were reduced by 1.24% (a total 39.67km^2 forested area lost). Meanwhile, cultivated crop land cover increased by 19.25% during this period (gaining 6.83 km^2). Hay/pasture land cover decreased by -7.60% (losing -36.97 km^2), and developed lands increased by 38.48% (gaining 3.33 km^2).

While agricultural and developed lands both increased between 2001 and 2016, these changes do not correlate with increases in nutrient loading over the same time period. To further support that urbanization or development are *not* driving an increase of nutrients to the reservoir, population data from the US Census was compared for the same time frame, finding that population within watershed counties has decreased since 2010 (Figure 1.3.2). Land cover *change* is most likely not the main driver of HABs on the Allegheny Reservoir, however specific point and non-point sources of nutrients associated with particular land uses are worth unpacking more and are more deeply explored in Section 3.

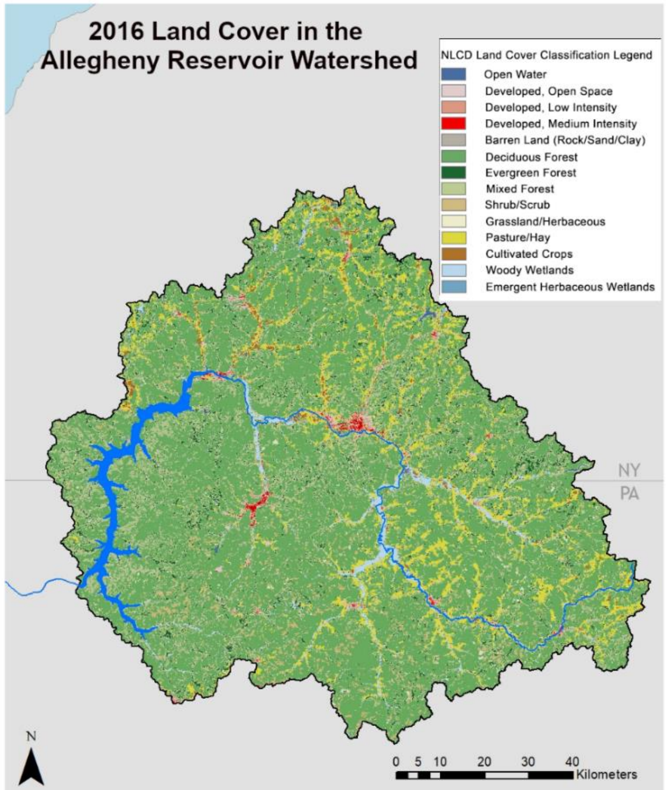


Figure 1.3.1. National Land Cover Database (USGS) classification map of land covers present in the Allegheny Reservoir watershed in 2016.

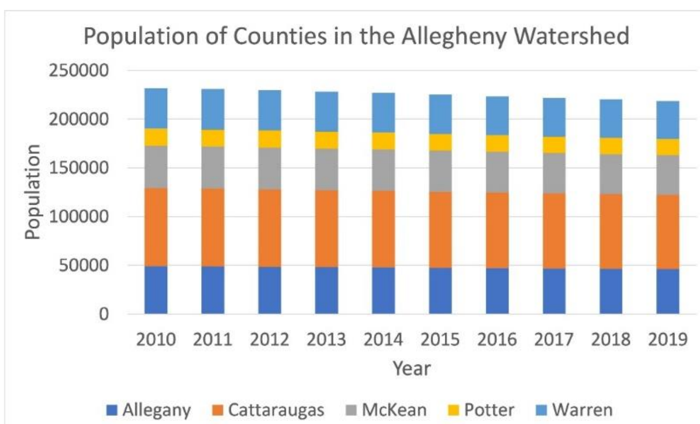


Figure 1.3.2 Population in the Allegheny Watershed by County.

References Cited

Beaulac, M. N., & Reckhow, K. H. (1982). An Examination of Land Use-Nutrient Export Relationships. JAWRA Journal of the American Water Resources Association, 18(6), 1013-1024.

Byrnes, D. K., Meter, K. J. V. & Basu, N. B. Long-Term Shifts in U.S. Nitrogen Sources and Sinks Revealed by the New TREND-Nitrogen Data Set (1930–2017). Glob. Biogeochem. Cycles 34, e2020GB006626 (2020).

Lenat, D. R., & Crawford, J. K. (1994). Effects of land use on water quality and aquatic biota of three North Carolina Piedmont streams. Hydrobiologia, 294(3), 185-199.

U.S. Census Bureau, Population Division (2020). *CC-EST2019-AGESEX-36: Annual County and Puerto Rico Municipio Resident Population Estimates by Selected Age Groups and Sex: April 1, 2010 to July 1, 2019* [Data set]. https://www.census.gov/data/tables/time-series/demo/popest/2010s-counties-detail.html.

U.S. Census Bureau, Population Division (2020). *CC-EST2019-AGESEX-42: Annual County and Puerto Rico Municipio Resident Population Estimates by Selected Age Groups and Sex: April 1, 2010 to July 1, 2019* [Data set]. https://www.census.gov/data/tables/time-series/demo/popest/2010s-counties-detail.html.

2 Algal Dynamics

2.1 Trophic Status Index (Elijah Hall)

Question(s)	How does the trophic state index of blooms vary temporally within the Allegheny Reservoir?
	Has trophic state changed over time?
Data Sources	DATABASE COE PITTS 2019 CELLS TOTAL, DB COE PITTS CELLS 2007-2018
Results File	2.1Hall_TSI

Rationale

The trophic state index (TSI) is a classification scheme that quantifies and characterizes waterbodies based upon biological productivity, or biomass growth fueled by photosynthesis. There are three major trophic classifications: oligotrophic (<35), mesotrophic (35-50), and eutrophic (>50) (Carlson, 1977). A fourth classification, hyper-eutrophic, has been given to systems with an index greater than 65, indicating dense algal populations. Algal bloom prevalence increases as the trophic state changes from oligotrophic to eutrophic. This classification system is commonly used to rate the health of a water system and can give insight into excess nutrients traveling into the system (Bilgin, 2020). Depending on the trophic status of a waterbody, algal blooms become more prevalent, requiring increased remediation practices to reduce algal dominance (Fuller and Jodoin, 2016).

Methods

TSI can be quantified using three independent variables: chlorophyll pigment, total phosphorous, and Secchi disk depth (Carlson and Simpson, 1996). However, the USACE uses a similar index which utilizes phytoplankton biovolume instead of the three variables. This index ranges from 1 for ultra-oligotrophic, low algal prevalence, waterbodies to 100 hyper-eutrophic, high algal presence, waterbodies. The equation is as follows:

$$TSI=(\log_2(B+1)) \times 5$$

where B is the phytoplankton biovolume in $((\mu m)3/ml) \div 1000$. TSI values were averaged for each month to create a comparison.

Results

TSI values ranged from 21.16 - 108.09 with a mean of 49.41. Of the TSI data values provided by the USACE, 9.94% of the values indicate oligotrophic conditions with most found in the winter to early spring months, 47.32% indicate mesotrophic conditions, 32.41% indicate eutrophic conditions, and 10.34% of the values indicate hyper-eutrophic conditions. This is concerning as over 40% of the provided data indicates that health conditions on the Allegheny Reservoir are poor (eutrophic or hyper eutrophic) whereupon most eutrophic or hyper eutrophic conditions occur in the summer.

Mean annual box plot distributions for yearly TSI values show a decreased from 2008 – 2010 but increased in the following years until 2014 where the mean values have remained generally consistent (Figure 2.1.1.A). Monthly mean June and August TSI values followed the same trend with lower mean values until 2012 (Figure 2.1.1.B and Figure 2.1.1.C). Following 2012, June values were consistent, but August TSI values are more variable but have generally continued to increase since 2012. The year 2017 exhibited the highest mean TSI values in all figures with the highest productivity during that year potentially being attributed to warm temperatures, low precipitation, or higher nutrient inputs that fueled algal growth. Most yearly TSI distributions are above the eutrophic boundary in recent years (2013 – 2019) exhibiting a reduction in waterbody health. However, in September, mean TSI has decreased since 2017, perhaps signaling that blooms have been ending earlier since that time, recent years have shown a reduction in trophic state going against what other distributions have shown (Figure 2.1.1.D).

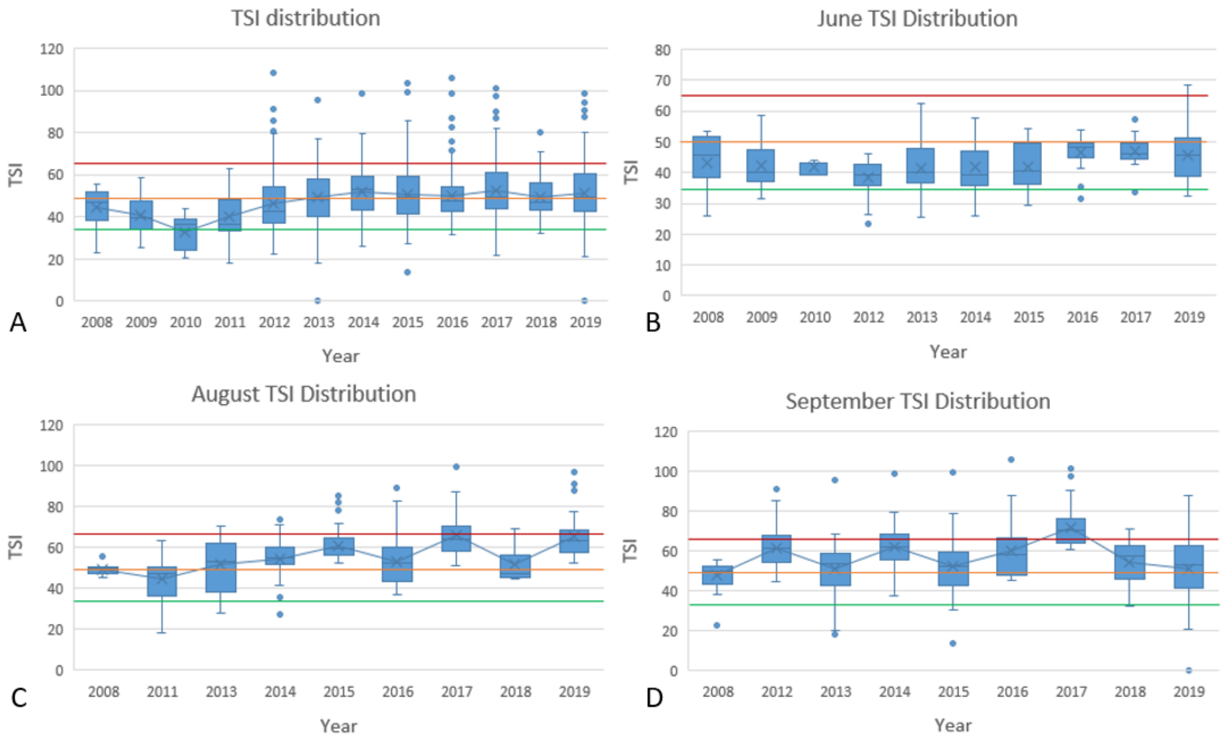


Figure 2.1.1: Average TSI values for 2008 – 2019. Values below the green line indicate oligotrophic conditions, below orange indicating mesotrophic, below red indicating eutrophic, and above the red line indicates hyper-eutrophic conditions. (A) represents average yearly TSI. (B) represents average TSI values for June months. (C) represents average TSI values for August months. (D) represents average TSI values for September months.

References Cited

Bilgin, A. (2020). Trophic state and limiting nutrient evaluations using trophic state/level index methods: A case study of Borçka Dam Lake. Environmental Monitoring and Assessment, 192(12), 794. https://doi.org/10.1007/s10661-020-08741-0

Carlson, R. E., & Simpson, J. (1996). A Coordinator's Guide to Volunteer Lake Monitoring Methods. North American Lake Management Society, 96, 305.

Fuller, L. M. (Lori M.), & Jodoin, R. S. (2016). Estimation of a trophic state index for selected inland lakes in Michigan, 1999-2013. U.S. Department of the Interior, U.S. Geological Survey.

Robert E. Carlson. (1977). A Trophic State Index for Lakes. Limnology and Oceanography, 22(2), 361–369.

2.2 Algal community populations relative to nutrient concentrations (Timothy Suder)

Question(s)	How does Algal community speciation fluctuate temporally and spatially with nutrient fluctuations?
Data Sources	KIN Nutrient Data 2012-2016, KIN Lab Data 2016-2018, and DB COE PITTS CELLS 2007-2018
Results File	2.2Suder_KIN_Algal_Populations 2.2Suder_KIN_Long_Time_Scale_Nutrient_Data

Rationale

Algae are generally dependent on the dissolved and particulate nitrogen and phosphorus species that exist within an aquatic system. Additionally, while this has been studied for algal populations as a whole, these generalities do not reflect the nutrient dependence of specific algal species (Pham et. al., 2018). The major groups of interest when studying algae are Cyanobacteria and Eukaryotic Algae that are, classified into discrete kingdoms. This means, biologically, that these groups are particularly dissimilar, which may lead to dependence on separate nutrient regimes for growth and proliferation. This is an important distinction to be drawn when discussing HABs, as toxic freshwater HABs are dominated by Cyanobacterial species, that may have different nutrient requirements to become expressed as the dominant specie within a bloom (Morse et. al., 2014). Therefore, understanding how algal blooms shift between Eukaryotic algae and Cyanobacteria with shifting nutrient regimes is important to understand how to control the growth and impact of HABs.

Methods

To study the algal dynamics and understand how they are affected by nutrient concentrations and limitations within the Allegheny Reservoir, algal population and nutrient concentration data for a cross-section of sampling sites was evaluated over a seven-year period from 2011 to 2018. The changes in Eukaryotic algae and cyanobacteria are illustrated with respect to time and distance from the Kinzua dam.

Results

The algal population data has no significant trends with time or distance from the dam (Eukaryotic algae r2=0.0253, p=0.2770; Cyanobacteria r2=0.0100, p=0.6047) (Figure 2.2.1). This is likely due to a dependence on combined nutrient dynamics and water temperature, which shows seasonality resulting in a non-linear trend temporally.

We observed significant trends in concentrations of Ammonia with time and with distance from the dam (r2=0.5952, p=1.2312E-5) and Nitrite/Nitrate concentration (r2=0.3243, p=0.0357) (Figure 2.2.2). The Ammonia concentration have increased in a linearly since 2012 (slope=8.9552E-5 ,0.0327 mg L^{-1} yr^{-1}) and generally increases upriver away from the Kinzua Dam (slope=3.8565E-4).

The Nitrite/Nitrate concentration has decreased since 2012 (slope=-8.0027E-5) and generally increases upriver with distance from the Kinzua Dam. (slope=0.0031). No significant trends were observed for concentrations of Total phosphorous, TKN, or N/P.

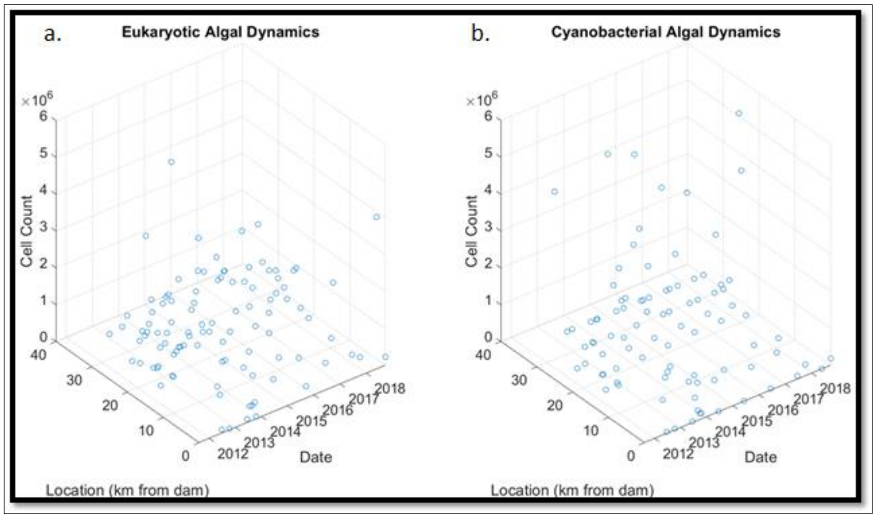


Figure 2.2.1- This figure documents the shift in a) Eukaryotic Algae and b) Cyanobacteria as a function of time and distance from the Kinzua Dam.

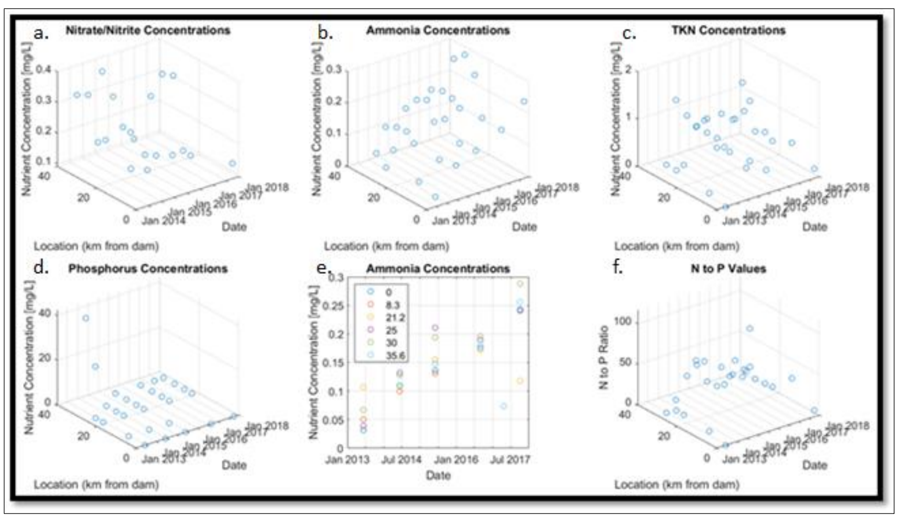


Figure 2.2.2- This figure documents the shift in Nutrient Concentration as a function of time and distance from the Kinzua Dam. Plotted in three dimensions are a) Nitrate/Nitrite, b) Ammonia, c) TKN, d) Total Phosphorus, and f) N/P. The e) Ammonia concentration is also plotted on a two-dimensional graph color coded to indicate distance away from the dam.

References Cited:

Pham, T. L.; Utsumi, M. An Overview of the Accumulation of Microcystins in Aquatic Ecosystems. Journal of Environmental Management. Academic Press May 1, 2018, pp 520–529. https://doi.org/10.1016/j.jenvman.2018.01.077.

Morse, R. E.; Mulholland, M. R.; Egerton, T. A.; Marshall, H. G. Phytoplankton and Nutrient Dynamics in a Tidally Dominated Eutrophic Estuary: Daily Variability and Controls on Bloom Formation. Mar. Ecol. Prog. Ser. 2014, 503, 59–74. https://doi.org/10.3354/meps10743.

3 Nutrient Sources

3.1 Agriculture (Patrick Dunn)

Question(s)	Does agriculture introduce a significant amount of nitrogen and phosphorus to the watershed?
	[if more than one, add the other here]
Data Sources	USDA CropScape, Byrnes et al. TREND-nitrogen, USDA ERS Fertilizer Use
Results File	3.1Dunn_CropAgricultureNutrients

Rationale

The use of inorganic nutrient fertilizers for crop agriculture has increased vastly over the last century due to increased food demands and industrialization (Alexandratos et al., 2012). The essential nutrients, nitrogen (N) and phosphorus (P), are applied extensively across cropland in the U.S., with annual inputs of 13 and 4 million tons respectively (USDA ERS, 2019). The application of these nutrients is highly inefficient, with an estimated 50% of N and 75% of P being lost to the environment (Lal et al., 2018; Dhillon et al., 2017). These large fluxes of excess nutrients to the environment directly impact surface waters and make agriculture one of the main culprits in causing 30% of all U.S. lakes to be categorized as eutrophic (EPA, 2017). Harmful algal blooms (HABs) are common in lake systems that are eutrophic with elevated N and P concentrations (Paerl et al., 2020). Managing the inputs of both nutrients is important for mitigating the annual presence of HABs (Paerl et al., 2020). Since agricultural inputs are often critical for the formation of HABs, the following analysis aims to elucidate if crop agriculture plays a significant role in loading nutrients to the watershed of the Allegheny Reservoir.

Methods

A mass balance approach, adapted from Byrnes et al., 2020, was used to estimate N and P loads from crop agriculture for the Allegheny watershed draining to the Allegheny Reservoir. The USDA Cropland Data Layer was used in GIS to quantify the areal extent of crop types within the watershed, for the period 2008-2020 (USDA NASS, 2020). For this analysis, we focused on crops comprising over 95% of all cropland in the watershed during the study period including hay, corn, soybean, alfalfa, and winter wheat. The annual “excess N” and “excess P” for each of the crops was calculated using the mass balance equations below.

$$Excess\ N = \sum\left(\left(\frac{N\ Fertilizer}{Area} + \frac{N\ Fixation}{Area} - \frac{N\ Crop\ Uptake}{Area}\right) * Crop\ Area\right) \quad (1)$$

$$Excess\ P = \sum\left(\left(\frac{P\ Fertilizer}{Area} - \frac{P\ Crop\ Uptake}{Area}\right) * Crop\ Area\right) \quad (2)$$

In the mass balances (Equations 1 & 2), total "excess N" and "excess P" were calculated for each crop type by first summing fertilizer application rates (kg/ha). Fertilizer applications per area were determined for each crop based on the average of USDA annual survey data for Pennsylvania and New York (USDA ERS, 2019), or they were determined by using the recommended applications of each nutrient for an estimated yield (see Agriculture README). The amount of nutrient removed by crop production and harvesting (kg/ha) was subtracted from the fertilizer rates. Crop uptake of N and P was determined using the USDA crop nutrient tool for estimated yields (USDA PLANTS, 2020). For calculation of "excess N", N fixation rates (kg/ha) from cultivation of N-fixing crops like soybeans were added to fertilizer application rates as an additional N source. N fixation rates were determined for the N fixing plants, alfalfa and soybean, using literature values for estimated yields. The areal extent (ha) of each crop type was then used to calculate excess N or P for each crop type, then summed for all crops in each county. The flux of excess N and P per area basis was determined by dividing the total loads by the total area of the watershed (564,000 ha).

Results

The total land area used for crop agriculture within the watershed was consistent and small over the study period, with 4.8 ± 0.95% of land being cultivated. The most prominent crop in the watershed over the study period was hay (3.6 ± 0.88%) followed by corn (0.78 ± 0.13%), alfalfa (0.25 ± 0.08%), soybean (0.12 ± 0.03%), and winter wheat (0.060 ± 0.018%). Annually, an estimated average of $3.6 \bullet 10^6$ kg of N and $1.4 \bullet 10^6$ kg of P fertilizers is applied to lands within the watershed. An additional $3.5 \bullet 10^5$ kg of N is fixed from soybean and alfalfa crops. Crops remove $3.5 \bullet 10^6$ kg and $5.1 \bullet 10^5$ kg of this N and P respectively. Taken together, this leaves an excess of 0.39 ± 0.16 kg/ha of N and 1.5 ± 0.34 kg/ha of P within the watershed (Figure 3.1.1A).

To judge the accuracy of this analysis, the results were compared to a similar study, by Byrnes et al., 2020, that determined the excess N for all U.S. counties. The average N excess from crop agriculture for the counties contained within the watershed (Allegany, Cattaraugus, McKean, Potter, and Warren) from 2008-2017 was found to be 0.44 kg/ha, which is comparable with the value determined for the Allegheny Reservoir watershed. Compared to all counties, the Allegheny Reservoir watershed falls beneath the 10^{th} percentile for N flux for crop agriculture (Figure 3.1.1B). Unfortunately, no present study has performed a nationwide study of excess P, making an assessment of the accuracy and severity for this study's value difficult. However, it is inferred that excess N and P from crop agriculture scale similarly, meaning fluxes of P within the watershed are also low from a national perspective.

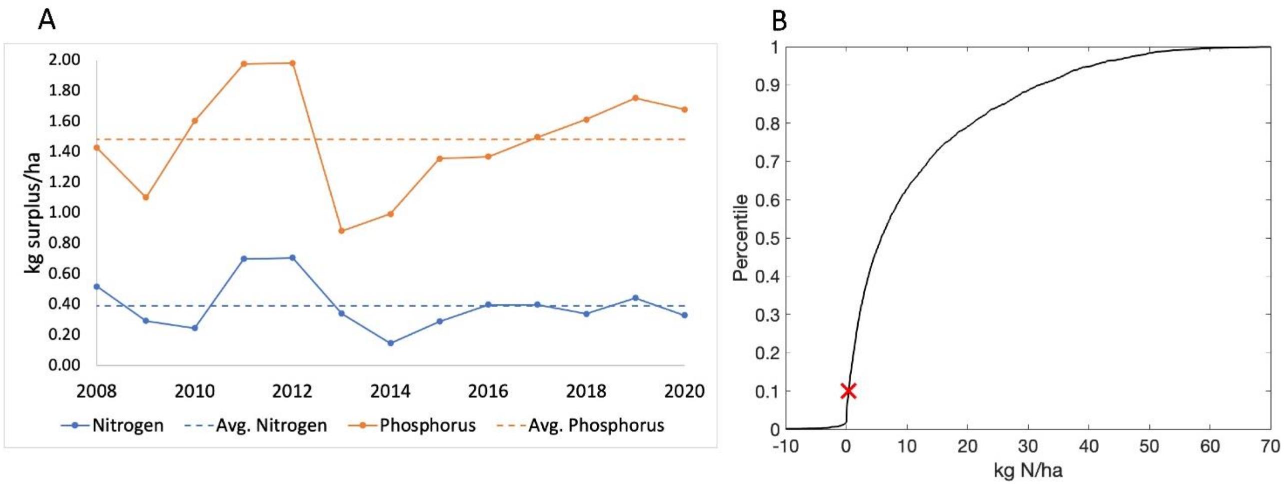


Figure 3.1.1 (A) Yearly surplus and averages of N and P in kg/ha within the Allegheny Reservoir watershed from 2008 to 2020, and (B) cumulative distribution curve of N inputs (kg/ha) for all U.S. counties and the relative position of the Allegheny Reservoir watershed (red marker).

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3.2 Wastewater and other point source inputs (Brandon Brewster)

Question(s)	What is the estimated annual nutrient load from wastewater effluent to the reservoir?
Data Sources	USEPA-HYPOXIA-TASK-FORCE-ECHO-TOOL, LRP_GAGES.xls, LRP WQ Stations 20190226, LRP WQ Sampling Stations KIN SHN, NLDC land cover database from 2001-2016, CSO Outfall Locations - 2018.xls,
Results File	3.2Brewster_PointSources

Rationale:

The Allegheny Reservoir and surrounding watershed are home to point sources of of nutrients and other industrial effluent that can impact the water chemistry of surface and groundwater. Because HABs directly rely on available nitrogen and phosphorus concentrations it is crucial to identify the primary point source(s) of these inputs.

Methods:

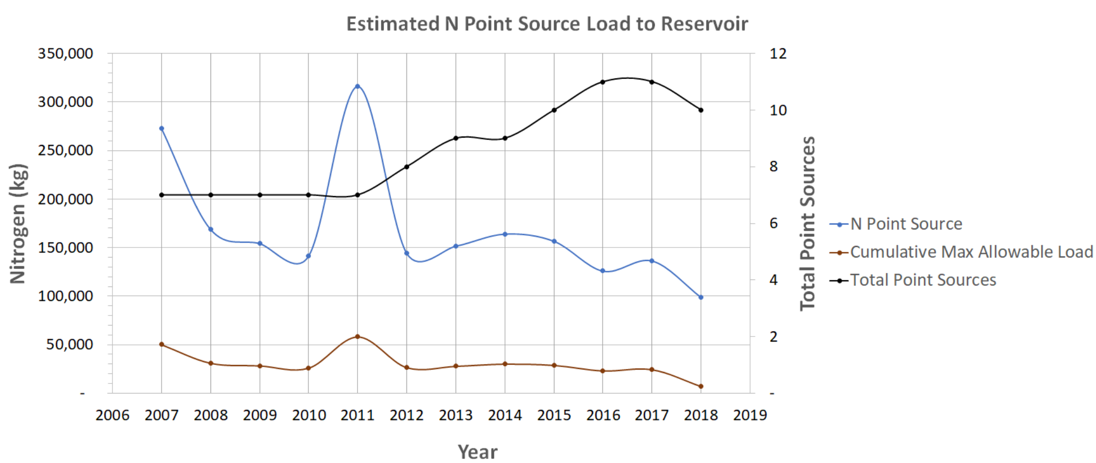
To map and quantify available effluent and treatment plant data, we used the USEPA's Hypoxia Task Force Echo tool (USEPA-HYPOXIA-TASK-FORCE-ECHO-TOOL). The ECHO database compiles existing U.S. EPA National Pollutant Discharge Elimination System (NPDES) permits and estimates total annual nitrogen and phosphorous fluxes from each permitted facility. For this analysis, we queried and quantified all point sources within the boundaries of Hydrologic Unit Code (HUC) #05010001 from 2007 to 2018. The resulting data was analyzed to determine total nitrogen and total phosphorous loadings by point source (lbs/year).

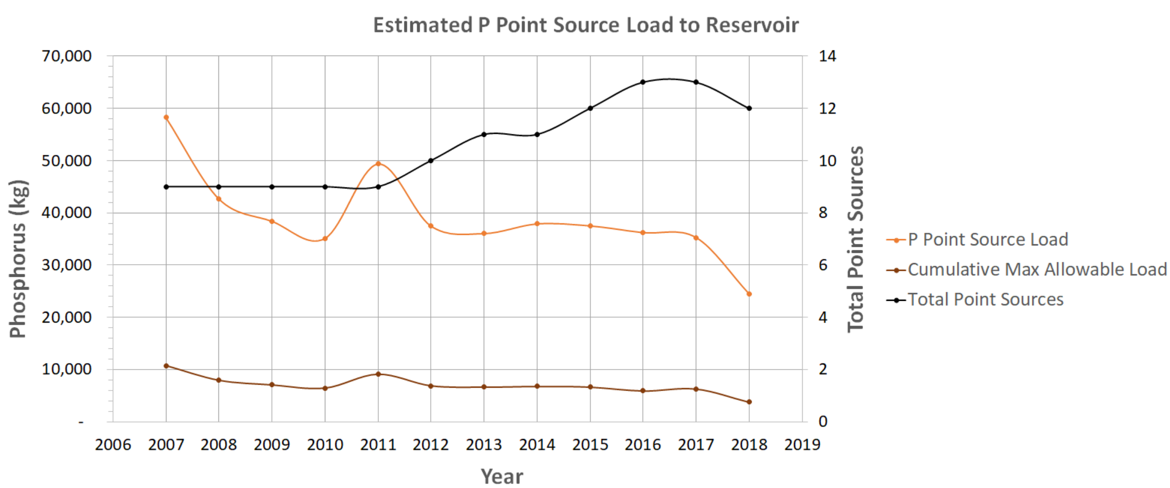
To further refine the geographic scope, we chose a subset of ~12 (year dependent) point sources in direct proximity to the Allegheny Reservoir that represent the cumulative nutrient load. These nutrient load data were summed and converted to kg/year for each year and plotted in (Figures 3.2.1). For additional context, we also evaluate cumulative maximum allowable loads for both N&P on an annual basis and the total number of point sources reporting.

Results:

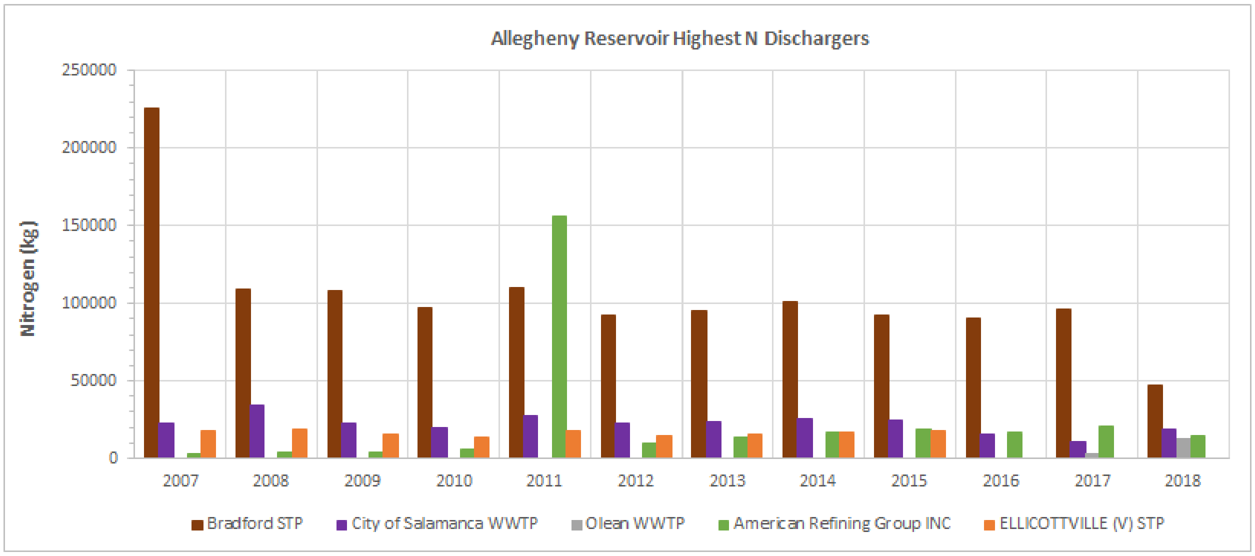
Peak N and P loads occurred in 2007 (273,249 kg N and 58,281 kg P) and 2011 (316,196 kg N and 49,371 kg P) with a general decrease since 2011 to 98,787 kg and 24,504 kg of N and P in 2018, respectively. In specific instances, cumulative maximum allowable load data were not reported for certain point sources though they reported a discharge for the same year. Specifically, this occurs from the year 2017 to 2018 in the Nitrogen data and from 2014 to 2018 in the Phosphorous data. Therefore, within those ranges the cumulative maximum allowable load is slightly lower than reality. In order to evaluate the relationship between each plant and its influence on the reservoir the highest dischargers were identified (See NP_AROnly.xls) and their discharge data plotted in (Figures 3.2.2.). All point sources exceed their maximum allowable annual loads, both on an individual basis, and cumulatively from 2007 (273,249 kg N, 58,281 kg P) to 2018 (98,787 kg N, 24,504 kg P) (Figures 3.2.1). In 2018, this exceedance was the equivalent of 91,797 and 20,718 kg of N and P, respectively. Additionally, we thought that the decreasing trend in discharge and increasing trend in reporting point source facilities (Figures 3.2.1) could be explained by those point source facilities who were reporting zero discharge (see NP_AROnly.xls). However, upon further investigation it seems that the only instances where point source facilities reporting zero discharge was a factor in the cumulative trend is with the Olean WWTP, who only reported N discharge starting in 2017, and the Ellicottville STP, who stopped reporting N after 2015 (Figure 3.2.2).

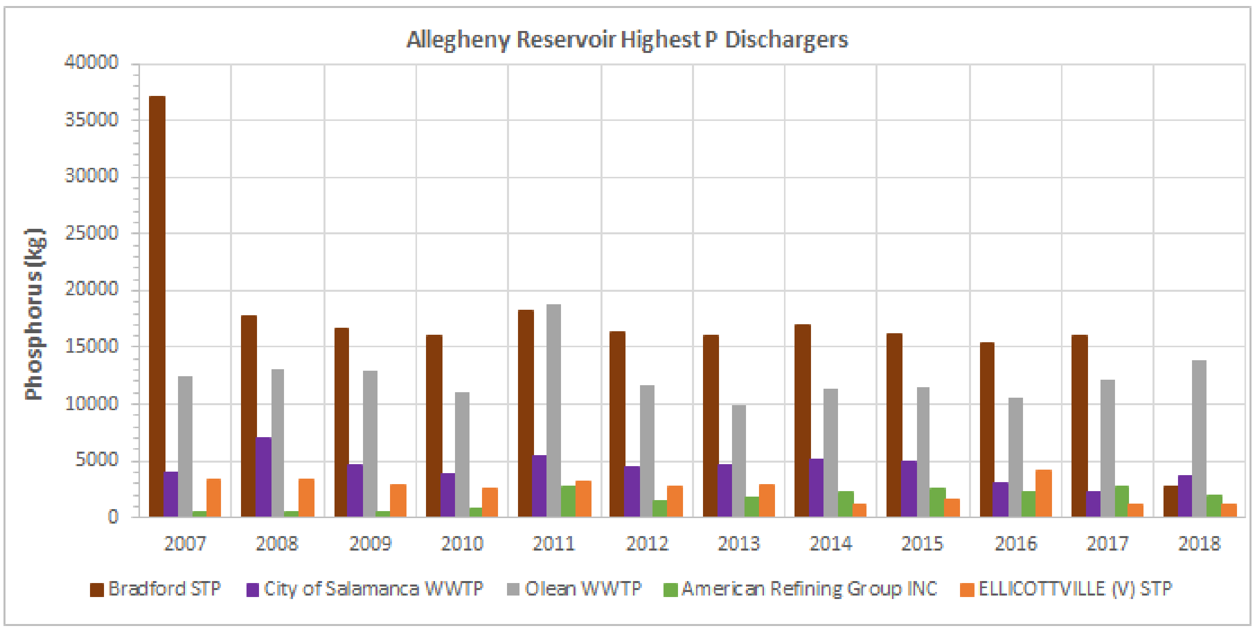
The highest N dischargers to the reservoir are Bradford Sewage treatment Plant (STP) (generally > 90,000 kgyr^{-1} N), American Refining Group INC (Responsible for the huge spike in 2011, ~20,000 kgyr^{-1} N otherwise), City of Salamanca WWTP (~25,000 kgyr^{-1} N) , and Ellicottville STP (~17,000 kgyr^{-1} N) (Figures 3.2.2). The highest P dischargers to the reservoir are Bradford Sewage Treatment Plant (~17,000 kgyr^{-1} P), Olean WWTP (~13,000 kgyr^{-1} P), and the City of Salamanca WWTP (~5,000 kgyr^{-1} P) (Figures 3.2.2). Given that the cumulative point source nutrient fluxes to the reservoir exceed N >~100,000 kgyr^{-1} and P >~35,000 kgyr^{-1}, it is important to consider how these fluxes compare to total N and P sources to the Reservoir and the influence of its hydrological connectivity with the reservoir.



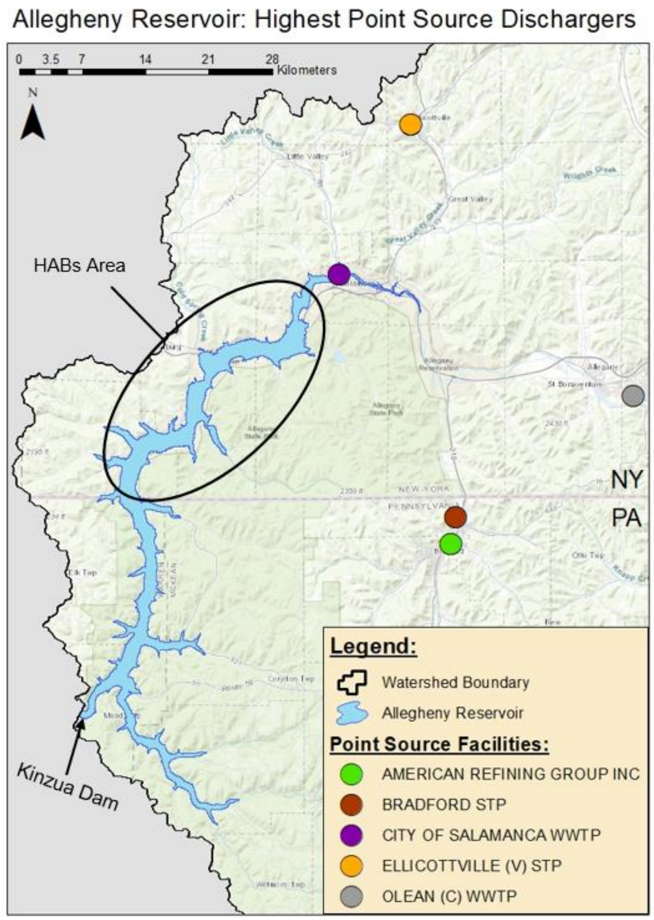


Figures 3.2.1: The above figures represent the nitrogen and phosphorus point source loads to the reservoir (kg/year) respectively. In addition to the total point source loads, the plots also show the total number of point sources discharging for a particular year, and the cumulative maximum allowable load for those same sources.





Figures 3.2.2: The above figures show the highest dischargers to the Allegheny Reservoir of Nitrogen and Phosphorus point source pollution. Each point source is labeled with a specific color that is consistent with Figure 3.2.3 to assist with spatial analysis and provide location-based context as to their influence on the reservoir.



Figures 3.2.3: Pictured above is the Allegheny Reservoir (blue), and western portion of the watershed outlined in black with a gray background. Additionally, the highest point source facilities are represented by the same colors as in Figures 3.2.3 to further explore their spatial importance to the reservoir. Annotations identifying the Kinzua dam, and the general Harmful Algal Bloom (HABs area) prevalence area, are included to provide additional context.

3.3 Legacy nutrients (Matthew Beck)

Question(s)	What are the historic agricultural nitrogen loads in the watershed and how have they changed over time?
	How have inputs from different nitrogen sources changed overtime?
Data Sources	Byrnes, Danyka K; Van Meter, Kimberly J; Basu, Nandita B (2020): Trajectories Nutrient Dataset for Nitrogen (TREND-nitrogen). PANGAEA, https://doi.org/10.1594/PANGAEA.917583
Results File	3.3Beck_LegacyN

Rationale:

In some human-impacted ecosystems, nutrients are available in excess of biotic demand. Nutrients that remain in the ecosystem for an extended period of time (i.e., years) are referred to as "legacy" nutrients and are typically stored in soils or sediments. Legacy nitrogen (N) is particularly common due to its presence in human and animal excrement, along with its increased use in N-based fertilizers for agriculture. Legacy N can contribute to the formation of harmful algal blooms (HABs) in lentic, or slow-moving, bodies of water. Legacy nitrogen stored in soils of the watershed surrounding the Allegheny Reservoir may be a long-term potential source of N to the Reservoir. If current nitrogen loading is not the cause of HAB proliferation, then historic nitrogen loads may contribute. As our analyses considers all nutrient sources to the Reservoir, "...it is increasingly understood that N emissions from agricultural landscapes are a function not only of current-year N inputs but also of legacy N that may have accumulated over decades..." (Byrnes et al., 2020). Studying the legacy N of the Allegheny Reservoir will provide a more complete context of the nutrient dynamics in the region.

Methods:

To study legacy nitrogen in the watershed, historic data were acquired from the TREND-Nitrogen dataset compiled by Byrnes et al. (2020) that contains nitrogen loading data for all U.S. counties by major source. For this study, data was used for the counties of McKean, PA; Warren, PA; Potter, PA; Cattaraugus, NY; and Allegany, NY that include or are adjacent to the Allegheny Reservoir. TREND-Nitrogen includes annual nitrogen inputs from crop and pasture agriculture (in the form of biological N fixation), livestock manure, fertilizer, human waste, and atmospheric deposition. These inputs are offset by removal of N through crop N uptake and harvesting.

For these analyses, we modified the Brynes et al calculation to account for agricultural-related N activity. The new equation is as follows: Total Agricultural N = Manure N Inputs + Biological N Fixation + Agricultural N Fertilizer – Crop Uptake. Annual N input and output values were aggregated for each of the five counties and each mass balance component (kg N/ha). The annual N loading rate (kg N/ha) was averaged over the five counties and multiplied by the Allegheny Reservoir watershed area to estimate the mean N input or output (kg N) for each N mass balance component (Fig. 3.3.1).

Figure 3.3.1 also shows the total yearly excess agricultural N load. Each mass balance component's input is displayed in Fig. 3.3.2, with atmospheric N and human waste N also accounted for. Atmospheric N was also isolated to show its overall trend in deposition (Fig. 3.3.3). The total legacy N input (kg N/ha) from 1930-2017 for the watershed was compared to the distribution of legacy N loads for all other U.S. counties for additional context (Fig. 3.3.4).

Results:

The average agricultural N input per year increased between 1935 and 1985, but then decreased to approximately 1945 levels in 2012 (9.6 and 9.5 kg/ha for 1945 and 2012, respectively) (Figure 3.3.1). Average N removal generally decreased annually since 1930 from 7.9 kg N/ha to 4.8 kg N/ha. By nature of the increased input and decreased uptake, excess yearly N increased from 1.6 kg N/ha to 5.3 kg N/ha from 1930 to 2017.

Our analyses indicate that atmospheric deposition and manure make large contributions to the percentage of total N input (Figure 3.3.2). On average, from 1930 to 2017, the annual N input from atmospheric deposition is 7,271,634 kg, or about 51% of all N that enters the ecosystem and watershed surrounding the Allegheny Reservoir (Figure 3.3.2). Manure produces an average of 3,393,529 kg N annually, or 24% of the N mass input. Agriculture inputs 2,308,173 kg N (16%), N Fertilizer produces just 698,721 kg N (5%), and Human Waste introduces a mere 484,841 kg N (3%).

The average yearly fertilizer input increases from 0.2 kg N/ha in 1930 to 1.6 kg N/ha in 2017 (Figure 3.3.2). Adjusted for the watershed area (564,000 ha), this is from 113,000 kg N to 920,000 kg N. Atmospheric N deposition is the highest contributor of the legacy nutrient. Its value increases overall by 4.9 kg N/ha, or 2,780,000 kg N over the entire watershed. I have isolated the trend in atmospheric N deposition so that it is easier to see fluctuation (Figure 3.3.3). Livestock manure and human waste inputs remain fairly constant from 1930 to 2017.

Compared to all U.S. counties' legacy N loading from 1930-2017, the Allegheny Reservoir watershed falls under the 40th percentile. This shows that the watershed area is not storing an abnormally high amount of N.

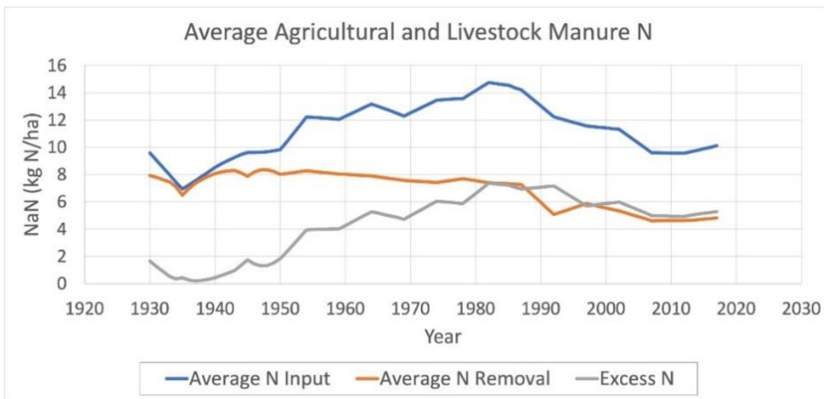


Figure 3.3.1. Average Annual Agricultural and Manure N in the Allegheny Watershed. The blue line is the total input of N from agriculture and manure, and the orange line is the total output/uptake by crops. The gray line is the excess N remaining from each year's agricultural N mass budget.

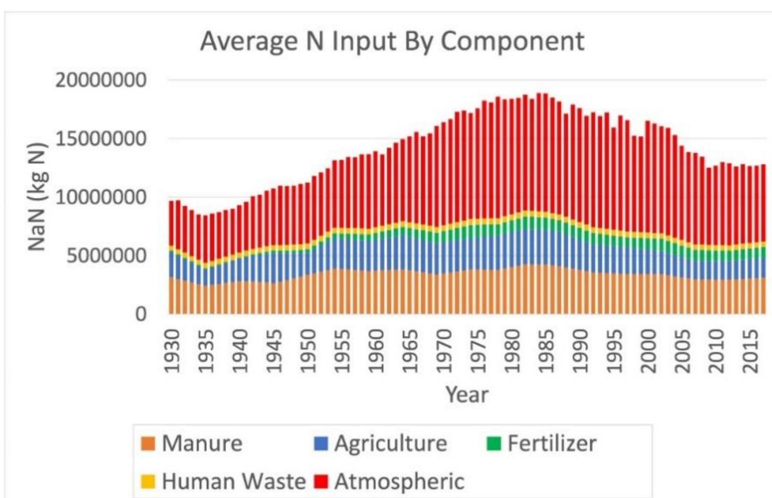


Figure 3.3.2. Average N Input by Mass Balance Component for the Allegheny Watershed. Includes both anthropogenic sources and data for atmospheric N deposition. The agriculture bar includes biological N fixation inputs. The fertilizer bar includes both domestic and agricultural N fertilizer inputs.

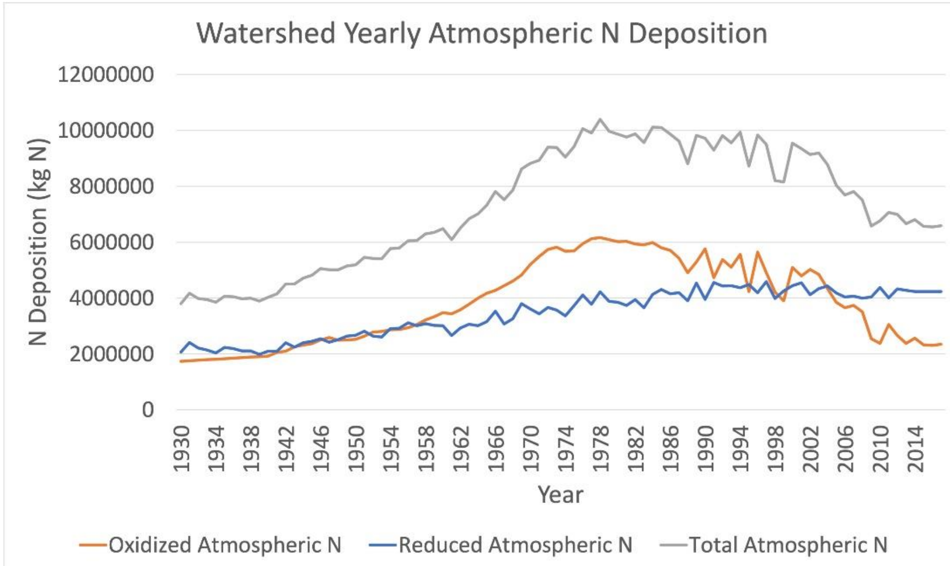


Figure 3.3.3. Yearly Atmospheric N Deposited in the Watershed.

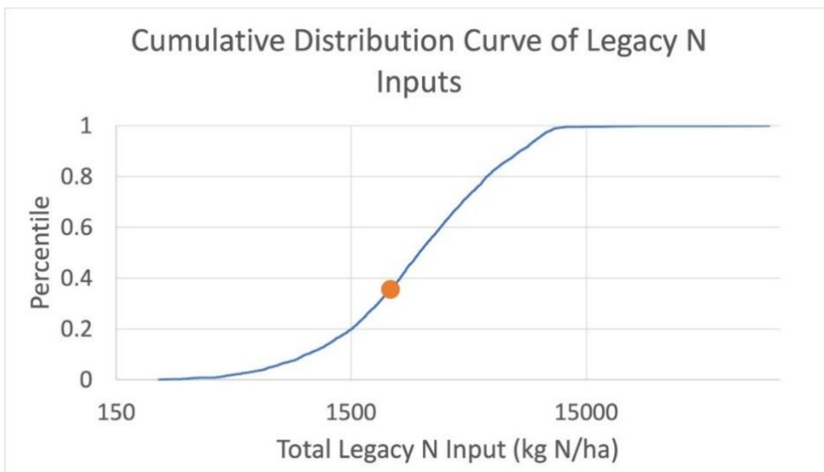


Figure 3.3.4. Cumulative distribution curve of Total Legacy N Inputs (kg/ha) for all U.S. counties and the relative position of the legacy N loading to the Allegheny Reservoir watershed (orange marker).

References Cited:

Byrnes, Danyka K; Van Meter, Kimberly J; Basu, Nandita B (2020): Long-term shifts in U.S. nitrogen sources and sinks revealed by the new TREND-nitrogen dataset (1930-2017). Global Biogeochemical Cycles, https://doi.org/10.1029/2020GB006626

4 Climate and Hydrological Drivers

4.1 Spring and summer runoff (Abby Yancy)

Question(s)	Have spring and summer discharges from the Allegheny River changed over time?
	[if more than one, add the other here]
Data Sources	Discharge records from the USGS gage on the Allegheny River at Salamanca, NY, Olean, NY and Port Allegany, PA
Results File	4.1Yancy_SalamancaFlow.R ; 4.1Yancy_SalamancaFlow.xlsx

Rationale:

To understand the potential role climate change plays in algal bloom formation, it is necessary to assess whether any changes have occurred in spring and summer runoff. Spring runoff transports nutrients, such as nitrogen, downstream to lentic conditions in the reservoir where algal growth typically occurs (Jones et al 2017). Streamflow is impacted by climate and anthropogenic interactions, with national-scale studies indicating a trend of increasing precipitation and streamflow in eastern parts of the U.S. (Patterson et al 2012). Anthropogenic infrastructure, such as dams and reservoirs, influence streamflow and have the potential to obscure climate effects on streamflow (Patterson et al 2012). If flows (discharge) of the Allegheny River upstream from the Allegheny Reservoir follow similar climatic trends, higher rates of nutrient-rich spring runoff, followed by low flow conditions in the summer, could be a potential driver of the annual algal blooms.

Methods:

Long-term records of discharge from the Allegheny River were examined at the United States Geological Survey (USGS) gage at Salamanca, New York (42°09'23", 78°42'55"; USGS 03011020), located approximately 15 miles upstream from the start of the reservoir. Daily mean discharge data at the site was recorded from 1903 to 2020. Daily mean discharge at Salamanca above a threshold of the ninetieth percentile was plotted to understand the distribution of high flow conditions over the time period in the spring season consisting of March, April and May. A vertical line was added to indicate the completion of dam construction in 1966 (Rosier 1995). Additionally, records from two gages at Olean, New York (42°04'23", 78°27'04"; USGS 03010820) and Port Allegany, PA (41°49'07", 78°17'35"; USGS 03007800) were compared to the Salamanca gage site to determine if the records followed similar trends from 2010 to 2020. The Olean and Port Allegany gages are located approximately 35 and 70 miles, respectively, upstream from the start of the reservoir. Annual mean daily discharge at Salamanca, Olean, and Port Allegany for the 2010-2020 record were plotted for the spring season with smoothed estimates created using methods by Cleveland (1979) and Cleveland and Devlin (1988) in the Exploration and Graphics for RivEr Trends (EGRET) package in R Studio (Hirsh and De Cicco, 2014; R Core Team, 2021). The standard deviation of the log of discharge was plotted to visualize changes in variability at the three gage locations. To examine the long-term records for variation in seasonal discharge at Salamanca, thirty-day maximum, thirty-day minimum and standard deviation of the log of discharge was plotted with smoothed estimates for the spring and summer seasons, summer consisting of the months June, July and August. All data retrieval and analysis of the USGS data was performed using the dataRetrieval and EGRET packages in R Studio (Hirsh and De Cicco, 2014; R Core Team, 2021).

Annual mean, maximum, minimum, and top 10% threshold of spring discharge from 2010-2019, excluding 2011, was plotted with trendlines in Microsoft Excel (2019) at Salamanca to examine recent trends. Additionally, annual mean, maximum, minimum and bottom 10% threshold of summer discharge was plotted with trendlines in Microsoft Excel (2019) at Salamanca for the same years to determine summer streamflow trends following spring.

Results:

The construction of the dam decreased high flow conditions in spring and the trend continues into the most recent years (Figure 4.1.1). Because we expected an increase in spring discharge rates and frequency in recent years, these records were compared to Olean and Port Allegany to determine if Salamanca is in the "transition zone" of the reservoir (i.e., discharge at Salamanca is close enough to the reservoir to be impacted by the dam). However, all three sites have similar trends of decreasing discharge and variation (Figure 4.1.2). After comparison, the use of Salamanca for flow history analysis is justified. Consistent with observations, spring maximum records show a decreasing trend over the entire record, with spring minimum rates increasing (Figure 4.1.3). Summer maximum discharge rates remain steady; however, minimum discharge rates begin to increase after approximately 1960 (Figure 4.1.3).

Because the smoothing methods in EGRET were developed for longer records and shorter records show higher sensitivity to outliers, various statistics of spring and summer discharge were plotted with trendlines in Microsoft Excel (2019) to examine recent trends (2010-19).

Spring 2011 was anomalously wet. When the spring of 2011 was excluded, annual mean, maximum and minimum discharge have increased since 2010—contrasting previous observations using EGRET, but consistent with expectations (Figure 4.1.4). For example, annual mean discharge in the spring has increased by approximately 172 cfs/yr. Similar to previous observations, annual statistics of summer discharge follow an increasing trend as well (Figure 4.1.5). However, summer mean is increasing at a rate 67 cubic feet per second per year (CFS/yr) less than spring mean (Figures 4.1.4 & 4.1.5). Likewise, annual summer minimum is increasing at a rate 52 CFS/yr less than spring minimum (Figures 4.1.4 & 4.1.5). This difference in rates of increase indicates an important contrast between seasonal flow conditions that will increase if trends continue. However, it is important to note that the rate at which summer maximum discharge is increasing is 164 CFS/yr greater than that of spring (Figures 4.1.4 & 4.1.5). Presumably from precipitation events; although, further analysis is needed.

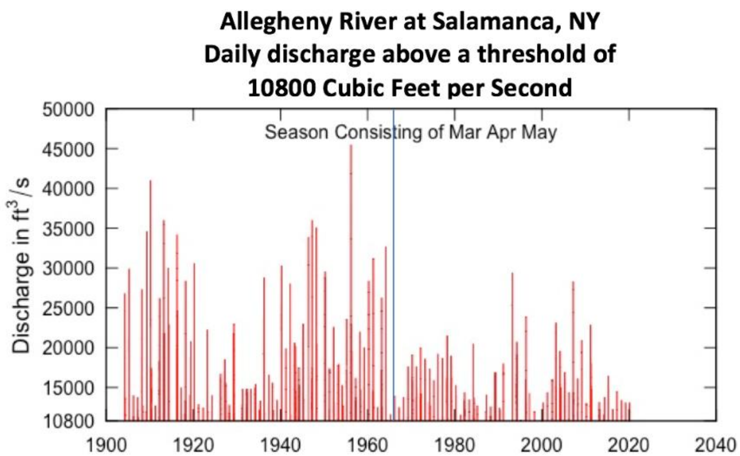


Figure 4.1.1: Spring Discharge of the Allegheny River at Salamanca, NY above a threshold of the ninetieth percentile of spring discharge values (10,800 CFS) from 1903-2020. Blue line indicating completion of dam construction in 1966.

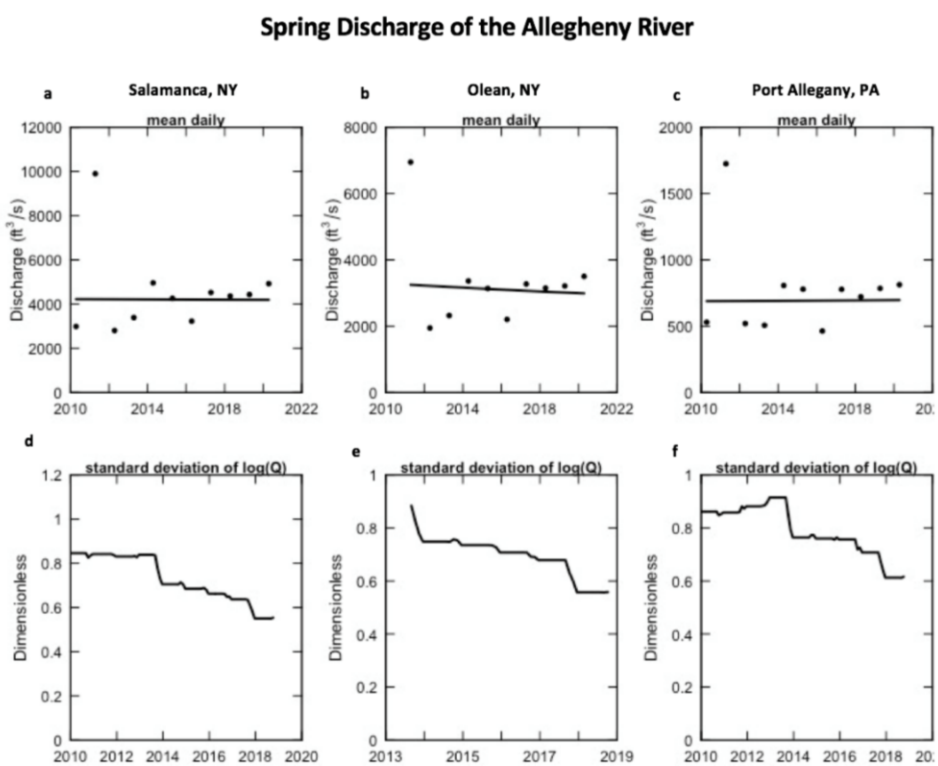


Figure 4.1.2: Spring discharge of the Allegheny River at Salamanca, NY, Olean, NY, and Port Allegany, PA from 2010-2020. Distance from reservoir increasing from left to right. A) Annual mean of spring discharge at Salamanca, NY. B) Annual mean of spring discharge at Olean, NY. C) Annual mean of spring discharge at Port Allegany, PA. D) Spring discharge variability: standard deviation of the log of discharge at Salamanca, NY. E) Spring discharge variability: standard deviation of the log of discharge at Olean, NY. F) Spring discharge variability: standard deviation of the log of discharge at Port Allegany, PA.

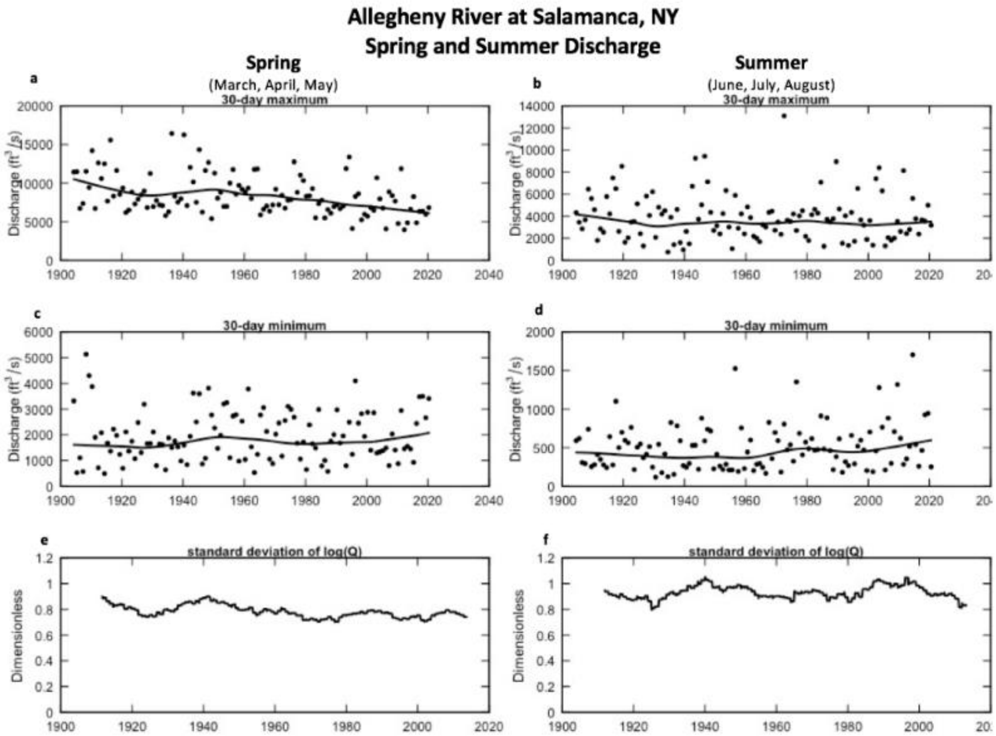


Figure 4.1.3: Spring and Summer discharge of the Allegheny River at Salamanca, NY from 1903 to 2020. A) 30-day maximum daily mean spring discharge. B) 30-day maximum daily mean summer discharge. C) 30-day minimum daily mean spring discharge. D) 30-day minimum mean summer discharge. E) Spring discharge variability: standard deviation of the log of discharge. F) Summer discharge variability: standard deviation of the log of discharge.

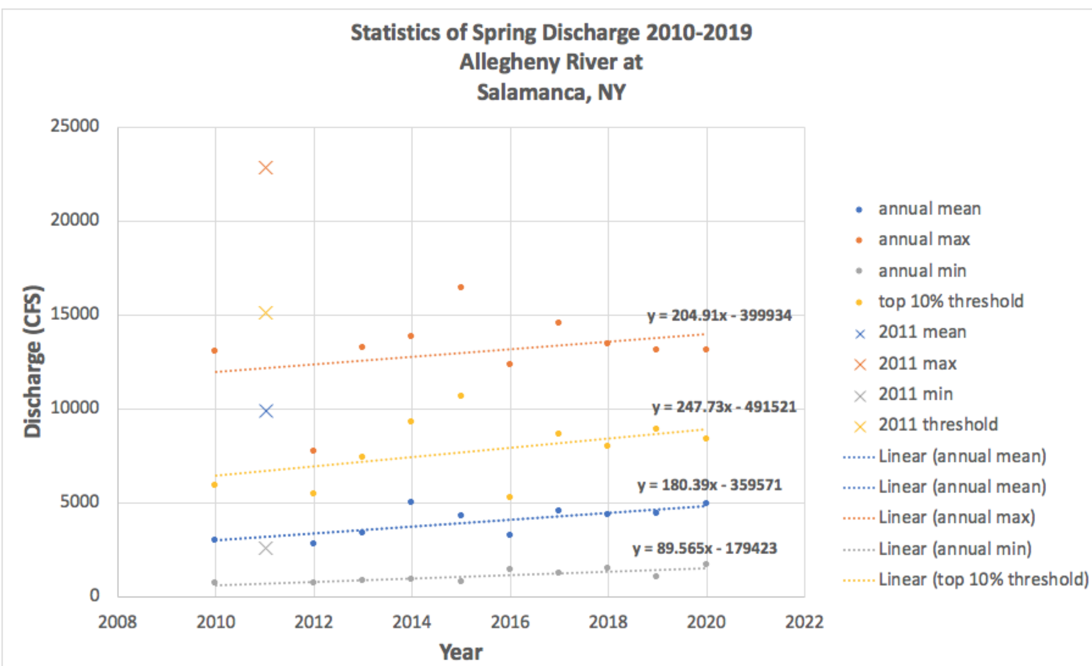


Figure 4.1.4: Annual mean, maximum, minimum and top 10% threshold of spring discharge from 2010-2019 with trendlines for each statistic (2011 excluded in calculations). Datapoints for 2011 indicated with an "x".

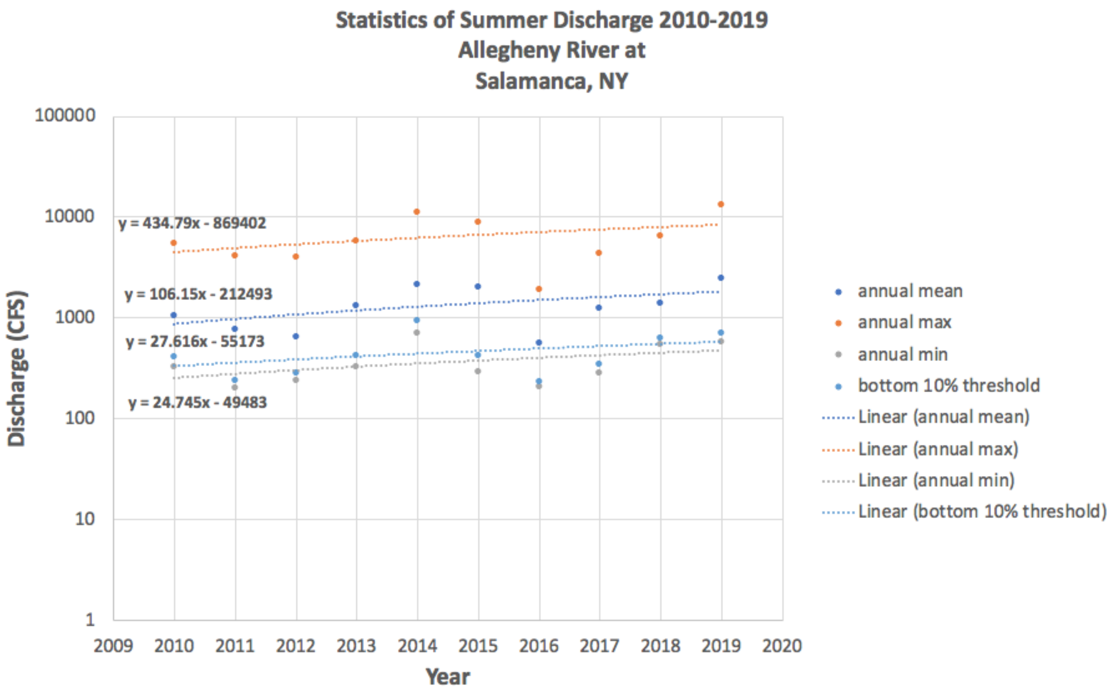


Figure 4.1.5: Annual mean, maximum, minimum and bottom 10% threshold of summer discharge from 2010-2019 with trendlines for each statistic on a logarithmic scale.

References:

Hirsch, R.M., and De Cicco, L.A., User guide to Exploration and Graphics for RivEr Trends (EGRET) and dataRetrieval: R packages for hydrologic data (version 2.0, February 2015): U.S. Geological Survey Techniques and Methods book 4, chap. A10, 93 p. (2014).

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Rossier, P. C. Dam Building and Treaty Breaking: The Kinzua Dam Controversy, 1936-1958. The Penn. Mag. Of History and Bio. 119, 345-368 (1995).

4.2 Kinzua Dam Outflow Changes (Jamie Vornlocher)

Question(s)	Are there long-term changes in outflow at the Kinzua Dam?
	If so, are these long-term changes correlated with precipitation in the watershed of the Allegheny Reservoir?
Data Sources	EGRET package in RStudio using USGS gage Kinzua Dam, PA discharge data; NOAA precipitation data from Wellsville Municipal Airport in Allegany County, NY
Results File	4.2Vornlocher_KinzuaFlow_Precip.R, 4.2Vornlocher_Figure4.2.1.jpeg, 4.2Vornlocher_Figure4.2.2.jpeg

Rationale:

The Kinzua Dam and Allegheny Reservoir were constructed in the 1960s to improve water quality, provide navigational depth, and mitigate flooding upstream of the city of Pittsburgh (Rosier, 1995). The completion of the Kinzua Dam has allowed for controlled outflow of water from the reservoir in response to various factors (i.e., precipitation events). Investigating controlled outflow discharge over long periods of time may yield insight on trends in climate events and anthropogenic use (Patterson et al., 2013) that have occurred since the completion of the Kinzua Dam.

Methods:

Long term changes in outflow discharge at the Allegheny Reservoir were examined annually from 2010 to 2020 at the United States Geological Survey (USGS) gage site at Kinzua Dam, Pennsylvania (41°50'29", 79°00'44"; USGS 03012550). Data retrieval from the USGS was performed using the dataRetrieval and Exploration and Graphics for RivEr Trends (EGRET) packages in R (Hirsh and De Cicco, 2014; R Core Team, 2021). Mean hourly precipitation values from within the watershed of the reservoir were collected from the National Oceanic and Atmospheric Administration (NOAA) Data Center at the Wellsville Municipal Airport (ELZ) in Allegany County, New York (42°6'34", 77°59'31"). The weather station is located 89 kilometers ENE upstream from the Kinzua Dam at 647.4 meters in elevation (NOAA, 2021) within the watershed of the Allegheny Reservoir. Annual precipitation records from 2010 to 2020 were used in comparison to outflow discharge. The warm seasons were analyzed, with spring representing March through May and summer representing June through August. Cold seasons (fall and winter) were not included in this study. Fall (September through November) and winter (December through February) were omitted due to the dam remaining open all season (Drum et al., 2017). All analyses were performed in RStudio version 1.2.5033 using (R Core Team, 2021).

Results:

Outflow discharges and precipitation amounts spanning 2010-2020 were plotted for spring and summer of each year (Figure 2). The average discharge at Kinzua Dam varies seasonally, with the highest mean discharge occurring during spring (147.79 m^3/s) and lowest discharge during summer (63.41 m^3/s). Despite higher discharge during the spring compared to the summer, mean hourly summer precipitation was higher than spring precipitation (summer: 0.0102 inches/hour; spring: 0.0071 inches/hour).

Outlier analysis of warm season precipitation revealed 2011 is an outlier for the spring. No outliers were detected from the summer precipitation data (Figure 4.2.1). Because of this, 2011 was omitted from regression analysis for the spring.

There is no significant trend in mean hourly summer precipitation over the study period (Figure 4.2.2). During the spring season, there is a significant increase in mean hourly spring precipitation during the study period ($R^2 = 0.58$; $p = 0.006$; Figure 4.2.2). Mean annual discharge at Kinzua Dam has generally increased since 2010 and has increased linearly since 2012. This data is consistent with climate change predictions for the northeastern and eastern portions of the nearby Ohio River watershed, where increased rainfall and river discharges between 2040 and 2099 may amount to 35% to 50% greater spring flows (Drum et al., 2017). It is plausible similar trends can be applied to the Allegheny Reservoir watershed. It is unclear in the future if the correlation between dam discharge and precipitation will change, as flood control may become a more critical factor in the future based on projections.

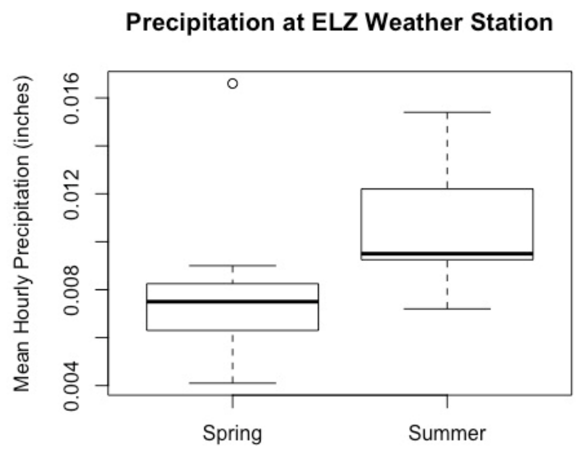

Figure 4.2.1: Outlier analysis of warm season precipitation data at the ELZ weather station for 2010-2020.

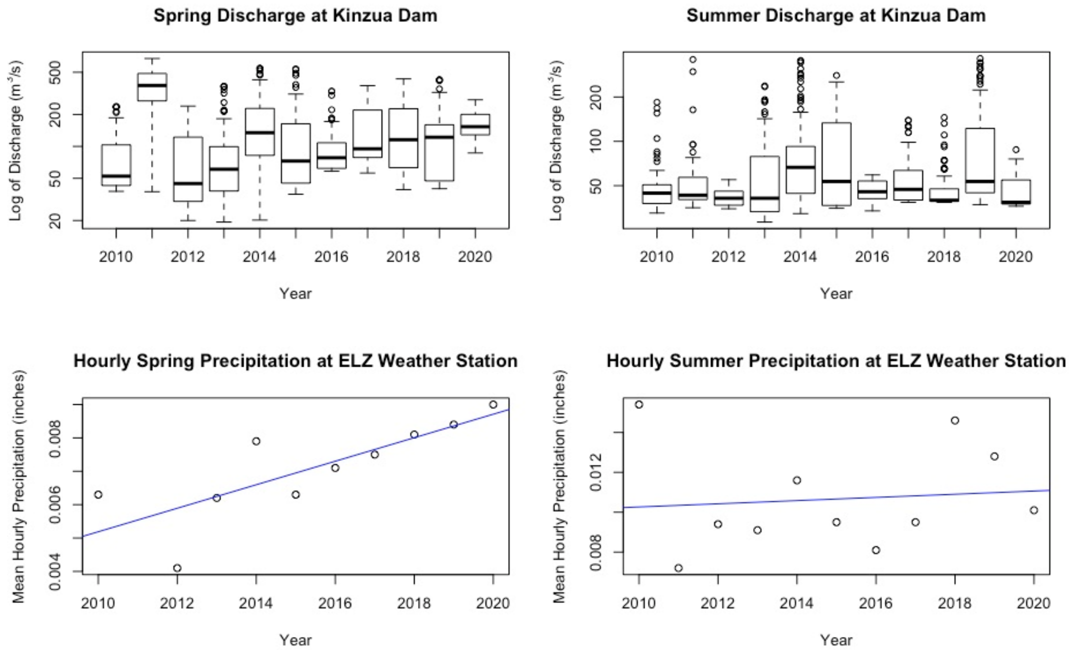

Figure 4.2.2: Warm season outflow discharge at Kinzua Dam and regression analysis of mean hourly precipitation at the ELZ weather station for 2010-2020.

References Cited

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4.3 Water temperature (Alexandra Pizzi)

Question(s)	Have surface water temperatures increased over time? How do they compare to thresholds?
Data Sources	KIN Outflow Temp 2013-2016
Results File	4.3Pizzi_WaterTemp

Rationale:

As global temperatures rise with climate change, more severe and more frequent Cyano-HABs are expected in water bodies (EPA, 2019). Monitoring long-term changes in seasonal temperatures is important to predict future Cyano-HABS. Cyanobacteria growth typically becomes problematic when temperatures reach 68 degrees F (20C), suggesting peak bloom months are between July and October when water temperatures are highest (EPA, 2019). However, Microcystis can grow at temperatures as low as 59 degrees, making any increase in average water temperatures extremely crucial (EPA, 2019).

Methods:

Average monthly temperatures of outflow water from the Allegheny Reservoir, near Kinzua Dam, from years 2013 - 2016 were analyzed. Temperatures were taken at hourly intervals. The temperatures recorded during peak Cyano-HAB season (July-September) over the four years were also plotted to show average, median, highest, and lowest temperatures overall.

Results:

Between the years 2013 and 2016, the yearly average outflow temperatures have increased by 1.78 degrees from 50.95 to 52.73 degrees. These increases seem very minor but can lead to earlier bloom seasons and an overall increase in bloom bio-volume. During the bloom period spanning July-September, temperatures are frequently at or above 68 degrees F, leading to the increase in bloom volume we are seeing. Figure 4.3.2 shows the variation of temperatures during the bloom season in each year 2013-2016. We see a similar trend here where the highest recorded temperatures are increasing from 2014-2016.

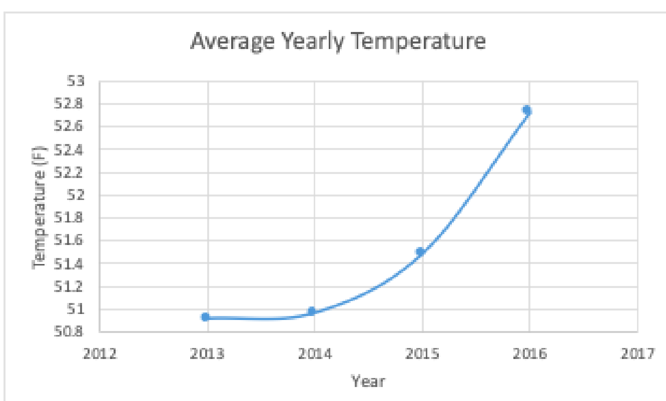

Figure 4.3.1: Average yearly outflow temperatures of the Allegheny Reservoir show a sharp increase from 2013-2016.

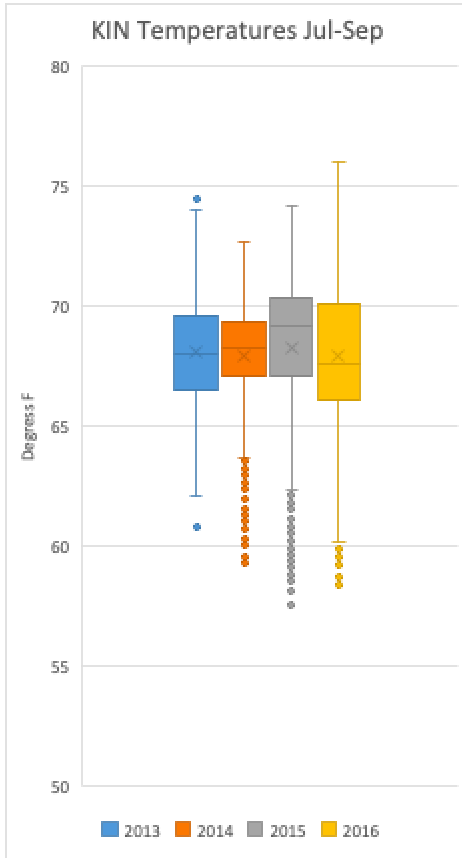

Figure 4.3.2: Outflow temperatures of the Allegheny Reservoir during peak bloom months.

References Cited:
US EPA "Climate Change and Harmful Algal Blooms", Dec 2019

4.4 Lake stratification (Patrick Dunn)

Question(s)	Does thermal stratification occur in the reservoir?
	Does thermal stratification cause nutrient recycling in the reservoir?
Data Sources	2016 KIN WQ Buoy Data, KIN Lab Data 2016-2018
Results File	4.4Dunn_Strat_Temp 4.4Dunn_Strat_Nutrient

Rationale:

Nutrients from external sources can enter the water column of lakes and accumulate in lakebed sediments over time (Hou et al., 2013). When recycled, the internal loading of these nutrients can increase nutrient concentrations and exacerbate eutrophication. Harmful algal blooms (HABs) are known to take advantage of eutrophic conditions to promote bloom formation.

Recycling of lakebed-bound nutrients can occur through the process of thermal stratification, where a lake will form distinct thermal layers during warm weather in the summer (Morse et al., 2014). Stratification deters mixing between the oxygen rich surface layer (epilimnion) and the cooler layer near the lakebed (hypolimnion) causing benthic anoxic conditions (Weinke et al., 2018; Lannergård et al., 2020). The lower dissolved oxygen levels at the lakebed promote the release of sediment-bound nutrients to the water column and thus provide an internal source of nutrients for bloom formation (Hou et al., 2013; Lannergård et al., 2020). This regeneration of nutrients makes it possible for HABs to colonize in lake systems with managed or limited nutrient loads (Paerl et al., 2020). The following analysis aims to determine if thermal stratification occurs at the Allegheny Reservoir, and if so, whether it is causing internal loading of nutrients essential to HAB formation.

Methods:

Temperature data was collected from the reservoir surface to the lakebed of the Allegheny Reservoir at 3-foot intervals hourly from 4/4/2016 to 11/8/2016. A buoy was located at the Kinzua Dam where depths from surface to bed ranged from about a maximum of 130 ft to a minimum of 110 ft depending on the level of the reservoir. In order to determine if thermal stratification was occurring, temperature at depths of 0 – 105 ft at 15 ft intervals was visualized using Microsoft Excel. The dissolved oxygen concentration was analyzed by depth at three time points (5/11/2016, 6/9/2016 and 8/31/2016). To determine if internal nutrient loading was occurring, concentrations of the macro- nutrients (total phosphorus, nitrate and nitrite, ammonium) and micro-nutrients (zinc, aluminum, copper, manganese and iron) required for algal growth were analyzed by depth for the date 8/31/2016. Dissolved oxygen and nutrient were analyzed by binning concentrations at depths of 0-15 ft, 15-60 ft, and 60-130 ft below the surface. A One-way ANOVA with Tukey's multiple comparison test was performed using GraphPad Prism to determine if there was a significant difference between concentrations at different depths of the reservoir ($\alpha = 0.05$).

Results:

Thermal stratification began in the Allegheny Reservoir in early May 2016 and plateaued at a point of maximum stratification that extended from June to early August 2016 (Figure 4.4.1). During this period, surface temperatures on average were 33% warmer than the lakebed, indicating thermal stratification. After early August, temperatures at the lakebed warmed and surface temperatures cooled leading to minimal stratification by October when lake turnover occurred. It was expected that dissolved oxygen would decrease with depth following stratification due to a lack of mixing between the surface and deeper thermal layers. Dissolved oxygen had slight but significant differences between depths on 5/10/2016 and 6/9/2016 (Figure 4.4.2). However, by 8/31/2016, following the peak stratification period, the reservoir had large significant differences in oxygen levels by depth, with near-anoxic conditions occurring at 60-130 ft (Figure 4.4.2). With knowledge of low oxygen levels occurring at 60-130 ft, it was expected that nutrient and trace metal concentrations would increase with depth following desorption from sediments at the lakebed in this low-oxygen environment. Our analysis of nutrients and trace metals revealed that nitrate and nitrite and iron concentrations were significantly higher from 60-130 ft as compared to other depths (Figure 4.4.3). Ammonium also had significantly higher concentration at 60-130 ft as compared to near the surface (0-15 ft) (Figure 4.4.3). Total phosphorus, manganese, zinc, aluminum, and copper did not display statistical significance between the groups. However, zinc, manganese, and aluminum displayed similar trends with increasing concentrations with depth but these differences were not significant (Figure 4.4.3). Other elements (magnesium, calcium, chromium, and mercury) had no trend or significant differences between groups (data not shown).

The results indicate that the Allegheny Reservoir undergoes thermal stratification, which causes near-anoxic conditions at the lakebed. The low oxygen levels at the lakebed can explain the increase in concentrations of iron and inorganic nitrogen species at greater depths in the reservoir and thus indicate these nutrients are internally regenerated due to thermal stratification. Surprisingly, phosphorus, which is commonly described as a nutrient that undergoes internal loading following benthic anoxia, was not found to increase in concentration at greater depths. Another potential explanation for reduced nutrient concentrations of the inorganic nitrogen species and iron near the surface is immobilization of these nutrients into organic matter by algal blooms which occurred during this period. However, the fact that phosphorus was not depleted at the surface contradicts this explanation. Further measurements of analytes by depth as stratification is occurring would allow for measurement of the flux of nutrients and metals from the lakebed.

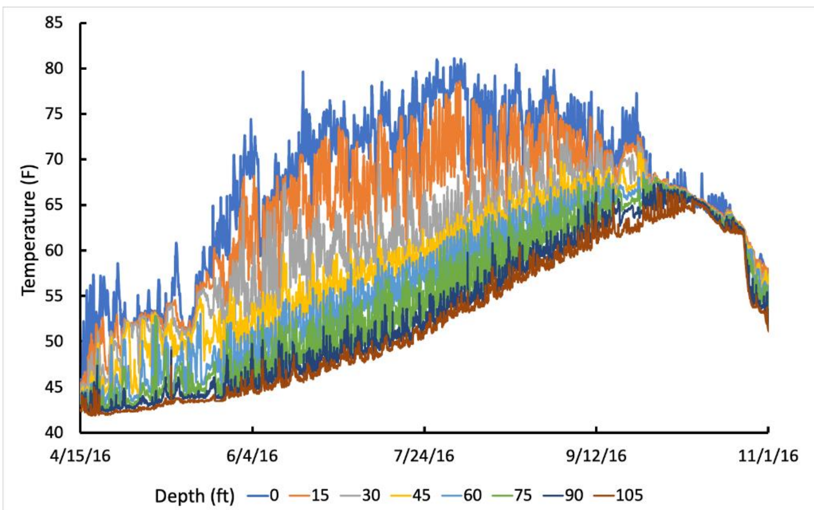

Figure 4.4.1. Hourly reservoir temperature from 4/4/2016 to 11/8/2016 at depths from 0 to 105 ft at intervals of 15 ft.

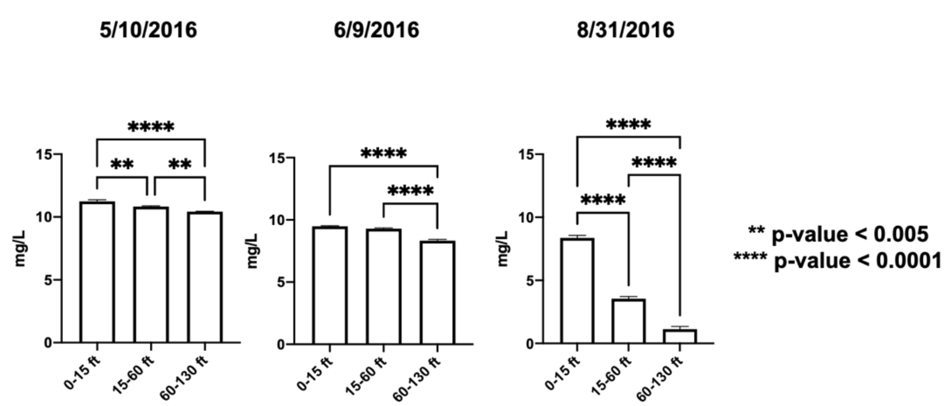

Figure 4.4.2. Dissolved oxygen concentration at binned depths of 0-15 ft, 15-60 ft, and 60-130 ft at three time points. Binned depths compared at each time point through Tukey's multiple comparison test. Significant difference and level denoted by stars.

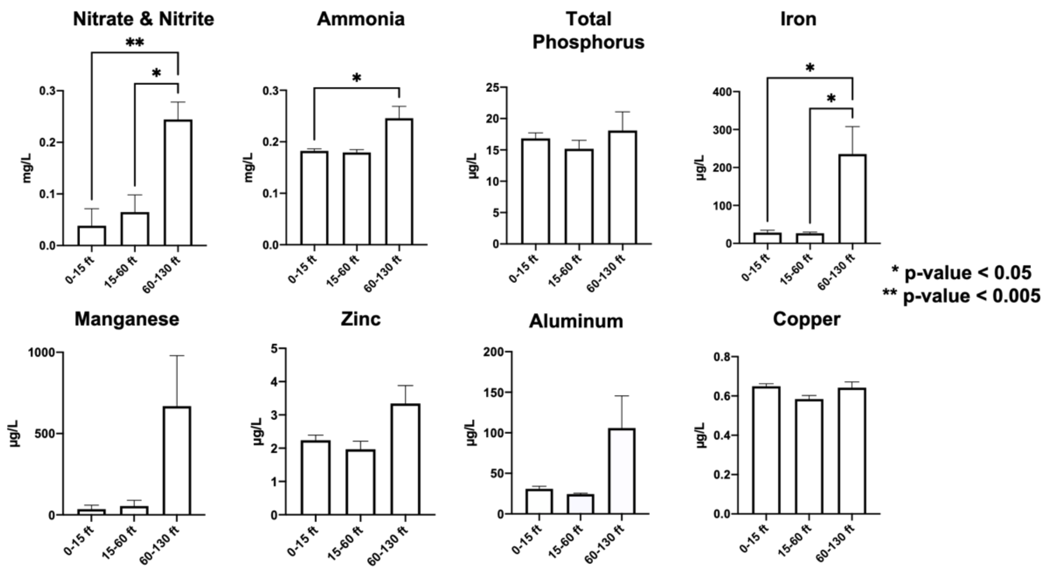

Figure 4.4.3. Select algal essential nutrient and trace element concentrations at binned depths of 0-15 ft, 15-60 ft, and 60-130ft on 8/31/206. Binned depths compared at each time point through Tukey's multiple comparison test. Significant difference and level denoted by stars.

References:

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5 Synthesis

5.1 Recap of Findings

Section	Topic	Question	Main Findings
Introduction	Water Quality Standards	How do nutrient concentrations in the Allegheny Reservoir compare to EPA standards?	– Nutrient concentrations in the Allegheny Reservoir are significantly higher than the EPA's p25 guidance levels. – Nitrate/nitrite exceeds reference levels by several orders of magnitude, with values remaining mostly constant across several years – TKN and P show a gradually increasing trend over time – TKN and ammonia levels do not follow the same trend
	Algal and Toxin Standards	How do recent algal blooms and toxin concentrations compare to WHO and EPA standards?	– Peak bloom season, where we see the highest algal biovolume occurs between August and October. – Microcystin contributes the most to the biovolume in the reservoir and has alone exceeded WHO high risk standards. – In 2019, toxin concentration of Microcystis exceeded both EPA and WHO standards, reaching 66.2 ug/L.
	Land Use-Change	How has land use changed over time in the Allegheny Reservoir watershed?	– Agricultural and developed lands increased between 2001 and 2016, but these changes are not correlated with increases in nutrient loading. – Land cover change is not a main driver of HABs on the Allegheny Reservoir.
Algal Dynamics	Trophic Status Index	How does the trophic state index vary temporally within the Allegheny Reservoir?	– Over 40% of all TSI data points were above the eutrophic boundary; highest TSI in the summer months. – Yearly TSI decreased from 2008 – 2010 but increased until 2014 and have remained steady. – June and August TSI trends were generally in agreement; however, September TSI values have decreased since 2017
	Algal community relative to nutrient concentrations	How do algal communities change with temporal, spatial, and nutrient fluctuations?	– Only ammonia and Nitrate/Nitrite showed any significant trends where both nutrients had higher concentrations up the reservoir, away from the Kinzua Dam. – Ammonia concentrations have linearly increased over time whereas Nitrate/Nitrite has decreased over time. – No trends in Eukaryotic algal or Cyanobacterial concentrations
Nutrient Sources	Agriculture	Does crop agriculture lead to significant N and P loading in the watershed of the Allegheny Reservoir?	– Cultivation of the five most prevalent crops in the watershed results in an average annual loading of 0.39 kg/ha N and 1.48 kg/ha P. – The watershed falls below the 10^{th} percentile for N loading as compared to all U.S. counties.
	Point sources	How do point sources of N and P influence the Allegheny Reservoir?	– Total N and P from point sources decreased from 2007 to 2018; however "zero" reporting a frequent concern. – All five point source examined in detail exceeded their permitted N and P discharge, every year from 2007 to 2018.

Section	Topic	Question	Main Findings
	Legacy nutrients	How have legacy agricultural N inputs and other sources changed overtime?	– Atmospheric N deposition (51%) and Livestock Manure N (24%) are the largest N inputs from 1930 to 2017. – Compared to U.S. counties, watershed N inputs are in the 35th percentile of total legacy N loads.
Climate and Hydrological Drivers	Spring and summer runoff	Have spring and summer discharges to the Allegheny Reservoir changed over time?	– Both spring and summer annual discharge are increasing. – Spring is increasing at a greater rate than summer, with the exception of annual maximum.
	Kinzua Dam Outflow Changes	Are there long-term changes in outflow from the Kinzua Dam? Are there long-term changes in precipitation?	– Springtime precipitation has generally increased since 2010 and has increased linearly since 2012. – Discharge from the Kinzua Dam has increased over this same time period suggesting that higher rainfall is resulting in higher spring discharge volumes from the Dam. – There was no discernable trend in summertime precipitation over the period 2010 to 2020.
	Water temper-ature	Have surface water temperatures increased over time?	– Water temperature increased slightly from X to Y where temperatures are warming earlier. The latter suggests a longer bloom season.
	Lake stratifica-tion	Does thermal stratification occur? If so, is it leading to internal nutrient loading?	– Thermal stratification occurred in May 2016 and continued through September 2016. During this time, dissolved oxygen levels reached near-anoxic conditions (1.1 mg/l) at greater depths (60-130 ft). – Some nutrient concentrations increased in deeper portions of the reservoir (60-130 ft) following stratification indicating that internal loading of nitrate/nitrite, ammonium, and iron is occurring.

5.2 Threats to Drinking Water (Kate Zidar)

Question(s)	Do CyanoHAB blooms on the Allegheny reservoir threaten drinking water sources? Could toxins reach downstream population centers?
Data Sources	NPEDES permits for Surface Water DW intakes, USGS stream flow data
Results File	5.2Zidar_DrinkingWater

CyanoHABs may produce toxins (e.g., microcystins) that are harmful to humans and the environment (Paerl & Otten, 2013). Cyanotoxins can persist in the water for days to weeks after cell death (Schmidt et al., 2014), and reside in sediments and food webs of aquatic ecosystems long term (Pham & Utsumi, 2018). The downstream waters of the Allegheny River provide drinking water for major population centers such as the City of Pittsburgh, and CyanoHABs on the reservoir may impact this drinking water source.

To determine potential impacts of cyanotoxins in the Allegheny Reservoir on downstream drinking water sources, drinking water intakes were mapped in ArcGIS and scaled by population served. Travel time downstream was estimated by comparing discharge peaks at the Kinzua Dam to discharge peaks at the Natrona USGS stream gage just upstream from Pittsburgh.

According to stream gage records and as confirmed by ACE staff (R. Reilly, personal communication, March 25, 2021), travel time between the Kinzua Dam and the Natrona gage near Pittsburgh is estimated to be about five days. Within the same span of river, municipal surface water intakes draw from the Allegheny main stem to serve a population of approximately 837,345 people with major intakes at Brady Township, New Kensington, and the greater Pittsburgh area. Moreover, this stretch of river is used as a source for several vended water companies (Glacier and Culligan) servicing additional customers.

Much is not known here: Do cyanotoxins degrade differently during lotic transport vs. the lentic waters where they bloom? While data shows some cells in dam discharge, USACE does test dam discharge when they find cells, and they have never seen anything over the limit for detection. At present, the onus is really on the drinking water intake operators to proactively detect the presence of cyanotoxins in raw and treated drinking water sources on the Allegheny River. With increasing magnitude of CyanoHAB events on the Allegheny Reservoir, the potential limitation of the Allegheny River as a drinking water resource should be considered.

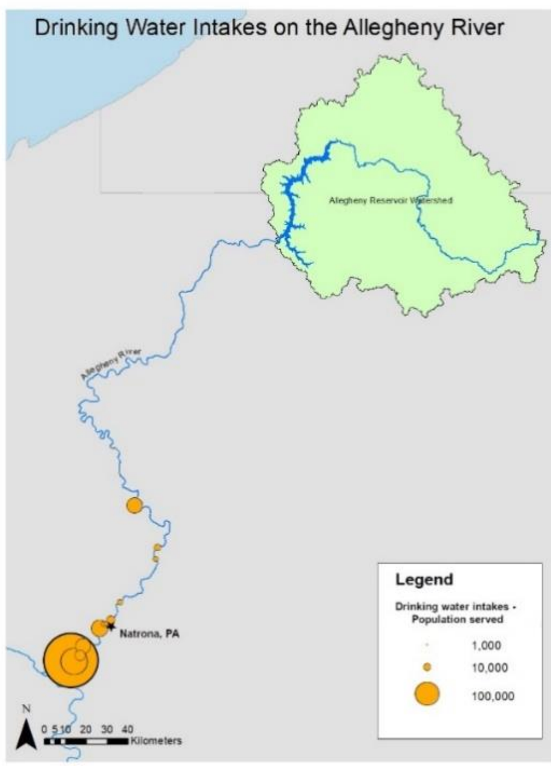

Figure 5,2,1: Drinking water intakes and population size served along the Allegheny River downstream from Allegheny Reservoir. Natrona gage location noted to indicate the approximate distance water may travel in five days, well under estimated half-life of cyanotoxins.

References Cited:

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Schmidt, J.R.; Wilhelm, S.W.; Boyer, G.L. The Fate of Microcystins in the Environment and Challenges for Monitoring. Toxins 2014, 6, 3354-3387. https://doi.org/10.3390/toxins6123354

5.3 Nutrient loads to the Allegheny Watershed and Reservoir (Patrick Dunn)

Question(s)	How do nutrient loads from different sources compare?
Data Sources	USEPA-HYPOXIA-TASK-FORCE-ECHO-TOOL, Byrnes, Danyka K; Van Meter, Kimberly J; Basu, Nandita B (2020): Trajectories Nutrient Dataset for Nitrogen (TREND-nitrogen). PANGAEA, USDA CropScape, USDA ERS Fertilizer Use
Results File	5.3Dunn_TotalNLoads 5.3Beck_LegacyN_NLCD

When comparing the total estimated loads from the various sources of N and P to the watershed of the Allegheny Reservoir, it is apparent that certain sources comprise a vast majority (Figures 5.1 and 5.2). For N, deposition and livestock inputs on average constituted 95.6 ± 0.01% of the total annual load from 2008 to 2017. Crop agriculture was the source for 2.19 ± 0.01% of all nitrogen. Point sources (i.e., wastewater effluent streams) accounted for just 2.23 ± 0.01% of the total loading over this period. For P, crop agriculture resulted in 92.0 ± 0.03% compared to 8.04 ± 0.04% for point sources.

However, previous analysis in this report has shown that the relative inputs of total nitrogen from livestock, deposition, and agriculture are low as compared to other U.S. counties (~35th percentile). It is expected that P inputs will scale similarly with N inputs on a relative comparison with all counties due to having the same sources as N (crop agriculture, livestock, wastewater). It is also important to note that deposition, livestock, and crop agriculture are nonpoint sources to land over large areas, whereas point sources directly discharge effluent to streams in the Allegheny Reservoir watershed. The hydrologic connectivity of these point sources allows for quicker and more efficient transport of nutrients at higher concentrations to the reservoir than nonpoint sources. Nonpoint source nutrients require precipitation for transport to streams, have variable hydrologic connectivity depending on location, can undergo biotransformation, and can adsorb to sediments causing less efficient transport to the reservoir over longer periods of time.

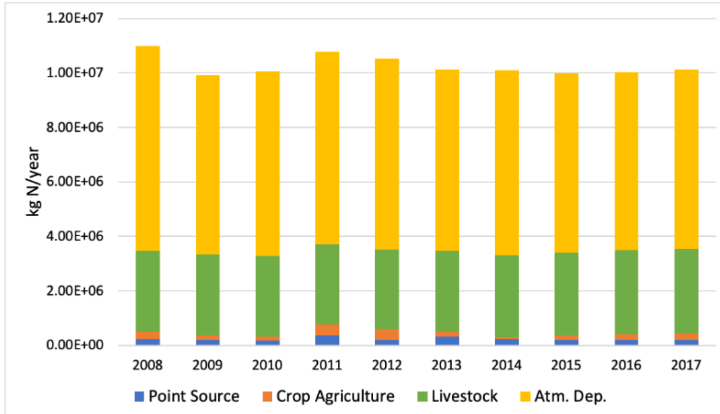

Figure 5.3.1. Combined N loads (kg/year) from various sources from 2008 – 2017 within the watershed of the Allegheny Reservoir.

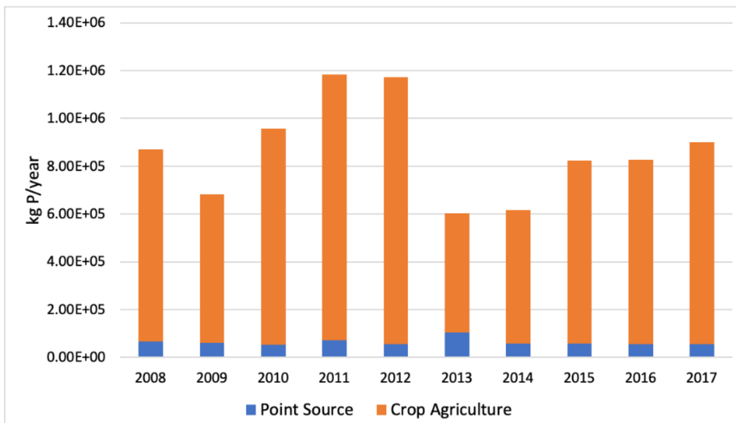

Figure 5.3.2. Combined P loads (kg/year) from various sources from 2008 – 2017 within the watershed of the Allegheny Reservoir.

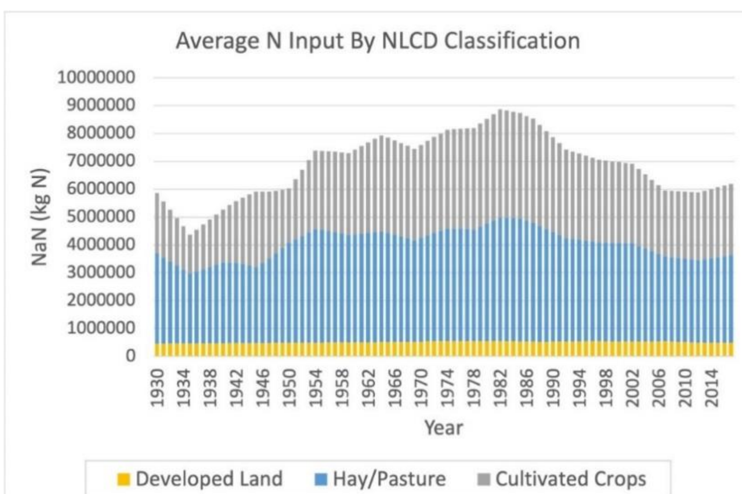

Figure 5.3.3: Legacy N Inputs in the watershed categorized by NLCD classification. Recent years show a slight increasing trend for N generated on Hay/Pasture (from manure) and Cultivated Crops (from fertilizer) land covers.

Management of external nutrient sources can have limited effectiveness in lake systems that undergo internal loading of nutrients from benthic sediments following anoxia from thermal stratification (Ostrofsky et al., 2019). Analyses performed for this report indicate that within the Allegheny Reservoir, thermal stratification occurs which causes near-anoxic conditions at the lakebed. Nutrient analysis also indicated that certain nutrients (inorganic N and iron) were internally loaded due to increased concentrations by depth following lakebed anoxia. However, other nutrients expected to be released from anoxic sediments were not found to be in increased concentrations at greater depths. In addition, these findings are based on measurements from one day (8/31/16). Limited measurements and unexpected results for some nutrients made it difficult to confirm internal loading of nutrients.

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5.4 Recent hydrological trends and extreme events (Abby Yancy)

Question(s)	How do extreme events in the last 10 years compare to other years?
Data Sources	Daily mean discharge records from the USGS gage on the Allegheny River at Salamanca, NY.
Results File	5.4Yancy_ExtremeEvents.xslx

Recent hydrological trends of increasing spring and summer streamflow, along with extreme precipitation events may reveal a potential driver of increased cyano-HAB formation on the Allegheny Reservoir (Section 4.1). Spring of 2011 was anomalously wet compared to other years in the 2010-2019 study period (Figure 5.4.1). The high flow conditions are then followed by summer discharges that are relatively low compared to the same period (Figure 5.4.2). Overall, the flow duration curve shape reveals that the high flow conditions occurring for short amounts of time are a result of precipitation events (Figure 5.4.3). When daily mean discharge for both spring and summer of 2011 were compared to the flow duration curve for the 2010-2019 period, 76% of days in spring had a mean flow that was only exceeded 10% or less of the time from 2010-2019, meaning that there were frequent, high flow conditions that would have transported nutrients from non-point sources throughout the watershed (Figure 5.4.3). These high flow conditions were followed by a summer consisting of 38% of days with flows that were exceeded 90% or more during the time period (Figure 5.4.3). With nearly half of the summer 2011 days in extremely low flow conditions, this would have created long residence times, higher water temperatures and elevated nutrient concentrations that all contribute to cyano-HAB formation. The extreme precipitation events can transport nutrients from non-point sources into the reservoir. Further, the high flow conditions can cause overflow and flooding at point sources with high hydrological connectivity to the system. However, this does not explain the presence of algal blooms predating the study interval (dating back to the 1970's). Additional analysis of extreme events in previous years to is needed to explain recurring cyano-HAB formation.

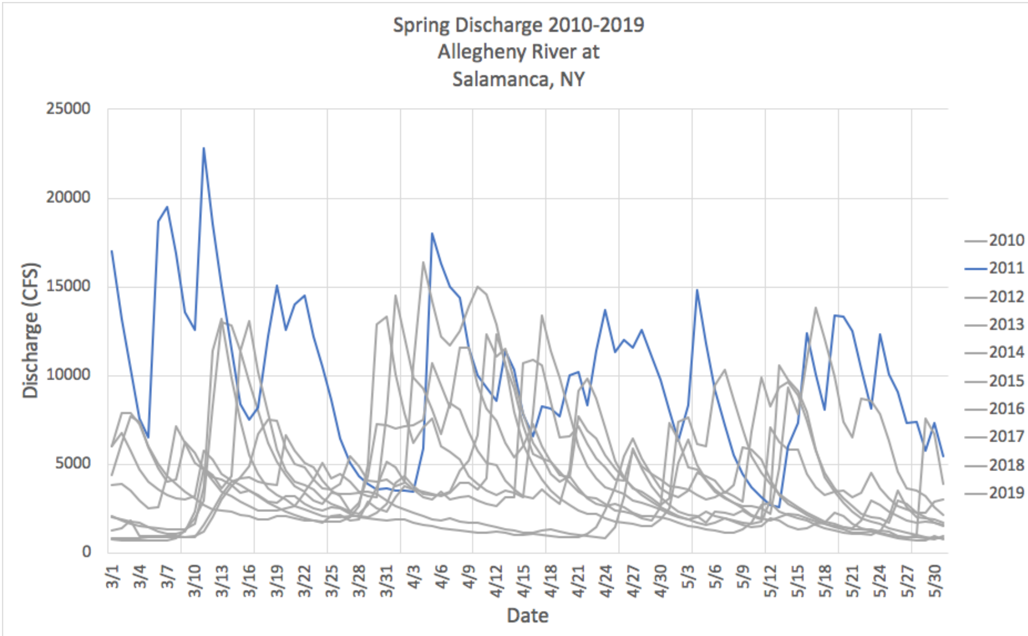

Figure 5.4.1: Daily mean spring discharge time series by year for 2010 to 2019 record. Spring of 2011 in blue for contrast from time series of other years.

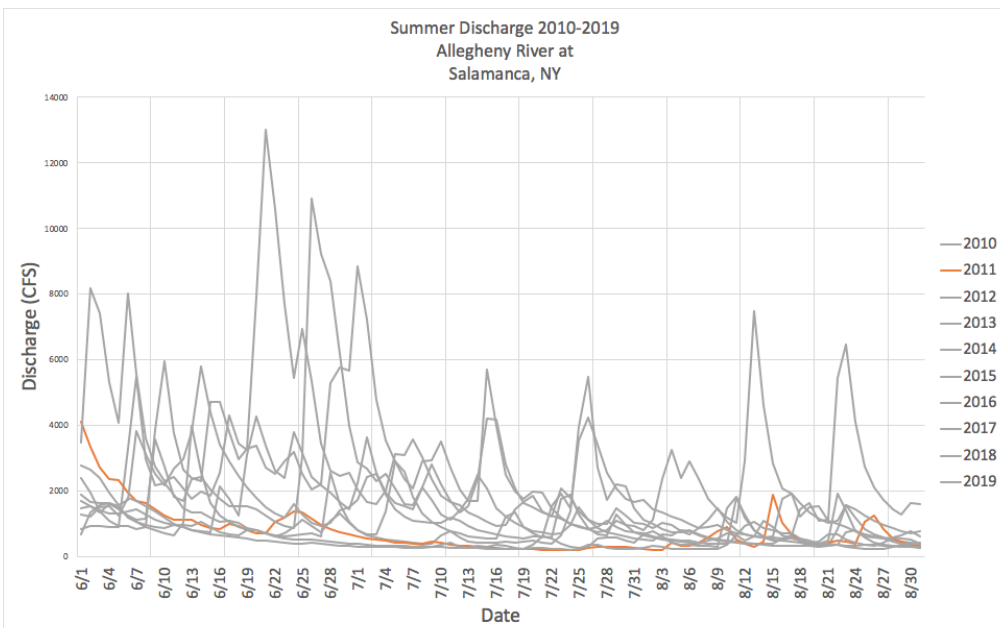

Figure 5.4.2: Daily mean summer discharge time series by year for 2010 to 2019 record. Summer of 2011 in orange for contrast.

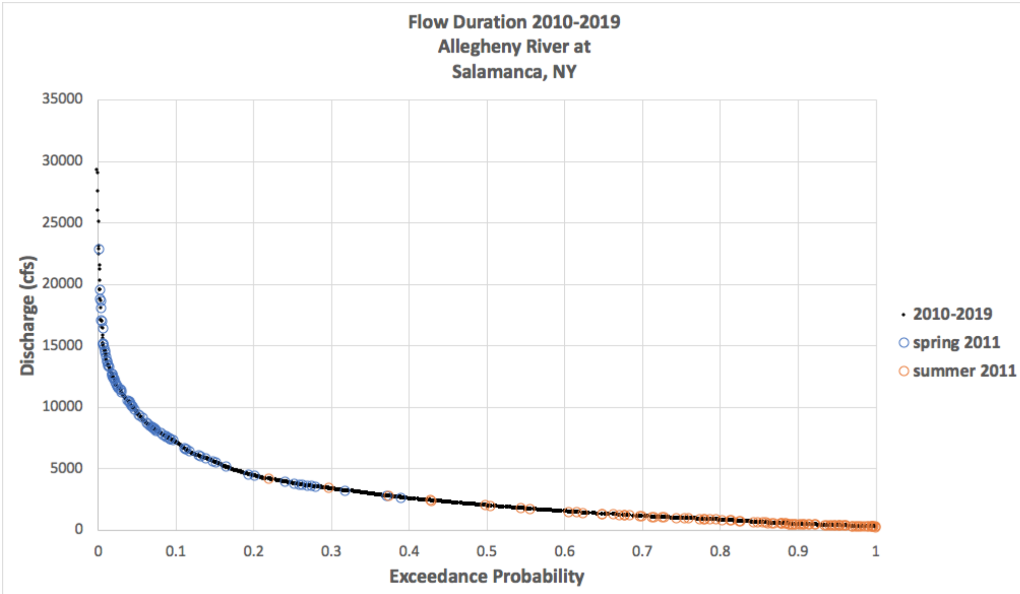

Figure 5.4.3: Flow duration curve of the Allegheny River at Salamanca, NY for daily mean discharge from 2010-2019. Blue points correspond to spring of 2011. Orange points correspond to summer of 2011.

5.5 "THERES SOMETHING ABOUT 2011"

Question(s)	How has the extreme event of spring and summer of 2011 affected nutrient transport and algal growth?
Data Sources	Daily mean discharge records from the USGS gage on the Allegheny River at Salamanca, NY. Precipitation data from NOAA station at Allegany State Park (Salamanca, NY).
Results File	5.5Yancy_2011.xlsx

Beginning in 2012, cyano-HABs increased in frequency and intensity, with longer durations affecting larger portions of the reservoir (R. Reilly, personal communication). The blooms occur in the upper most 10-mile reach of the reservoir located on Seneca Nation of Indians (SNI) Territory—the area closest to inflow from the Allegheny River. Following discussion in Section 5.4, the events of 2011 foreshadow environmental conditions in the reservoir with continued climate change.

The high flow conditions throughout the entire spring of 2011 are in response to frequent precipitation events (Figure 5.5.1). These extreme flow conditions in spring 2011 were followed by below normal precipitation volumes and subsequent discharge (Figure 5.5.2). Rain events in the spring of 2011 would transport nutrient rich water from point and non-point sources to contribute to TSI and algal growth. The low flow conditions in the summer then give the transported nutrients time to settle and accumulate in reservoir sediments, resulting in the intense algal blooms starting in 2012. These climatic events were manifested in the following changes we observed.

- There was a significant spike in N and P effluent from seven point sources with high hydrologic connectivity to the reservoir after an anomalously wet spring in 2011(Figure 3.2.1).
- Surplus N and P from agriculture suggest above average inputs (Figure 3.1.1 A) during 2011 and 2012. Agriculture is an example of a non-point source of nutrients that would be transported during precipitation anomalies, such as spring of 2011.

- The result of precipitation during spring and summer of 2011 can be seen in the trophic state index (TSI) trends, discussed in Section 1.2. Mean annual distributions of TSI values show an increasing trend beginning in 2011 and continuing until 2014, with higher distributions of values in mesotrophic and eutrophic conditions, specifically 2012-2014 (Figure 2.1.1 A). A similar trend can be seen for values in August, specifically (Figure 2.1.1 C). During August of 2011, most values of TSI are in mesotrophic conditions. TSI conditions continued to increase in the following years until all values are in eutrophic and hyper-eutrophic conditions by 2015 (Figure 2.1.1 C). The response of TSI following 2011 is an example of how extreme events result in long-lasting effects.

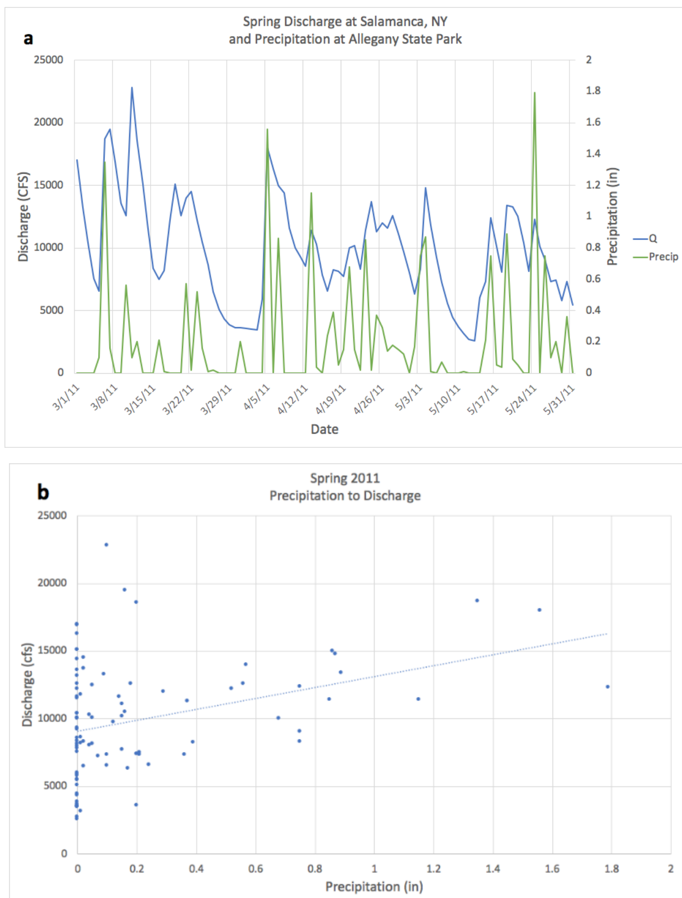

Figure 5.5.1: Spring of 2011 discharge and precipitation at Salamanca, NY. A) Plot of discharge response to precipitation during spring. B) Plot of correlation between precipitation and discharge.

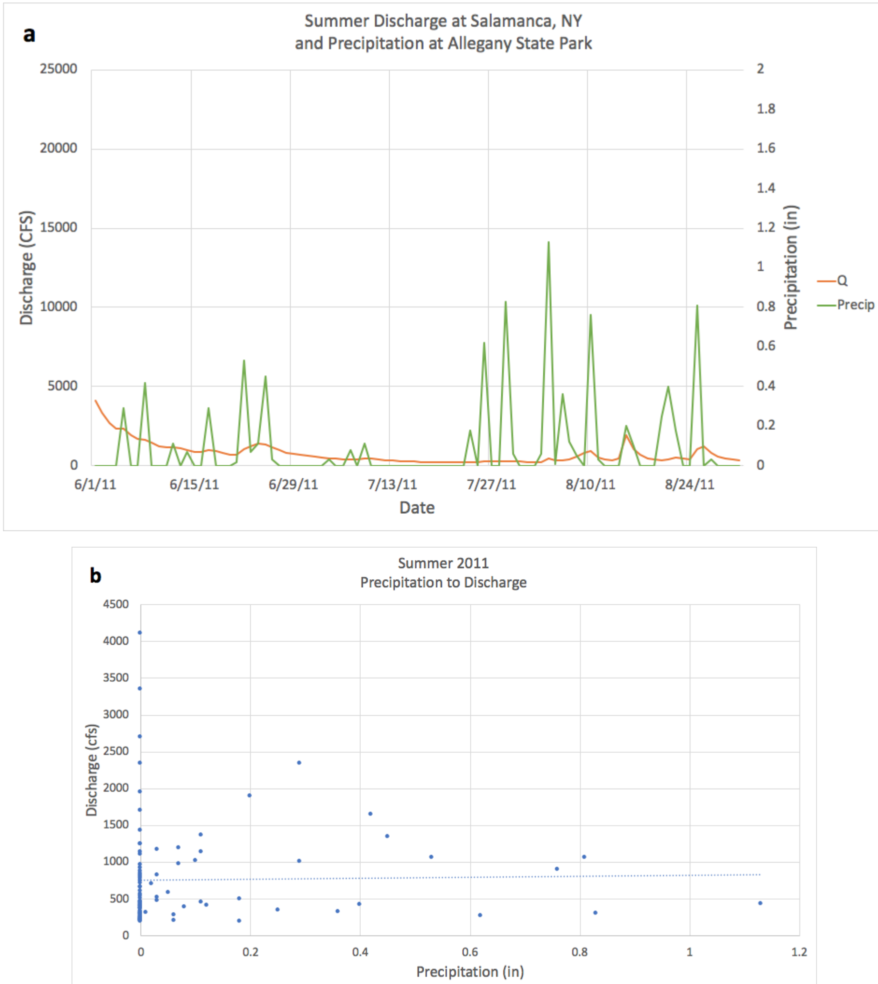

Figure 5.5.2: Summer of 2011 discharge and precipitation at Salamanca, NY. A) Plot of discharge response to precipitation. B) Plot of correlation between precipitation and discharge.

5.6 Algal Dynamics and Temperature

Question(s)	How does reservoir temperature compare to algal growth?
Data Sources	KIN Outflow Temp 2013-2016
Results File	5.6Suder_AlgaeTempCompare

In the study of algal dynamics, it is known that algae generally experience growth and decay that roughly follows the fluctuations in temperature. To see if this trend is consistent for the Allegheny Reservoir, the sub-hourly temperature data collected at the outflow of the Kinzua Dam was plotted against the time resolved data for the algal population at site KIN 1003, shown in Figure 7.1, which is up-river from the Kinzua Dam. It is clear that there is a consistent periodic trend in the data that seems to be consistent with the hypothesis that the algal population experiences growth and decay following the temperature pattern. However, due to the infrequent nature of the algal population measurements, nothing more can really be said about the data. It would be useful in the future to gather algal population data at finer time scales to understand the relationship between the algal population growth/decay and air temperature over smaller intervals.

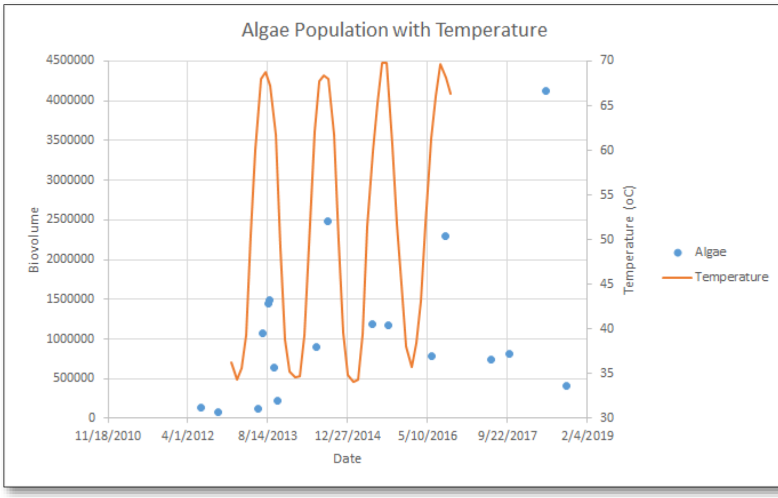

Figure 5.6.1: This figure displays the fluctuation in temperature over time at the outflow of the Kinzua dam plotted against the biovolume of the HABs over the same timescale.

6 Caveats

Question(s)	Is the ratio of iron to phosphorus causing the reservoir to be phosphorus limited during oxic conditions?
Data Sources	KIN Lab Data 2016-2018
Results File	2.2Suder_KIN_Long_Time_Scale_Nutrient_Data

Iron(III) is capable of binding phosphorus effectively within benthic sediments acting as a sink for phosphorus under oxic conditions (Søndergaard et al., 2003). Consequently, lake systems with high iron/phosphorus (Fe/P) ratios (10-15) in the sediment can buffer P loading and regulate P cycling under aerobic conditions (Søndergaard et. al. 2003; Jensen et. al. 1992). Algal biomass formation in lakes of this nature is often P-limited when oxygen-rich (Blomqvist et. al. 2004). To access the degree of iron-bound phosphorus present in the reservoir Fe/P was plotted spatially and temporally. Unfortunately, there are a few issues that have kept us from looking at and discussing this nutrient ratio. The first issue is that the Iron data provided is not extensive and for the purposes of our exploration there was little that could be determined from this data, as there were too few points to make a real trend analysis possible, as can be seen in Figure 6.1. As well, it appears that to get the Fe/P ratio that would be useful for understanding algal dynamics it would be necessary to take measurement for Iron and Phosphorus available in the sediment/bottom water, which is only done in one particular location at one time point. This could be useful analysis in the future, but more work will need to be done to collect a more extensive Iron nutrient regime temporally.

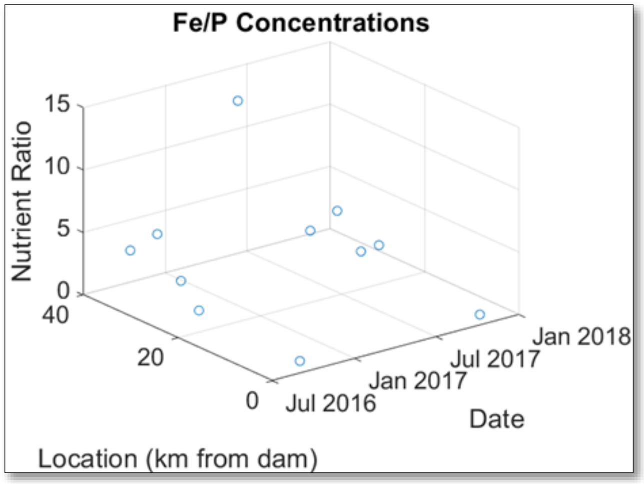

Figure 6.1: This figure shows the relationship between iron and phosphorus both spatially and temporally.

References Cited

Søndergaard, M., Jensen, J. P. & Jeppesen, E. Role of sediment and internal loading of phosphorus in shallow lakes. Hydrobiologia 506, 135–145 (2003).

Jensen, H. S., Kristensen, P., Jeppesen, E. & Skytthe, A. Iron:phosphorus ratio in surface sediment as an indicator of phosphate release from aerobic sediments in shallow lakes. Hydrobiologia 235, 731–743 (1992).

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7 Recommendations

It is important to recognize that the Seneca Nation faces disproportionate negative impacts from the ongoing water quality issues in the Reservoir. Thus, the needs of the Seneca Nation should be prioritized, and serve as a guide as to what problems should be addressed first, and how. We feel that changes made to the operation, maintenance, and management of the Reservoir should be established and implemented with the collaboration and approval of representatives and leaders of the Seneca Nation.

Secondly, cyano-HABs are ecologically and biogeochemically complex and are generally not well understood even among experts. Therefore, we acknowledge that the recommendations we offer are based on incomplete knowledge and data and that they should be treated as such. Below we offer our recommendations to fill knowledge and data gaps, mitigate bloom formation through reduction of nutrient inputs, and reservoir operations.

7.1 Data and Knowledge Gaps

- In order to determine the possible effect of internal nutrient loading, it is recommended that dissolved oxygen and nutrient concentrations (inorganic N, inorganic P, and micro-nutrients) be monitored by depth before and after thermal stratification occurs. By assessing concentration changes by depth before and after stratification. Measured dissolved nutrient concentrations can be used to quantify the extent of internal nutrient recycling from anoxic reservoir sediments (Nürnberg et al., 2012)..

- We recommend high-resolution time series analysis of algal community composition and microcystin concentrations with concurrent, co-located nutrient concentrations and water temperature. This would allow for a much deeper understanding of the dynamics between community changes, nutrient limitation, and temperature over a bloom season. Even if isolated to a single location, this information would be extremely valuable.

7.2 Mitigation of Bloom Formation

- Currently, the EPA ECHO online database is limited to point source facilities that report annual discharge relative to their maximum allowable loads. "Zero" reporting by facilities precludes an in depth understanding of the role of point sources in the eutrophication of the Reservoir and changes over time. We recommended that permit data is consistently gathered and updated to avoid instances where facilities either report zero discharge or report discharge with no maximum allowable load to reference.
- This investigation into the influence of point source nutrient discharge on the Allegheny Reservoir has made it clear that according to the EPA's ECHO data, all facilities that we focused on for our detailed analyses exceeded their maximum allowable loads by significant amounts (City of Salamanca WWTP, Ellicottville STP, Olean WWTP, Limestone WWTP, Little Valley STP, American Refining Group INC, Dewdrop Campground STP, Bradford STP, Wolf Run Marina, and Willow bay recreation area STP). We recommend that permits are enforced to order reduce the substantial nutrient exceedances from these point sources.
- Through analysis of precipitation in the region over the past decade, it was found that there was a significant trend of increasing hourly precipitation in spring (Figure 4.2.2). In addition, the intensity (in/hr) of the top 10% of rain events in spring also has a significantly increasing trend (data not shown). The flux of non-point source nutrients is governed by precipitation (Jones et al., 2018), indicating that increasingly higher spring precipitation volumes due to climate change will continue to increase nutrient transport to the reservoir. To mitigate the transport of these external nutrients, the following proactive land use practices are recommended:
  - Agricultural land use practices to reduce nutrient leaching and erosion such as cover cropping, reduced tillage, and leaving crop residues on fields.
  - Pasture practices to reduce nutrient leaching and erosion such as rotational grazing.
  - Wetland restoration in the watershed for nutrient removal from non-point sources (Cheng et al., 2020).
- We recommend an in-depth assessment of how dam operations may be modified in the future to minimize the occurrence, spatial extent, and duration of cyano-HABs in light of ongoing climate changes. For example, decreasing summer residence time may decrease the likelihood of cyano-HAB formation. Additionally, storing higher volumes of water in spring to increase summer lake volume may also be helpful. However, given the complexity of the reservoir ecosystem, these assessments should be holistic in their approach and consider the impact of increased spring nutrient fluxes, changing discharge and precipitation volumes.

- In the short-term, we recommend the consideration of physical, non-chemical remediation approaches to lessen the impact of hazard of cyano-HABs. For example, surface skimmers could mechanically remove the cyano-HABs from the reservoir surface.

8 Acknowledgements

We would like to thank the US ACE for their generosity in extending access to the data that was analyzed in this report.