Investigating Low Flow Augmentation Impacts on Whitney Point Lake and Adjacent Rivers from 2008-2017: A 10-Year Review

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Introduction

The Susquehanna River Basin Commission (Commission) has a longstanding commitment to low flow management in the basin. Consumptive use (CU) regulations require that projects mitigate their CU during low flow periods. Mitigation is intended to eliminate manmade impacts caused by CU-water that is taken from the basin but not returned to it-to ensure water is available for downstream uses, including environmental needs. In addition to CU mitigation projects, environmental release projects have also been studied and implemented. The overarching objective for low flow management projects is to offset CU and improve environmental conditions during low flow periods. One specific focus area seeking to improve downstream ecosystems through low flow augmentation is Whitney Point.

Whitney Point is a U.S. Army Corps of Engineers (USACE) reservoir on the Otselic River located in Broome County, NY. Dating back to the mid-1990s the Commission, USACE, and the New York State Department of Environmental Conservation (NYSDEC) had discussions regarding the implementation of a water management and environmental restoration project at Whitney Point Lake. The primary purpose of the Whitney Point reservoir is to provide flood control for the reaches of Tioughnioga River downstream of Whitney Point Village, the lower reaches of the Chenango River, and the Susquehanna River downstream to Binghamton, NY (USACE, 2001). In 2001, the results of a feasibility study recommended a project consisting of modification of an existing USACE reservoir for the purpose of enhancing downstream environments and improving in-lake resources, under Section 1135 of the Water Resources Development Act.

Prior to 2009, Whitney Point Lake was operated with a 7-foot winter drawdown to allow for additional storage for spring rain and snow melt. Recreation is considered a secondary purpose of the lake. The feasibility study stated that the implementation of the new reservoir operational plan would not impact flood control operations and would ensure that all recreational uses would remain or be enhanced. With the adoption of the updated reservoir regulation manual, new operations included maintaining a year-round pool elevation of 973.0 ft. This provided 8,500 acre-feet of total conservation storage for downstream low flow augmentation of up to 100 cubic feet per second (cfs), as well as improving in-lake conditions for wetland plants and fish. Specifically, this included7,500 acre-feet for releases when flow at the U.S. Geological Survey (USGS) Waverly gage dropped below 700 cfs and 100 acre-feet to ensure a minimum flow of 150 cfs at Chenango Forks gage.

A more detailed plan of the low flow augmentation schedule is available in the reservoir regulation manual for Whitney Point Lake (USACE, 2001). In general, the amount of water (above inflow) released starts off at a total of 50 cfs and ramps up based on the duration of a low flow event and the number of days remaining in the annual low flow period (July – November). If net inflow to the lake should drop below 10 cfs, the release is maintained at 10 cfs to satisfy the minimum outflow target for the 1-mile reach of the Otselic River immediately below the dam.

Stated ecosystem goals of project modifications included assumed benefits to almost 60 miles of stream habitat from the dam to Waverly, especially riffle and shallow run areas that may be dewatered during extended low flow periods. By providing additional flow at critical times, it was expected that the adverse effects of low flow can be avoided, or at least minimized. The beneficial effects of flow augmentation were presumed to be additional cover, higher macroinvertebrate production, more species diversity, and healthier populations.

An adaptive management plan (AMP) was established in 2009 to guide monitoring activities and was set to be in place for a 5-year period, ending in 2013. In total, 10 years of monitoring have been done within the Whitney Point study area under various funding mechanisms from 2008-2017. The long-term goal of the monitoring plan was to evaluate impacts of project modifications on downstream hydrology and aquatic ecosystems from a low flow management perspective. Additional goals included documenting any changes in lake water quality, macroinvertebrate communities, and submerged aquatic vegetation (SAV) in the lake as a result of the revised reservoir operations. Also, the constructed wetlands at the northern end of the lake were monitored frequently as they became established and withstood a variety of hydrologic conditions.

Methods

Field Methods

Sampling design originally included 10 stream sites within the watersheds surrounding Whitney Point Lake (Steffy, 2013). After the first five years of intensive monitoring at all 10 sites, the monitoring was scaled back to four sites, which represented the critical spatial coverage to continue to monitor impacts (Figure 1). This report focuses on the four sites that were sampled consistently through the 10-year period from 2008-2017.

Data collected at each sampling location included lab water chemistry, in-situ field chemistry, macroinvertebrate collection, fish survey, and physical habitat assessment. Fish were not collected at the Chenango River site after 2012. General stream sampling methods included one pass, 40-minute timed tote barge electroshocking for fish and the NYSDEC standard macroinvertebrate collection protocol of 5 meter/5 minute diagonal composite across a riffle with an aquatic net. Due to limitations associated with streamflow, fish were sampled 24 times and macroinvertebrates were sampled 32 times at four sites during the study period (Table 1; Figure 1).

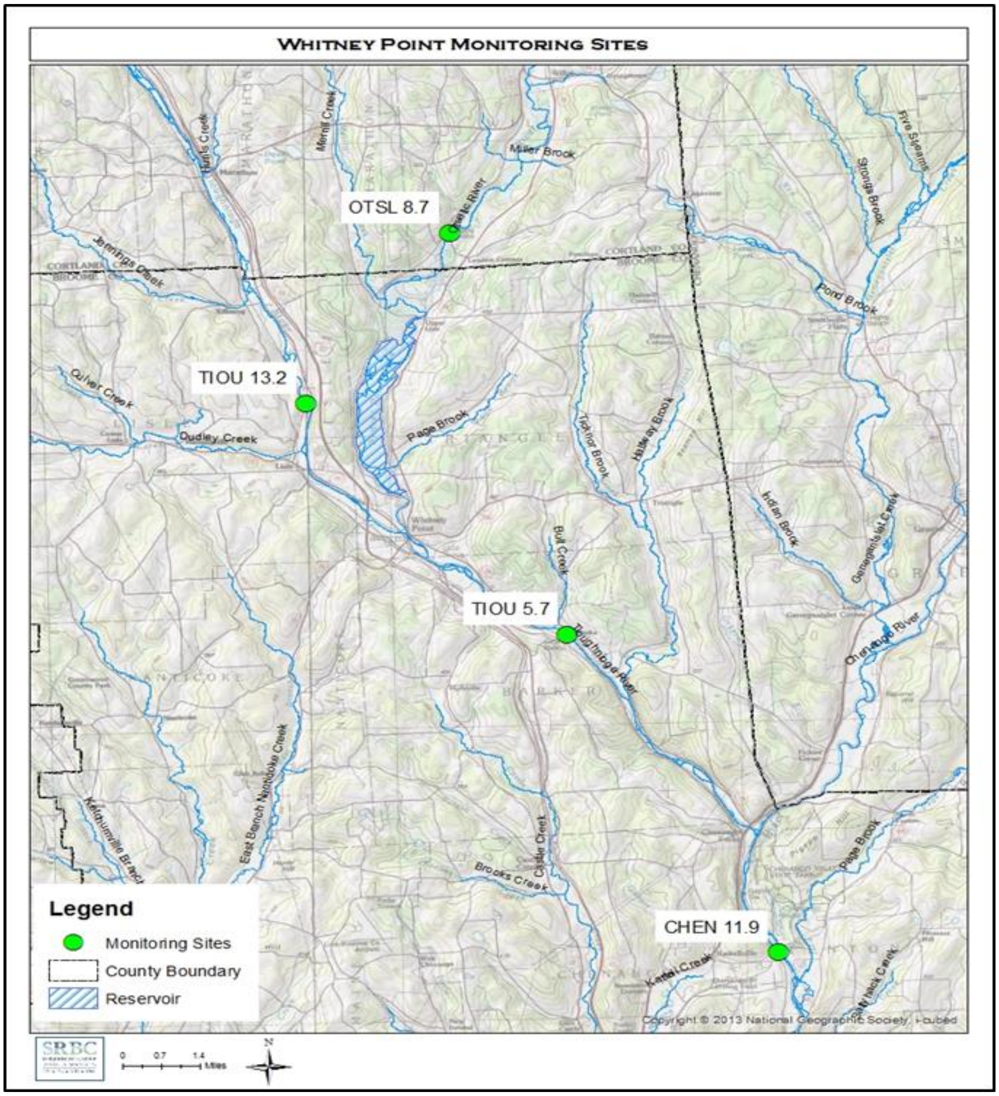

Figure 1. Map of Whitney Point Phase II Study Sites

Table 1. ***Fish and Macroinvertebrate Samples Collected by Year and Monitoring Site (Numbers in totals column/row reflect total number of fish and macroinvertebrate samples (Fish, Macros).)***

Year	CHEN 11.9	OTSL 8.7	TIOU 13.2	TIOU 5.7	Totals
2008	Fish, Macros	Fish, Macros			**2, 2**
2009	Fish, Macros	Fish, Macros	Fish, Macros	Fish, Macros	**4, 4**
2010	Fish, Macros	Fish, Macros	Fish, Macros	Fish, Macros	**4, 4**
2011	Fish, Macros	Fish, Macros	Fish, Macros	Fish, Macros	**4, 4**
2012	Fish, Macros	Fish, Macros	Fish, Macros	Fish, Macros	**4, 4**
2013		Macros	Macros		**0, 2**
2014					**0, 0**
2015	Macros	Fish, Macros	Fish, Macros	Fish, Macros	**3, 4**
2016	Macros	Macros	Macros	Macros	**0, 4**
2017	Macros	Fish, Macros	Fish, Macros	Fish, Macros	**3, 4**
Totals	**5, 8**	**7, 9**	**6, 8**	**6, 7**	**24, 32**

Water samples were collected using depth integrated sampling across the width of the stream channel, instream field chemistry was collected using a multi-parameter meter, and habitat was assessed using a standard Rapid Bioassessment Protocol (RBP). Lake water samples were taken within the photic zone using a VanDorn sample bottle. Macroinvertebrates were collected in-lake using a ponar dredge when conditions allowed and an aquatic net when appropriate. SAV surveys were done using a density estimate method at the same 10 locations throughout the study period, and standard quadrant methods were employed to monitor wetland plants distribution. More detailed information about sampling protocols and procedures can be found in the Quality Assurance Project Plan (Commission, 2008).

Data Analysis Methods

Fish and macroinvertebrate assemblage data were used to calculate ecological metrics for each taxa group. Additional and complimentary analysis of biological community data was completed using Primer v7 and other statistical tests were done using MiniTab. The metrics described below were used as response variables in subsequent statistical analysis.

A variety of statistical analyses were used to determine if variation in biological communities were impacted by differences in hydrologic conditions. The hierarchical nature of this dataset, where 32 biological observations were nested within four monitoring sites, required the use of multilevel models to account for this pseudoreplication (Wagner et al., 2006). We chose to use linear mixed effect (LME) models with a random site intercept to allow intercepts to vary for each monitoring site.

We performed model selection on LME models for each of the six biological response variables described below. For each biological response, single explanatory variable models were constructed. A total of 10 explanatory variables were tested:

i. five hydrological variables for each water year in which biological sampling was conducted, including Richards-Baker Flashiness Index, and percent departure from long-term P_{10}, P_{50}, and P_{90} streamflows;
ii. three air temperature variables for each water year in which biological sampling was conducted, including ºC departure from long-term P_{10}, P_{50}, and P_{90} air temperatures;
iii. nutrient enrichment category Susquehanna Water Quality Index (SWQI) score; and
iv. Julian day to account for seasonality of observations.

For each biological response, the 10 single explanatory variable models and a null model containing only a random stream intercept were evaluated using Akaike's information criterion corrected for small sample size (AIC_c). The model with the lowest AIC_c value was determined to have the most support, while competing models had a Δ_i (AIC_i - AIC_{min}) < 2. All explanatory variables included in competing models and their associated interactions were then included in a full model. Model selection was once again performed using AIC_c, and parameter estimates of explanatory variables included in final competing models were reported.

All models were compared using maximum likelihood estimation due to differing combinations of fixed effects contained in each model. Diagnostic plots of all models were examined in order to ensure homoscedasticity was attained, residuals were approximately normally distributed, and individual observations did not have undue influence on the relationship. All statistical analysis was conducted in R version 3.5.1 (R Core Team, 2018). The lme4 package (Bates et al., 2015) was used to construct LME models and the dredge() function in the MuMIn package (Barton, 2018) was used for model selection.

Biological Metrics

Macroinvertebrates

1. **Taxa Richness:** The total number of unique organism types (commonly defined at a particular taxonomic level such as family, genus, or species) is taxa richness. Taxa richness tends to decrease with increasing stressors because fewer organism types are tolerant of stressors.

2. **Percent Sensitive Individuals (%$PTV_{0\text{-}3}$):** Taxa are assigned values that reflect sensitivity to stressors. %$PTV_{0\text{-}3}$ is the proportion of stress-intolerant organisms. %$PTV_{0\text{-}3}$ decreases as stressors accumulate in the aquatic setting due to loss of sensitive community members.

3. **Percent Ephemeroptera, Plecoptera, Trichoptera (%EPT):** The insect orders Ephemeroptera, Plecoptera, and Trichoptera (EPT) represent mayflies (E), stoneflies (P), and caddisflies (T), respectively. %EPT is the combined proportion of all EPT organisms in the survey. The aquatic life stages of EPT generally are not tolerant of watershed stressors; therefore, %EPT tends to diminish with increasing environmental degradation.

Fish Metrics

1. **Percent Tolerant Individuals (%Tolerant):** Taxa are assigned values that reflect sensitivity to organic pollution. %Tolerant is the proportion of pollution tolerant fishes. %Tolerant increases as stressors accumulate in the aquatic setting due to loss of sensitive community members.

2. **Percent Fluvial Specialists (%FS):** Fluvial specialist species require lotic habitats for a majority of their life history. Due to their dependence on lotic systems, the %FS is expected to decrease with increasing flow alteration (Kinsolving and Bain, 1993; Freeman and Marcinek, 2006; Kanno and Vokoun, 2010).

3. **Percent Periodic Strategists (%Periodic):** Periodic life history strategists grow to large sizes, have late sexual maturation, and high fecundity under suitable conditions. These species will be favored in streams with seasonal, yet predictable flow regimes that create periodically suitable environments. Such streams usually possess large spatial and temporal heterogeneity. %Periodic is expected to decrease with increasing flow alteration (Winemiller, 2005; McManamay et al., 2014).

Additionally, the Richards-Baker Flashiness Index (Baker et al., 2004) was calculated for each water year when sampling was conducted (2008-2017). This index measures oscillations relative to the cumulative streamflow to indicate the flashiness of streamflow during the time span.

Hydrology

Hydrological analyses were conducted in order to examine the contribution of Whitney Point low flow releases to monitoring sites downstream, and to compare annual flow regimes to a long-term period of record. Average daily streamflow data were compiled for a common period of record (1970-2017) from three USGS streamflow gages. Then, the drainage area ratio method (Emerson et al., 2005; Equation 1) was applied to estimate streamflow at each monitoring site (Table 2).

$$Q_{ungaged} = \frac{DA_{ungaged}}{DA_{gaged}} x Q_{gaged} \qquad \textbf{\textit{Equation 1}}$$

where $Q_{ungaged}$ is the flow at the ungaged location, Q_{gaged} is the flow at the reference gage, $DA_{ungagged}$ is the drainage area of the ungaged location, and DA_{gaged} is the drainage area at reference gage.

Table 2. Information Regarding USGS Gages Used to Estimate Streamflow at Monitoring Sites

Gage No.	Gage Location	Gage : Monitoring Site Drainage Area (mi^2)	Monitoring Site
01510000	OTSELIC RIVER AT CINCINNATUS, NY	147 : 218	OTSL 8.7
01512500	CHENANGO RIVER NEAR CHENANGO FORKS, NY	1483 : 1483	CHEN 11.9
01512500	CHENANGO RIVER NEAR CHENANGO FORKS, NY	1483 : 730	TIOU 5.7
01509000	TIOUGHNIOGA RIVER AT CORTLAND, NY	292 : 419	TIOU 13.2

Flow statistics were also generated for all sites for the period of record and for water years (October 1 – September 30) when monitoring was conducted (2008-2017). Flow statistics examined were 10, 50, and 90 percent exceedance values (P_{10}, P_{50}, P_{90}), which represented high, median, and low flows, respectively. A visual representation of P_x values for monitoring sites below (CHEN 11.9) and above (TIOU 13.2) impacts of reservoir operations are shown in Figure 2A/B. Subsequently, departures of each P_x value were determined for each water year by comparing to the long-term period of record, in percent cfs difference.

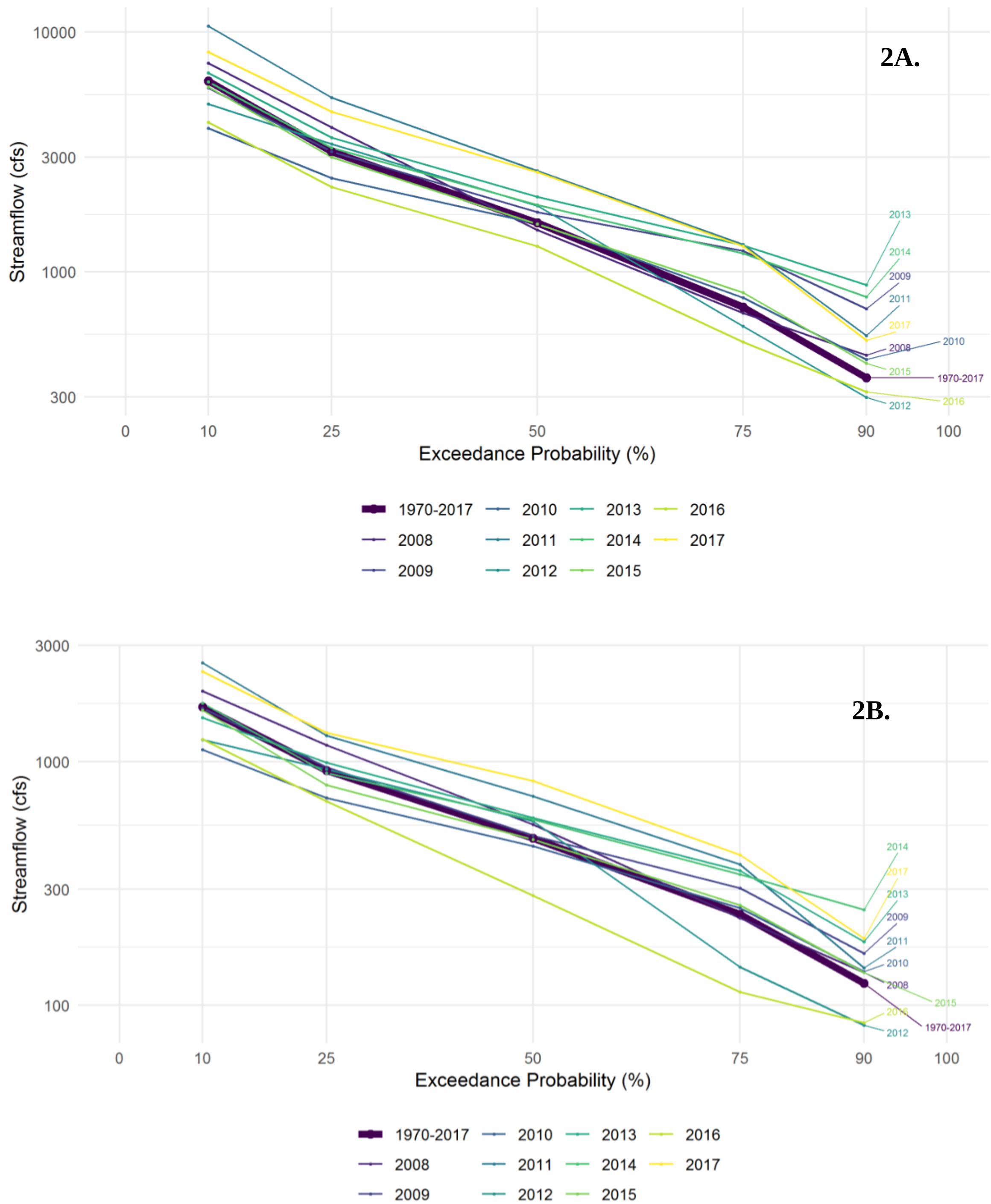

Figure 2A and 2B. Examples of Flow Exceedance Probabilities for the Long-term Period of Record (1970-2017) and Water Years 2008-2017 at One Monitoring Site Impacted by Reservoir Operations ((A) CHEN 11.9) and One Site Above All Reservoir Impacts ((B) TIOU 13.2)

Once streamflow was estimated for each site, release data from Whitney Point were combined with streamflow from monitoring stations downstream (TIOU 5.7 and CHEN 11.9) to examine the contributions of releases to onsite streamflow. Annual flow statistics were generated with and without releases, and compared to the long-term period of record.

Air Temperature

Since long-term datasets of water temperature were not available, air temperature was used as a surrogate (Caldwell et. al., 2014). Air temperature was available for the same period of record (1970-2017) from the Greater Binghamton Airport (GBA), which was in close proximity (8-12 miles) from monitoring sites (Northeast Regional Climate Center, http://www.nrcc.cornell.edu/). Average daily data were compiled and analyzed as described above for streamflow. P_{10}, P_{50}, and P_{90} air temperature exceedance statistics were examined, which represented high, median, and low temperatures, respectively. A visual representation of P_x values for the air temperatures are shown in Figure 3. Subsequently, departures of each P_x value were determined for each water year by comparing to the long-term period of record, in ºC.

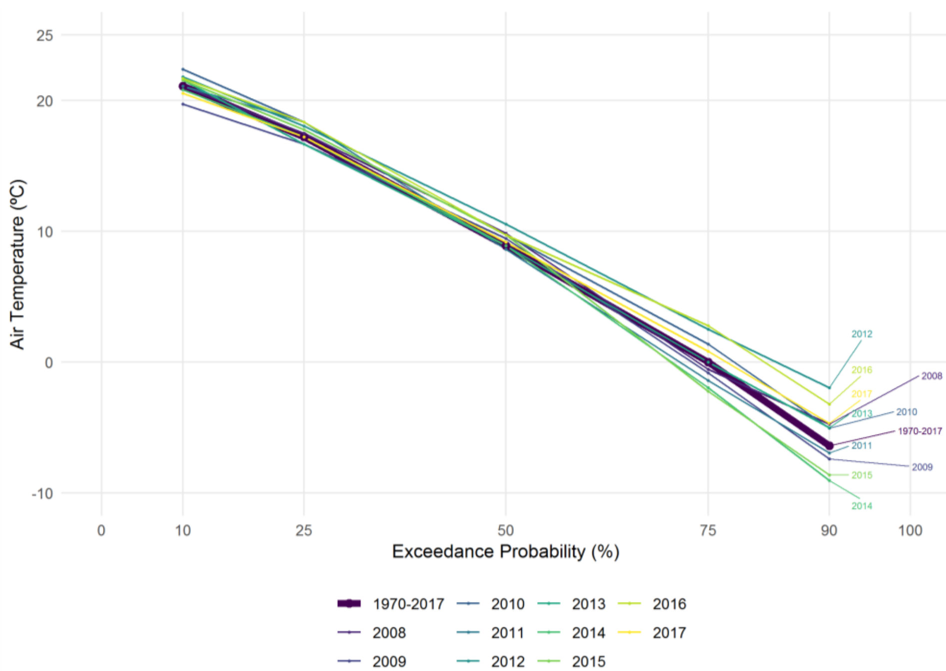

Figure 3. Air Temperature Exceedance Probabilities for the Long-term Period of Record (1970-2017) and Water Years 2008-2017 at the Greater Binghamton Airport

Water Quality

Discrete water quality samples were collected during each site visit for lab analysis. The parameter suite included total phosphorus, nitrate, and total organic carbon, which allowed calculation of the nutrient enrichment category score of the SWQI (Berry et al., *in preparation*). This nutrient enrichment SWQI score serves as an indication of water quality on a 0-100 scale (0=worst, 100=best), in comparison to other surface waters throughout the basin.

Results

Hydrology

Compared to the long-term period of record (1970-2017), water years 2008-2017 experienced higher than typical streamflows, especially for median and low flows. The year 2011 experienced the highest departures for P_{10} and P_{50} flows, which coincided with Tropical Storm Lee and Hurricane Irene. Only 2012 and 2016 exhibited lower P_{50} and P_{90} flows compared to the period of record (Figure 4). Streamflow flashiness was highest for all sites in 2011, also likely due to Tropical Storm Lee and Hurricane Irene. The upstream site on the Otselic River (OTSL 8.7) was the site with highest flashiness for all years, not surprisingly as it is the smallest of the four sites. The two sites downstream of the reservoir (CHEN 11.9 and TIOU 5.7) are identical due to using the same reference gage to estimate streamflow.

Low flow releases from Whitney Point Lake are initiated based on either of two USGS gage flows reaching a target threshold for three consecutive days. The target threshold for the Susquehanna River at Waverly gage (USGS 01515000) is 700 cfs and the target threshold for Chenango River at Chenango Forks is 150 cfs. During the long-term period of record (1970-2017), these low flow targets were only reached 3.3 percent and 0.4 percent of days, respectively. The low flow targets were developed based on a longer period of record going back to the 1930s which included more drought periods than the more proximate historical period of 1970-2017.

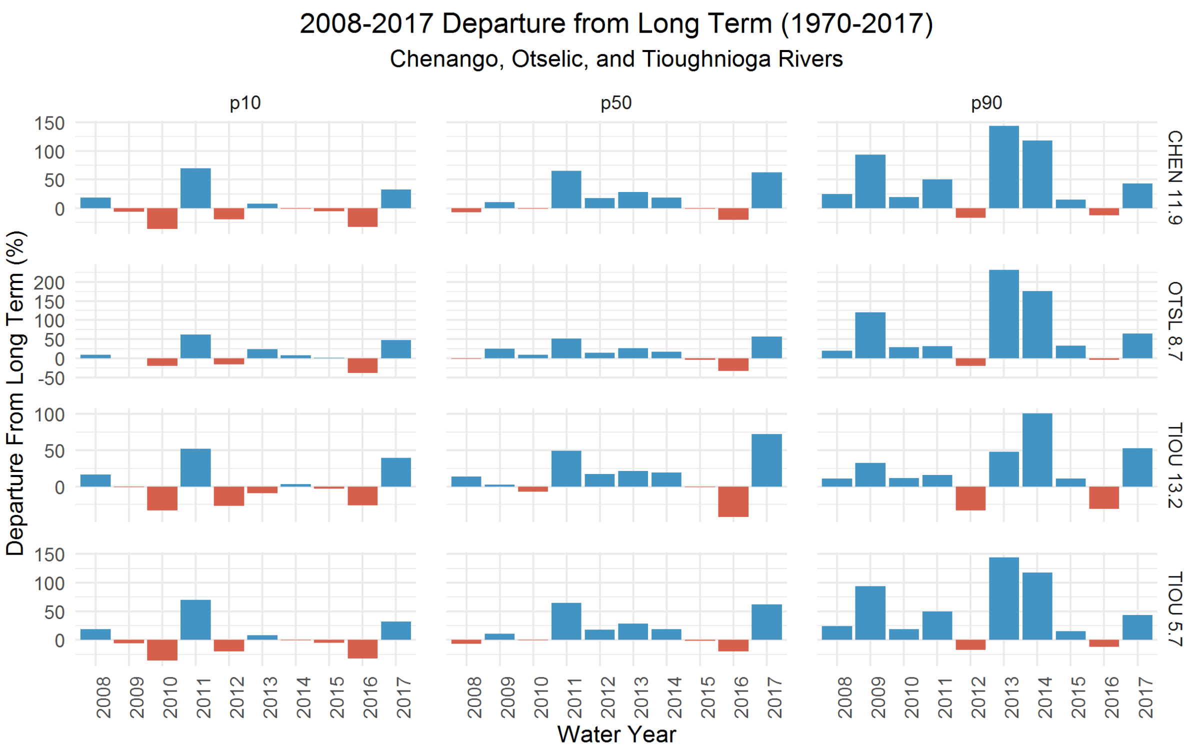

Figure 4. ***P_{10}, P_{50}, and P_{90} Streamflow (%) Departure from Long-term Period of Record (1970-2017) at Monitoring Sites for Water Years 2008-2017 (Blue bars indicate positive departure (increased streamflow) and red bars indicate negative departure.)***

Air Temperature

Compared to the long-term period of record (1970-2017), years 2008-2017 experienced warmer than typical air temperatures. Similarly to flow statistics, a P_{10} air temperature corresponds to high temperatures, where the air temperature is warmer only 10 percent of the time and P_{90} air temperatures correspond to low temperatures that are exceeded 90 percent of the time. Positive (warmer) departures were observed in greater than 50% of years for high, median, and low air temperatures. The magnitude of departures from normal were largest for low (P_{90}) temperatures (Figure 5).

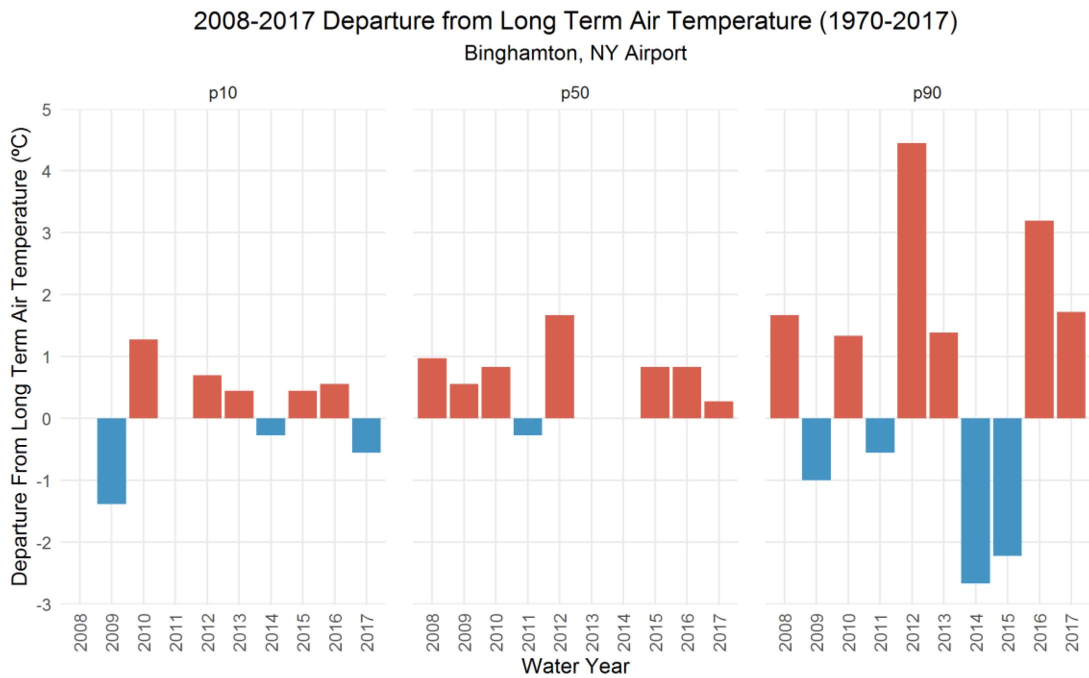

Figure 5. ***P_{10}, P_{50}, and P_{90} Air Temperature (ºC) Departure from Long-term Period of Record (1970-2017) at the Greater Binghamton Airport for Water Years 2008-2017 (Red bars indicate positive departure (increased temperature) and blue bars indicate negative departure.)***

Whitney Point Lake Release Contributions to Streamflow at Downstream Monitoring Sites

During a 16-day period from September 30 to October 20, 2016, Whitney Point Lake made low flow releases between 34 – 102 cfs (mean 51.6 cfs). The pool elevation was drawn down approximately 0.75 feet total over the duration of the release. These releases affected both downstream monitoring sites, TIOU 5.7 and CHEN 11.9, which are 5.2 and 13.6 miles downstream of Whitney Point Lake, respectively. A precipitation event began to increase streamflow on October 21, 2016, which effectively ended the low flow releases (Figure 6).

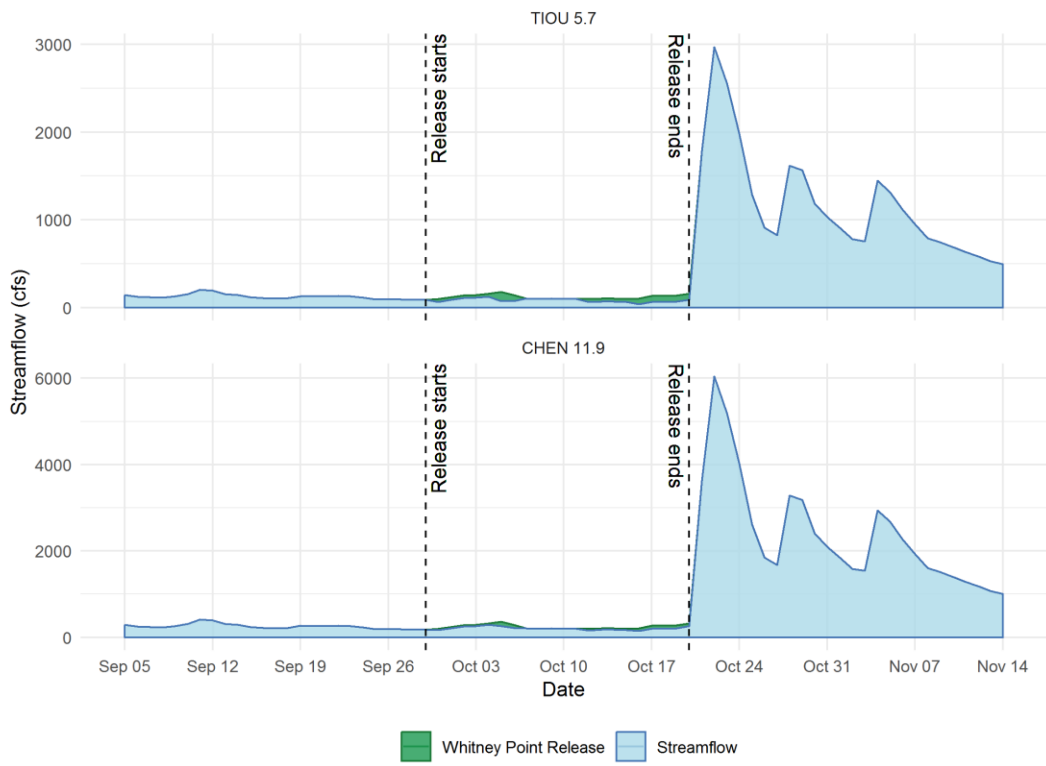

Figure 6. ***Hydrographs of Monitoring Sites Situated Downstream of Whitney Point Lake, and the Contributions of 2016 Low Flow Releases to Streamflow at Respective Sites***

Although the low flow release appears minor when viewed as part of the hydrograph, low flow percent exceedance statistics for water year 2017 are noticeably altered at TIOU 5.7 and CHEN 11.9. Specifically, P_{95} and P_{99} decreased when the release was subtracted from streamflow at each site (Figure 7). Without low flow releases, P_{95} and P_{99} values for water year 2017 were 19% and 25% below the long term, respectively, at TIOU 5.7. However, when including the low flow releases, the departures were 20% and 15% above the long term, for P_{95} and P_{99}, respectively, at TIOU 5.7. This effect was also observed at CHEN 11.9, although departures were not as low without releases (Figure 8). This reduced influence is most likely due to the greater distance from Whitney Point Lake and larger contributing drainage area.

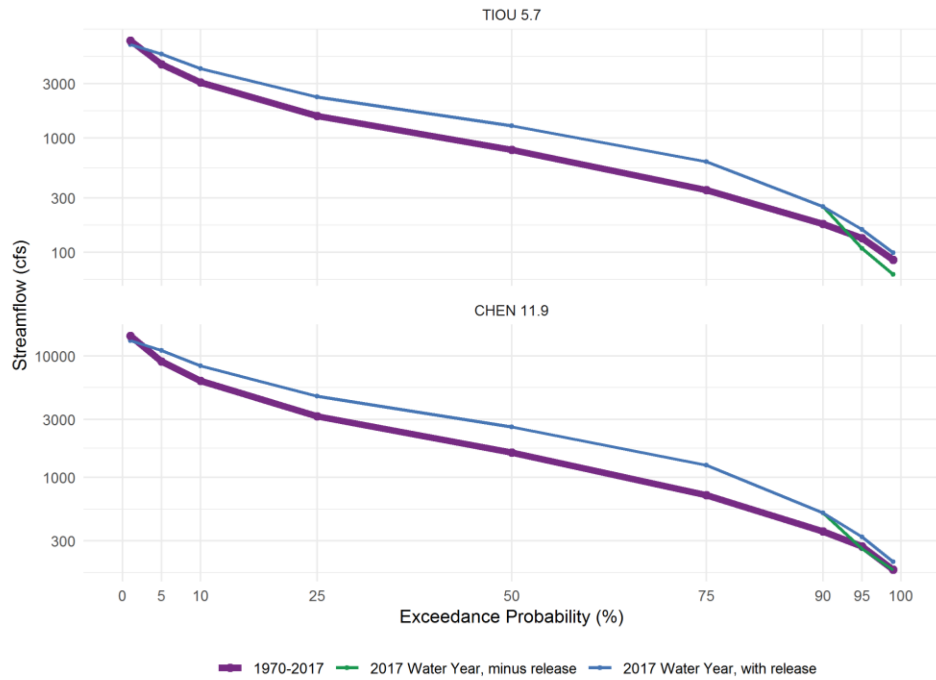

Figure 7. ***Flow Exceedance Probabilities for the Long-term Period of Record (1970-2017) and Water Year 2017 at Monitoring Sites TIOU 5.7 and CHEN 11.9 (Low flow releases were made from Whitney Point Lake during water year 2017, which altered P_{95} and P_{99} annual statistics.)***

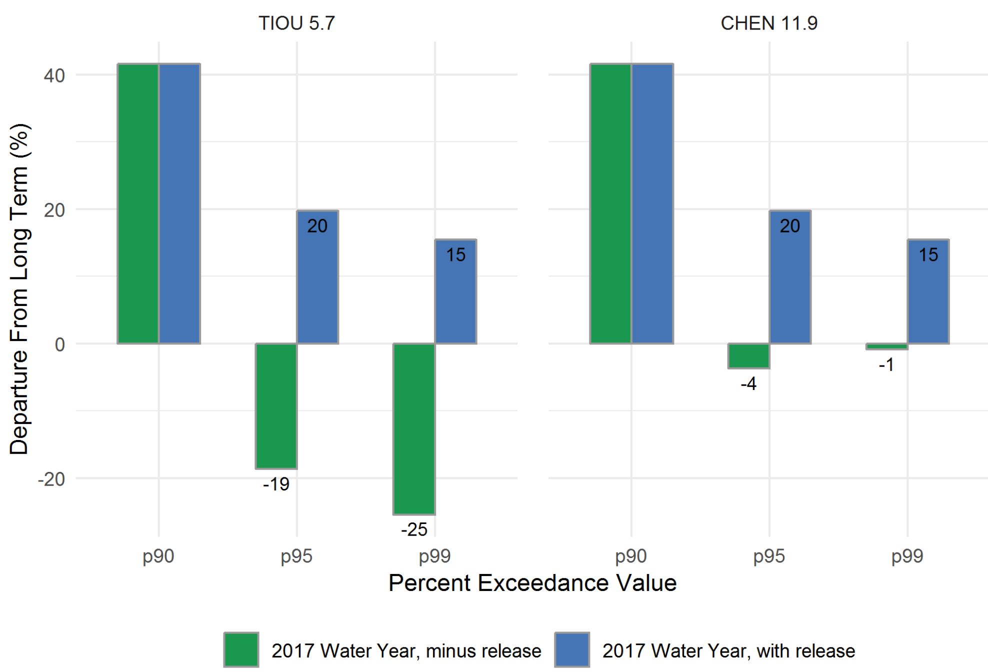

Figure 8. ***P_{90}, P_{95}, and P_{99} Streamflow (%) Departure from Long-term Period of Record (1970-2017) at Monitoring Sites for Water Year 2017 When Low Flow Releases Were Made from Whitney Point Lake (Green bars indicate departure for streamflow at monitoring sites without the low flow releases; blue bars indicate departure including releases.)***

Biological Communities

<u>Macroinvertebrates</u>

The two upstream sites (OTSL 8.7 and TIOU 13.2) were not impacted at all by the operations of Whitney Point Reservoir. The site affected most directly by reservoir operations was TIOU 5.7, as it was about 4 miles downstream of the reservoir and streamflows were most readily impacted from flow coming from the reservoir. The site on the Chenango River, CHEN 11.9, was influenced by reservoir operations, although to a lesser extent given its distance from the outflow as well as the large drainage area of the Chenango that is not influenced by the dam. The metrics that were examined are expected to vary based on various stressors, including flow alteration. Macroinvertebrate metrics varied across years and monitoring sites during the study period. OTSL 8.7 had the highest median taxa richness, while CHEN 11.9 had highest $\%PTV_{0\text{-}3}$ and % EPT (Figure 9).

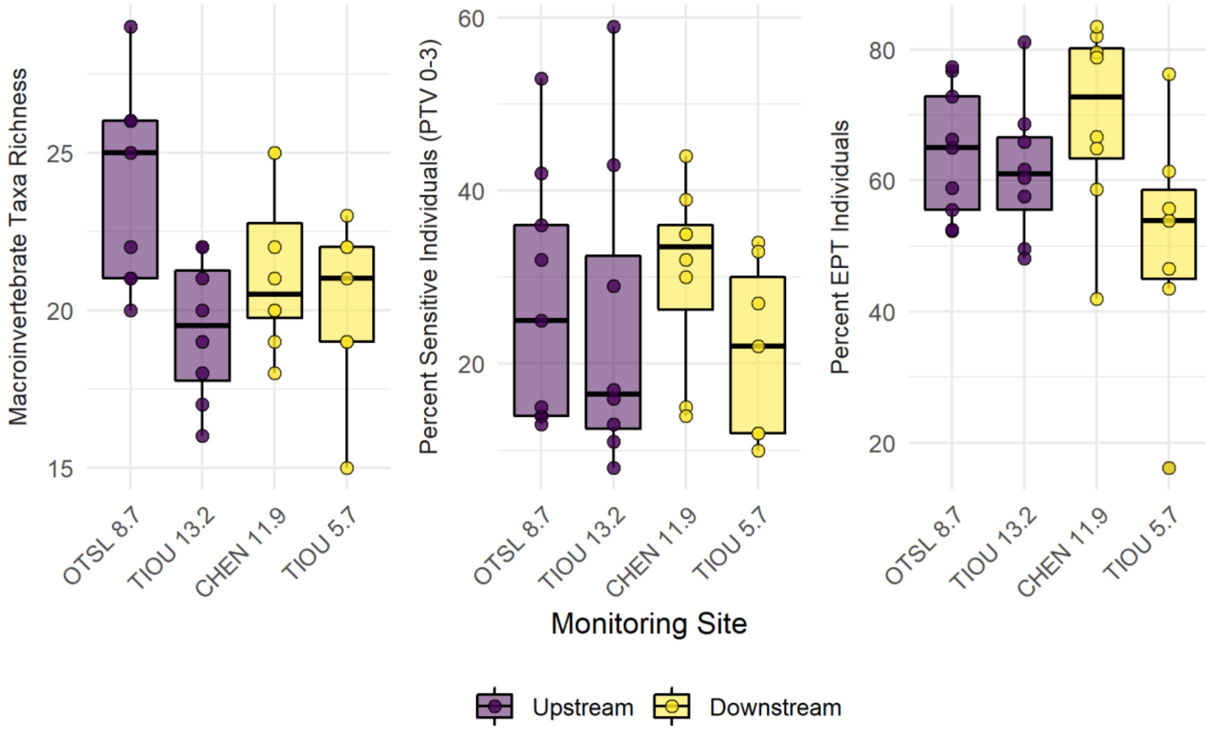

Figure 9. ***Box Plot of Macroinvertebrate Metrics at Monitoring Sites (Individual data points are shown as circles; the dark line in middle of box represents median value (50^th^ percentile). The top line of the box represents the 75th percentile, while the bottom line of the box represents the 25^th^ percentile. Whiskers denote the range of 1.5 times the interquartile range; any points outside the whiskers can be considered outliers.)***

Additionally, an analysis of the whole macroinvertebrate community revealed significant differences between sites (ANOSIM R= 0.315 p= 0.001) and between years (ANOSIM R= 0.460 p=0.001), emphasizing the need for a random intercept that accounts for differences between streams within a linear model.

The select macroinvertebrate metrics for these sites generally responded as would be expected, as the site most impacted by reservoir operations, TIOU 5.7, scored the poorest. Interestingly, the site with no flow alteration, OTSL 8.7, did not always have the highest proportion of sensitive taxa but it did have the highest number of taxa overall. The Chenango River, which is downstream of Whitney Point reservoir and impacted to some extent by reservoir operations, supported better macroinvertebrate communities than would be expected for a river that size.

Fish

Fish metrics also varied across years and monitoring sites during the study period. OTSL 8.7 had the lowest median percentage of tolerant fishes (%Tolerant), while TIOU 13.2 and CHEN 11.9 had the highest percentage of fluvial specialists (%FS) and periodic life history strategists (%Periodic), respectively (Figure 10). The absence of a relationship between flow alteration and percent periodic fish species may indicate that the reservoir is having a negligible impact on the relative abundance of periodic life history fish species.

Similarly to macroinvertebrate assemblages, whole fish communities were also examined in addition to selected summary metrics and significant differences were found in fish communities between sites (ANOSIM R=0.599 p=0.001) and year (ANOSIM R=0.235 p=0.013).

Not all fish metrics responded predictably to flow alteration; specifically, more periodic strategists were collected at the two flow altered sites. The least altered site did have the fewest tolerant (most sensitive) species but the greatest proportion of fluvial specialists were found at the largest site, CHEN 11.9. This could be an artifact of sampling biases inherent in fish sampling a large river like the Chenango River with wading methods. Not all habitats can be accessed so shallow riffle habitats are sampled disproportionally more just due to accessibility.

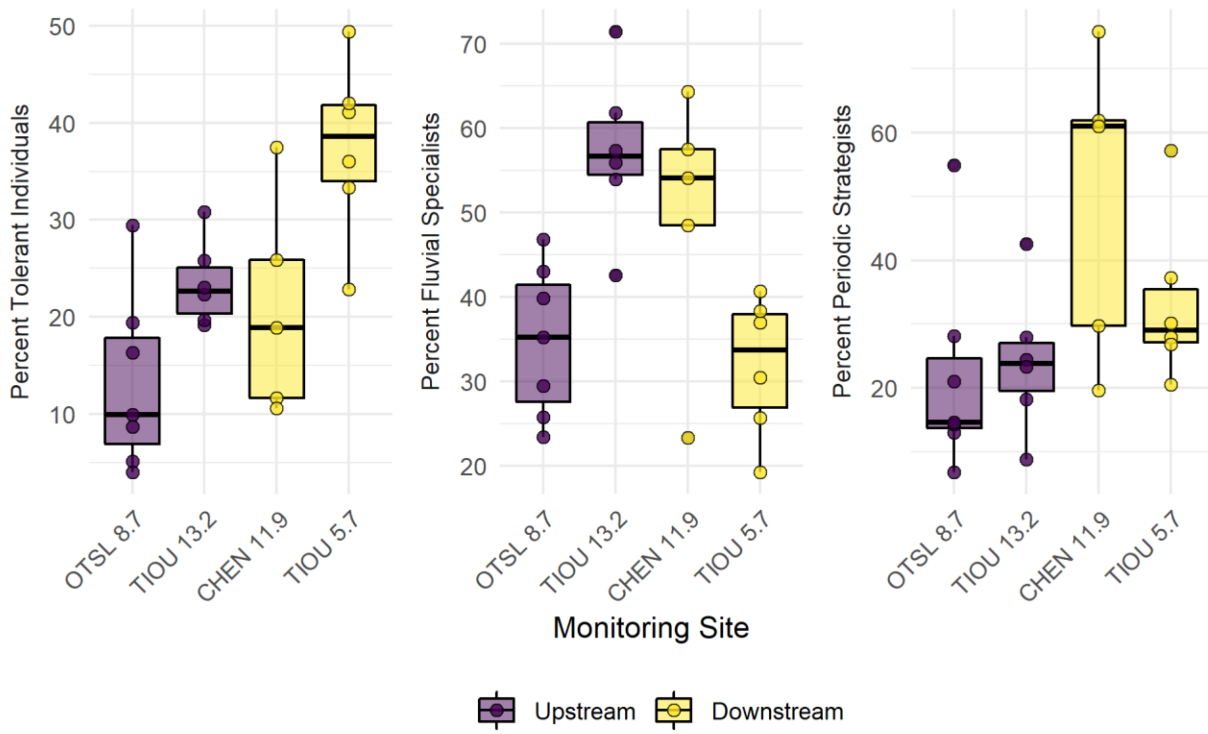

Figure 10. Box Plot of Fish Metrics at Monitoring Sites (Individual data points are shown as circles; the dark line in the middle of box represents median value (50th percentile). The top line of the box represents the 75th percentile, while the bottom line of the box represents the 25th percentile. Whiskers denote the range of 1.5 times the interquartile range; any points outside the whiskers can be considered outliers.)

<u>Water Quality</u>

Nutrient enrichment SWQI scores ranged from 21-73.7 across study sites. Stream sites with higher SWQI scores have lower nutrient concentrations and thus, better water quality. TIOU 13.2 showed the highest levels of nutrient enrichment, while OTSL 8.7 was lowest (Figure 11). Both of these sites are above any impacts of reservoir operations.

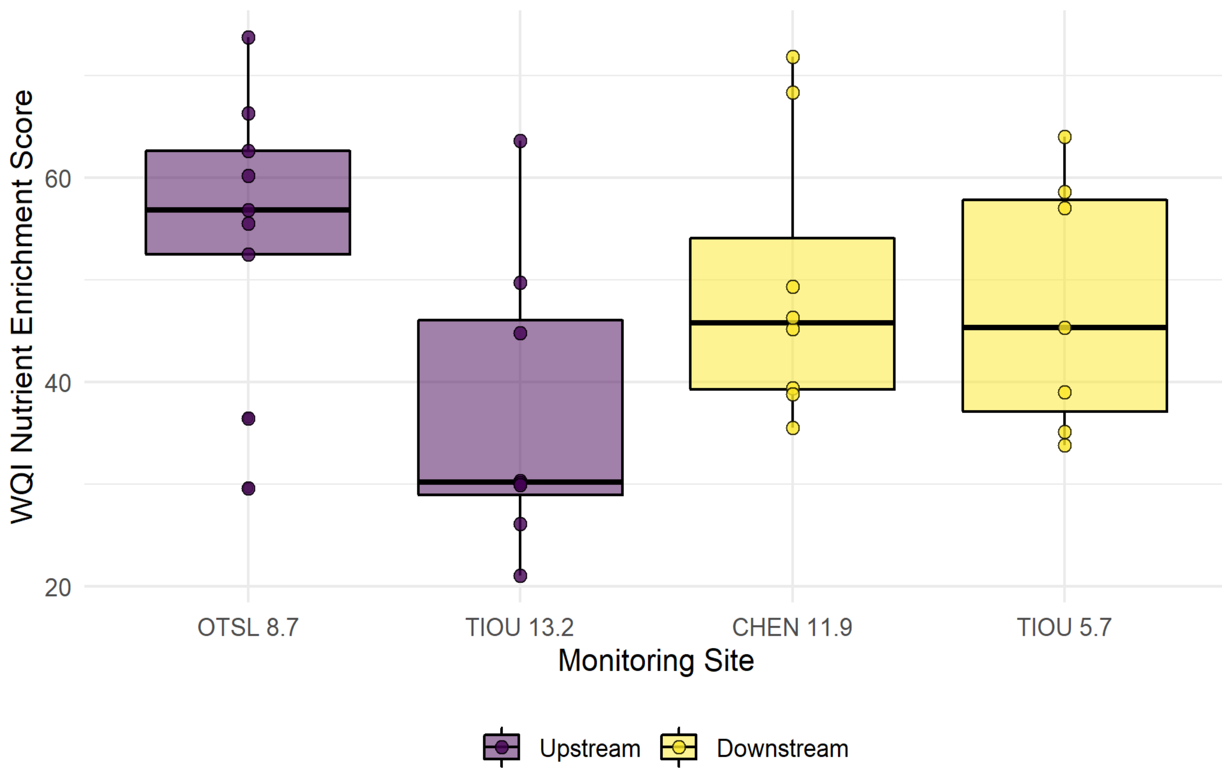

Figure 11. Box Plot of Susquehanna Water Quality Index Nutrient Enrichment Category Score at Monitoring Sites (Higher scores on y-axis indicate lower levels of nutrient enrichment. Individual data points are shown as circles; the dark line in middle of box represents median value (50th percentile). The top line of the box represents the 75th percentile, while the bottom line of the box represents the 25th percentile. Whiskers denote the range of 1.5 times the interquartile range; any points outside the whiskers can be considered outliers.)

Statistical Modeling

<u>Macroinvertebrates</u>

Macroinvertebrate taxa richness was best described by the percent departure from long-term P_{50} air temperatures. A competing model indicated that richness decreased with increasing median streamflow departures. When both variables were included, the model described 33% of variation in taxa richness. Taxa richness is impacted by increased temperature and high flows.

The $\%PTV_{0\text{-}3}$, a measure of sensitive taxa, response was best described by a model including P_{90} air temperature departure, Julian day, and their interaction. Additionally, the inclusion of an interaction term indicated that temperature and seasonality affected $\%PTV_{0\text{-}3}$ differentially. When both variables and their interaction were included, the final model described 47% of variation in $\%PTV_{0\text{-}3}$. The percentage of sensitive taxa comprising a macroinvertebrate community is impacted by air temperature and when the sample is taken.

The metric of percent EPT taxa was the least well explained metric, but results do point to the importance of high flows. Models including percent departure from P_{10} and P_{50} long-term streamflow received the most support for describing variation in % EPT. These models described between 12-15% of variation in % EPT. EPT taxa within a macroinvertebrate community are impacted more by high flows than low flows.

Fish

The percent of tolerant fishes observed within a fish community was impacted by P_{10} air temperature (ºC) and P_{90} streamflow (%) departure from long-term, nutrient enrichment SWQI score, and Richards-Baker Flashiness Index. The parameter estimates indicated that more tolerant fishes were present with increasing high air temperatures and nutrient enrichment, while fewer tolerant fishes were present with increasing low flow departures and stream flashiness. These models described between 29-55% of variation in % tolerant fishes.

The percent of fluvial specialists observed within a fish community was impacted by nutrient enrichment SWQI score, P_{10} air temperature, and P_{50} streamflow (%) departure from long term. Sites with more nutrient enrichment had fewer fluvial specialists, while cooler temperature and near median flows results in more fluvial specialists. These models described between 26-38% of variation in %FS.

The percent of periodic fish species observed within a fish community within this model was solely impacted by P_{50} streamflow (%) departure from long-term. The parameter estimates indicated that departure from P_{50} streamflows, resulted in fewer periodic strategists. This model described 25% of variation in % periodic fish.

Overall, low/median flow departures and median/high air temperature departures were considered most meaningful for macroinvertebrate responses. Nutrient enrichment WQI score, median and high flow departures, and low air temperature departures were most meaningful for fish responses (Table 3).

Table 3. Summary of Slope Estimates for Competing Models for Each Response Variable

Taxa group	Response Variable	Julian Day	Nutrient Enrichment WQI Score	Richards Baker Flashiness Index	Flow (% Departure) P_{10}	Flow (% Departure) P_{50}	Flow (% Departure) P_{90}	Air Temperature (ºC Departure) P_{10}	Air Temperature (ºC Departure) P_{50}	Air Temperature (ºC Departure) P_{90}
Macro-invertebrate	Taxa Richness					-0.04			2.19	
	$\%PTV_{0\text{-}3}$	0.35								-4.81
	%EPT				0.15	0.14				
Fish	%Tolerant		-0.235	-66.538			-0.079	3.455		
	%FS		0.248			0.09		3.134		
	%Periodic					-0.277				

Legend				
Strong Positive Effect	Slight Positive Effect	Slight Negative Effect	Strong Negative Effect	No Effect

Lake

Three main indicators were monitored consistently in Whitney Point Lake: water quality, macroinvertebrates, and SAV. Documentation of lake conditions under the new reservoir water control plan was an important part of the study. Baseline seasonal water quality data were collected at three locations (historical USACE sites) in the lake three times between June and October each year. One of the main water quality concerns in the lake was the nutrients and how increased nutrient concentrations may impact SAV and be detrimental to recreation. Nutrient water quality index scores were calculated for lake samples taken throughout the 10-year sampling period. Nitrate, phosphorus, and total organic carbon (TOC) concentrations were fairly consistent between sites but there was some variation temporally (Figure 12).

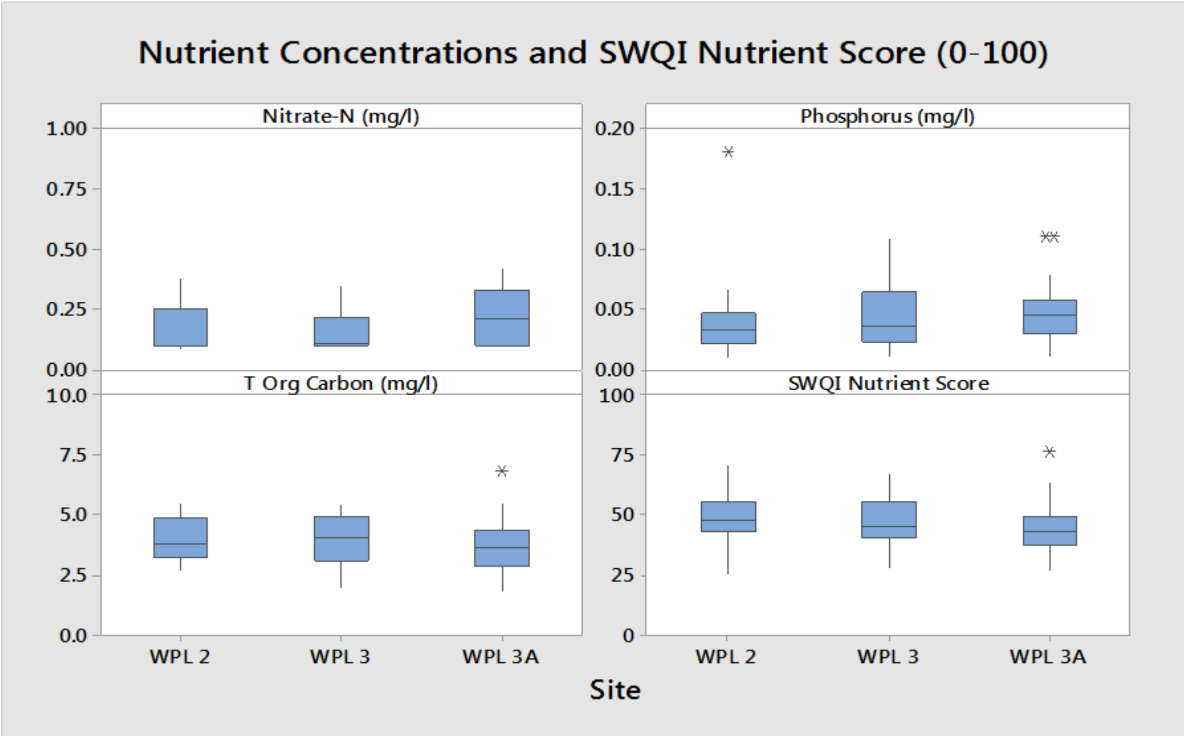

Figure 12. Box Plots Showing Nutrient Concentrations and SWQI Scores in Whitney Point Reservoir

In order to examine these temporal differences, nutrient SWQI scores for each site were plotted over time (Figure 13). Interestingly, the best SWQI scores (lowest nutrients) were observed in July 2011, prior to the record flooding cause by Tropical Storm Lee and Hurricane Irene. This was followed by the worst SWQI scores in September 2011, shortly after the flooding had subsided. By October 2011, SWQI scores had rebounded to the general range that was observed throughout the study period.

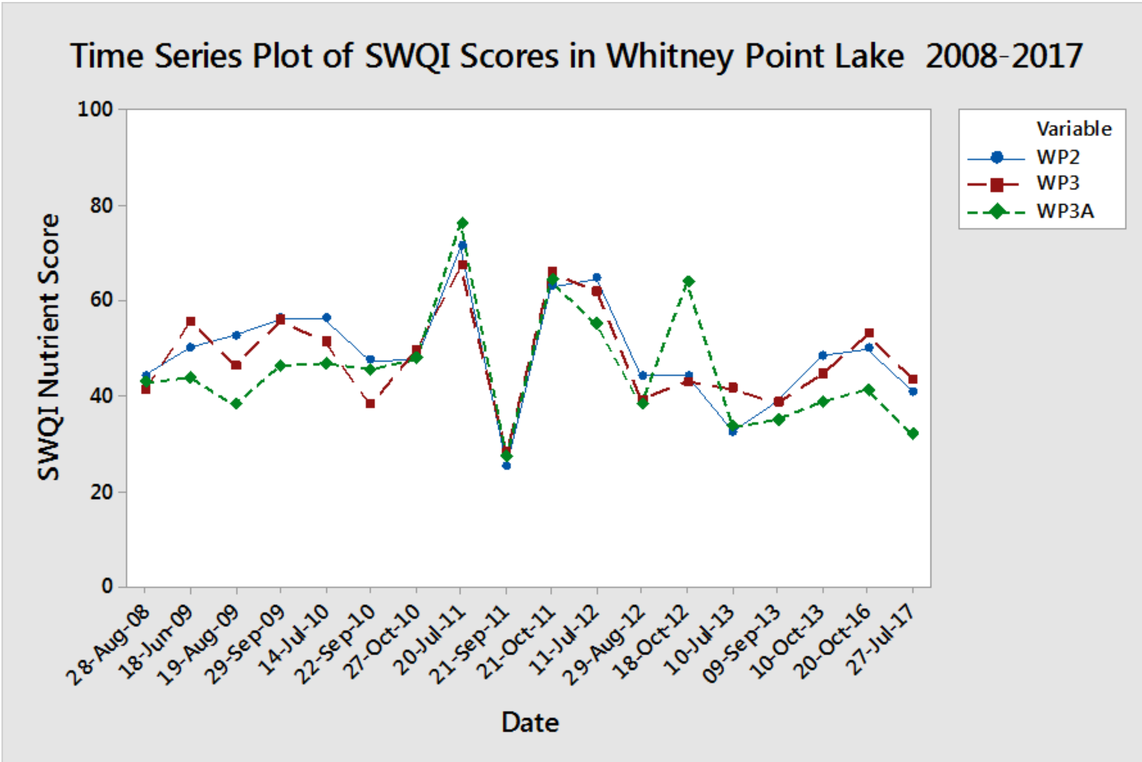

***Figure 13.** SWQI Nutrient Score Over Time, 2008-2017 (Site WP2 is located at the southern end of the lake, near the dam. Site WP3 is located mid-lake near the western shore, and site WP3A is in the northern part of the lake closer to the eastern shore.)*

Macroinvertebrate samples were collected from the littoral zone of the lake twice a year with the objective of documenting biological conditions in the lake, but also to confirm the presence of the burrowing mayfly genera *Hexagenia*. At the onset of this project, there was some concern over the possible effects of a summer low flow release on this genera which often burrow in fine sediments along the edges of lakes (Merrit and Cummins, 2008). The most abundant taxon, at greater than 40 percent of all taxa collected, was Chironomidae, which is typical for lentic macroinvertebrate communities. The second most abundant taxon was the genera of mayfly *Caenis*, which are also often found in lakes as they prefer ponded or slow moving water and are adapted to fine sediments. The burrowing mayfly genera *Hexagenia* comprised about 2 percent of all the organisms collected and were the fourth most abundant.

The third indicator that was monitored within Whitney Point Lake was SAV. SAV is an important part of lake ecosystems as it provides food, cover, and uptakes excess nutrients. However, it can become a nuisance to recreational activities in highly productive lakes, especially if non-native species are introduced. In Whitney Point Lake, SAV was monitored at least annually to document species presence, dominance, extent, and general response to climatic conditions. Because of the concern regarding recreational impacts, a majority of the sites were around heavily-used recreational areas. There were four species of SAV found in the open water portion of the lake-three of which are non-native species. The most dominant aquatic plant in Whitney Point Lake was *Myriophyllum spicatum* (Eurasian watermilfoil). Also found were *Najas minor* (European Naiad), *Hydrilla verticillata* (hydrilla), and *Ceratophyllum demersum* (coontail). Coontail is the only native species found in the lake. In general, less than 10 percent of the lake surface is covered in SAV. SAV is primarily abundant in shallow shoreline areas, particularly in small cove areas. The highest density of SAV was found in depths between two and five feet.

Wetlands

As part of the Whitney Point environmental restoration project, a two-acre wetland was constructed in the northwestern cove area of the lake in 2009. In addition to the wetlands, two islands were constructed between the open water of the lake and the wetlands to provide protection for the wetlands and additional beneficial wildlife and fish habitat. Seven types of vegetation were planted in the wetlands: Pickerel Weed, Softstem Bulrush, Common Rush, Arrow Arum, Spatterdock, American Bur Reed, and American Sweet Flag.

The wetlands are fully inundated (average depth 10.5 inches) when the lake is at normal pool level. The constructed wetlands survived and adapted through a wide ranging variety of conditions. Generally, the wetlands did well and were well established and thriving at the end of the 10 years. Overall, the constructed wetlands and islands have been successful as they have stabilized and continue to display healthy plant growth. During the planned five-foot maintenance drawdown of Whitney Point Lake in fall 2012, the wetlands were not inundated for the first time since they had been planted. The wetlands were dewatered for about a month with vegetation experiencing different levels of exposure. Vegetation survey results post-flooding (2012) and in post-drawdown (2013) seem to suggest that flooding has more adverse impacts on the wetlands than dewatering. Short-term dewatering did not seem to impact the wetlands positively or negatively, which is an encouraging sign that the wetlands will survive any future environmental releases from the lake.

Discussion

Ten years of monitoring within the Whitney Point study area have resulted in valuable insights into this type of monitoring and the evaluation of low flow augmentation. Environmental effects on biological communities are complex and multidimensional. The results generated show value of looking at annual conditions compared to the long-term. Model performance demonstrates that even during a period largely devoid of low flows, variation in streamflow, air temperature, and seasonality were instrumental in the structure of biological communities. The downstream impacts of reservoir operations for Whitney Point Lake are relatively minor and the impacts on hydrologic conditions seem to be minimal. Flow exceedance curves for each water year of the 10-year data collection period look similar at sites above and below the reservoir. However, even a 16-day release of a modest amount of water from Whitney Point Lake during a low flow period was enough to noticeably alter the magnitude of low flow percent exceedance statistics at monitoring sites downstream. This demonstrates the outsized effect releases can have during stressed hydrologic periods, which could reduce impacts to stream ecology during low flow events. While the hydrologic impact of the low flow augmentation is easily quantifiable, the direct benefit to ecosystems is harder to definitively demonstrate. Historically, hydrologic benefits have been seen as sufficient for CU mitigation, but more recently an effort has been made to evaluate ecosystem benefits. While additional water in times of low flow is not detrimental to aquatic ecosystems, in large systems like the Tioughnioga and Chenango Rivers that are wide and low gradient and not readily dewatered, 30-50 cfs is not generally preserving habitat that would otherwise be lost. Subsequent studies might include continuous instream monitoring in order to better quantify water quality benefits above and beyond just water quantity.

Linear mixed effects models revealed high levels of support for models including high and median flow explanatory variables and indicated that deviations from these flow metrics are important biological drivers. The lack of low flows observed during this time period may have resulted in the lack of support for low flow explanatory variables. Future climate projections indicate increased precipitation will likely occur, making low flows more infrequent, as we observed through hydrological analysis. Operational plans for low flow augmentation from Whitney Point Lake remain crucial for downstream aquatic ecosystems to offset potential problems associated with low flow periods, even if they occur with decreased frequency.

Target flow threshold values for low flow augmentation from Whitney Point Lake were developed based on a period of record which included historic droughts of the 1930s and 1960s. More recent records from 1970-2017 show that a 150 cfs streamflow occurred at the Chenango Forks gage on just 0.4% of days. Since this is the gage within the target study area where the most benefits from a low flow augmentation would be realized, it seems unlikely that this threshold would be reached prior to that of the Waverly gage on the Susquehanna River, which is 50 miles downstream and therefore realizes a reduced benefit from the low flow augmentation.

Lastly, the peripheral improvements to Whitney Point Lake included in the AMP have functioned as designed and none of the potential unintended consequences for in-lake conditions came to fruition. Routine monitoring for 10 years showed consistent water quality and biological assemblages, as well as no noticeable change in density of species of SAV. Constructed wetlands have survived extreme flooding events and moderate, short-term drawdowns for maintenance events. The wetlands continue to stabilize the upper portion of the lake and provide important habitat for in-lake fisheries.

Conclusions

The Commission continues to focus research efforts on low flow management in light of CU mitigation and ecosystem flows. Lessons learned from the analysis of 10 years' worth of data in the Whitney Point study area point to successful hydrologic impacts of low flow augmentation, in keeping stream flow above a P_{95} and a P_{99} flow statistic. The stated goals regarding benefits to downstream ecosystems were more difficult to document, although this may be largely due to the infrequency of which low flow augmentation occurred (once in 10 years). Data analysis show that streamflow departures from long-term mean do impact biological metrics but high and median flow departures were just as important as low flow departures. In many instances, time of year, temperature, and water quality had more of an impact on a specific biological metric than any flow-related metric. The need remains for a monitoring design that better shows impacts of low flow augmentation on downstream ecosystems, but this may continue to be difficult as climate change results in fewer low flow events.

Recommendations

As a next step stemming from the results of this work, we recommend the development of a broader Low Flow Monitoring Protocol that incorporates other Commission low flow management projects, current low flow release projects, and federal/state lakes that are targeted for low flow management, as well as lessons learned from recent Commission research examining specific issues related to ecological flows. Bringing together water availability tools and an understanding of potentially stressed areas across the basin coupled with ecosystem flow questions will provide greater insight into how these three realms overlap.

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