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Nutrient Loading and Discharge for Virginia Lakes: A Two Year Study

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Abstract

Nitrogen and phosphorus entering the Chesapeake Bay must be reduced to meet the requirements of the Environmental Protection Agency (EPA) 2010 Chesapeake Bay Total Maximum Daily Load (TMDL). Lake fertilization by the Virginia Department of Game and Inland Fisheries (VDGIF) is both an accepted management tool for fisheries enhancement and necessary when allochthonous sources are limited. The problem is whether or not the addition of fertilizers to recreational fishing lakes is contributing to nutrient loading of the Bay. Since March 2017 we have been conducting a comprehensive lake water chemistry evaluation of four lakes in the watershed of the Bay: Lake Brittle, Burke Lake, Huntsman Lake, and Lake Shenandoah. The first two were fertilized by application of Sportmax® during the summer. Samples were taken at each lake from feeder streams, tailwaters and within-lakes, assayed and compared for the evaluation. More than twenty chemical and analytical parameters have been measured. Stream gauge records were used to develop loading and discharge values for water volume, that were combined with observed concentration values to produce nutrient budget data. For the sixteen months to date, we have found that total nitrogen (average two week loading and release in kg) for the four lakes has been: Brittle (380; 147), Burke (355; 102), Huntsman (118; 247) and Shenandoah (458; 216) and for phosphorus: Brittle (16.2; 4.7), Burke (67.4; 7.1), Huntsman (3.9; 15.1), and Shenandoah (6.0; 4.4). The data indicate that all three VDGIF lakes are currently storing both nitrogen and phosphorus, while Huntsman Lake is releasing more nutrient than is currently entering. Huntsman was dredged and refilled in 2014 and we believe that the disturbance may be a contributing factor to the nitrogen and phosphorus release. Sediment analysis revealed that all four lakes have phosphorus stored in the muds.

Keywords: Chesapeake Bay, Lake Fertilization, Nutrient Budgeting

1. Introduction

The Chesapeake Bay is a 4500 square miles (11601 km^2), estuary spanning the states of Maryland and Virginia, feeding into the Atlantic Ocean between Cape Henry and Cape Charles. The Chesapeake Bay watershed is made of over 150 major streams consisting of more than 64000 square miles (166000 km^2) spanning across eight states.[1] The Bay and its tributaries act as a significant area for seafood production, notably clams and oysters. A significant decrease in the catch rate of oysters and other species led to considerable public concern about the deterioration of the Bay.[2] Declines were partly attributed to the discharge of nutrients (nitrogen and phosphorus compounds) and sediment from human activities in urban areas that stimulated algal blooms and reduced transparency.[3] Over twenty-five years of research led to the Environmental Protection Agency (EPA) establishing the Chesapeake Bay Total Maximum Daily Load (TMDL) on December 29, 2010.[4] A TMDL is a plan for restoring impaired waters that designates a maximum amount of a pollutant that can enter a body of water, described in the Clean Water Act.[5,6] The Chesapeake Bay TMDL defines goals of reducing nitrogen, phosphorus, and sediment that enters the Bay from its watershed.[7] Virginia contributed 46% and 43% of the total nitrogen and phosphorus, respectively, that entered the Bay in the 2009 reference year.

Many of Virginia's constructed lakes serve the purpose of providing opportunities for recreational fishing. The funds used to construct these reservoirs come from the purchase of Virginia Fishing Licenses and from taxes on the sale of sport fishing gear.[8] These lakes are owned by a Virginia state agency known as the Virginia Department of Game and Inland Fisheries (VDGIF). Thus, VDGIF has an obligation to provide quality angling opportunities for the lakes they own. VDGIF staff biologists have stocked various game and other fish species to create populations that differ from riverside fishing. The stocked game fishes can also provide the size and numbers desired by anglers that were previously not possible, prior to impoundment. Stocking of fish however, is not as cost effective for fish production as the development of a cycle of growth and recruitment by natural processes. The food web begins with the presence of elements of life in the water of a reservoir being available to sustain primary production. Primary production is the growth of phytoplankton in the upper layer of water in a lake.[9] Phytoplankton serve as a food source for zooplankton, which provide food for insects, then fishes.[10] Most of the elements of life (carbon, oxygen, etc.) are abundant in a reservoir, but phosphorus and nitrogen are usually the limiting factor for biological productivity. This is the case in the Piedmont region of Virginia, where nutrient runoff from the landscape has been historically low. Thus, VDGIF staff have enhanced fisheries production by the seasonal addition of fertilizer in several Virginia lakes that serve recreational fishing opportunities.

Fisheries managers have been dosing lakes with various types of fertilizers for decades. Fertilizers consist of nearly any mixture that contains nitrogen, phosphorus, and/or potassium. In recent years, lake fertilization products such as Sportmax® 10-52-4 or 10-34-0 have been marketed. The three number designation is the percentage of the product as nitrogen, phosphorus pentoxide (P_2O_5), and potash (K_2O), respectively. The goal is to add an appropriate amount of fertilizer to stimulate phytoplankton production in the first meter of the water column in the waterbody. Even though the addition of nutrients to a lake adds the possibility for a net discharge of nitrogen and phosphorus compounds, a well-managed lake should have no net discharge of nutrients. All nitrogen and phosphorus should be cycled through the food chain and ultimately be taken up by fish biomass or deposited in the mud and detritus at the lake bottom.

Nitrogen and phosphorus entering the Chesapeake Bay must be reduced to meet the requirements of the 2010 Chesapeake Bay TMDL. Lake fertilization is a tool for fisheries when naturally occurring nutrients are not at a high enough concentration in the water column. The problem is whether or not the addition of fertilizers to recreational fishing lakes is contributing to the nutrient loading of the Bay and thereby conflicting with efforts made by municipalities to reduce nutrient loading. This report describes the project conducted to provide comprehensive lake water chemistry evaluation of three lakes in the watershed. Data were used to calculate nutrient budgets to see if there is a significant release of phosphorus and nitrogen compounds due to fertilization. Data were also used to evaluate if nutrient addition is achieving fisheries management goals and to better estimate the amount of fertilizer necessary for future applications.

2. Methods

Guidelines for this project, established by the Virginia Department of Environmental Quality (VDEQ), indicate that one year of monitoring at no less than monthly intervals is required, encompassing a growing season one year cycle from March to February. We began Phase I of this project March 1, 2017 and ended May 31, 2018. It became evident that we needed to continue the project into a second year. Thus, Phase II sample collection began following Phase I and continued to February 2019. The project ended May 31, 2019.

In this report three of the five lakes investigated in the project are reported on. Two of lakes, Lake Brittle and Burke Lake, are fertilized annually by VDGIF and were chosen for this study. The lakes are two of the oldest Virginia lakes built with funds provided by the United States Federal Aid in Sport Fish Restoration Act. Both lakes are located in northern Virginia in suburban/urban areas in close proximity to large human populations and experience sizable fishing pressure. Fisheries managers fertilize these two lakes multiple times during the growing season. The third lake presented is also located in northern Virginia, Huntsman Lake was chosen to act as a comparison lake for the study. Huntsman Lake is located two miles from Burke Lake and is not fertilized by the addition of chemical fertilizer. Ready access and that it had refilled following dredging in 2014 were two reasons for its selection. General descriptions for each of the three lakes reported on in this study are summarized in **Table 1.**

For each lake during the period March 2017 to February 2019, monthly water samples were collected and on site measurements were made for the feeder stream(s) and tail water discharge. Three times during the growing season (March to October), water samples were taken and on site measurements made from the epi-, meta-, and hypo- limnion at different locations in the lake pool. Samples were identified for laboratory processing by a two-letter designation of the lake followed by a three-digit number with the value increasing from the tailwater through the lake pool to the influent streams.

Table 1. Morphologic and other characteristics of the three lakes of this report

	Brittle	**Burke**	**Huntsman**
Year Built	1954	1960	1973
Surface Area (ac)	77	218	28
Ownership	VDGIF	VDGIF	Fairfax Co.
Elevation (m)	122	109	73
Max Depth (m)	8	12.2	4
Mean Depth (m)	3	5.2	3
Volume (acre ft)	735	3190	264
Watershed (ac)	3072	2010	1491
W/S area ratio	1.7	0.4	2.2
Detention (days)	82	295	53
Primary Stream	South Run W	South Run E	Middle Run
Second Stream	xx	Opossum Run	Xx
Other input	xx	xx	Xx
Watershed	Chesapeake	Chesapeake	Chesapeake
Latitude	38.749° N	38.755° N	38.754° N
Longitude	77.690° W	78.295° W	77.256° W

Chemical analyses were performed on water samples as described in the APHA (2012) and other standard methods guides (Hach, YSI, etc.). All analyses were performed with standard calibrations, blanks and quality assurance checks. Some analyses were performed on samples filtered with 0.25 µm PTFE syringe filters (Fisherbrand 09-730-19) to avoid clogging of instrument sample inlet lines. Some samples were analyzed without filtration. All chemicals were purchased as A.C.S. grade or better from state contract suppliers (Thermo-Fisher, Sigma, Alfa Aesar). Laboratory glassware and other supplies were obtained primarily from Fisher Scientific. Water samples were carefully collected, stored, transported, and assayed from the field sites in opaque, pre-cleaned high density polyethylene bottles (or glass for some analytes) and returned to the lab and maintained at 4ºC, preserved as necessary with analyses done within protocol limitations. Measurements done in the field were those that had to be done on site or would likely change in transport (temperature, dissolved oxygen [D.O], Secchi, chlorophyll a). During twenty-four months of sampling 509 water samples were returned to the lab for analysis. An overview of the analyses by parameter is provided below.

Total phosphorus (TP, μg/L), the primary nutrient element of interest in this study, can be present in a wide variety of forms including PO_4^{3-}, polyphosphates, organic phosphorus, HPO_4^{2-}, $H_2PO_4^-$, etc. All phosphorus in each water sample was converted to orthophosphate by reaction (APHA method 4500-p B. 5) with ammonium persulfate and sulfuric acid, combined with a colorimetric reagent (potassium molybdate) (APHA method 4500-p E.) and then determined with a spectrophotometer (Agilent 8453 UV-Vis Diode Array) at 880 nm, with a 5 cm quartz cuvette.

Biologically available total nitrogen (TN, mg/L) was present in three forms in the water samples: nitrate-N (NO_3-N), ammonia-N (NH_3/NH_4^+-N), and organic-N (TKN-N). Total nitrogen was calculated by summing the results for all three forms of nitrogen. Ion chromatography (below) was used for the analysis of nitrate and ammonia, while TKN was determined by Hach Method 10242: TNT 880 test kit, DRB 200 reactor and DR 1900 spectrophotometer.

Ion chromatography was used to determine the concentration of base cations (Na^+, NH_4^+, K^+, Mg^{2+}, and Ca^{2+}, mg/L) and acid anions (Cl^-, NO_3^-, and SO_4^{2-}, mg/L). Filtered water samples were separated using a Dionex Ionpac CS 12A column with 20 mM methanesulfonic acid eluent (for cations) or Dionex Ionpac AS with 23 mM potassium hydroxide eluent (for anions). The ions were detected using a suppressed conductivity detector in a Dionex ICS 3000 or Thermo Dionex ICS 5000 ion chromatographs.

Secchi disk (SD, m) measurements were performed using a standard 8" disk suspended into water from a boat between 10 am and 3 pm on a bright clear day with the sun behind the standing sampler. The length of rope from the surface to disappearance recorded and averaged over multiple measurements.

Chlorophyll-a (CA, μg/L) concentration was used to measure planktonic algae. In year 1, samples collected in the field were analyzed in the laboratory by extraction (APHA method 10200-H.1.b.) and fluorescence (APHA method 10200-H.3.). In year 2, field measurements were made on site with a chlorophyll sensor (YSI. Pro DSS 4-port sampling system) calibrated with Rhodamine WT standard.

Sportmax® trophy grower 10-52-4 was used for fertilization. The water soluble product contains potassium nitrate (KNO_3) and ammonium phosphate ($(NH_4)_3PO_4$) in a mixture that delivers 9% NH_4^+-N and 1% NO_3^--N, 52% P_2O_5 (22.7% elemental P), and 4% potash (K_2O, 2.7% elemental K). Lake applications were done by hand from 40-pound bags distributed discontinuously in the upper third of the treated lakes. Target distribution was 8 pounds per surface acre, followed by four monthly treatments of 4 pounds per surface acre. The total annual mass of product was 1950 and 6000 pounds for Lakes Brittle and Burke, respectively.

There are no discharge gauges located in the watershed of any of the lakes in this study. However, there are gauges in nearby watersheds that were used as surrogates. Data were routinely assessed for these gauges from the internet[11] to estimate discharge for the northern Virginia lakes. A two week (14 day) average was calculated then multiplied by a ratio of the watershed area for each lake to that of the reference gauge to give the value of discharge into each lake. The same value was used for the effluent discharge with the assumption that additional input would be offset by an equal amount of evaporation. Two-week discharge averages were used since it was observed that shorter periods would skew data due to storm events near the monthly sample collection dates. Discharge data calculated from Cedar Creek for Lake Brittle and from Accotink Creek for both Burke Lake and Huntsman Lake. The concentration of a given parameter was multiplied by discharge values for each lake to give the mass entering and exiting each month. The input values included the mass of nitrogen and phosphorus artificially added by the fertilization for Brittle and Burke Lakes. Difference (delta) values were obtained by subtraction of the effluent values from the influent values. When difference values were positive more of a particular parameter was entering than exiting the lake.

In 1977 Carlson developed an index system that combines three common water parameters: Secchi depth, chlorophyll pigment and total phosphorus into a simple metric known as the Trophic State Index (TSI) useful for lake managers in the assessment of productivity and fish production.[12] The index (TSI) is based on algae production and ties to the traditional attribute status of oligotrophic, mesotrophic, eutrophic, and hypereutrophic (**Table 2**)[12]. The lake TSI values were determined no less than three times each year for all three lakes in this report. Values were calculated from the following equations [(SD) is Secchi depth in meters, (CA) is chlorophyll-a μg/L and (TP) is total phosphorus in μg/L].

$$TSI(SD) = 60-14.41*\ln(SD)$$
$$TSI(CA) = 9.81*\ln(CA) + 30.16$$
$$TSI(TP) = 14.42*\ln(TP) + 4.15$$

Table 2: TSI Values, Components and Attributes.[12]

TSI	**SD (m)**	**CA (µg/L)**	**TP (µg/L)**	**Attributes**
< 30	> 8	< 0.95	< 6	**Oligotrophy:** Clear water, oxygen throughout the year in the hypolimnion.
30 – 40	8 – 4	0.95 – 2.6	6 – 12	Hypolimnia of shallower lakes may become anoxic.
40 – 50	4 – 2	2.6 – 7.3	12 – 24	**Mesotrophy:** Water moderately clear; increasing probability of hypolimnetic anoxia during summer.
50 – 60	2 – 1	7.3 – 20	24 – 48	**Eutrophy:** Anoxic hypolimnia, macrophyte problems possible.
60 – 70	0.5 – 1	20 – 56	48 – 96	Blue-green algae dominate, algal scums and macrophyte problems.
70 – 80	0.25 – 0.5	56 – 155	96 – 192	**Hypereutrophy:** (light limited productivity). Dense algae and macrophytes.

3. Results and Discussion

The TSI values for the three lakes were calculated and averaged (when appropriate) based on measurements made from the lake pool surface samples. It is thought by some researchers that averaging TSI values may not be the best approach to describing lake trophic states, but the values are useful since they provide a simple overview of the seasonal and overall productivity of algal biomass. Companies that market fertilizer products usually indicate that Secchi depth be read as a metric for monitoring due to its simplicity and that most field personnel are not able to routinely have phosphorus or chlorophyll a readings available. Application rates of 4 pounds per acre at two week intervals are recommended to begin annually in late February or early March and continue until October with a target goal of maintaining SD < 0.5 meters. The TSI(SD) at such a rate would be 70 which is at the boundary of eutrophic and hypereutrophic. When the objective of the lake management is fish production and not drinking or swimming water this objective makes sense.

The average TSI values (**Table 3**) indicated that Lake Brittle was highly eutrophic with a range from high mesotrophic to hypereutrophic, Burke Lake was also highly eutrophic with range from mesotrophic to hypereutrophic, and Huntsman Lake was hypereutrophic with a range of highly eutrophic to extremely hypereutrophic. Average TSI values do not adequately demonstrate any significant variation between the three parameters. The highest TSI values occurred during the warm summer period when fertilizer was being applied, and had the lowest values during the winter months. The actual application of 1848 and 5232 pounds of fertilizer per year for Brittle and Burke, respectively, is about half of that recommended by supplier, yet is maintaining the two lakes at a balance between adequate and excessive. There is no significant differences in the average TSI values between the two years of this study even though there was 78% more rainfall in the second year that the first. Both the mass and the frequency of fertilization events selected by VDGIF are working to achieve the desired trophic status of the lakes even with high variations in rainfall and runoff.

Table 3: Compiled average TSI values for Lakes Brittle, Burke, Huntsman, Keokee and Shenandoah. Averages were calculated for all lake surface samples from TSI values obtained for Secchi depth (SD), chlorophyll a (CA) and total phosphorus (TP).

Year Month	**Brittle**	**Burke**	**Huntsman**
2017 Mar			
2017 Apr	53 ± 9	41 ± 9	63 ± 7
2017 May	63 ± 15		
2017 Jun	64 ± 22		
2017 Jul	63 ± 21	59 ± 19	100 ± 17
2017 Aug	65 ± 7		
2017 Sep	90 ± 26	60 ± 22	78 ± 31
2017 Oct	68 ± 31		
2017 Nov	64 ± 29		
2017 Dec	66 ± 29		
2018 Jan	48 ± 3		
2018 Feb	49 ± 4		
2018 Mar	54 ± 9		
2018 Apr	79 ± 26	64 ± 28	89 ± 22
2018 May	83 ± 30	92 ± 30	
2018 Jun	82 ± 27	94 ± 26	
2018 Jul	69 ± 27	79 ± 26	98 ± 26
2018 Aug	77 ± 28	77 ± 28	
2018 Sep	65 ± 29	65 ± 29	68 ± 28
2018 Oct	82 ± 30	82 ± 30	100 ± 20
2018 Nov	66 ± 29	66 ± 29	68 ± 11
2018 Dec	57 ± 14	57 ± 14	67 ± 20
2019 Jan	69 ± 29	60 ± 15	67 ± 20

2019 Feb	67 ± 30	57 ± 20	65 ± 15
Average	**67 ± 11**	**68 ± 15**	**78 ± 15**

The main goal of this study was to determine if the VDGIF lake fertilization was contributing to the loading of phosphorus and nitrogen into the Chesapeake Bay. An estimate of the “natural” phosphorus and nitrogen entering the lake was made by measuring the upstream concentration of both nutrients and calculating the mass of each nutrient using the calculated discharges from stream gauge modeling. In the fertilized lakes the mass of phosphorus and nitrogen was calculated from the weight percent of phosphorus and nitrogen in the fertilizer added by VDGIF staff. These two values were used to determine the input and release of nitrogen and phosphorus while also accounting for the addition of fertilizer. **Figures 1-3** shows the total nitrogen monthly budget values for Brittle, Burke, and Huntsman for two week intervals prior to the sampling date. The delta value (blue diamond) reflects the monthly amount of phosphorus stored (positive values) or excess discharged (negative values). **Figure 4-6** shows the total phosphorus monthly budget values for Brittle, Burke, and Huntsman Lakes integrated for two week intervals prior to sampling date. The budget data indicate that both Brittle and Burke are not releasing nitrogen or phosphorus and are actually decreasing the amounts of these nutrients. This supports the observation that the fertilization is successful in its objective. A surprise observation was the unfertilized Lake Huntsman is discharging nutrients over both years of the study. This lake was partially dredged in 2014 and is shallow and is easily agitated. This agitation disturbs the sediments and provides an opportunity for sediments to provide phosphorus and nitrogen to the water column. The summary delta table (**Table 4**) suggests that a considerable amount of phosphorus and nitrogen are removed annually in Brittle and Burke. This is likely due to incorporation into biomass or deposition into the sediments.

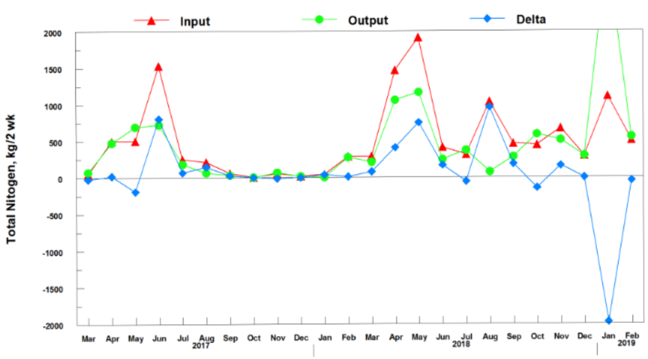

Figure 1. Total nitrogen budget for Lake Brittle.

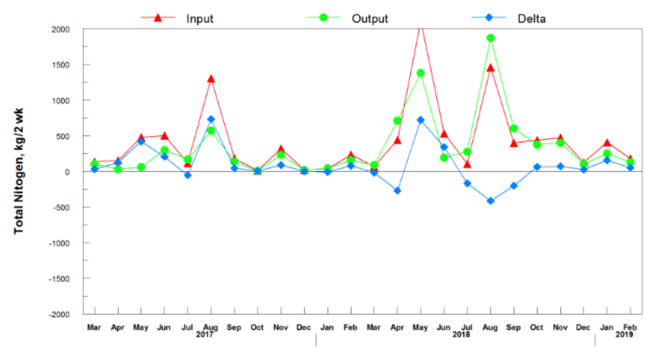

Figure 2. Total nitrogen budget for Burke Lake.

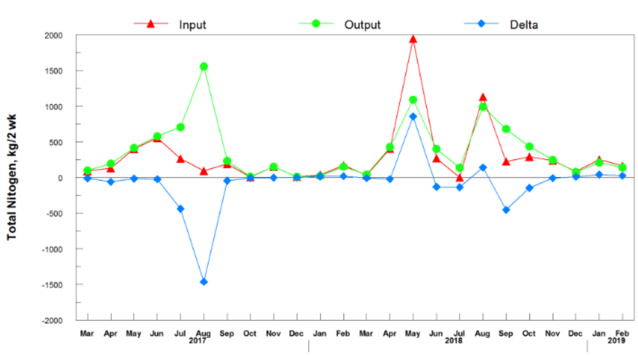

Figure 3. Total nitrogen budget for Huntsman Lake.

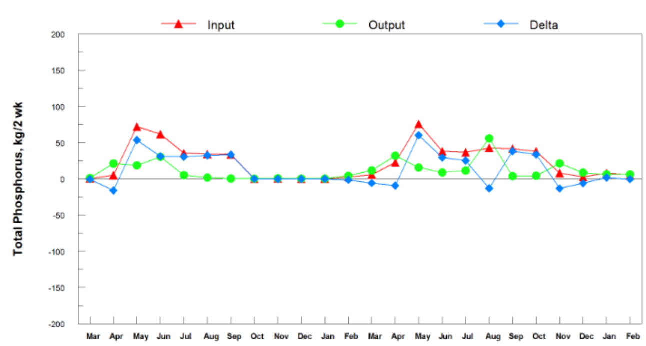

Figure 4. Total phosphorus budget for Lake Brittle.

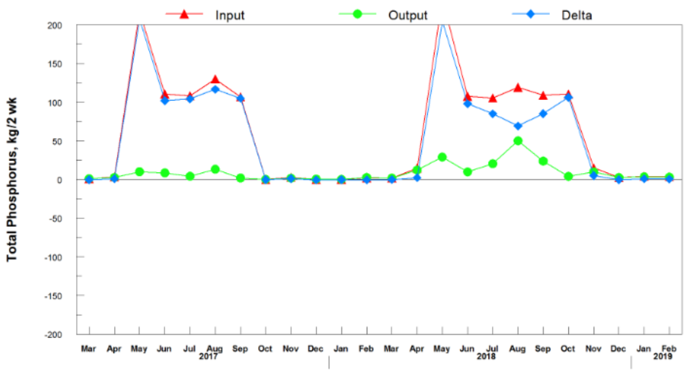

Figure 5. Total phosphorus budget for Burke Lake.

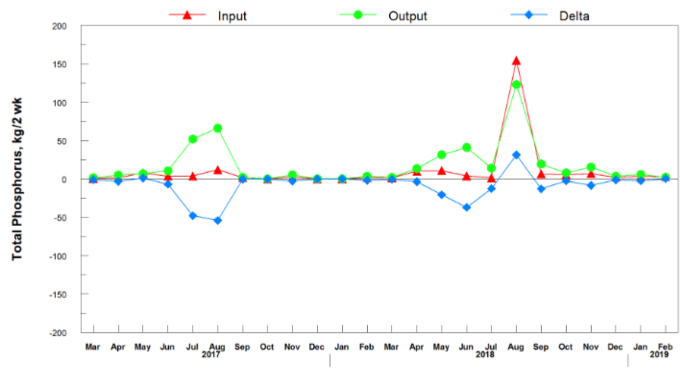

Figure 6. Total phosphorus budget for Huntsman Lake.

Table 4: Annual Nutrient Budgets for Years 1 & 2.

	Year 1: 2017 - 2018		Year 2: 2018 - 2019	
Lake Name	TN delta (kg)	TP delta (kg)	TN delta (kg)	TP delta (kg)
Brittle	+ 2208	+ 427	+ 6533	+ 362
Burke	+ 4172	+ 1658	+ 367	+ 1710
Huntsman	- 5401	- 300	+ 249	-177

4. Conclusion

Year two of the study enabled confirmation of results obtained from year one observations. The data obtained suggest that the fertilization of Lakes Brittle and Burke is providing a high dose of nutrients that are necessary to stimulate productivity. It is advised that fertilization of these two lakes continue with doses similar to those performed throughout this study. If fertilization were to stop, both lakes would likely decrease in algae and thus decrease in fish biomass. These lakes however, are not showing a net discharge of phosphorus or nitrogen that would increase the nutrient loading to the Chesapeake Bay. There is significant storage of these nutrients within both lakes. The unfertilized Lake Huntsman is showing a net release of nitrogen and phosphorus into the Chesapeake Bay. The sediments of this lake were disturbed by dredging in 2014. It is believed that this dredging caused a release of nutrients that were previously trapped in the sediments. Any future plans for dredging as a nutrient reduction technique should possibly be reconsidered.

5. Acknowledgements

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6. References

1. Lewis C. Linker , Richard A. Batiuk, Gary W. Shenk, and Carl F. Cerc." Development of the Chesapeake Bay Watershed Total Maximum Daily Load Allocation," Journal of the American Water Resources Association 49(5) (2013): 986-1006.
2. Shenk, Gary W. and Lewis C. Linker,. "Development and Application of the 2010 Chesapeake Bay Watershed Total Maximum Daily Load Model," Journal of the American Water Resources Association 49(5) (2013): 1042-1056.
3. Isaac D. Irby and Marjorie A. M. Friedrichs, "Evaluating Confidence in the Impact of Regulatory Nutrient Reduction on Chesapeake Bay Water Quality," Estuaries and Coasts 42 (2019): 15-32.
4. U.S. Environmental Protection Agency "Chesapeake Bay TMDL Document," EPA.gov, https://www.epa.gov/chesapeake-bay-tmdl/chesapeake-bay-tmdl-document
5. U.S. Clean Water Act, sec. 303(d), 33 U.S.C. § 1313(d)

6. U.S. Environmental Protection Agency "Clean Water Act Section 303(d): Impaired Waters and Total Maximum Daily Loads (TMDLs)," EPA.gov, https://www.epa.gov/tmdl
7. U.S. Environmental Protection Agency, "Chesapeake Bay Total Maximum Daily Load (TMDL)" EPA.gov, https://www.epa.gov/chesapeake-bay-tmdl
8. Department of Game & Inland Fisheries "DGIF-Owned Public Fishing Lakes" DGIF.Virginia.gov, https://www.dgif.virginia.gov/lakes/public-fishing/
9. C.S. Reynolds, The Ecology of Phytoplankton, (Cambridge University Press, 2006)
10. C.E. Boyd Pond Aquaculture Water Quality Management (Boston: Kluwer Academic Publishers, 1998) 226:305.
11. U.S. Geological Survey, "USGS Current Water Data for Virginia," Waterdata.USGS.gov, https://waterdata.usgs.gov/va/nwis/rt
12. R.E. Carlson and J. Simpson, "A Coordinator's Guide to Volunteer Lake Monitoring Methods," North American Lake Management Society (1996) 96.