Water and Nutrient Budget Model for Granite Lake, Barron County-2018

Introduction

This nutrient and water budget model utilized Bathtub reservoir model created by the US Army Corp of Engineers. It is a steady-state, mass balance empirical model. The focus for nutrient budget was phosphorus, which likely limits algae production in Granite Lake. This model is based on very limited data, so calibration is difficult and some assumptions were made to make the nutrients and water balance over the averaging period (0.58 years) of the growing season. Therefore, this initial model should be used with caution for making major management decisions. To better determine a more accurate budget of water and nutrients, more extensive and additional data would need to be collected.

Methods

The modeling of Granite Lake utilized the nutrient data from the inlet and outlet monitoring in 2018, as well as the in-lake nutrient concentrations. The monitored inlet water budget and nutrients were used to calibrate the un-monitored watershed. Base flow was estimated as well as runoff flow from inlet monitored flow. Septic information provided by LEAP was used to estimate the flux of phosphorus from septic systems.

The phosphorus sediment calculation used Canfield/Bachman natural lakes to create a steady-state, mass balanced nutrient budget. The water budget was mass balanced using inlet monitor data and outlet monitor data. Evaporation rates were estimated using published monthly evaporation rates from NLCD. Precipitation data was utilized from the Community Collaborative Rain, Hail and Snow Network (CoCoRaHS) website, from a station near Cumberland, WI. All data was entered into the empirical model Bathtub, and calibrated to predict nutrient budget for 2018.

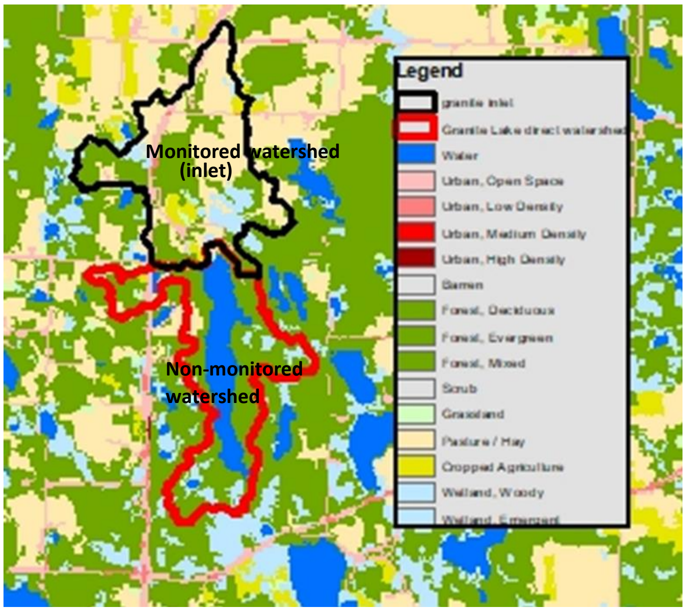
Since the trophic state of northern lakes pertains mainly to the growing season (May to Sept), the data collected was only during this season and the modeling was conducted for an averaging period of 0.58 years (7 months), since this was the time period that the inlet and outlet were monitored. The turnover ratio for this time period was 1.4, which is somewhat lower than the desired 2.0 for using seasonal averaging. However, since annual data was not available, the seasonal averaging of April through Oct. 31 was utilized.

The land use information is from NLCD, 2006. This land use is not very specific and is obviously several years old. Also, the land use not precise for near lake watershed as the land use graphic indicates most development in the riparian zone as forested. Aerial photographs from 2015 were used to digitize the residential land use immediate to the lake and integrated into the model. The two catchments that are directly linked to the lake were used. Watershed catchments that are internally drained (or into other bodies of water) were not utilized. These internally drained areas can contribute to groundwater nutrient flux based on land use effects on the water reaching Granite Lake, but this data is not available. The model ultimately should account for this water and nutrients as a mass balance. Also, water from the inlet is flowing from larger watershed, being contained in other surface water bodies prior to reaching Granite Lake. It is assumed that the monitored inlet flow and phosphorus concentration accounts for the inputs from those watershed areas.

The septic phosphorus loading was determined using capita year data, using a load of 0.3kg per capita year and 90% soil retention (most likely used in Wisconsin Lakes Modeling Suite and soil analysis would be needed to rationalize changing this value). The data provided was incomplete and the capita year so this estimate may have error.

The model was then implemented for the 2019 lake and precipitation data to determine total phosphorus load in 2019 for comparison and reflect to function of the model.

Results



Note: This map is only direct watershed and does not include the SW inlet watershed…

Land use (not correct needs updating so grayed it out):

Watershed (Direct catchments; no internal drain or drain into other surface water bodies)	Square kilometers	% of Total direct drained watershed
Monitored watershed (inlet)	2.99	59.4%
Non-gaged watershed	2.043	40.6%
SWest inlet (perenniall??) watershed	0.68 (some internally drained??	
Land use type		% of non-gaged watershed
Urban	0.131	6.4%
Grass/pasture/hay	0.12	5.8%
Wetland	0.27	13.2%
Agriculture/row crop	0.015	0.7%
Forest	1.507	73.8%
Granite Lake surface	0.627	

Monitored (gaged) Inlet data:

Parameter	Value	Value adjusted for model avg period of 0.58 yr
Base flow estimate	2.0 cfs	1.07 hm^3 for period
Over-land runoff flow estimate from base flow difference	0.83 cfs (gaged flow above base)	0.43 hm^3 for period
Total water input	2.83 cfs	1.5 hm^3 for period
Mean total phosphorus concentration	91 ug/L	
Phosphorus input (averaging period)	136.5 kg	

Outlet flow and nutrients (monitored 2018)

Total water output	4.0 hm^3 for period (and 0.4 hm^3 evaporation for total of 4.4 hm^3)
Mean total phosphorus	28 ug/L
Total phosphorus outflow	95.3 kg (model calculated for lake outflow, actual mass was higher)

Lake Physical/Chemical data parameters (2018)

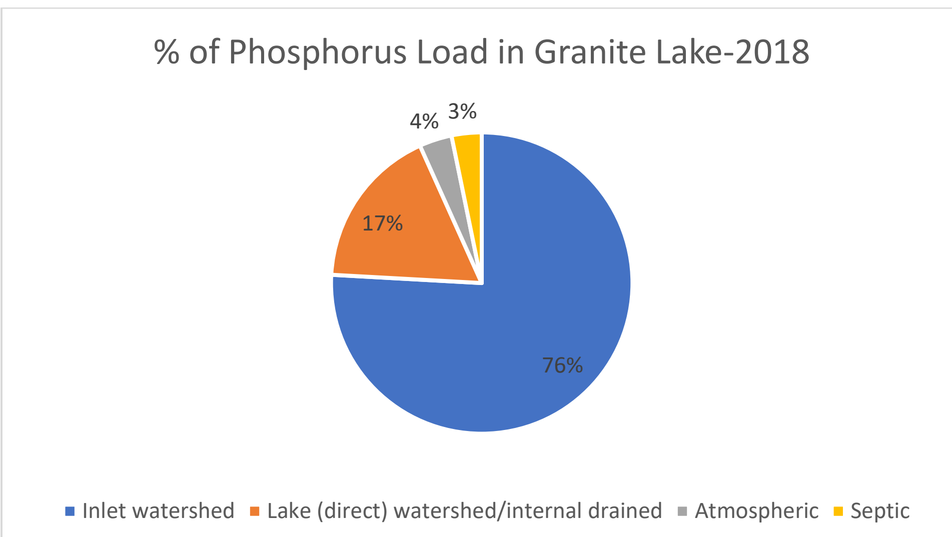
Volume of lake	2723 acre-feet (3.36 hm^3)
Mean depth	18 feet
Mean mixing depth	12 feet
Mean total phosphorus (GSM)	23.5
Mean chlorophyll-a (GSM)	8.2
Mean Secchi depth (GSM)	2.46

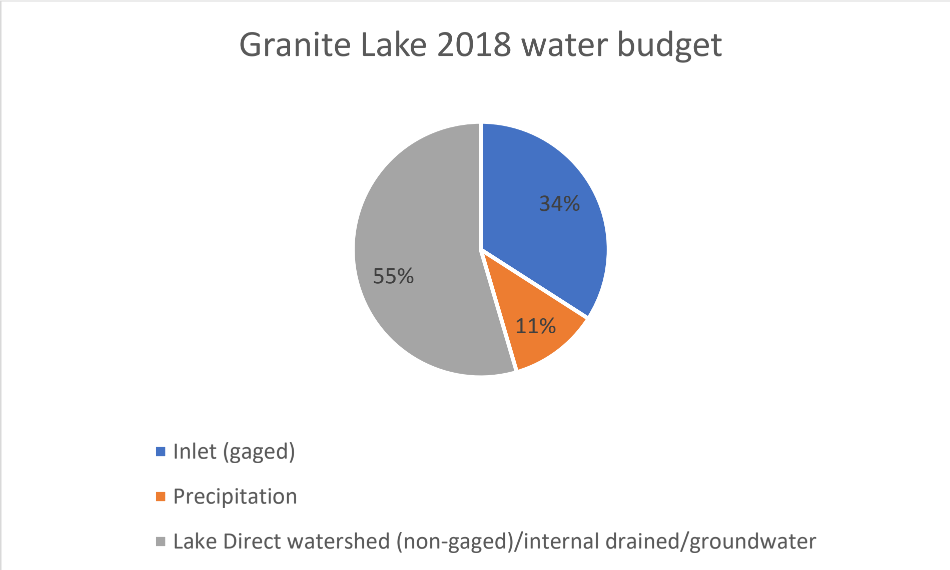
Model Calibration Results (GSM)-2018

Parameter	Observed from lake data	Predicted from model	Difference
Total P (ug/L)	23.5	24	0.5
Chlorophyll-a	8.2	8.0	0.2
Secchi depth	2.46	2.5	0.04

Granite Lake Model output-2018:

Water budget for model	Volume	% of load
Monitored watershed inlet	1.5 hm^3	34.1
Direct Lake watershed/Groundwater/internal drain	2.4 hm^3	54.5
Precipitation	0.5 hm^3	11.4
Total inflow	4.4 hm^3	
Water residence	321 days	
Phosphorus budget for model	**Mass**	**% of load**
Monitored watershed inlet (includes groundwater/internal drain)	136.5 kg	75.8
Non-monitored watershed/Indirect drained/Groundwater	31.3 kg	17.5
Septic systems	5.8 kg	3.2
Atmospheric deposition	6.3 kg	3.5
Total phosphorus load/averaging period (0.58 years)	180 kg	
Total outflow of phosphorus/avg period	95.3 kg	
Phosphorus retention	46.6%	





Predictions from PRESTO (Wisconsin DNR based on watershed data-include internal drainage)

PRESTO Model	Predicted range (lower-upper)/yr	Most likely value/yr
#1	197-1232 kg	434 kg
#2	73-691 kg	231 kg
Export coefficients	281-1252	634 kg

Application of model to <u>2019</u> (using precipitation and water quality values from 2019)

Mean total phosphorus (GSM)	29.7 ug/L
Mean chlorophyll-a (GSM)	13.2 ug/L
Mean Secchi depth (GSM)	1.55 m
Total load from model (calibrated from 2018)	203 kg (added 23 kg of internal loading to make fit, not based upon known data)

<u>2019</u> Model calibration results

Parameter	Observed from lake data	Predicted from model
Total P (ug/L)	29.7	30
Chlorophyll-a	13.2	12
Secchi depth	1.55	1.6

Phosphorus overall reduction (from model)	Change in chlorophyll conc.	Change in Secchi depth
10%	-2 ug/L	+0.2 meters
20%	-3 ug/L	+0.3 meters
40%	-6 ug/L	+0.6 meters

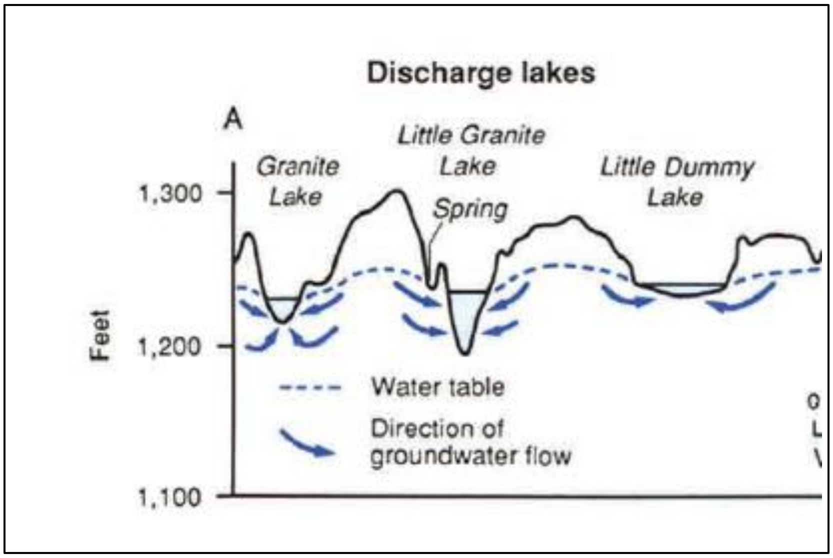
Discussion

The modeling of Granite Lake in this scenario is based upon limited data and is a starting point to evaluate the water and nutrient budgets. This model should be a better reflection of the watershed impacts of the watershed surrounding the watershed than simply using land use data and export coefficients. The PRESTO models tend to overestimate the flux of phosphorus into Granite Lake (model #2 is closest to this model). If the loads from model #1 and export coefficients model were placed into the model (even considering kg/year), the predicted phosphorus concentration in the lake would be far higher than what was actually observed in Granite Lake. As stated in the methods, the trophic state of the lake is impacted mostly during the growing season in northern lakes, so the response of algae growth from phosphorus flux should be reflected in this model. ***In the end, this model matches the in-lake data and should be an accurate measure of the total phosphorus load into Granite Lake in 2018***. The various sources by % is where the error would occur with the limited data.

The concentration of the phosphorus in the inlet was much higher than the concentration of the inflow of water from the non-monitored watershed. The land use is different in the monitored watershed which could account for some of the difference as well as nutrients in groundwater/internally drained water or release of nutrients from wetland flushing. This tributary water could enter the direct watershed area of the gaged inlet with higher nutrients as well. If the non-monitored watershed is adjusted to have the same concentration of inflow, the predicted phosphorus was substantially above measured values in Granite Lake. Therefore, there is a source of phosphorus in the inlet that seems to be lacking in the runoff of the watershed only.

Groundwater

The base flow of the monitored tributary (only perennial inlet) was used to establish a runoff value for the non-monitored watershed. This created a substantial shortage of water input in the water mass balance model. Groundwater inflow was added to accommodate this discrepancy. There is limited groundwater data for Barron County, but the maps that are available indicate groundwater is likely flowing into Granite Lake and outflowing via the outlet tributary from Granite Lake (and not outflowing as groundwater and therefore a discharge). The base flow of the inlet made up approximately 70.6% of the tributary inlet flow, which would indicate either groundwater flux/internally drained water into the tributary and/or filled wetlands releasing water into the stream flow or both.



No phosphorus data is available for groundwater entering Granite Lake, so the phosphorus concentration used in the model was determined by the mass balance. Also, there is likely groundwater that is a significant portion of the flow for the inlet. The phosphorus concentration in the groundwater potentially entering this inlet is not known and therefore the contribution of phosphorus via groundwater is unknown. **However, this phosphorus is accounted for in the monitoring data from the inlet.**

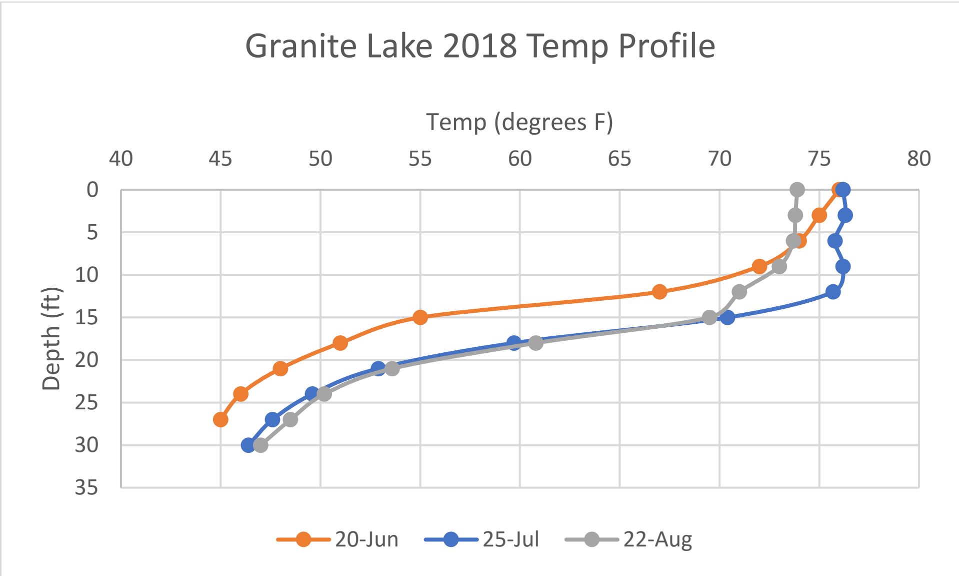
Internal load

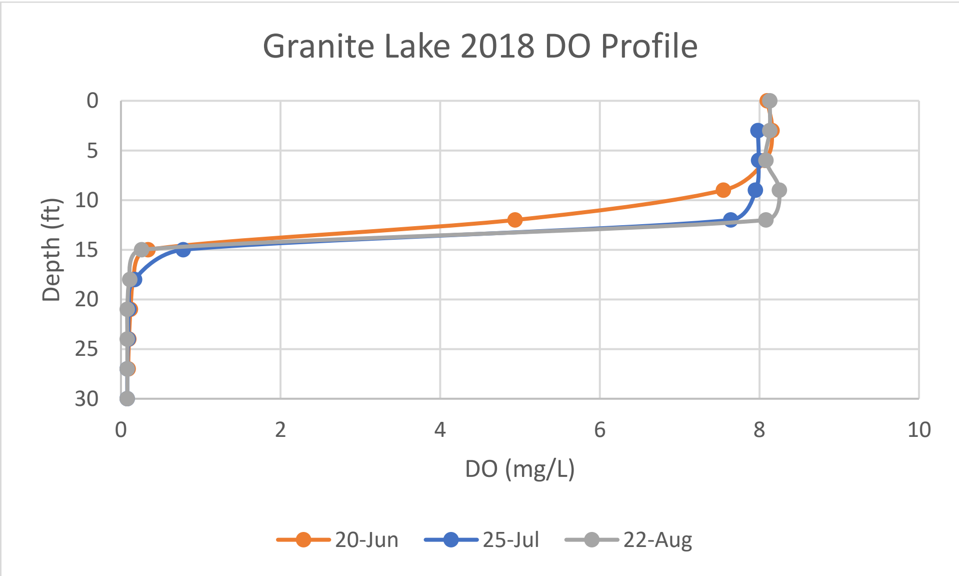
There appears to be an internal load (release of phosphorus from the sediments). When sediments become anoxic (DO<1-2 mg/L), if the sediments have bound phosphorus it will tend to release that phosphorus. This can result in an accumulation of phosphorus in the hypolimnion (bottom layer of water in stratified lake). If a lake is stratified, the potential for a flux of that phosphorus into the epilimnion (upper layer) where algae can grow may be limited. If the stratification is strong and little no mixing of the lake prior to fall overturn occurs, then the phosphorus does not reach the upper layer and result in significant algae growth. If stratification isn't strong, or the metalimnion (middle or transition layer) is closer to the surface, the phosphorus in the hypolimnion can mix into the upper layer and result in algae production.

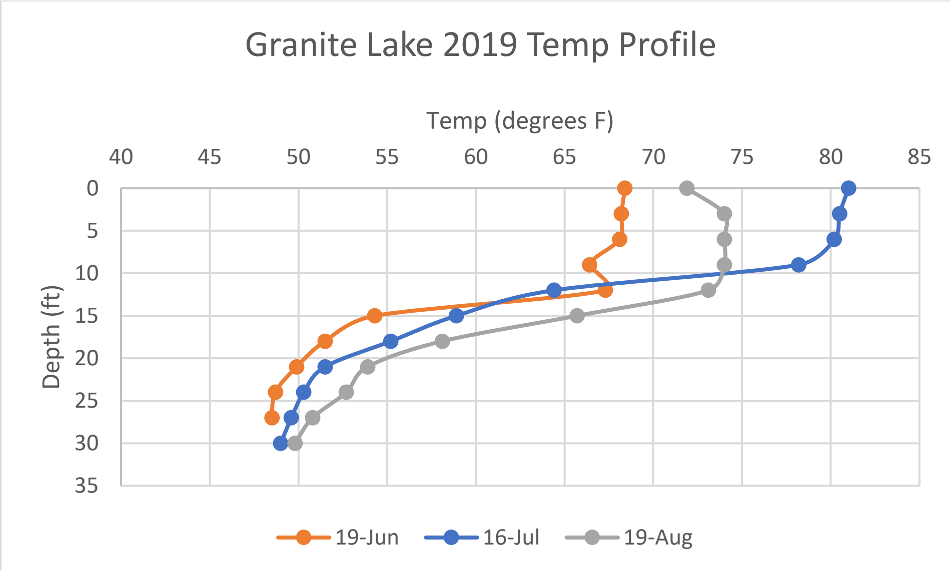
Granite Lake does appear to have internal loading based upon the large spike in lake phosphorus concentration in October. It undergoes anoxic conditions early in the summer and seems to remain strongly stratified during a large portion of the summer. There is likely a significant accumulation of phosphorus in the hypolimnion during June-August, which could be a significant load if/when the lake mixes.

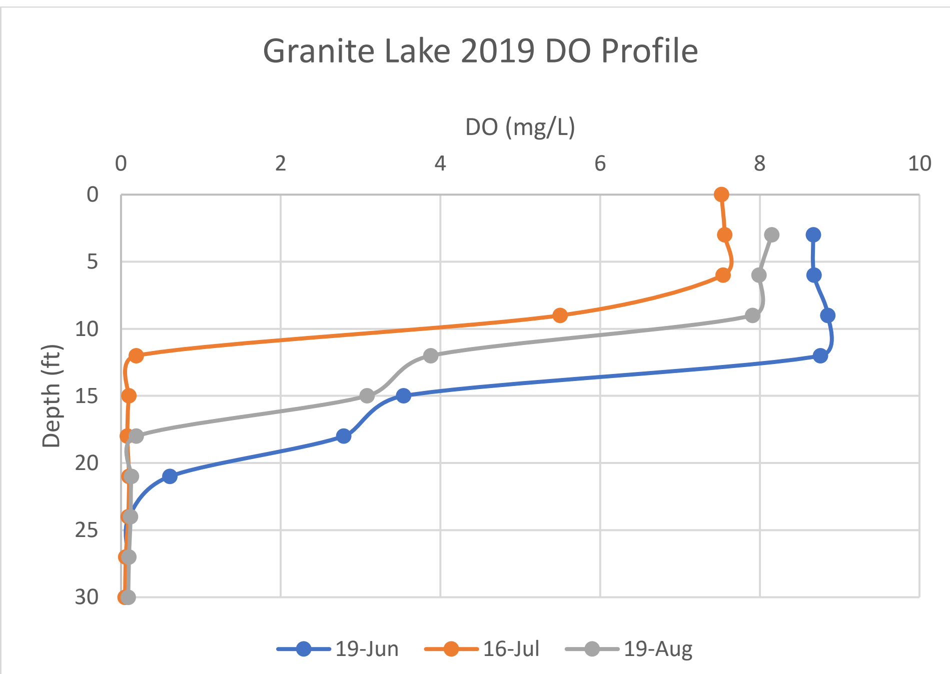
With limited profile and nutrient data throughout the growing season, it is not possible to determine if enough mixing took place prior to October to cause a flux of phosphorus into the epilimnion. The phosphorus concentration increase observed in 2018 during October would have required 67 kg of phosphorus and the increase in the fall of 2019 would have required 100 kg of phosphorus input. Not all of this increase may be due to internal loading alone (precipitation events would also contribute, but is unlikely a runoff flux would be enough to account for this large of an increase in concentration in

Granite Lake). Some of this increase may have been from high concentration phosphorus from the hypolimnion mixing from the overturn of the lake and reaching the epilimnion. Since this occurred in October, the impact is not as much of a concern as if occurring earlier in the summer since it is at the end of the growing season. However, if mixing occurred earlier, this could lead to more algae production in the summer months. Since data to make this determination is lacking, there was no internal load used in the model.









In 2018, the depth of the metalimnion (interface between epilimnion and hypolimnion) was somewhat greater than in 2019. This could result in a higher potential for mixing and allowing phosphorus to flux from the deeper layer into the upper layer, resulting in algae production and reduced water clarity in 2019. The internal load could result in phosphorus loading prior to the fall turnover if any mixing occurred. This could account for the higher chlorophyll and lower water clarity in 2019 as compared to 2019. More extensive temperature profile data as well as nutrient profiles would be needed to make this determination. It is likely, at least in 2019, that some internal loading occurred in Granite Lake. Assuming contributions from groundwater remains similar, the watershed responds to the model consistently, then an internal load of about 23 kg was needed to match the in-lake concentrations of phosphorus in 2019.

The 2018 model showed a mean phosphorus concentration of outflow water higher than the mean concentration of the lake. This may indicate some internal loading as the outflow of phosphorus is more than the inflow. This could also be due to the location of the outflow water sampling location and the increased nutrients go introduced between the lake and the collection location.

Recommendations

Often times modeling water and nutrient budgets in lakes with limited data can create more questions than answers. In the case of Granite Lake, this initial model suggests a need for further data to better understand the budgets for his lake. The following are suggestions for data collection if there is more interest in the sources of water and nutrients for Granite Lake.

Watershed evaluation-The land use of Granite Lake should be updated with the use of Lidar data. Lidar used in conjunction with elevation data in GIS mapping would allow a better understanding of areas the water is flowing directly into Granite Lake and where it is not (infiltrated or into another surface water body). The intensity of runoff could also be evaluated in response to storm events. Furthermore, if the watershed is divided into sub-watersheds, the highest contributing land areas can be determined to focus on best management practices (BMP's).

Lastly, monitoring the inlet tributary further upstream (in addition to the mouth already monitored), could reflect the concentration of nutrients as the water enters the last catchment of Granite Lake. Outflow as well as lake depth (stage) changes would allow better determination of the inflow of water from watershed runoff, separated from groundwater/internally drained inflow of water. The concentration of phosphorus in the inlet (north) is quite high. It may be good to evaluate potential sources as it appears to be a major contributor to the lake phosphorus.

Groundwater evaluation-It appears groundwater is contributing a large amount of water into Granite Lake. This estimate is based on very little data, and should be scrutinized with more data. Furthermore, the nutrient concentration of the groundwater entering Granite Lake is unknown and a value was used to balance the model. If his concentration is known, then the loading of phosphorus from groundwater can be determined. Although typically low, some areas in Wisconsin can have high phosphorus in groundwater. Internally drained portions of the watershed can contribute greatly to groundwater phosphorus. Groundwater samples can be conducted from springs and/or shallow water wells that likely don't get affected by septic.

Internal load- The internal load in Granite Lake was predicted to occur but is based upon limited data. The internal load in Granite Lake could be significant in any given year. Determining the internal load of Granite Lake could be determined by measuring phosphorus (both total and soluble reactive) at various depths throughout the summer. This allows the determination of the accumulation of phosphorus in the hypolimnion. Also iron (and sulfate possibly) can be measure near bottom to verify sediment release More frequent temperature/DO profiles would also help evaluate the strength of stratification as well as any potential mixing prior to fall overturn, that can make phosphorus concentrations increase in the epilimnion, resulting in more algae and less water clarity (or install a logging thermistor string with DO logger at hypolimnion level to get daily data). If it is determined that the internal load is significant and mitigation is wanted, then sediment cores can be studied to get a precise release rate from sediments.

Data Collection time period- Modeling water budget and nutrient budget in lakes should be based on several years of data rather than a single year. The likelihood of one year being different than an "average" year is high. Therefore, error or misrepresentation of the lake dynamics can be very high. At least two years of data should be collected, preferably 3-4 years would provide more accuracy in the model estimates. In the case of Granite Lake, 2018 had significantly different in-lake data than in 2019, but there is no flow data for 2019 to compare. It is also recommended a rain gauge be used (and maybe an evaporation pan) on site to give more precise storm event data for the lake location.