WATER QUALITY GOAL | MEMORANDUM

TO: Joan Gorga, Town of Antrim

FROM: Laura Diemer, FB Environmental Associates

SUBJECT: Gregg Lake Water Quality Goal Documentation (Tasks 16-17) and Pollutant Load Reductions Needed (Task 23)

DATE: July 23, 2019

CC: Forrest Bell, FB Environmental Associates; Don Kretchmer, DK Water Resource Consulting

This memo summarizes steps undertaken to set a water quality goal for Gregg Lake. The water quality goal was based on discussions among project partners and stakeholders. The goal will be used to measure the success of future watershed management actions, which will be a major component of the Gregg Lake Watershed Management Plan.

PROBLEM BACKGROUND

According to the 303(d) New Hampshire List of Impaired Waters, Gregg Lake is impaired for aquatic life use due to elevated total phosphorus, elevated chlorophyll-a, and low pH. Low levels of oxygen (<5 ppm) in the hypolimnion (e.g., bottom waters) are common in Gregg Lake and stimulate significant internal phosphorus loading from bottom sediments. Anecdotal evidence suggests that algae blooms are becoming more prevalent and the first suspected cyanobacteria bloom was noted in September 2018.

Low dissolved oxygen in lake systems is often indicative of enhanced loading of nutrients, particularly phosphorus, from nonpoint source (NPS) pollution in stormwater runoff from developed and agricultural land uses. Unmitigated sources of pollution (i.e., phosphorus) are expected to increase as development or other human activities in the watershed increase (e.g., conversion of small, seasonal properties to large, year-round homes). An increase in in-lake phosphorus concentration, as well as associated algae growth, will contribute to dissolved oxygen depletion as algal cells and other organic matter sink, die, and decompose in the deeper sections of the lake. Low oxygen in bottom waters of Gregg Lake is already causing a significant release of phosphorus from bottom sediment (a.k.a., internal phosphorus loading) as evidenced by the large difference between bottom and surface phosphorus concentrations. Low dissolved oxygen may also be the result of existing (such as shoreline erosion from high water levels and wave action from high speed boats) or legacy (such as from historic farming or logging) loading of organic matter, which generates a high sediment oxygen demand while the organic matter is decomposed.

ASSIMILATIVE CAPACITY

The assimilative capacity of a waterbody describes the amount of pollutant that can be added to a waterbody without causing a violation of the water quality criteria. For oligotrophic waterbodies such as Gregg Lake, the water quality criteria are set at 8 ppb for total phosphorus and 3.3 ppb for chlorophyll-a. NHDES requires 10% of the criteria be kept in reserve; therefore, median total phosphorus and chlorophyll-a must be at or below 7.2 ppb and 3.0 ppb, respectively, to achieve Tier 2 High Quality Water status. Support determinations are based on the nutrient stressor (phosphorus) and response indicator (chlorophyll-a), with chlorophyll-a dictating the assessment if both chlorophyll-a and total phosphorus data are available and the assessments differ.

Results of the assimilative capacity analysis for Gregg Lake show that Gregg Lake is Tier 2 for high quality waters for total phosphorus but impaired for chlorophyll-a (Table 1). Total phosphorus in Gregg Lake is well below the NHDES Aquatic Life Use criteria for oligotrophic lakes and reflects excellent water quality. In contrast, chlorophyll-a in Gregg Lake is above the NHDES Aquatic Life Use criteria for oligotrophic lakes and reflects poor water quality. Because chlorophyll-a dictates the assessment, Gregg Lake is considered impaired and cannot assimilate additional nutrients.

TABLE 1. Assimilative capacity (AC) analysis results for Gregg Lake.

Parameter	AC Threshold (ppb)	Existing Median WQ (ppb)	Remaining AC (ppb)	Analysis Results
Total Phosphorus	7.2	6.8	+0.4	Tier 2 (High Quality)
Chlorophyll-a	3.0	3.9	-0.9	Impaired

PHOSPHORUS-CHLOROPHYLL-A RELATIONSHIP

We found no significant relationship between chlorophyll-a and total phosphorus in the epilimnion, metalimnion, and hypolimnion for all samples (Figure 1), suggesting that other factors may be controlling productivity in Gregg Lake. Other explanations for the lack of response in chlorophyll-a with phosphorus include the following:

- **Food chain out of balance.** A decade-old fish study showed a substantial yellow perch population in Gregg Lake. Yellow perch are planktivorous fish that graze on zooplankton. A depleted zooplankton population would reduce grazing pressure on phytoplankton (i.e., chlorophyll-a).
- **Phytoplankton movement and concentration.** Cyanobacteria and gloeotrichia can move vertically in the water column to collect nutrients, bringing them up to the surface. These phytoplankton populations can also be blown and concentrated in shallow areas.
- **Nearshore nutrient sources.** Shoreline erosion and runoff to shallow areas may be concentrating nutrients and stimulating localized algal blooms.
- **Increase in other growth needs.** Elevated levels of other limiting nutrients such as nitrogen and iron may also be controlling algae and plant growth in Gregg Lake.

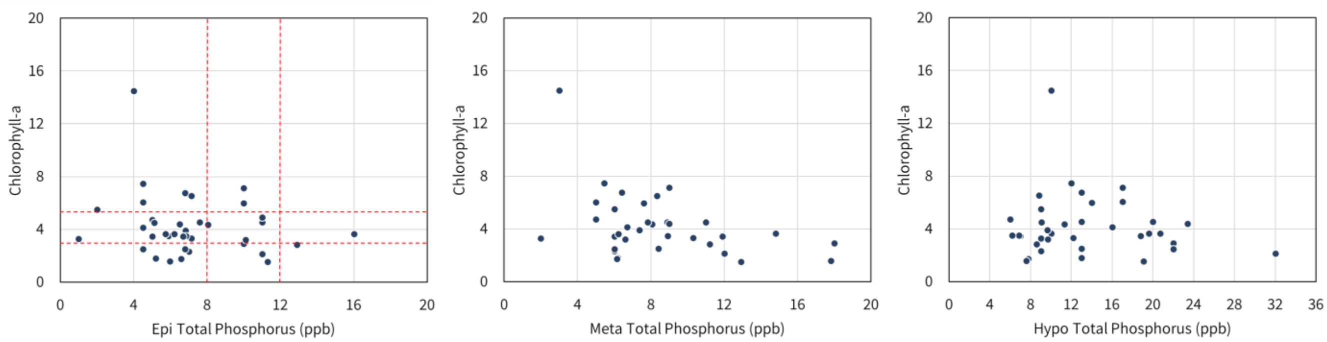

FIGURE 1. The relationship between chlorophyll-a and total phosphorus in Gregg Lake deep spot (GREANTD) shows that chlorophyll-a (measure of algae) in unresponsive to changes in total phosphorus concentration in the epilimnion, metalimnion, and hypolimnion, at least as a seasonal scale when most samples were collected. Thresholds (red lines) for chlorophyll-a and total phosphorus for oligotrophic (3.3 ppb Chl-a, 8 ppb TP) and mesotrophic (5 ppb Chl-a, 12 ppb TP) waterbodies per NHDES are shown for epilimnion chlorophyll-a and total phosphorus figure only.

LAKE LOADING RESPONSE MODEL RESULTS

A second analysis was used to link watershed loading conditions with in-lake total phosphorus and chlorophyll-a concentrations to predict past, current, and future water quality in Gregg Lake. An Excel-based model, known as the Lake Loading Response Model (LLRM), was used to develop a water and phosphorus loading budget for the lake and its tributaries. Water and phosphorus loads (in the form of mass and concentration) are traced from sources in the watershed, through tributary basins, and into the lake. The model incorporates data about land cover, watershed boundaries, point sources, septic systems, waterfowl, rainfall, and an estimate of internal lake loading, combined with many coefficients and equations from scientific literature on lakes and nutrient cycles.

Overall, model predictions were in good agreement with observed data and were within <1% to 3% relative percent difference of observed mean annual total phosphorus, chlorophyll-a, and Secchi disk transparency (Table 2). It is important to note that the LLRM does not explicitly account for all the biogeochemical processes occurring within a waterbody that contribute to overall water quality and is less accurate at predicting chlorophyll-a and Secchi disk transparency. For example, chlorophyll-a is estimated strictly from nutrient loading, but other factors strongly affect algae growth, including low light from suspended sediment, grazing by zooplankton, presence of heterotrophic algae, and flushing effects from high flows. There were insufficient data available to evaluate the influence of these other factors on observed chlorophyll-a concentrations and Secchi disk transparency readings.

Watershed runoff combined with baseflow (72%) was the largest phosphorus loading contribution across all sources to Gregg Lake, followed by atmospheric deposition (9%), internal loading (9%), septic systems (6%), and waterfowl (4%) (Table 3). Development in the watershed is most concentrated around the shoreline where septic systems or holding tanks are located within a short distance to the water, leaving little horizontal (and sometimes vertical) space for proper filtration of wastewater effluent. Improper maintenance or siting of these systems can cause failures, which leach untreated, nutrient-rich wastewater effluent to the lake.

Internal loading is also a concern for Gregg Lake given that low dissolved oxygen in bottom waters is causing a significant release of phosphorus from bottom sediments (as evidenced by the moderate difference between bottom and surface phosphorus concentrations (7.8 ppb)). Low flushing rate in late summer may further exacerbate internal loading as both the duration of anoxia and the residence time for nutrients are prolonged.

TABLE 2. In-lake water quality predictions for Gregg Lake. TP = total phosphorus. Chl-a = chlorophyll-a. SDT = Secchi disk transparency.

Model Scenario	Median TP (ppb)	Predicted Median TP (ppb)	Mean Chl-a (ppb)	Predicted Mean Chl-a (ppb)	Mean SDT (m)	Predicted Mean SDT (m)
Pre-Development	--	3.4	--	2.0	--	8.3
Current (2018)	6.8 (8.2)	8.2	4.3	4.2	4.7	4.6
Future (2180)	--	17.6	--	8.8	--	2.6

**Median TP concentration of 6.8 ppb represents existing in-lake epilimnion TP from observed data. Median TP concentration of 8.2 ppb represents 20% greater than actual median values as the value used to calibrate the model. Most lake data are collected in summer when TP concentrations are typically lower than annual average concentrations for which the model predicts*

Once the model is calibrated for current in-lake phosphorus concentration, we can then manipulate land cover and other factor loadings to estimate pre-development loading (e.g., what in-lake phosphorus concentration was prior to human development or the best possible water quality for the lake), as well as future loading (e.g., what in-lake phosphorus concentration will be following full buildout of the watershed under current zoning standards).

Pre-development loading estimation showed that total phosphorus loading increased by 118%, from 45 kg/yr prior to European settlement to 98 kg/yr under current conditions, for Gregg Lake (Table 3). These additional phosphorus sources are coming from development in the watershed (especially in the direct shoreline of Gregg Lake), septic systems, atmospheric dust, and internal loading (Tables 3). Water quality prior to settlement was likely excellent with extremely low phosphorus and chlorophyll-a concentrations and high water clarity (Table 2).

Future loading estimation showed that total phosphorus loading may increase by 115%, from 98 kg/yr under current conditions to 211 kg/yr at full build-out (2180) under current zoning, for Gregg Lake (Table 3). Additional phosphorus will be generated from more development in the watershed (especially from the direct shoreline of Gregg Lake, followed by Willard Mountain and Hattie Brown Road sub-basins), greater atmospheric dust, more septic systems, and enhanced internal loading (Table 3). The model predicted significantly higher (worse) phosphorus (17.6 ppb), higher (worse) chlorophyll-a (8.8 ppb), and lower (worse) water clarity (2.6 m) compared to current conditions (Table 2).

TABLE 3. Total phosphorus (TP) and water loading summary by source.

SOURCE	PRE-DEVELOPMENT			CURRENT (2018)			FUTURE (2180)		
	TP (KG/YR)	%	WATER (CU.M/YR)	TP (KG/YR)	%	WATER (CU.M/YR)	TP (KG/YR)	%	WATER (CU.M/YR)
ATMOSPHERIC	6	13%	629,700	9	9%	629,700	20	10%	629,700
INTERNAL	0	0%	0	9	9%	0	28	13%	0
WATERFOWL	3	7%	0	3	4%	0	3	2%	0
SEPTIC SYSTEM	0	0%	0	6	6%	4,874	13	6%	10,428
WATERSHED LOAD	36	80%	7,538,936	71	72%	7,542,824	146	69%	7,551,326
TOTAL LOAD TO LAKE	**45**	**100%**	**8,168,636**	**98**	**100%**	**8,177,398**	**211**	**100%**	**8,191,454**

Based on model analysis of pre-development, current, and future water quality conditions, Gregg Lake is at risk for water quality degradation from future development under current zoning. Additional phosphorus loading from the watershed and internal sediments will likely accelerate water quality degradation of the lake, though the relationship between total phosphorus and chlorophyll-a appears to not be directly causal at least at a seasonal scale when most samples were collected. However, the model predicted both total phosphorus and chlorophyll-a well at the annual average scale, indicating that total phosphorus is still an important driver of chlorophyll-a concentrations in Gregg Lake. Gregg Lake has already surpassed the maximum oligotrophic criterion for chlorophyll-a at 3.3 ppb despite the relatively low total phosphorus concentration in the lake that shows a remaining assimilative capacity of 0.4 ppb. Given Gregg Lake's recreational and aquatic habitat value in the region, it will be crucial to both maximize land conservation of intact forestland and consider zoning ordinance amendments that encourage low impact development techniques on existing and new development.

WATER QUALITY GOAL & OBJECTIVES

The model results revealed changes in total phosphorus loading and in-lake total phosphorus concentrations over time from pre-development through future conditions. We can use these results to make informed management decisions and set an appropriate water quality goal for Gregg Lake. The committee met to discuss the water quality goal and objectives on July 12, 2019.

The goal of the Gregg Lake Watershed Management Plan is **to improve water quality in Gregg Lake to meet a seasonal (May 24-Sept 15) average chlorophyll-a concentration of 3.0 ppb or less and reduce the extent and duration of low oxygen in bottom waters**. This goal will be achieved by accomplishing two objectives.

Objective 1: Reduce or offset phosphorus loading to Gregg Lake by 27 kg/yr in the next 10 years.

- The estimated total phosphorus load increase from new development by 2028 is predicted at 7 kg/yr.
- The existing total phosphorus load will need to be reduced by 20 kg/yr to achieve 3.0 ppb chlorophyll-a.

Objective 2: Investigate other factors impacting water quality in Gregg Lake.

- Complete a study to determine if water levels in Gregg Lake are set at an appropriate height to protect the shoreline from erosion.
- Consider enforcing a no wake area within 500 ft of the shoreline and in at least 20 ft of water.
- Review results of a recent NHFGD fish study of Gregg Lake to determine if there is a food chain imbalance. If an imbalance is suspected or unclear, then complete a study that documents change in the abundance and diversity of zooplankton over the course of a year. Look for a loss of larger-bodied Cladocerans like Daphnia, which are preferred prey for planktivorous fish. If the study finds a food chain imbalance, then consider stocking the lake with piscivorous fish to control the planktivorous fish (which will increase zooplankton populations and decrease phytoplankton or algae).
- Integrate additional parameters to the regular monitoring program, such as total nitrogen, total and dissolved organic carbon, iron, etc.
- Collect and analyze a sediment core in the deep spot of Gregg Lake to determine legacy impacts from changes in sediment and nutrient loading due to landscape alterations over time.

The interim goals for each objective and their options allow flexibility in re-assessing water quality objectives following more data collection and expected increases in phosphorus loading from new development in the watershed over the next 10 or more years (Table 4). Understanding where water quality will be following watershed improvements compared to where water quality should have been following no action will help guide adaptive changes to interim goals (e.g., goals are on track or goals are falling short). If the goals are not being met due to lack of funding or other resources for implementation projects versus due to increases in phosphorus loading from new development outpacing reductions in phosphorus loading from improvements to existing development, then this creates much different conditions from which to adjust interim goals. For each interim goal year, the committee should meet to update the water quality data and model and assess why goals are or are not being met. The group will then decide on how to adjust the next interim goals to better reflect water quality conditions and practical limitations to implementation.

TABLE 4. Summary of water quality objectives for Gregg Lake.

Water Quality Objective	Interim Goals/Benchmarks		
	2020	2023	2028
1. Reduce phosphorus loading to Gregg Lake by 27 kg/yr.	Achieve 5 kg/yr reduction in TP loading; prevent or offset 3 kg/yr in TP loading from new development	Achieve 10 kg/yr reduction in TP loading; prevent or offset 5 kg/yr in TP loading from new development; re-evaluate water quality and track progress	Achieve 20 kg/yr reduction in TP loading; prevent or offset 7 kg/yr in TP loading from new development; re-evaluate water quality and track progress
2. Investigate other factors impacting water quality in Gregg Lake.	Complete studies to determine other influencing factors on water quality	Complete studies to determine other influencing factors on water quality; implement any solutions as a result of the studies; re-evaluate water quality and track progress	Complete studies to determine other influencing factors on water quality; implement any solutions as a result of the studies; re-evaluate water quality and track progress

POLLUTANT LOAD REDUCTIONS TO ACHIEVE GOAL

A watershed survey was completed to identify hotspots of pollutant loading to Gregg Lake. The survey focused on areas of significant sediment erosion. Sediment can carry nutrients, such as phosphorus, to surface waters during runoff events. Treatment of the 30 sites identified would reduce phosphorus loading to Gregg Lake by an estimated 11 kg/yr. Treatment of the top 10 sites identified would reduce loading to Gregg Lake by an estimated 10 kg/yr. It is important to note that the watershed survey identified erosion sites from public access points (e.g., roads, common areas) unless information was provided by private landowners; it can be assumed that a significant amount of the phosphorus-laden sediment entering Gregg Lake likely comes from the cumulative impact of private shoreline properties. While a shoreline survey was not completed for Gregg Lake, we can estimate that treating stormwater runoff from developed parcels would reduce phosphorus loading per property by either 2 kg/yr for severe erosion and runoff issues or 0.2 kg/yr for moderate erosion and runoff issues.

The strategy for reducing pollutant loading to Gregg Lake will be dependent on available funding and labor resources but will likely include a combination of approaches (larger watershed BMP sites and smaller residential shoreline BMP sites; Table 5). Another significant but difficult to quantify strategy for reducing phosphorus loading to the lake is revising local ordinances to set low impact development requirements on new construction. With a dedicated stakeholder group in place and with the help of grant funding, it is possible to achieve target phosphorus reductions and meet the established water quality goal for Gregg Lake in the next 10 years.

TABLE 5. Summary of total phosphorus (TP) reductions and estimated costs for BMP implementations at Gregg Lake.

BMP Site Categories	TP Reduction (kg/yr)	Estimated Cost
Watershed Survey Sites (10)	10	$500,000-$845,000
High-Medium Impact Shoreline Sites (20)	20	$50,000-$100,000
Ordinance Revisions to include LID	TBD	TBD
Total	**30**	**$550,000-$945,000**