WATER QUALITY GOAL | MEMORANDUM

FB environmental

TO: Pat Tarpey, Lake Winnipesaukee Association

FROM: Laura Diemer, FB Environmental Associates

SUBJECT: MBI Water Quality Goal Documentation

DATE: May 10, 2016

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

This memo summarizes rationale for determining water quality goals for the Moultonborough Bay Inlet. Water quality goals were based on multiple discussions (in-person and via email correspondence) among project partners and stakeholders.

STUDY DESIGN AND SITE SELECTION

The Moultonborough Bay Inlet (MBI) represents a unique system for study because it is not a true lake, but rather part of a larger lake system (Lake Winnipesaukee). The morphology (shape) and bathymetry (depth) of MBI is fairly irregular, causing the formation of individual basins, bays, or inlets within the study system that impact water and nutrient movement (flushing), and subsequently, system function and health. Given these characteristics of MBI, the Inlet was divided into three individual basins (Basin 1, 2, and 3) for modeling, data analysis, and goal setting purposes. One of the challenges posed by this division is the lack of consistent, long-term data for each of the three basins. The number of sites and frequency of sampling in MBI has varied over the 20-year period with more consistent sampling occurring in the last 5 years. A summary of sampling site data is provided in Table 1.

TABLE 1. Summary of sampling site data for Moultonborough Bay Inlet.

Station ID	Depth (ft)	Station Name	MBI Basin	Median TP (ppb)*	n	Years Sampled	Statistical Diff (p<0.05)**
WMO00GL	25	Green's Basin	Basin 1	11.6	22	2010-15	A
WMO01BL	35	Blanchard's Island	Basin 2	10.4	2	2011	AB
WMOLEML	20	Lees Mills	Basin 3	12.8	4	2010, 2012	AB
WMOSTLL	30	State's Landing	Basin 3	9.5	15	2010-14	AB
WMO01LL	50	Little Ganzy	Basin 3	9.6	4	2010-11	AB
WMO0SSL	40	Suissevalle	Basin 3	8.4	21	2010-15	B
WMO10AL	55	Black Point	Basin 3	7.1	22	2001-02, 2010-15	B

**Based on seasonal (5/24-9/15) and recent (2006-2015) data*

***Based on Welch's one-way analysis of variance and Games-Howell post-hoc test*

For Basin 1, WMO00GL (Green's Basin) has been sampled regularly since 2010 (n=22); therefore, the dataset was assumed to be a good representation of current water quality conditions. For Basin 2, WMO01BL (Blanchard's Island) was only sampled twice in 2011. More data will be needed to better inform the LLRM, assimilative capacity, and goals for Basin 2. The plan will include interim goals and milestones to reassess Basin 2 following several years (at least 5 years) of regular data collection. For Basin 3, there are multiple sites that have been monitored for total phosphorus (TP) at varying frequencies: WMOLEML (Lees Mills), WMOSTLL (State's Landing), WMO01LL (Little Ganzy), WMO0SSL (Suissevalle), and WMO10AL (Black Point). These sites vary in depth (since there is no true deep spot) and spatial distribution across Basin 3 (Figure 1), suggesting that these sites experience different flow patterns and inputs from the corresponding drainage area to each site. Despite this, no statistically-significant difference (α<0.05) in TP data were found among Basin 3 sites, though accounting for the heteroscedasticity in the sample size data among sites using Welch's ANOVA ensures sensitivity to Type I (false positive) errors (Table 1).

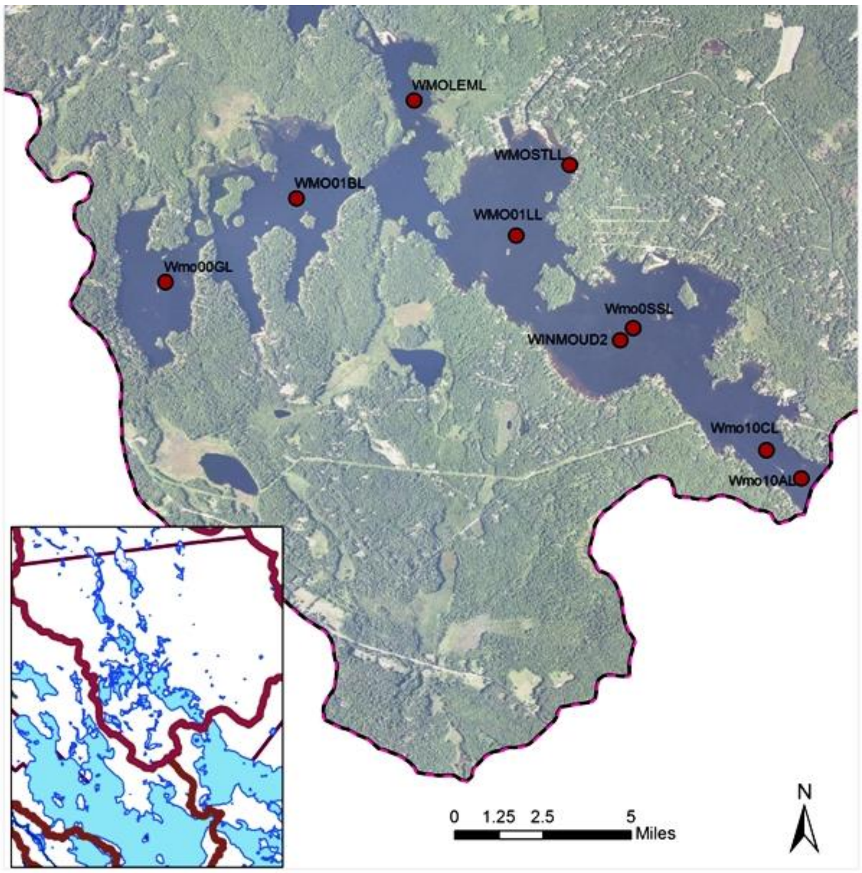

FIGURE 1. Moultonborough Bay water quality monitoring sites. Note: WINMOUD2 and WMO10CL are inactive stations without recent total phosphorus data.

Given the lower TP concentrations measured at WMO0SSL (Suissevalle) and WMO10AL (Black Point) and the proximity of these sites to the southern outlet of MBI, it is very likely that these sites are influenced by mixing with the larger Lake Winnipesaukee system, and therefore, may not be representative of inputs from the MBI watershed. It is recommended that a single, representative station be established for Basin 3 at WMO01LL (Little Ganzy). This station is deep (50 ft) and centrally-situated within the basin, so that a good portion of watershed inputs is accounted for and the station is located above the two lower stations where mixing from Lake Winnipesaukee may be an issue. Despite WMO01LL (Little Ganzy) being only sampled four times from 2010-11, the median TP is in good agreement with nearby sites: WMOSTLL (State's Landing) upstream along the east shoreline of MBI and WMO0SSL (Suissevalle) downstream in an area likely diluted by mixing with Lake Winnipesaukee. Therefore, WMO01LL (Little Ganzy) was used for the assimilative capacity analysis and goal with the intention that these values be updated and checked after more data are collected. The plan will include interim goals and milestones to reassess Basin 3 following several years (at least 5 years) of regular data collection.

ASSIMILATIVE CAPACITY

MBI shares Lake Winnipesaukee's oligotrophic classification, which forms the basis for MBI's assimilative capacity analysis and subsequent water quality goals. 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, the water quality criteria are set at 8 ppb TP and 3.3 ppb chlorophyll-a (Chl-a). NHDES requires 10% of the criteria be kept in reserve; therefore, median TP and Chl-a must be at or below 7.2 ppb TP and 3.0 ppb Chl-a, respectively, to achieve Tier 2 High Quality Water status. Support determinations are based on the nutrient stressor (TP) and response indicator (Chl-a), with Chl-a dictating the assessment if both Chl-a and TP data are available and the assessments differ.

For MBI, Basin 1 is considered impaired for both TP and Chl-a, while Basins 2 and 3 are potential non-supports due to insufficient, but likely lower than reserve capacity, Chl-a data (Table 2). The analysis revealed that Basin 1 requires the most reductions in TP and is at most risk for elevated nutrient input and algal blooms that can impact Basin 2 (and Basin 3 minimally), while Basins 2 and 3 may also have considerable reductions needed for TP if Chl-a levels are in fact a significant issue. However, data from multiple sites within Basin 3 show that Chl-a is better than the criterion (3.3 ppb) and reserve capacity threshold (3.0 ppb) for oligotrophic systems. Until more Chl-a data are collected for Basin 2 and 3 sites, the water quality goal will be based on the achievement of 7.2 ppb for TP with the understanding that this goal may change given the likely acceptable Chl-a levels in MBI.

TABLE 2. Summary of assimilative capacity analysis results for Moultonborough Bay Inlet. Existing data reflects seasonal (5/24-9/15) and recent (2006-2015) data.

Station ID	Station Name	MBI Basin	Existing Median TP (ppb)*	Remaining TP Assim Capacity (ppb)	Existing Median Chl-a (ppb)	Remaining Chl-a Assim Capacity (ppb)	Assim Capacity Category
WMO00GL	Green's Basin	Basin 1	11.6	-4.4	3.3	-0.3	Impaired
WMO01BL	Blanchard's Island	Basin 2	10.4	-3.2	no data	no data	PNS/IF*
WMO01LL	Little Ganzy	Basin 3	9.6	-2.4	no data	no data	PNS/IF*

Assimilative Capacity Analysis Categories
Tier 2 = Better than Criterion and Reserve Capacity
Tier 1 = Better than Criterion, but within the Reserve Capacity (no remaining capacity)
Impaired = Worse than Criterion (no remaining capacity and not within the Reserve Capacity)
**PNS/IF = Potential Non-Support / Insufficient Info*

LAKE LOADING RESPONSE MODEL RESULTS

A second analysis was used to link watershed loading conditions with in-lake TP and Chl-a concentrations to predict past, current, and future water quality in MBI. An Excel-based model, known as the Lake Loading Response Model (LLRM), was used to develop a water and phosphorus loading budget for the Inlet and its tributaries. Water and phosphorus loads (in the form of mass and concentration) are traced from various sources in the watershed, through tributary basins, and into the Inlet. 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.

Basin 1 model was calibrated to WMO00GL (Green's Basin) data; Basin 2 model was calibrated to WMO01BL (Blanchard's Island) data; and Basin 3 was calibrated to the median of WMO10AL (Black Point), WMO01LL (Little Ganzy), WMO0SSL (Suissevalle), WMOLEML (Lees Mills), and WMOSTLL (State's Landing) data.

Although we recommend the water quality goal be based on a single, representative station, an aggregate of station data was used for input to the model to ensure robustness of model calibration. The difference between methods is relatively small (summer median TP of 9.0 ppb for aggregated sites and summer median TP of 9.6 ppb for WMO01LL (Little Ganzy)). These data also reflect all existing data (regardless of season or year up to 2014) since the model takes into account year-round median TP, which is typically higher than summer median TP. Therefore, the existing median TP shown in Table 3 reflects all data median TP (2005-2014) available multiplied by a factor of 1.2 (assuming actual annual TP is 20% higher than summer TP).

The model predicted within 3% difference of observed median TP for Basins 1 and 3 (Table 3). We left a 28% difference between modeled and observed in-lake TP concentrations for Basin 2 due to the lack of data (n=2) for the Blanchard's Island station. The median in-lake TP concentration of 12.5 ppb may not be representative of the basin. Without a more robust dataset, it is difficult to calibrate the model. Attenuation factors that were appropriate for other similar tributaries with data were used consistently and no further calibration was done for Basin 2. Interestingly, despite the model predicting variable (low or high) median TP concentrations compared to observation data, the model consistently predicted higher-than-observed Chl-a concentrations and lower-than-observed mean water clarity (Table 3). This suggests that other factors aside from phosphorus may be controlling observed water quality (i.e., the general empirical equations used in the LLRM do not fully account for all the biogeochemical processes occurring within the Inlet that contribute to the overall water quality condition).

TABLE 3. In-lake water quality predictions for Basins 1, 2, and 3. Note: median TP concentrations represent 20% greater than actual median values to account for year-round variation. This is because most data are collected in the summer when TP concentrations are typically lower than the annual average concentrations.

Basin	Median TP (ppb)	Predicted Median TP (ppb)	Mean Chl-a (ppb)	Predicted Mean Chl-a (ppb)	Mean SDT (m)	Predicted Mean SDT (m)
Basin 1	14.9	14.8	4.0	5.2	4.6	2.9
Basin 2	12.5	9.4	2.0	2.9	--	4.1
Basin 3	10.8	11.1	2.3	3.6	5.3	3.6

Once the model is calibrated for current in-lake TP concentration, we can then manipulate land use and other factor loadings to estimate historical and future TP loading (e.g., what in-lake TP concentration was prior to human development and what in-lake TP concentration will be following full buildout of the watershed under current zoning restrictions). A comparison of historical, current, and future in-lake TP concentrations for the three basins is shown in Figure 2.

Historical median in-lake TP concentration ranged from 2.9-4.9 ppb compared to 9.4-14.8 ppb for the three basins under current conditions (Figure 2). This represents an increase of 64-130% compared to current conditions. Basin 3 Direct and Shannon Brook subdrainages changed the most from historical to current conditions, likely a result of concentrated development in these drainages. The historic assessment is useful to provide an estimate of the best possible water quality for the Inlet. In this case, historical in-lake TP concentrations are well within oligotrophic criteria, suggesting that an oligotrophic classification and goal may be at least theoretically realistic for MBI.

The model predicted an in-lake TP concentration of 22.5, 14.5, and 16.6 ppb in Basins 1, 2, and 3, respectively, at full buildout in 2058 (based on conservative 20-year average annual growth rate of 1.58%). This represents an increase of 40-43% compared to current conditions. Any new increases in phosphorus to a lake can disrupt the ecological balance in favor of increased algal growth, resulting in degraded water clarity. Shannon Brook is most at risk for increases in TP loading as a result of increased development.

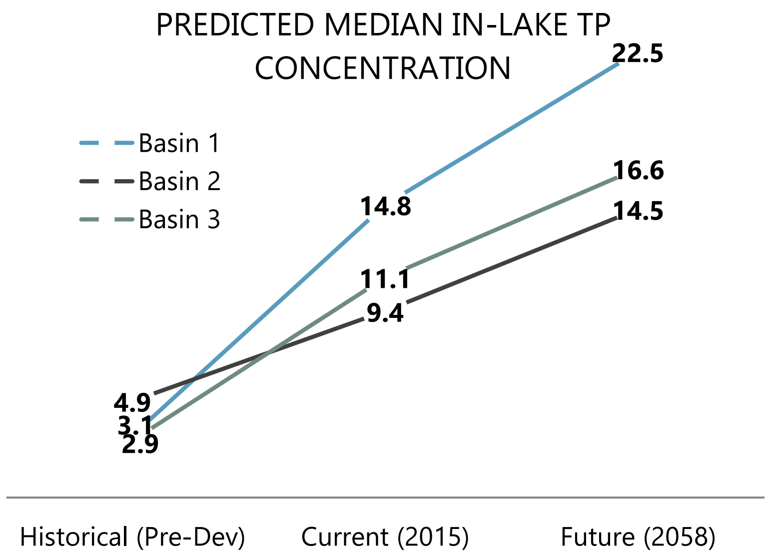

FIGURE 2. Historical, current, and future in-lake total phosphorus concentrations for Basins 1, 2, and 3.

WATER QUALITY GOALS

The model results revealed changes in TP loading and in-lake TP concentrations over time from historical pre-development through future conditions. We can use these results to make informed management decisions and set an appropriate water quality goal for MBI. Modeled historical pre-development conditions revealed in-lake TP concentrations well within oligotrophic criteria, suggesting that applying an oligotrophic classification to the goals may at least be theoretically realistic for MBI. Given this, the ultimate water quality goal of 7.2 ppb TP (for summer median epilimnion TP) was applied to Basins 1, 2, and 3, along with adaptable interim goals and milestones that help achieve this ultimate goal over the next 20 or more years. Future water quality monitoring in MBI should establish a single, sentinel sampling station in each of the three basins (Basin 1 = WMO00GL (Green's Basin); Basin 2 = WMO01BL (Blanchard's Island); Basin 3 = WMO01LL (Little Ganzy)). These stations are deep and centrally-located within each basin, so that a good portion of watershed inputs is accounted for and the Basin 3 station is located above the two lower stations where mixing from Lake Winnipesaukee may be an issue. Limiting the number of monitored stations may also be a more practical approach to future water quality monitoring given uncertainties in funding and labor resources.

The following describes interim goals, milestones, and goal adaptation strategies for the three basins:

- BASIN 1 requires a 42% (26 kg/yr) reduction in TP loading to achieve the oligotrophic classification goal of 7.2 ppb for in-lake summer median epilimnion TP (Table 4). Current in-lake Chl-a concentrations require a 10% reduction to achieve the oligotrophic classification goal of 3.0 ppb for in-lake summer median epilimnion Chl-a; this Chl-a goal could be achieved with only a 9% (6 kg/yr) reduction in TP loading. Basin 1 has experienced the greatest increase in in-lake TP concentration since pre-development and will continue on a more aggressive upward trajectory than the other two basins. Any improvement or degradation in Basin 1 water quality will decrease or increase in-lake TP concentrations by 14% for Basin 2 and 1% for Basin 3. Since Basin 1 is at most risk for elevated nutrient inputs and algal blooms, has the lowest total TP load reduction needed (26 kg/yr), and drains a relatively small, manageable watershed, Basin 1 may be ideal for priority project implementation to achieve the water quality goal on a faster timescale. Successful projects in the Basin 1 drainage can serve as examples to be replicated in the other basin drainages. This prioritization hinges on local resident engagement throughout the process.

- BASIN 2 requires a 31% (27 kg/yr) reduction in TP loading to achieve the oligotrophic classification goal of 7.2 ppb for in-lake summer median epilimnion TP (Table 4). These reduction estimates are based on minimal data; therefore, we recommend collecting several years of data (epilimnion and hypolimnion TP, Chl-a, and SDT) for WMO01BL (Blanchard's Island), updating the LLRM for Basin 2, and revisiting the water quality goal in 5 years. One important consideration for the Basin 2 water quality goal is Chl-a, which dictates support determinations. Preliminary data show that Chl-a may be better than the reserve capacity threshold (3.0 ppb) for oligotrophic systems, but until more data are collected for Basin 2, the water quality goal will be based on the achievement of 7.2 ppb TP with the understanding that this goal may change given the likely acceptable Chl-a levels in Basin 2. **NOTE:** the model predicted higher-than-observed Chl-a for Basin 2, indicating that other factors aside from TP may be controlling observed water quality; therefore, we recommend that a study be conducted to assess other factor limitations to algal growth within Basin 2 to better inform the water quality goal should those factors change in the future.

- BASIN 3 requires a 20% (242 kg/yr) reduction in TP loading to achieve the oligotrophic classification goal of 7.2 ppb for in-lake summer median epilimnion TP (Table 4). These reduction estimates are based on an aggregate of multiple sites within Basin 3, but future monitoring and modeling should focus on a single, sentinel station for Basin 3; therefore, we recommend collecting several years of data (epilimnion and hypolimnion TP, Chl-a, and SDT) for WMO01LL (Little Ganzy), updating the LLRM for Basin 3, and revisiting the water quality goal in 5 years. Implementation projects should begin right away in the Basin 3 drainage, particularly in the direct shoreline and Shannon Brook drainages where development is concentrated (Suissevalle) and at most risk for new development. Development in the direct shoreline and Shannon Brook drainages account for 107 kg/yr and 96 kg/yr, respectively, of TP loading to Basin 3, both of which account for a significant portion of the total TP load reduction needed (242 kg/yr). One important consideration for the Basin 3 water quality goal is Chl-a, which dictates support determinations. Preliminary data show that Chl-a may be better than the reserve capacity threshold (3.0 ppb) for oligotrophic systems, but until more data are collected for WMO01LL (Little Ganzy), the water quality goal will be based on the achievement of 7.2 ppb TP with the understanding that this goal may change given the likely acceptable Chl-a levels in Basin 3. **NOTE:** the model predicted higher-than-observed Chl-a for Basin 3, indicating that other factors aside from TP may be controlling observed water quality; therefore, we recommend that a study be conducted to assess other factor limitations to algal growth within Basin 3 to better inform the water quality goal should those factors change in the future.

An important consideration for adjusting interim goals during the adaptive management process is how the expected increase in TP loading following new development in the watershed will impact ultimate and interim water quality goals. Over the next 20 years, new development using business-as-usual regulations will likely increase current TP loading by 16, 22, and 294 kg/yr to Basins 1, 2, and 3, respectively (Table 4). This will hinder progress toward achieving ultimate and interim goals. Given this consideration, it will be just as important to focus on updating municipal regulations to incorporate more stringent water quality protections during new development as it will be to minimize TP loading from existing development.

TABLE 4. Summary of TP load reductions based on water quality goals for each basin.

Basin	% TP Reduction Needed to Achieve Oligo Criterion	TP Load Reduction Needed to Achieve Oligo Criterion (kg/yr)	% Chl-a Reduction Needed to Achieve Oligo Criterion	% TP Reduction Needed to Achieve % Chl-a Reduction	TP Load Reduction Needed to Achieve % Chl-a Reduction (kg/yr)	Estimated TP Load Increase from New Development from 2016-2035 (kg/yr)	Estimated Total TP Load Reduction Needed if Stay on Development Trajectory from 2016-2035 (kg/yr)
Basin 1	42%	26	10%	9%	6	16	42
Basin 2	31%	27	Likely 0%	Likely 0%	Likely 0	22	49
Basin 3	20%	242	Likely 0%	Likely 0%	Likely 0	294	536

Ultimate and interim water quality goals for each basin are outlined in Table 5. The interim goals allow flexibility in re-assessing water quality goals following more data collection and incorporation of expected increases in TP loading with new development in the watershed over the next 20 years. Understanding where we will be following watershed improvements compared to where we 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 for implementation projects versus new development TP loading outpacing improvements to existing development TP loading, this creates much different conditions from which to adjust interim goals. For each interim goal year, the committee should meet to update water quality data and model and assess why goals are or are not being met. The committee will then decide on how to adjust the next interim goals to better reflect water quality conditions and practical limitations to implementation.

It is also important to note that there are several larger ponds within the Basin 3 drainage that should set their own water quality goals and TP reduction goals to help improve water quality in MBI.

TABLE 5. Summary of ultimate and interim water quality goals for each basin in MBI.

Goal	Interim Goals/Benchmarks		
	2021	2026	2036
Basin 1: reduce TP loading by 42% (26 kg/yr) to achieve 7.2 ppb for in-lake summer median epi TP	Achieve 9% (6 kg/yr) reduction in TP loading and re-assess Chl-a response *prioritize for implementation projects	Achieve 25% (16 kg/yr) reduction in TP loading and update LLRM to account for development increases *prioritize for implementation projects	Achieve 42% (26 kg/yr) reduction in TP loading and update LLRM to account for development increases *prioritize for implementation projects
Basin 2: reduce TP loading by 31% (27 kg/yr) to achieve 7.2 ppb for in-lake summer median epi TP	Collect 5 years of data at WMO01BL (Blanchard's Island), update LLRM, and revisit goal	Achieve 15% (13 kg/yr) reduction in TP loading and update LLRM to account for development increases	Achieve 31% (27 kg/yr) reduction in TP loading and update LLRM to account for development increases
Basin 3: reduce TP loading by 20% (242 kg/yr) to achieve 7.2 ppb for in-lake summer median epi TP	Achieve 5% (61 kg/yr) reduction in TP loading *prioritize Suissevalle for implementation projects; Collect 5 years of data at WMO01LL (Little Ganzy), update LLRM, and revisit goal	Achieve 10% (121 kg/yr) reduction in TP loading and update LLRM to account for development increases *prioritize Suissevalle for implementation projects	Achieve 20% (242 kg/yr) reduction in TP loading and update LLRM to account for development increases *prioritize Suissevalle for implementation projects