TOTAL MAXIMUM DAILY (ANNUAL PHOSPHORUS) LOAD Report

TOOTHAKER POND

Franklin County, Maine

<u>Toothaker Pond</u> TMDL Report

Maine DEPLW 2004 - 0669

DEPARTMENT OF ENVIRONMENTAL PROTECTION · STATE OF MAINE ·

Maine Department of Environmental Protection

Maine Association of Conservation Districts

Final EPA Submittal Report - September 13, 2004

TOOTHAKER POND - Total Maximum Daily (Annual Phosphorus) Load

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Study Methodology & Background Information

Toothaker Pond background information was obtained by a review of Maine DEP files, including the previous 1984 Maine DEP (314) lake/watershed study, as well as several field visits. The 1984 (314) report contains the following information: (1) data on estimated flows and phosphorus concentrations from the Maine Department of Inland Fisheries & Wildlife trout hatchery on Meadow Brook at the time; (2) an analysis of the flushing rates of the pond based on pre- and post-diversion scenarios; (3) land use phosphorus load estimates; and (4) modeling to determine the effects of the trout hatchery and flow conditions. The evidence is convincing that algae blooms were the result of historic phosphorus loadings from the trout hatchery effluent. At the time, modeling suggested that the pond might have similar total phosphorus conditions after the diversion, since even though the TP loading was reduced, the flushing rate would be around 20% of pre-diversion levels. After the 1972 diversion of Meadow Brook, it was hoped that the TP levels would be reduced over time, as the lake re-adjusted to lower total phosphorus inputs.

Prior to 2003, in-lake data were too few to assess whether this had been happening, but residents complained that there was a substantial bloom in 2000 and 2001. Maine DEP data show that the 2001 bloom was as severe as almost any in the State that year, and the few total phosphorus measures suggest that the pond has been in the 18-19 ppb range in late summer.

In order to evaluate Toothaker Pond remediation options, current and potential phosphorus sources were estimated under different scenarios. This report contains the following updated information: (1) data on estimated flows and total phosphorus concentrations from the existing trout hatchery; (2) an analysis of the flushing rates of the pond based on pre and post-diversion scenarios; (3) land use phosphorus load estimates; and (4) modeling to determine the effects of various flow and loading scenarios. A preliminary evaluation of pond restoration options is also provided.

This TMDL report includes evaluation work done for Toothaker Pond during 2003-2004, including field checking earlier Maine DEP field work, a re-estimation of road lengths and conditions, lake and stream data, and phosphorus loading estimates from land use, hatchery and other nutrient sources in the Toothaker Pond and Meadow Brook watersheds, as well as results of a lake response modeling exercise. The discharge flow and total phosphorus concentration data for the *Phillips Fish Hatchery* was assembled for several years, ending in December 2002. Lake volumes and depths were surveyed to allow for modeling and a reevaluation of the hydrology, including the current estimated flushing rate of Toothaker Pond.

TOOTHAKER Pond TMDL, Franklin County, Maine

DESCRIPTION of WATERBODY (MIDAS Number 2336) and WATERSHED

TOOTHAKER POND is a 23-acre waterbody situated within the town of Phillips (DeLorme Atlas, Map 19), in Franklin County, located in west-central Maine. Toothaker Pond has a direct watershed area (see Figure 1) of 44 acres (0.07 square miles) and is located within the Town of Phillips. Toothaker Pond has a maximum depth of 14.3 feet (4.4 meters), an overall mean depth of 8.73 feet (2.7 meters) and a flushing rate of 0.81 times per year (Maine DEP 2003).

Drainage System – Toothaker Pond is best described as a woodland kettle hole with no major inlets, but an outlet that flows west intermittently into Orbeton Stream which drains to the Sandy River and eventually joins with the Kennebec River. The pond's drainage system has changed over time as the cultural uses of the landscape have changed. In the early 1900's (1903-04), Meadow Brook was diverted to flow into Toothaker Pond to allow for Berlin Mill sawmill operations on the pond shoreline. After the sawmill ceased operations, a Maine Department of Inland Fisheries & Wildlife (Maine DIFW) fish (trout) hatchery began operating on Meadow Brook in the 1950's. By 1972, algal blooms were common and intense enough to prompt Maine DIFW to remove the hatchery flow from the lake by diverting the entire flow of Meadow Brook, which had contributed approximately 81% of Toothaker Pond's watershed, thereby significantly reducing the pond's altered flushing rate.

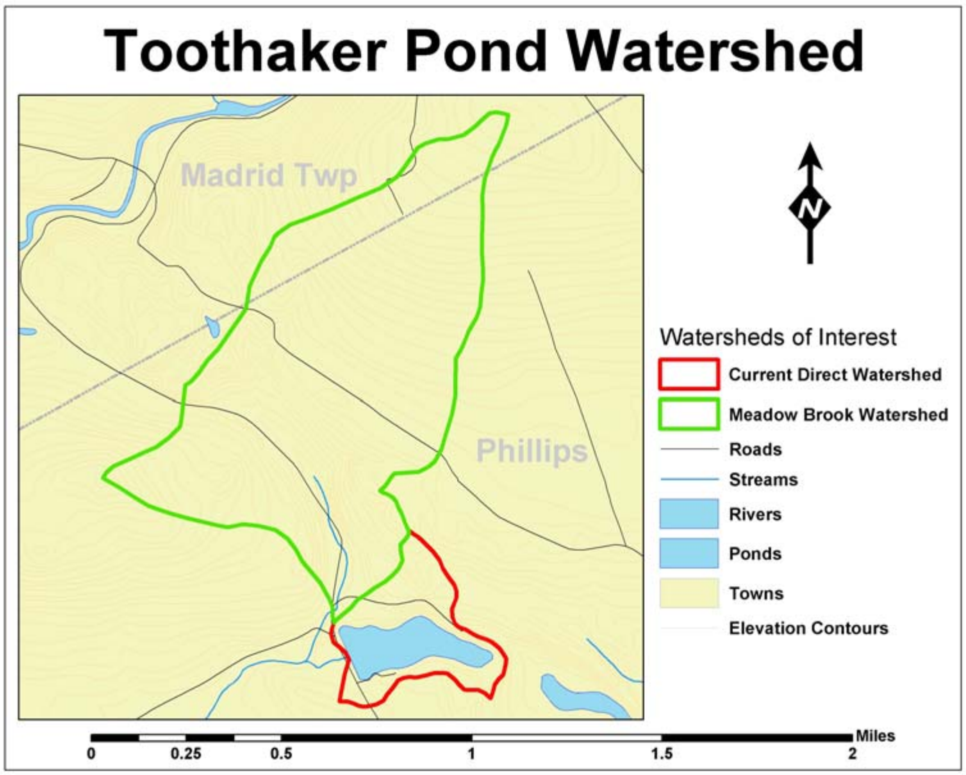
Principle Uses: The dominant current human use of Toothaker Pond is recreational, which includes boating, fishing and beach/residential use. There is not public boat launch, per se, although car-top boats can be hand carried/launched at the foot of Fish Hatchery Road.

Human Development: Historically, excessive phosphorus generated from several sources including road runoff, faulty/non-existent septic systems and/or sink spouts of the 12 camps surrounding the pond, and the upstream fish hatchery effluent. Today, the Toothaker Pond watershed is sparsely developed, with only one dozen seasonal camps located along the shoreline of the pond and without the past Meadow Brook - Phillips Fish Hatchery contribution.

Water Quality Information

Toothaker Pond has had a history of continuous poor water quality, as evidenced by minimal Secchi disk transparency readings over several decades. Despite significant year-to-year variation, annual bloom or near bloom conditions occur in all of the years monitored. Algae blooms may have been the result of historic phosphorus loading from fish hatchery flow. The pond may also have been showing some residual effects from the apparent alteration of its depth and sediment inputs due to the sawmill established at the beginning of the 1900's.

Figure 1: Toothaker Pond Watershed Map



Water Quality Monitoring: (Source: Maine DEP and VLMP 2003; Maine DIFW 2002) Water quality data for Toothaker Pond has been collected intermittently since 1979 (1979-84, 1998, 2001-03). This water quality assessment is based on 10 years of Secchi disk transparency (SDT) measures, epilimnion core total phosphorus (TP) and chlorophyll-a monitoring data, as well as associated water chemistry monitoring data.

Water Quality Measures: (Source: DEP and VLMP 2003) Toothaker Pond, a non-colored lake (average color 23 SPU), has a historical range of SDT measures from 0.6 to 4.5 meters, with an average of 2.3 m, an epilimnion core TP range of 12 to 54 with an average of 25 parts per billion (ppb), and chlorophyll-a measures ranging from 3.9 to 43.9, with an average of 16.2 ppb, indicative of high algae growth during the summer. Recent dissolved oxygen (DO) profiles indicate some DO depletion in deeper areas of the lake (4-meter mark). The potential for total phosphorus to leave the bottom sediments and become available to algae in the water column (internal loading) is moderate to high. Together, these data show a documented historical trend of increasing trophic state for Toothaker Pond, in direct violation of the Maine Class GPA water quality criteria which requires a stable or decreasing trophic state.

Priority Ranking, Pollutant of Concern and Algae Bloom History: Toothaker Pond is listed on Maine's 2000 303(d) list of waters in non-attainment of Maine state water quality standards and was moved up in the priority development order due to stakeholder interest and the need to complete an accelerated approach to lakes TMDL development. The Toothaker Pond TMDL has been developed for total phosphorus, the major limiting nutrient to algae growth in freshwater lakes in Maine. Maine DEP/VLMP 2003 water quality records show that Secchi disk transparencies of less than 2.0 meters were evident in 7 of the 10 years of record.

Natural Environmental Background Levels for Toothaker Pond were not separated from the total nonpoint source load because of the limited and general nature of available information. Without more and detailed site-specific information on nonpoint source loading, it is very difficult to separate natural background from the total nonpoint source load (US-EPA 1999). There are no known point sources of pollutants to Toothaker Pond.

WATER QUALITY STANDARDS & TARGET GOALS

Maine State Water Quality Standard for nutrients which are narrative, are as follows *(July 1994 Maine Revised Statutes Title 38, Article 4-A*): "Great Ponds Class A (GPA) waters shall have a stable or decreasing trophic state (based on appropriate measures, e.g., total phosphorus, chlorophyll a, Secchi disk transparency) subject only to natural fluctuations, and be free of culturally induced algae blooms which impair their potential use and enjoyment."

Maine DEP's functional definition of nuisance algae blooms include episodic occurrence of Secchi disk transparencies (SDTs) < 2 meters for lakes with low levels of apparent color (<30 SPU) and for higher color lakes where low SDT readings are accompanied by elevated chlorophyll a levels. Toothaker Pond is a non-colored lake (average color 23 SPU), with an average SDT of 2.3 m (7.2 feet), in association with elevated average chlorophyll a levels of 25 ppb (1979 -2003). Toothaker Pond does not meet water quality standards due to the repeated and sustained annual summertime nuisance algae blooms. This water quality assessment uses historic documented conditions as the primary basis for comparison. Given the context of "impaired use and enjoyment," along with a realistic interpretation of Maine's goal-oriented Water Quality Standards (WQS), Maine DEP has determined that episodic, non-cyanobacteria based algae blooms (e.g. diatoms), limited to the fall or spring periods only, are in WQS attainment for GPA waters.

Designated Uses and Antidegradation Policy: Toothaker Pond is designated as a GPA (Great Pond Class A) water in the Maine DEP state water quality regulations. Designated uses for GPA waters in general include: water supply; primary/secondary contact recreation (swimming and fishing); hydro-electric power generation; navigation; and fish and wildlife habitat. No change of land use in the watershed of a Class GPA water body may, by itself or in combination with other activities, cause water quality degradation that would impair designated uses of downstream GPA waters or cause an increase in their trophic state. Maine's anti-degradation policy requires that "existing in-stream water uses, and the level of water quality necessary to sustain those uses, must be maintained and protected."

Numeric Water Quality Target: The water quality goal for Toothaker Pond is to halt its trend of increasing trophic state so that it can meet the Maine DEP standard of stable or decreasing trophic state. The numeric (in-lake) water quality target for Toothaker Pond, to meet this goal, is set at 13 ppb total phosphorus (5 kg TP/yr). Since numeric criteria for phosphorus do not exist in Maine's water quality regulations - and would be less accurate targets than those derived from this study - we employed best professional judgment to select a target in-lake total phosphorus concentration that would attain the narrative water quality standard. Spring-time total phosphorus levels in Toothaker Pond during 2003 approximated 13 ppb. In contrast, the upper range of in-lake total phosphorus concentrations during summer and fall periods was 19 to 28 ppb.

The numeric water quality goal of 13 ppb for total phosphorus in Toothaker Pond was based on available water quality data. It is felt that with regular attainment of this P-target goal, that Toothaker Pond would consistently remain "bloom-free" as reflected in suitable (water quality attainment) measures of both Secchi disk transparency (> 2.0 meters) and chlorophyll-a (< 8.0 ppb).

ESTIMATED PHOSPHORUS EXPORT BY LAND USE CLASS

Table 1 (following page) details the numerical data used to evaluate external phosphorus loading for the Toothaker Pond direct watershed.

Table 1. Estimated Total Phosphorus Export by Land Use Class for the Toothaker Pond Direct Watershed.

LAND USE	Total Area Acres	Total Area Hectares	TP Coeff. Avg. kg/P/ha	TP Exp. Avg. kg TP	TP Coeff. Range kg/P/ha	Tot Land Area %	TP Exp Avg %
Developed Land Area							
Shoreline Camp Lots	6.0	2.4	0.35	0.8	0.25 - 1.75	8.9%	15%
Shoreline Septic Systems	Septic	Model*		2.0	2 - 6	-	36%
Roadways	0.8	0.3	2	0.7	0.63 - 10.1	1.2%	12%
Sub-totals	**7**	**3**		**4**		**10%**	**63%**
Non-Developed Land Area							
Inactive/Passively Managed Forest	35.4	15.1	0.04	0.6	0.01 - 0.04	52.5%	11%
Wetlands	2.5	1.0	0.02	0.0	0.02 - 0.83	3.7%	0%
Lake Surface Area	22.7	9.2	0.16	1.5	0.11 - 0.21	33.7%	26%
Sub-totals	**61**	**25**		**2**		**90%**	**37%**
Total Direct Watershed	**67**	**28**		**6**		**100%**	**100%**

* using low estimate from septic system model

Total Phosphorus Land Use Loads

Total phosphorus load measures are provided as a range of values to reflect the degree of uncertainty generally associated with such relative estimates (Walker 2000). The watershed total phosphorus loads were primarily determined using literature and locally-derived export coefficients as found in Schroeder (1979), Reckhow et al. (1980), Dennis (1986), Dennis et al. (1992), and Bouchard et al. (1995) for residential properties and roadways.

In some cases (primarily roadways) selected phosphorus loading coefficients were reduced to account for the estimated bioavailability of the soil runoff sources according to available literature (Lee et al. 1980 and Sonzogni et al. 1982) and to better account for algal available-P export values as reflected in Dennis et al. (1992). These adjustments accounted not only for the readily available SRP (soluble-reactive-phosphorus) in the runoff, but also a substantial portion of the particulate inorganic component, particularly the P which is weakly adsorbed on the surface of soil particles (relative to discussion in Chapra 1997, pg. 524). **Note:** *These adjustments in P-load coefficients did not effectively alter the overall conclusions and final recommendations of the Toothaker Pond TMDL report.*

Shoreline Camp Lots: The phosphorus loading coefficient used (0.35 kg ha/yr) was developed using information on residential lot stormwater export of algal available phosphorus as derived from Dennis et al (1992). The developed shoreline area accounts for about 9% of the total land area and accounts for 15% of the total phosphorus load to Toothaker Pond.

Shoreline Septic Systems: In order to estimate total phosphorus loading from shoreline septic systems, a simple model was used based on information obtained for an earlier DEP study. Estimates of the loading from shoreline septic systems on Toothaker Pond range from a low of 1.8 kg/TP to 5.6 kg/TP. Using the low end of the range, 2 kg/TP, septic systems account for 36% of the total phosphorus load (6 kg/TP) to Toothaker Pond.

Roadways: The total phosphorus loading coefficient for roadways (2.0 kg/ha) was chosen, in part, from previous studies of rural Maine highways (Dudley et al. 1997), as well as best professional judgment (Jeff Dennis, Maine DEP). Roadways in the Toothaker Pond direct watershed account for 1.2% of the land area and 12% of the total phosphorus load.

Non-Developmental Phosphorus Loading: The phosphorus export coefficient for forested land (0.04) is based on a New England regional study (Likens et al 1977). Inactive/passively managed forest within the Toothaker Pond watershed accounts for 53% of the land area and 11% of the total phosphorus load. Wetlands account for less than 4% of the land area and 0% of the total phosphorus load to Toothaker Pond.

Atmospheric Deposition (Open Water): The lower total phosphorus loading coefficient chosen for atmospheric deposition (0.16 kg TP/ha) is similar to that used for the China Lake TMDL (Kennebec County), while the upper range (0.21 kg TP/ha) generally reflects a watershed that is 50 percent forested, combined with agricultural areas interspersed with urban/suburban land uses (Reckhow et al. 1980). Toothaker Pond surface waters (9.2 ha) comprise 34% of the direct watershed area (29 ha) and accounts for an estimated 1.5 kg of total phosphorus, representing 26% of the total phosphorus load (6 kg) entering Toothaker Pond.

Phosphorus Load Summary

It is our professional opinion that the selected export coefficients are appropriate for the Toothaker Pond watershed. Results of the land use analysis indicate that a best estimate of the present total phosphorus loading from external (direct watershed generated) nonpoint source pollution approximates 6 kg TP/yr. This annual external watershed generated loading to Toothaker Pond equates to a total phosphorus loading modeled at 15.5 ppb (6 kg TP/year) - 1 kg above the TMDL target goal of 13 ppb (5 kg TP/year).

LINKING WATER QUALITY and POLLUTANT SOURCES

Assimilative Loading Capacity: The Toothaker Pond TMDL is expressed as an annual load as opposed to a daily load. As specified in 40 C.F.R. 130.2(i), TMDLs may be expressed in terms of either mass per unit time, toxicity, or other appropriate measures. Although Toothaker Pond has a relatively slow flushing rate of 0.81 flush/yr, we believe it is appropriate and justifiable to express the Toothaker Pond TMDL as an annual load.

The Toothaker Pond basin lake assimilative capacity is capped at 5 kg TP/yr, as derived from the empirical phosphorus retention model based on a target goal of 13 ppb. This value reflects the modeled annual phosphorus loading responsible for current trophic state conditions, based on a long term goal of maintaining average phosphorus concentrations at or below 13 ppb.

Future Development: The Maine DEP water quality goal of maintaining a stable trophic state includes a reduction of current P-loading which accounts for both recent P-loading as well as potential future development in the watershed. The methods used by Maine DEP to estimate future growth (Dennis et al. 1992) are inherently conservative, as they provide for relatively high-end regional growth estimates and largely non-mitigated P-export from new development. This provides an additional non-quantified margin of safety to ensure the attainment of state water quality goals. Previously unaccounted P-loading from anticipated future development in the Toothaker Pond watershed approximates 0.20 kg annually (0.5 x 1 ppb change in trophic state = 0.39 kg).

Undoubtedly, human growth will continue to occur in the Toothaker Pond watershed, contributing new sources of phosphorus to the lake. Hence, existing phosphorus source loads must be reduced to allow for anticipated new sources of phosphorus to Toothaker Pond.

Phosphorus Reductions Needed: A change of 1 ppb of phosphorus concentration in Toothaker Pond equates to 0.39 kg. The difference between the target goal of 13 ppb and the average summertime total phosphorus concentration (24 ppb) is 4.30 kg (11 x 0.39). Given a 0.20 kg allocation for future development (0.5 x 0.39), the total amount of phosphorus needed to be reduced to maintain water quality standards is estimated to be 4.5 kg (4.3 + 0.2)

Internal Lake Sediment Phosphorus Mass: The relative contribution of internal sources of total phosphorus within Toothaker Pond - in terms of sediment TP recycling - were analyzed (using lake volume-weighted mass differences between late spring and late summer/early fall) and estimated on the basis of water column TP data from 2003. Phosphorus concentrations and total mass estimates for 2003 do not indicate any clear pattern of internal recycling over the sampling season. Evidence of low oxygen-mediated sediment release is also not obvious. Instead, it is likely that transient low oxygen conditions contribute, but do not dominate the sediment release of phosphorus. Despite oxic conditions at least 0.5 m above the sediment surface, it is likely that a steady precipitation-release process keeps phosphorus concentration high during the entire open water season without producing a late summer peak. In conclusion, the only real source of phosphorus large enough to account for Toothaker pond's poor water quality conditions is indeed sediment-related, however, confounding substrate composition factors make it difficult to effectively measure this contribution. Studies are in progress to determine causal relationships relative to sediment-phosphorus transfer and water quality.

Linking Pollutant Loading to a Numeric Target: The basin loading assimilative capacity for Toothaker Pond was set at 5 kg/yr of total phosphorus to meet the numeric water quality target of 13 ppb of total phosphorus. A phosphorus retention model, calibrated to in-lake phosphorus data, was used to link phosphorus loading to numeric target.

Supporting Documentation for the Toothaker Pond TMDL Analysis includes the following: DEP and VLMP water quality monitoring data, and specification of a phosphorus retention model – including both empirical models and retention coefficients.

Total Phosphorus Retention Model (after Dillon and Rigler 1974 and others)

L = P (A z p) / (1-R) where,

5 = **L** = external total phosphorus load capacity (kg TP/year)
13.0 = **P** = spring overturn total phosphorus concentration (ppb)
0.09 = **A** = lake basin surface area (km^2)
2.66 = **z** = mean depth of lake basin (m) **A z p = 0.19**
0.81 = **p** = annual flushing rate (flushes/year)
0.5 = **1- R** = phosphorus retention coefficient, where:
0.5 = **R = 1 / (1+ sq.rt. p)** (Larsen and Mercier 1976)

Previous use of the Vollenwieder (Dillon and Rigler 1974) type empirical model for Maine lakes, e.g., Cobbossee, Madawaska, Sebasticook, and China lakes, East, Webber, Threemile and Threecornered ponds, Mousam, Highland, and Annabessacook lakes, and Pleasant and

Sabattus pond TMDLs (Maine DEP 2000-2004) have all shown this approach to be effective in linking watershed phosphorus loadings to existing in-lake total phosphorus concentrations.

Strengths and Weaknesses in the Overall TMDL Analytical Process: The Toothaker Pond TMDL was developed using existing lake water quality monitoring data, derived watershed export coefficients (Reckhow et al. 1980, Maine DEP 1981 and 1989, Dennis 1986, Dennis and McPhedran 1991, Dennis et al. 1992, Bouchard et al. 1995, Soranno et al. 1996, and Mattson and Isaac 1999, and Monagle 1995) and a phosphorus retention model which incorporates both empirically derived and observed retention coefficients (Vollenwieder 1969, Dillon 1974, Dillon and Rigler 1974 a and b, and 1975, Kirchner and Dillon 1975). Use of the Larsen and Mercier (1976) total phosphorus retention term, based on localized data (northeast and north-central U.S.) from 20 lakes in the US-EPA National Eutrophication Survey (US-EPA-New England) provides a more accurate model for northeastern regional lakes.

Strengths:

- ❖ Approach is commonly accepted practice in lake management
- ❖ Makes best use of available water quality monitoring data
- ❖ Based upon experience with other lakes in the northeastern U.S. region, the empirical phosphorus retention model was determined to be appropriate for the application lake.

Weaknesses:

- ❖ Inherent uncertainty of TP load estimates (Reckhow 1979, Walker 2000) and associated variability and generality of TP loading coefficients.

Critical Conditions occur in Toothaker Pond during late summer and early autumn, when the potential (both occurrence and frequency) of nuisance algae blooms are greatest. The loading capacity of 13 ppb of total phosphorus was set to achieve desired water quality standards during this critical time period, and will also provide adequate protection throughout the year (see Seasonal Variation).

LOAD ALLOCATIONS (LA's) The load allocation for Toothaker Pond equals 5 kg TP on an annual basis and represents, in part, that portion of the lake's assimilative capacity allocated to non-point (overland) sources of phosphorus. Direct and indirect external TP sources (approx-imating 6 kg annually) have been identified and accounted for in the land-use breakdown portrayed in Table 1. As previously mentioned, it was not possible to separate natural background from non-point pollution sources in this watershed because of the limited and general nature of the available information.

WASTE LOAD ALLOCATIONS (WLA's): There are no known existing point sources of pollution (including regulated storm-water sources) in the Toothaker Pond watershed, hence, the waste load allocation for all existing and future point sources is set at 0 (zero) kg/year of total phosphorus.

MARGIN OF SAFETY (MOS): An implicit margin of safety was generally incorporated into the Toothaker Pond TMDL through the conservative selection of the numeric water quality target, as well as the selection of relatively conservative phosphorus export loading coefficients for cultural pollution sources (Table 1). Based on both the Toothaker Pond historical records and a summary of statewide Maine lakes water quality data for non-colored (< 30 SPU lakes) - the target of 13 ppb (5 kg TP/yr in Toothaker Pond) represents a highly conservative goal to assure attainment of Maine DEP water quality goals of non-sustained and non-repeated blue-green summer-time algae blooms due to NPS pollution or cultural eutrophication and stable or decreasing trophic state. The statewide data base for non-colored Maine lakes indicate that summer nuisance algae blooms (growth of algae which causes Secchi disk transparency to be less than 2 meters) are more likely to occur at 17 ppb or above. The difference between the in-lake target of 13 ppb (5.00 kg) and 17 ppb (6.56 kg) represents a 24% implicit margin of safety for Toothaker Pond. A non-quantified margin of safety for attainment of state water quality goals is also provided by the inherently conservative methods used by Maine DEP to estimate future growth in the Toothaker Pond watershed.

SEASONAL VARIATION: The Toothaker Pond TMDL is protective of all seasons, as the allowable annual load was developed to be protective of the most sensitive time of year – during the summer and early fall, when conditions most favor growth of algae and aquatic macrophytes. With an average annual flushing rate of 0.81, the average annual phosphorus loading is critical to the water quality in Toothaker Pond. Maine DEP lake biologists, as a general rule, use more than six flushes annually (bi-monthly) as the cutoff for considering seasonal variation as a major factor (to distinguish lakes vs. rivers) in the evaluation of total phosphorus loadings in aquatic environments in Maine.

Water Quality Monitoring Plan: Historically, the water quality of Toothaker Pond has been monitored via measures of Secchi disk transparencies during the open water months for the 1979 -1984 time period and 1998 and 2001 to 2003. Chlorophyll-a, total alkalinity and total phosphorus have also been measured during the same time period. Color and conductivity have been monitored for 7 out of the 10 years the pond has been monitored. Continued long-term water quality monitoring within Toothaker Pond will be conducted through the continued efforts of the VLMP in cooperation with Maine DEP. Under this planned, post-TMDL water quality-monitoring scenario, sufficient data will be acquired to adequately track seasonal and inter-annual variation and long-term trends in water quality in Toothaker Pond. A post-TMDL adaptive management status report will be prepared five to ten years following EPA approval.

Implementation Plan and Reasonable Assurances: Toothaker Pond is a waterbody that has impaired water quality mainly as a result of historical and present-day nonpoint source (NPS) pollution. Specific recommendations regarding options for in-lake remediation based on a variety of scenarios appear in the section entitled Recommendations for In-Lake Restoration (following page).

Methods for Estimating Lake Phosphorus Loading

Phosphorus loading estimates include relative watershed areas involved in various scenarios, which allowed for the current limited direct watershed of Meadow Brook and hatchery discharge. Besides watershed NPS sources, loading of P to Meadow Brook used hatchery supplied flow data and discharge monitoring reports of P concentrations. These include average daily flows and monthly composite total P concentrations from the hatchery. Phosphorus grab samples were taken every two weeks from March-December of 2003 at three points on Meadow Brook: just below the hatchery; at the stream water bypassing the hatchery just above the confluence; and, at the culvert about 400 feet upstream from the pond. These provide reasonable estimates of the potential P loads during most days, but neglect high flow (storm event) situations and may underestimate the loading.

The results of the stream grab samples allowed for estimation of the relative amount of flow from groundwater entering below the hatchery plus the upper stream bypassing the hatchery. This assumed that the change in P concentrations at the downstream site compared to the two upstream sites was the result of dilution by groundwater entering at the same concentration as the "west" station. By dilution, the calculated ratio of the hatchery discharge to all other flow in Meadow Brook was about 0.64:1 (range of 0.3 - 3.5 for 15 of 17 dates sampled). That is, the hatchery used about 40% of all flow. However, there was considerable variation with summer low stream flows providing very low dilution. This compares with total watershed flow yield estimates based on HA7 (0.61 m/yr x watershed area) and monitored hatchery flows (average about 0.46 million cubic meters/yr) which suggests that the hatchery discharges about 46% of all flow in Meadow Brook.

On May 11, 2004, Meadow Brook base flow was also estimated by use of a pygmy (Gurley) meter just below the hatchery and just above the culvert which diverts the stream near the lake. The flows were 0.9 and 1.6 c/f/s. Thus, hatchery flow appear to be about 56% of the total stream flow on that date.

Recommendations for In-Lake Restoration

Flow diversion/modification of Meadow Brook:

Estimated lake conditions evaluated for effect on lake total phosphorus:

1) Current situation, with a limited watershed area and low flushing rate
2) Diverting all of Meadow Brook flow into the pond but without hatchery P discharge
3) Diverting all of Meadow Brook flow into the pond and including hatchery P discharge
4) Diverting hatchery outflow around the pond and the rest of Meadow Brook flow (about 50%) into the pond without any hatchery P input
5) Diverting stream into the lake during 7 months (Oct-April) during times of higher dilution and stream flow.

Modeling the current scenario is likely not accurate, since the pond is functioning like a kettle hole (no stream inflow or outflow) and the usual Vollenwieder model was developed with a lake data set which is substantially different in size, hydrology and loading. Another problem is that calculating current direct watershed water input and P loading is likely inaccurate since there are no tributaries and the soils of the watershed may be permeable enough that little actual runoff occurs (vs. groundwater infiltration).

Under current circumstances, diverting the entire stream into the lake would probably increase lake phosphorus due to the hatchery load, despite a substantial increase in flushing rate. If the hatchery P discharge was removed, the expected lake concentration would be about 8-9 ppb. If half the volume of Meadow Brook (exclusive of hatchery flow) can be diverted to the lake, expected lake concentration would be about 8. Without allowance for internal loading, the predicted TP concentrations could drop from the current 15-20+ ppb to around 7 ppb. The seven-month diversion scenario would result in about 16 ppb, not enough to avoid algal blooms.

<u>Cost and feasibility</u>: A very rough cost estimate for piping ca. 0.5-1.0 MGD was provided by DEP engineering staff. This was predicated on using a 12-inch pipe, and may be conservative, given the flows reported (0.2-0.6 MGD). However, there is little savings going to a smaller pipe size. About 2,600 feet of pipe would be required. In addition, about 300-400 feet of new open channel, 30 feet of 24+ inch culvert would be needed to re-direct the stream flow. Lake outlet culvert renovation and channel cleaning is not included in these costs.

Preliminary Design evaluation	= $10,000-15,000
Pipe installation 2600 ft at $50+/ft	= $130,000 +
Engineering and oversight	= $32,000
Pump station	= $100,000
<u>New open channel and outlet work</u>	<u>= not estimated</u>
Total (w/out pump station)	$172,000 +
Total (with pump station)	$272,000

A dual pump station would have operation and maintenance costs estimated at $18,720 each year plus $4,000/yr. long term capital replacement costs. These are based on operating cost of a similarly-sized unit in a municipal system (B. De Haas, DEP). Other assumptions are: $50,000 construction cost, 20 year life cycle for 80% of the equipment (generator, pumps, electrical, heating systems etc.), and 5% inflation/yr. This does not include any costs for maintenance of the collection system.

NRPA licensing issues also need to be dealt with. Disruption of the stream channel to install a gravity pipe could be substantial even if excavation would not be necessary (e.g. installing a pipe and concrete collars in or near the channel with constant flow to avoid freeze up). One option to avoid substantial disruption of the stream channel would be to lay the pipe under the road and use a pump station as noted above.

Other considerations remain to be assessed, including:

a) Biological effects on the current stream channel which would see lower flows, potentially slight increase in temperature and higher nutrient concentrations (N and solids have not been assessed, but could be estimated). Per our Bio-assessment Program staff, the current stream channel (assessed in 1998) meets Class A standards, but may show some slight enrichment below the hatchery.

b) Likely conditions developed in the re-established outflow stream (lake surface water), especially under summer conditions. Since there is not aquatic habitat there now, it would be a net gain, depending on the answer to (a) above.

Aluminum treatment - Phosphorus inactivation:

The use of buffered alum (typically aluminum sulfate and sodium aluminate) is well-tested technique that has been used in Maine four times. Of these, three (Conchewagon, Annabess-acook, and Chickawaukie lakes) are considered successes and one (Threemile Pond) was not. One difficulty in treatment design is calculating the proper dose. A number of methods are available (see Cooke and Welch 2000), but all require several assumptions. However, field experience has shown that longevity of successful treatments has ranged from essentially permanent to the more usual 8-10 years. There have also been a number of treatments that failed to produce expected effects for more than a few years. These were usually the result of inadequate reduction of external loads, inadequate dosing rates or application techniques, or other factors such as bio-turbation or wind re-suspension.

A dosing estimate was done according to the method of Rydin and Welch (1998). This is based on the weakly-bound P content of the upper 4-10 cm of lake sediment. Enough Al (100:1) is added to neutralize all of the P likely to be available for re-mineralization, diffusion, and eventual transport to the water column. In March of 2004, sediment cores were obtained from three stations in the lake at depths 0f 10-14 ft. and sectioned in the field into 2.5 cm increments. These were analyzed by Colby College (Dr. Whitney King lab) using the extraction scheme cited above. This includes ammonium chloride extraction followed by buffered di-thionate. The total of these fractions should include loosely sorbed and iron-related phosphorus. The mean 0-5 cm and 0-10 cm estimates were 0.0098% and 0.014% P on a dry weight basis. On an areal basis, this means that between 24 and 68 g Al/sq. meter would be needed to achieve a 100:1 ratio in a treatment.

Using the rationale of Eberhardt (in Welch and Cooke 2000) dosing for this pond should likely exceed 20 g Al per square meter. This assumes:

10 year longevity
5 mg/m^2/yr release rate
75005 m^2 of active sediment area (area < 2 meter)
100 days/year active release

<u>Cost</u>: Based on ca. 35-40 g/Al/m^2 dosing rate, the rough estimated cost from TeeMark Corp (Tom Eberhardt) was ca. $23,000. However, the quoted price requires that the contractor has another operation in the region. Without this it would be much more expensive to mobilize for a treatment. An alternative would be for a contractor in this region to bid on a project, with or without subcontracting to use TeeMark's equipment typically used on small jobs such as this.

<u>Other Chemical treatments:</u> Relatively few case studies are available to evaluate the effectiveness and longevity of other chemical treatments. (see Cooke and Welch 2000, and Welch and Cooke 1995). In addition, the ability to calculate required doses, especially for calcium amendments, is poorly developed.

<u>Calcium treatments</u>: Case studies on these methods suggest that treatments with slaked lime (Ca(OH)2) may be beneficial in <u>hard water</u> lakes (pH >9), but only for only short time frames (ca. 2 years). It also requires careful acid buffering, probably with alum. However, the cost of materials and application for buffered, slaked lime combined with the low effectiveness, makes aluminum applications preferable (Tom Eberhardt, personal communication).

Soft water lakes, such as Toothaker Pond are likely to see Ca dissolve readily and thus less likely to bind P (the core sample in 8/03 had 2.44 mg/L total Ca). Use of limestone has not been especially effective in field trials.

<u>Calcium nitrate-treatment</u>: This technique is intended to enhance P binding in the sediments and to provide an alternate oxidizing source (nitrate) to reduce DO demand and increase redox potential in the sediments. To date, relatively few of these treatments have been done since aluminum treatments have proved more universally effective.

<u>Iron Additions</u>: Lakes with low sediment Fe/P ratios (ca. < 10) may respond better to other chemical treatments such as alum with the addition of iron. A typical agent used in Ferric chloride, but careful pH control is required and the difficulty of handling the material has discouraged its use. There is little clear information on which to base dosing. As a stand alone treatment, additional iron would have to raise the Fe/P ratio in sediment or in the lake water column (the latter only likely under re-suspension or anoxic conditions). In addition, low oxygen condition may inhibit P fixation and Fe solubilization, though the transient low oxygen conditions in this pond are not likely to be a major problem.

The extent to which Toothaker Pond sediments are deficient in Fe has not been determined. Additionally, Pearce et al, did not find a clear indication that Fe was a uniformly controlling factor in P release, albeit in anoxic hypolimnia.

<u>Artificial circulation/aeration:</u>

It is not clear that artificial circulation will be of any benefit. These systems are usually employed where there are considerable anoxia developed in hypolimnia, sub-optimal DO for aquatic life in large areas of the pond volume, or substantial metals, phosphorus or ammonia buildup in deep waters. None of these conditions apply here.

Oxygen profiles do suggest that the sediment surface/bottom water respiration exerts significant DO consumption on the lower 1% of the lake's volume or roughly 7% of the sediment area. This does not extend to the water above, and DO usually stays > 6 ppm throughout the upper water column. Temperature profiles suggest that the lake is only transiently stratified.

One potential advantage of enhanced circulation may be to disrupt any anoxic micro-layers that develop on the sediment surface and thereby limit P loss from the sediment. However, it is likely that the strongly reducing nature of the sediment would provide a gradient of P to diffuse into the water column regardless of the oxygen status of this zone. Since the upper reaches of the pond are oxic, the ability of the pond to re-precipitate P via Fe mechanisms is probably not adequate and the release rate is high enough to keep concentrations high regardless of sedimentation. There is a possibility that increased circulation over the bottom would increase the rate of P diffusion into surface waters by reducing the P concentration gradient at the sediment surface.

Cost: In small ponds, the most effective operations involve slow circulation, preferably by means of slow speed impellers or sometimes bubble diffusers. The latter are less energy efficient or effective. Preliminary quotes received from two sources (Solar Bee, Dickinson, ND. and CleanFlow , Plymouth MN) are roughly $16,000-30,000 for installation. Annual operating costs can be low, especially if a solar powered unit is chosen. Units requiring electrical supply and/or compressors are considerably more expensive due to maintenance and operating costs (ca. $500-1000/month).

Biomanipulation:

At this point, we do not have sufficient expertise to evaluate this as a method. However, ongoing pilot studies currently being carried out on East Pond (Oakland and Smithfield) by Maine DEP and the University of Maine with funding through US-EPA may be useful in the years to come. Zooplankton and phytoplankton samples taken from Toothaker Pond in August 2003 by Maine DEP have not yet been analyzed. These may allow some idea as to whether the size structure of the zooplankton population indicates an imbalance and reduced grazing efficiency. The pond was reportedly "reclaimed" for fish management in the 1970's and has been historically stocked, but not on a routine basis, with brook trout - as a put and take fishery (Maine DIFW). Originally surveyed in 1956 and resurveyed in 1992, pond reports issued by Maine DIFW list, in addition to golden shiners - northern redbelly dace, rainbow smelt and brook trout. Per request of Maine DEP, minnow-trapping in mid-June of 2004 by Maine DIFW (4 baited traps set for 46-hours each) resulted in relatively few fish present, primarily limited to golden shiner (n = 114) in association with yellow perch (n = 3), a new fish species record for

Toothaker Pond (Forrest Bonney and Dave Boucher, Maine DIFW). Fishery records indicate that Toothaker Pond "has a history of algal blooms caused by cultural eutrophication with an oxygen deficiency in the lower dephs" of the waterbody (Maine DIFW 1998 revision).

Methods Considered Not Feasible:

Barley Straw Application was initiated in May of 2001 and was considered unsuccessful. About 75 bales of straw were used for the entire project, remaining in the pond for a five-month period of time. Total project cost was about $1,300. As a result, the water quality for the summer of 2001 was slightly improved as there were no floating blankets of filamentous algae, but the pond did bloom.

Sediment dredging has a relatively good track record providing adequate removal is accomplished to below the enriched sediment level. Problems include expense, ca $140,000 ($20,000/ ha times >= 7 ha. for 1 meter removal in 1990 dollars) and environmental disruption.

Algaecides work for algal suppression. Problems include need for one of more annual treatments, long term expense, and Cu toxicity.

Drawdown problems include insufficient volume and lack of control structure, very long term response in low flushing situation

Hypolimnetic withdrawal: Problems include lack of stratification and concentration gradients, lack of control structure, insufficient inflow to maintain depth and habitat.

PUBLIC PARTICIPATION: Adequate ("full and meaningful") public participation in the Toothaker Pond TMDL development process was ensured through the following avenues:

1. September, 2002. Roy Bouchard (Maine DEP) held a public meeting to introduce the Toothaker Pond TMDL study, attended by 14 shoreline landowners.
2. August, 2003. DEP Memo from Roy Bouchard to Toothaker Pond shoreline landowners to update on the progress of the TMDL study.
3. July 2, 2004. Roy Bouchard held a public meeting to convey preliminary study results for the Toothaker Pond TMDL, attended by 12 shoreline landowners.

Stakeholder and Public Review Process was carried out during the one-month period of August 6 to September 6, 2004 with legal advertisement in the Franklin Journal and the Kennebec Journal (August 14-15 & 21-22, 2004) as follows: In accordance with Section 303(d) of the Clean Water Act, and implementation guidelines in 40 CFR Part 130 - the Maine Department of Environ-mental Protection has prepared a **Total Maximum Daily (Annual Phosphorus) Load (TMDL)** nutrient report for the **Toothaker Pond (DEPLW 2004-0069)** watershed, located within the town of Phillips in Franklin County, Maine. This TMDL report identifies and provides best estimates of non-point source phosphorus loads for all representative land use classes in the **Toothaker Pond direct watershed** and the total phosphorus reductions necessary to restore and maintain acceptable water quality conditions. A Public Review draft of this report may be viewed at Maine DEP Central Offices in Augusta (Ray Building, Hospital St., Route 9, Land & Water Bureau) or on-line: http://www.state.me.us/dep/blwq/comment.htm. Please send all comments in writing - by September 6, 2004, to Dave Halliwell, Lakes TMDL Program Manager, Maine DEP, SHS#17, Augusta, ME 04333, or e-mail: david.halliwell@maine.gov.

No stakeholder/public review comments were received during the allotted time period.

Maine Lake Total Maximum Daily Load (TMDL)

You may be wondering what the acronym 'TMDL' represents and what it is all about. TMDL is actually short for 'Total Maximum Daily Load.' This information, no doubt, does little to clarify TMDLs in most people's minds. However, when we think of this as an annual phosphorus load (*Annual Total Phosphorus Load),* it begins to make more sense.

Simply stated, excess nutrients or phosphorus in lakes promote nuisance algae growth/ blooms - resulting in the violation of water quality standards as measured by water clarity depths of less than 2 meters. A lake TMDL is prepared to estimate the total amount of total phosphorus that a lake can accept on an annual basis without harming water quality. Historically, development of TMDLs was first mandated by the Clean Water Act in 1972, and was applied primarily to *point sources* of water pollution. As a result of public pressure to further clean up water bodies, lake and stream TMDLs are now being prepared for watershed-generated *Non-Point Sources* (NPS) of pollution.

Nutrient enrichment of lakes through excess total phosphorus originating from watershed soil erosion has been generally recognized as the primary source of NPS pollution. Major land use activities contributing to the external phosphorus load in lakes include residential-commercial developments, roadways, agriculture, and commercial forestry. Statewide, there are 38 lakes in Maine which do not meet water quality standards due to excessive amounts of in-lake total phosphorus.

The first Maine lake TMDL was developed (1995) for Cobbossee Lake by the Cobbossee Watershed District (CWD) - under contract with Maine DEP and US-EPA. PCAP-TMDLs have been approved by US-EPA for Madawaska Lake (Aroostook County), Sebasticook Lake, East Pond (Belgrade Lakes), China Lake, Webber, Threemile and Threecornered Ponds (Kennebec County); Mousam and Highland (Duck) lakes in southern Maine; Annabessacook Lake and Pleasant Pond (CWD); Highland Lake - Bridgton and Sabattus Pond (final EPA approval); and Unity Pond in Waldo County (stakeholder review). TMDLs are presently being prepared by Maine DEP, with assistance from the Maine Association of Conservation Districts (MACD) and County Soil and Water Conservation Districts (SWCDs) - for Long Lake (under separate contract with LEA, Bridgton); Little Cobbossee Lake and Upper Narrows Pond (under separate contract w/ CWD). On-going lake TMDL studies include Togus, Lovejoy & Duckpuddle ponds.

Lake TMDL reports are based in part on available water quality data, including seasonal measures of total phosphorus, chlorophyll-a, Secchi disk transparencies, and dissolved oxygen-water temperature profiles. Actual reports include: a lake description; watershed GIS assessment and estimation of NPS pollutant sources; selection of a total phosphorus target goal (acceptable amount); allocation of watershed/land-use phosphorus loadings, and a public participation component to allow for stakeholder review.

TMDLs are important tools for maintaining and protecting acceptable lake water quality. They are primarily designed to 'get a handle' on the magnitude of the NPS pollution problem and to develop plans for implementing Best Management Practices (BMPs) to address the problem. Landowners and watershed groups are eligible to receive technical and financial assistance from state and federal natural resource agencies to reduce watershed total phosphorus loadings to the lake.

For further information, please contact Dave Halliwell, Maine Department of Environmental Protection, Lakes PCAP-TMDL Program Manager, SHS #17, Augusta, ME 04333 (287-7649).

Lake Specific References

Cooke, D. and E. Welch. 2000. Phosphorus inactivation in stratified and unstratified lakes and inflow interception. Workshop notes presented at NALMS, September 7, 2000. Miami, FL.

Pearce, A. , A. Amirbahman, R. Bouchard, S. Norton, and S. Kahl. 2003. Relationship between hypolimnetic phosphorus and iron release from eleven lakes in Maine. *Biogeochemistry* 65:369-386.

Rydin, E and E. B. Welch. 1998. Aluminum dose required to inactivate phosphate in lake sediments. *Water Resources* 32:2969:2967

Welch, B. 2004. Draft Analysis of phosphorus load and the water quality problems of Toothaker Pond. Maine Department of Environmental Protection, Augusta, Maine.

Welch, E. and G. D. Cooke. 1995. Internal phosphorus loading in shallow lakes: Importance and control. *Lake and Reservoir Management* 11(3):273-281.

General References

Barko, J.W., W.F. James, and W.D. Taylor. 1990. Effects of alum treatment on phosphorus and phytoplankton dynamics in a north-temperate reservoir: a synopsis. *Lake and Reservoir Management* 6:1-8.

Basile, A.A. and M.J. Vorhees. 1999. A practical approach for lake phosphorus Total Maximum Daily Load (TMDL) development. *US-EPA Region I*, Office of Ecosystem Protection, Boston, MA (July 1999).

Bostrom, B., G. Persson, and B. Broberg. 1988. Bioavailability of different phosphorus forms in freshwater systems. *Hydrobiologia* 170:133-155.

Bouchard, R., M. Higgins, and C. Rock. 1995. Using constructed wetland-pond systems to treat agricultural runoff: a watershed perspective. *Lake and Reservoir Management* 11 (1):29-36.

Butkus, S.R., E.B. Welch, R.R. Horner, and D.E. Spyridakis. 1988. Lake response modeling using biologically available phosphorus. *Journal of Water Pollution Control Federation* 60:1663-69.

Carlton, R.G. and R.G. Wetzel. 1988. Phosphorus flux from lake sediments: effect of epipelic algal oxygen production. *Limnology and Oceanography* 33(4):562-570.

Chapra, S.C. 1997. <u>Surface Water-Quality Modeling</u>. McGraw-Hill Companies, Inc.

Cooke, G.D., E.B. Welch, S.A. Peterson, and P.R. Newroth. 1986. <u>Lake and Reservoir Restoration</u>. Buttersworth, Boston, MA.

Correll, D.L., T.L. Wu, E.S. Friebele, and J. Miklas. 1978. Nutrient discharge from Rhode Island watersheds and their relationships to land use patterns. In: *Watershed Research in Eastern North America: A workshop to compare results*. Volume 1, February 28 - March 3, 1977. (mixed pine/hardwoods)

Dennis, W.K. and K.J. Sage. 1981. Phosphorus loading from agricultural runoff in Jock Stream, tributary to Cobbossee Lake, Maine: 1977-1980. *Cobbossee Watershed District*, Winthrop.

Dennis, J. 1986. Phosphorus export from a low-density residential watershed and an adjacent forested watershed. *Lake and Reservoir Management* 2:401-407.

Dennis, J., J. Noel, D. Miller, C. Elliot, M.E. Dennis, and C. Kuhns. 1992. Phosphorus Control in Lake Watersheds: A Technical Guide to Evaluating New Development. *Maine Department of Environmental Protection*, Augusta, Maine.

Dillon, P.J. 1974. A critical review of Vollenweider's nutrient budget model and other related models. *Water Resources Bulletin* 10:969-989.

Dillon, P.J. and F.H. Rigler. 1974a. The phosphorus-chlorophyll relationship for lakes. *Limnology and Oceanography* 19:767-773.

Dillon, P.J. and F.H. Rigler. 1974b. A test of a simple nutrient budget model predicting the phosphorus concentration in lake water. *Journal of the Fisheries Research Board of Canada* 31:1771-1778.

Dillon, P.J. and F.H. Rigler. 1975. A simple method for predicting the capacity of a lake for development based on lake trophic status. *Journal of the Fisheries Research Board of Canada* 32:1519-1531.

Dudley, R.W., S.A. Olson, and M. Handley. 1997. A preliminary study of runoff of selected contaminants from rural Maine highways. U.S. Geological Survey, Water-Resources Investigations Report 97-4041 (DOT, DEP, WRI), 18 pages.

Gasith, Avital and Sarig Gafny. 1990. Effects of water level fluctuation on the structure and function of the littoral zone. Pages 156-171 (Chapter 8) in: M.M. Tilzer and C. Serruya (eds.), *Large Lakes: Ecological Structure and Function*, Springer-Verlag, NY.

Heidtke, T.M. and M.T. Auer. 1992. Partitioning phosphorus loads: implications for lake restoration. *Journal of Water Resources Plan. Mgt.* 118(5):562-579.

James, W.F., R.H. Kennedy, and R.F. Gaubush. 1990. Effects of large-scale metalimnetic migrations on phosphorus dynamics in a north-temperate reservoir. *Canadian Journal of Fisheries and Aquatic Sciences* 47:156-162.

James, W.F. and J.W. Barko. 1991. Estimation of phosphorus exchange between littoral and pelagic zones during nighttime convective circulation. *Limnology and Oceanography* 36 (1):179-187.

Jemison, J.M. Jr., M.H. Wiedenhoeft, E.B. Mallory, A. Hartke, and T. Timms. 1997. A Survey of Best Management Practices on Maine Potato and Dairy Farms: Final Report. University of Maine Agricultural and Forest Experiment Station, Misc. Publ. 737, Orono, Maine.

Kallqvist, Torsten and Dag Berge. 1990. Biological availability of phosphorus in agricultural runoff compared to other phosphorus sources. *Verh. Internat. Verein. Limnol.* 24:214-217.

Kirchner, W.B. and P.J. Dillon. 1975. An empirical method of estimating the retention of phosphorus in lakes. *Water Resources Research* 11:182-183.

Larsen, D.P. and H.T. Mercier. 1976. Phosphorus retention capacity of lakes. *Journal of the Fisheries Research Board of Canada* 33:1742-1750.

Lee, G.F., R.A. Jones, and W. Rast. 1980. Availability of phosphorus to phytoplankton and its implications for phosphorus management strategies. Pages 259-308 (Ch.11) in: *Phosphorus Management Strategies for Lakes*, Ann Arbor Science Publishers, Inc.

Likens, G.E., F.H. Bormann, R.S. Pierce, J.S. Eaton, and N.M. Johnson. 1977. Bio-Geochemistry of a Forested Ecosystem. Springer-Verlag, Inc. New York, 146 pages.

Maine Department of Environmental Protection. 1999. Cobbossee Lake (Kennebec County, Maine) Final TMDL Addendum (to Monagle 1995). *Maine Department of Environmental Protection*, Augusta, Maine.

Marsden, Martin, W. 1989. Lake restoration by reducing external phosphorus loading: the influence of sediment phosphorus release (Special Review). *Freshwater Biology* 21(2):139-162.

Martin, T.A., N.A. Johnson, M.R. Penn & S.W. Effler. 1993. Measurement and verification of rates of sediment phosphorus release for a hypereutrophic urban lake. *Hydrobiologia* 253:301-309.

Mattson, M.D. and R.A. Isaac. 1999. Calibration of phosphorus export coefficients for total maximum daily loads of Massachusetts lakes. *Journal of Lake and Reservoir Management* 15(3):209-219.

Michigan Department of Environmental Quality. 1999. Pollutant Controlled Calculation and Documentation for Section 319 Watersheds *Training Manual*. Michigan DEQ, Surface Water Quality Division, Nonpoint Source Unit.

Monagle, W.J. 1995. Cobbossee Lake Total Maximum Daily Load (TMDL): Restoration of Cobbossee Lake through reduction of non-point sources of phosphorus. *Prepared for ME-DEP by Cobbossee Watershed District.*

Nurnberg, G.K. 1984. The prediction of internal phosphorus load in lakes with anoxic hypolimnia. *Limnology and Oceanography* 29:111-124.

Nurnberg, G.K. 1987. A comparison of internal phosphorus loads in-lakes with anoxic hypolimnia: Laboratory incubation versus in situ hypolimnetic phosphorus accumulation. *Limnology and Oceanography* 32(5):1160-1164.

Nurnberg, G.K. 1988. Prediction of phosphorus release rates from total and reductant-soluble phosphorus in anoxic lake sediments. *Canadian Journal of Fisheries and Aquatic Sciences* 45:453-462.

Nurnberg, G.K. 1995. Quantifying anoxia in lakes. *Limnology & Oceanography* 40(6):1100-11.

Reckhow, K.H. 1979. Uncertainty analysis applied to Vollenweider's phosphorus loading criteria. *Journal of the Water Pollution Control Federation* 51(8):2123-2128.

Reckhow, K.H., M.N. Beaulac, and J.T. Simpson. 1980. Modeling phosphorus loading and lake response under uncertainty: a manual and compilation of export coefficients. EPA 440/5-80-011, *US-EPA*, Washington, D.C.

Reckhow, K.H., J.T. Clemens, and R.C. Dodd. 1990. Statistical evaluation of mechanistic water-quality models. *Journal Environmental Engineering* 116:250-265.

Riley, E.T. and E.E. Prepas. 1985. Comparison of phosphorus-chlorophyll relationships in mixed and stratified lakes. *Canadian Journal of Fisheries and Aquatic Sciences* 42:831-835.

Rippey, B., N.J. Anderson, and R.H. Foy. 1997. Accuracy of diatom-inferred total phosphorus concentrations and the accelerated eutrophication of a lake due to reduced flushing and increased internal loading. *Canadian Journal of Fisheries and Aquatic Sciences* 54:2637-2646.

Schroeder, D.C. 1979. Phosphorus Export From Rural Maine Watersheds. *Land and Water Resources Center, University of Maine*, Orono, Completion Report.

Singer, M.J. and R.H. Rust. 1975. Phosphorus in surface runoff from a (northeastern United States) deciduous forest. *Journal of Environmental Quality* 4(3):307-311.

Sonzogni, W.C., S.C. Chapra, D.E. Armstrong, and T.J. Logan. 1982. Bioavailability of phosphorus inputs to lakes. *Journal of Environmental Quality* 11(4):555-562.

Soranno, P.A., S.L. Hubler, S.R. Carpenter, and R.C. Lathrop. 1996. Phosphorus loads to surface waters: a simple model to account for spatial pattern. *Ecological Applications* 6 (3):865-878.

Sparks, C.J. 1990. Lawn care chemical programs for phosphorus: information, education, and regulation. U.S. Environmental Protection Agency, Enhancing States' Lake Management Programs, pages 43-54. [Golf course application]

Stefan, H.G., G.M. Horsch, and J.W. Barko. 1989. A model for the estimation of convective exchange in the littoral region of a shallow lake during cooling. *Hydrobiologia* 174:225-234.

Tietjen, Elaine. 1986. Avoiding the China Lake Syndrome. Reprinted from *Habitat* - Journal of the Maine Audubon Society, 4 pages.

U.S. Environmental Protection Agency. 1999. Regional Guidance on Submittal Requirements for Lake and Reservoir Nutrient TMDLs. *US-EPA Office of Ecosystem Protection*, New England Region, Boston, MA.

U.S. Environmental Protection Agency. 2000a. Cobbossee Lake TMDL Approval Documentation. US-EPA/NES, January 26, 2000.

U.S. Environmental Protection Agency. 2000b. Madawaska Lake TMDL Final Approval Documentation. US-EPA/NES, July 24, 2000.

U.S. Environmental Protection Agency. 2001a. Sebasticook Lake TMDL Final Approval Documentation. US-EPA/NES, March 8, 2001.

U.S. Environmental Protection Agency. 2001b. East Pond TMDL Final Approval Documentation. US-EPA/NES, October 9, 2001.

U.S. Environmental Protection Agency. 2001c. China Lake TMDL Final Approval Documentation. US-EPA/NES, November 5, 2001.

U.S. Environmental Protection Agency. 2003a. Highland (Duck) Lake TMDL Final Approval Documentation. US-EPA/NES, June 18, 2003.

U.S. Environmental Protection Agency. 2003b. Webber Pond TMDL Final Approval Documentation. US-EPA/NES, September 10, 2003.

U.S. Environmental Protection Agency. 2003c. Threemile Pond TMDL Final Approval Documentation. US-EPA/NES, September 10, 2003.

U.S. Environmental Protection Agency. 2003d. Threecornered Pond TMDL Final Approval Documentation. US-EPA/NES, September 10, 2003.

U.S. Environmental Protection Agency. 2003e. Mousam Lake TMDL Final Approval Documentation. US-EPA/NES, September 29, 2003.

U.S. Environmental Protection Agency. 2004a. Annabessacook Lake TMDL Final Approval Documentation. US-EPA/NES, May 18, 2004.

U.S. Environmental Protection Agency. 2004b. Pleasant (Mud) Pond TMDL Final Approval Documentation. US-EPA/NES, May 20, 2004.

U.S. Environmental Protection Agency. 2004c. Sabattus Pond TMDL Final Approval Documentation. US-EPA/NES, August 12, 2004.

U.S. Environmental Protection Agency. 2004d. Highland Lake TMDL Final Approval Documentation. US-EPA/NES, August 12, 2004.

U.S. Environmental Protection Agency. 2003e. Unity Pond TMDL Final Approval Documentation. US-EPA/NES, September xx, 2004.

Vollenweider, R.A. 1969. Possibility and limits of elementary models concerning the budget of substances in lakes. *Arch. Hydrobiol.* 66:1-36.

Walker, W.W., Jr. 2000. Quantifying Uncertainty in Phosphorus TMDLs for Lakes. March 8, 2001 *Draft* Prepared for NEIWPCC and EPA Region.