Phosphorus Total Maximum Daily Load (TMDL)

for

Ticklenaked Pond

Waterbody VT14-07L02

October, 2009

(Approved by USEPA: November 30, 2009)

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with guidance from:

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1. Background

1.1 Introduction

Section 303(d) of the Clean Water Act requires waters that do not meet state water quality standards have a Total Maximum Daily Load (TMDL) analysis prepared. A TMDL is a document that articulates the maximum permissible load of any given pollutant that can enter a waterbody while allowing that waterbody to attain the water quality standards for that pollutant. This maximum load, called the total loading capacity, is divided into one allocation for the non-point source pollution load, and another for the point-source pollution load. The total loading capacity is also commonly reduced by a margin of safety, intended to ensure that implementation of the TMDL results in attainment of standards. The margin of safety accounts for uncertainties in each component of the TMDL.

Ticklenaked Pond, in Ryegate, Vermont, has had increasing water quality problems for several years. Late summer algae blooms, reduced water clarity, low deepwater dissolved oxygen, elevated pH, and recently, blooms of cyanobacteria are symptoms of systemic, excessive loadings of phosphorus to this lake. The Agency of Natural Resources (VTANR) identified Ticklenaked Pond as impaired and not meeting VT Water Quality Standards due to excessive phosphorus loading and resultant excessive algal production. Ticklenaked Pond is listed on the 2008 303(d) List of Impaired Waters where it is identified as a high priority for TMDL development. Excessive amounts of phosphorus in the lake feed algae growth to the extent that problem conditions are routinely present. Recently the Ticklenaked Pond Watershed Association, the Natural Resources Conservation Service, and watershed landowners have worked within the watershed to reduce sources of phosphorus. Simultaneously, VTDEC has carried out a comprehensive study of phosphorus loadings to the Pond, to prepare this TMDL.

This TMDL documents quantitative measured estimates of phosphorus loadings to the lake from watershed tributaries and from direct precipitation. This TMDL also provides quantitative modeled estimates of septic loads and internal phosphorus recycling. Internal recycling is a phenomenon whereby legacy phosphorus stored in the sediments of lakes is released to the overlying waters, accentuating phosphorus concentrations, and therefore algal blooms. This TMDL articulates the phosphorus load reductions needed to bring the lake into compliance with the Water Quality Standards, to meet the recreational needs of lake users and restore ecological integrity to the lake’s flora and fauna.

1.2 Description of Ticklenaked Pond

Ticklenaked Pond is a 54 acre lake which was impounded from a smaller, natural lake at some undetermined point in the past 200 years. Field observations of the earthworks at the lake’s southern end and outlet suggest that the water level was raised approximately two meters by the impoundment. Local historians report the purpose of this was to store water for a small sawmill, the remnants of which are on the banks of the Scotch Burn, just downstream of the lake outlet. The impounded area is 33% of the total lake area, and the impounded volume represents 26% of the total lake volume. The lake is 14.5 meters deep at the deepest hole (46 ft), and has a mean depth of 4.9 meters (16 ft). The lake volume is approximately 1.1M m^3, or 864 acre-feet.

The lake's watershed is 1,444 acres in size, and drains largely forested portions of the "Blue Mountain" area adjacent to the Groton State Forest. The watershed features several blocks of agricultural land, including pasture, barnyard, hayfield, and row crops, which are near or adjacent to the Scotch Burn upstream of the lake (Figure 1). Watershed land use acreages are described in Section 1.3.9. There is a prominent pasture area adjacent to the lake's northeast shore, which is actively grazed. In 1999, the shoreline adjacent to this pasture was fenced to keep cattle from accessing the lake; one of the first actions taken by the Ticklenaked Pond Watershed Association (TPWA) to address nutrient runoff to the pond.

1.3 Current Water Quality Conditions

1.3.1 Long-term water quality trends

Monitoring of Ticklenaked Pond has been carried out by the Spring Phosphorus and Vermont Lay Monitoring Programs since 1981 and 1999, respectively. The Spring Phosphorus Monitoring Program is designed to track long-term trends in total phosphorus in lakes statewide at spring-overturn. While not all lakes are measured annually, Ticklenaked Pond has an 18-year record since 1981 (Figure 2). The mean spring total phosphorus is 41 ppb (+/- 3.4), which is considerably higher than the summer mean measured by citizen monitors, and ranks in the top 3% of lakes statewide. These measurements are made in the central portion of the lake.

The Vermont Lay Monitoring Program trains citizen volunteers to collect summertime weekly measurements of total phosphorus, chlorophyll-a, and Secchi transparency. The mean total phosphorus based on the 8-year record is 34 parts-per-billion (+/- 2.8 std. err.), which ranks in the top 5% of all inland lakes monitored by the program. The mean chlorophyll-a is 15 ppb (+/- 1.6, top 5% of inland lakes), and the Secchi transparency is 1.5 meters (+/- 0.2). Lay Monitoring Program measurements provide an indication of water quality in the summer months when the lake is subject to maximum recreational use (Figure 2).

1.3.2 Intensive water quality investigations

A prior, three-year monitoring VTANR-led effort identified Ticklenaked Pond as impaired due to excessive phosphorus concentrations, and can be summarized in the following quote from the 303(d) listing documentation for the lake (VTDEC, 2003):

> "Ticklenaked Pond may exhibit violations of several existing water quality standards, including pH, dissolved oxygen, phosphorus, and habitat and biological integrity. A key deciding factor is the extent to which the apparent violations are attributable to natural factors. All of the issues outlined above are inter-related, and stem from excess nutrient accumulation. However, Ticklenaked Pond is protected from high winds, and has a relatively narrow configuration, which may inhibit complete mixing – an obvious natural influence on the phosphorus dynamics in the lake. Nevertheless, data shows that the lake mixed completely in 1998, 1999, and 2000.

> The available data indicate the following. Periodic fluxes of manure have entered the lake in recent history, and sediment continues to accumulate to the lake at a high rate. Phosphorus concentrations are the fourth highest in Vermont. Dissolved oxygen is insufficient to support warmwater fishery habitat in over ½ of the lake's volume. The pH in the top three meters of the lake is sufficiently high to affect aquatic biota approximately 1/3rd of the days sampled. The strongly cyanobacteria-dominated phytoplankton community would be defined as 'poor' based on VT's lake biocriteria system. Finally, there is no deepwater benthic community.
>
> The hypolimnion of Ticklenaked Pond has been shown to become anoxic very quickly after spring ice-out, and this anoxia persists until turnover, a period of 200 or more days per year. Thus the time period during which externally loaded phosphorus can bind to sediments below the oxycline is very limited. In addition, sediment core studies suggest that sediment particulate matter accumulation rates are high (≥ 6 mm yr $^{-1}$). Accordingly, the majority of that phosphorus which is loaded to the lake on particles may be rapidly sinking, but not able to adsorb to lake-bottom sediments due to the lack of chemical binding. Therefore, the observed high phosphorus concentrations in the lake may more likely be the product of *anoxic hypolimnetic storage* rather than the result of sediment phosphorus release. These findings indicate that measures to reduce nonpoint sources of nutrients are necessary and will improve lake water quality."

A major ambiguity in this prior analysis was the lack of reliable estimates of watershed loadings, which would be necessary to understand internal phosphorus recycling. As a result, VTANR carried out a comprehensive field program in support of this TMDL, with considerable support from USEPA. Automated instrumentation and intensive sampling was employed to generate a mass-balance for phosphorus to this nutrient-impaired lake. The purpose of the mass balance assessment was to identify influent phosphorus loads, internal loads, and to derive load allocations necessary to meet standards. The field program was carried out from May 26, 2005 through November 10, 2006.

The sampling strategy is described in the project Quality Assurance Project Plan (VTDEC, 2005). In brief, water flow and water quality were both monitored. For water flows, Scotch Burn and the lake surface were instrumented with water level stage recorders. Measurements of flow were acquired at both the lake inlet and outlet (TICKT01 and TICKO01) using an acoustic doppler current meter. Water quality samples were taken for multiple parameters at the main inlet tributary, several smaller tributaries, the outlet, and at two lake locations (Figure 3). Sampling frequency was weekly-biweekly for all sites, and in response to flow events, as needed, in the tributaries.

The dataset is comprehensive, comprising: lake samples, 40 dates; tributary samples, 70 dates; outlet samples, 53 dates. In addition, the project team collected 565 multiprobe casts from the lake, and fixed instrumentation provided in excess of 40,000 individual records for tributary and lake stage, as well as 206 precipitation event-days. Appendix A provides detailed results of the phosphorus load calculations carried out using the study results.

1.3.3 Approach to modeling

The general approach to modeling phosphorus in Ticklenaked Pond used measurements of watershed loads, and robust estimates of septic and internal loads, to model the in-lake phosphorus concentrations that result from these loads. Septic and internal load estimations and in-lake modeling relied on the Wisconsin Inland Lakes Modeling Suite (WILMS, WIDNR, 2001). WILMS offers several approaches to estimating in-lake phosphorus concentrations from loads, relying on well-accepted, published lake phosphorus models. In this TMDL, we rely primarily on the model of Nurnberg (1984), which was specifically designed to tease apart the external and internal components of total phosphorus loads to lakes. Once Nurnberg's model was parameterized, it was used to back-calculate the total loading capacity to meet the target phosphorus criterion.

1.3.4. Measured watershed loads

To calculate water inflows, a rating curve predicting inflow volume from river stage was calculated. To calculate water outflows, a rating curve predicting outflow volume from lake level was calculated. For ungauged areas, the mean observed residual in water outflows relative to inflows of 15.8% was attributed to loads from the very small ungauged tributaries 02 through 06, plus groundwater flow. This residual water inflow was allocated to tributaries 02 through 06 by pro-rating the tributary contributing areas relative to the total ungauged area. Total water loading to the lake for water-year 2006 was 3.06×10^6 m^3.

To calculate nutrient loads, total phosphorus concentrations measured from each of the tributaries and the outlet were related to simultaneously-measured water-stage, to generate stage-concentration relationships. Resulting predictions (and errors) for total phosphorus concentrations and measurement errors were estimated on an hourly basis from the stage measurements, and multiplied by water load. The resulting phosphorus loads were summed across the project period to derive annual loads. The total annual watershed phosphorus load for water-year 2006 was 202 kg.

Finally, since water-year 2006 was quite wet, the 2006 phosphorus load was adjusted to the mean water year load. This conversion was based on the understanding that the long-term mean flow was 57% of the 2006 water year mean flow, based on data from the proximal United States Geological Survey gauge in the Wells River. The adjusted total annual watershed phosphorus load for the mean water year was 115 kg. Methodological details underlying these calculations are shown in Appendix A. This TMDL is calculated based on the mean water year total watershed load of 115 kg/yr (Table 1) and the mean water year tributary flow volume of 1.74×10^6 m^3 (57% of the 2006 watershed inflow).

Table 1. Summary of total phosphorus loads from tributary streams to Ticklenaked Pond, Ryegate, VT, for water year 2006 and the mean water year.

	Load (Kg P)	Load (KgP) at standard water year (57% of 2006)
Scotch Burn	195.1	111
Trib 2	1.9	1.1
Trib 4	1.3	0.7
Trib 3	1.2	0.7
Trib 6	2.5	1.4
Total inlet load	202.1(± 27.96*)	115
Total outlet loss	105.3	72.9**

* Calculated standard error for total load
**Outflow loads are calculated at mean water year are calculated as the product of the mean annual TP and outflow volume.

1.3.5. Septic loads

Septic loading from properties directly adjacent to the lake was estimated using a procedure that relies on the number of persons annually using septic systems adjacent to the lake, the per-capita phosphorus delivery to septic systems, a factor relating to septic system integrity, and a factor relating to soil phosphorus retention. The per-capita contribution and soil and system factors were derived from a set of studies conducted on lakes by the State of Wisconsin, and provided in WILMS, and should be considered suitable for application in the Ticklenaked Pond watershed. Specific to Ticklenaked Pond, 25 camps were identified within 50 meters of the lakeshore using a geographic information system. To derive an annual count of persons using septic systems, we assumed four persons per camp, and an occupation of ½ year per camp, leading to the following estimate:

25 camps x 4 persons/camp x 0.5 yrs occupancy/camp = 50 person-years usage.

Septic phosphorus discharges to the lake ranged from < 1 kg/yr (assuming effective soil retention and adequate septic system design), to 8 kg/yr (assuming poorly-functioning systems and poor phosphorus retention in soils). The WILMS “most likely” value of 2.5 kg/yr was rounded up (3 kg/yr), and used in further analyses.

1.3.6. Internal phosphorus cycling and mass balance

To provide a more quantitative estimate of potential internal nutrient cycling, we modeled the magnitude of sediment-recycled phosphorus loads. WILMS offers four approaches for estimating internal phosphorus loading, described here from the system documentation.

Method 1 relies on the model of Nurnberg (1984) which separates out the external and internal loads using the equations:

$$P = \frac{L_{Ext}}{q_s}(1-R) + \frac{L_{Int}}{q_s}$$

$$R = \frac{15}{18 + q_s}$$

Where: P = annual average total phosphorus concentration, mg/l
Lext = areal annual external P load, $g/m^2/yr$
q_s = areal water load, m/yr
R = phosphorus retention coefficient, and
Lint = areal internal P load, $g/m^2/yr$

The internal loading term in the Nurnberg model represents the amount of internal load in excess of what would be found in an oxic lake with similar characteristics Nurnberg (1984).

Method 2 uses growing season P increases to estimate internal loading. This method calculates the increase in mass of phosphorus in the hypolimnion during anoxia to come up with a total internal load. Method 3 uses data quantifying the increase in phosphorus concentration in the fall. Method 4 uses empirical P release rates (low, most likely and high) and applies them to the average anoxic sediment area over the period of anoxia. The estimates for each method were similar, ranging from 24-47 kg/yr for the average water year (Table 2). The model of Nurnberg is most appropriate for calculating an annual mass balance, and therefore, the Method 1 estimate is used in the development of this TMDL.

Table 2. Internal P load estimates for Ticklenaked Pond derived using WILMS, derived for the average water-year.

Method	Kg P/yr
1. Nurnberg model	24
2. From growing season in situ phosphorus increases	38
3. From in situ phosphorus increases in the fall	47
4. From phosphorus release rate and anoxic area, using most likely p release rates	41

Using the terms of this model (Table 3), the total mass balance can be calculated as shown in Table 4. This model is used in Section 3 to determine total loading capacity. The total estimated annual load of phosphorus to Ticklenaked Pond at the mean water year is 144 kg.

Table 3. Nurnberg model parameters used to calculate mass balance for Ticklenaked Pond.

Nurnberg (1984) Model for the Standard Water Year			
Term	Units	Value	Comment
P observed	ug/l	41	Long-term mean Spring P
Wext	kg/yr	120	External P load, standard year
Lext	g/m2/yr	0.540	Areal external P load, standard year
Wint	kg/yr	24	Mass internal load, calculated as (Lint x A)/1000
Lint	g/m2/yr	0.114	Areal internal load, solved from Nurnberg model
A	m2	218,538	Lake Area, 54 acres
Q watershed	hm3/yr	1.740	Standard year water load (0.57 X 3.060 hm3/yr)
Q direct	hm3/yr	0.116	Standard year water load (direct to lake)
Q total	hm3/yr	1.856	Standard year water load (total)
Qs	m/yr	8.49	Calculated
R predicted		0.57	Calculated Nurnberg oxic lake model retention
R observed		0.37	Retention calculated from observed input/outflow

Table 4. Estimated annual phosphorus mass balance for Ticklenaked Pond by source category, for 2006 and for the mean water year.

Source of phosphorus load	Measured load in kg (± range), 2006 water year	Estimated load, mean water year[2]	Value used to calculate TMDL (kg)
Watershed tributaries	202 (175-229)[1]	115	115
Septic loads	2.5 (<1 – 8)	3	3
Direct precipitation	3.5	2	2
Internal load	19 (19-53)	24 (24-47)	24
Total annual load			144

1) Range is reported as +/– one standard error.
2) Total watershed load at mean water year = 0.57 * 2006 watershed load.

1.3.9 Apportioning the phosphorus loads to land use categories

The WILMS land-use export module was used to apportion the non-point source load to various land use categories (Table 5). Land use categories were: agricultural (row crop and pasture/hay); rural residential; forest; wetlands; direct precipitation to openwaters; and septic. Land use proportions were calculated from Vermont Center for Geographic Information (1996). Except for wetlands, applicable export coefficients were taken from Budd and Meals (1994) identified the most relevant coefficients for to the Lake Champlain Basin. Wetland export coefficients were taken from WILMS. After they were calculated, total load estimates were reduced in proportion to the difference between the "most likely" loads and the actual tributary loads at the mean water year. The estimates in Table 5 express the relative contribution of phosphorus from each land use category. The information provided by this analysis is used in the development of the implementation plan (Section 10).

Table 5. Export of phosphorus from various land uses

Land use class	Area	Adjusted loads (kg)	Percent of load
Agricultural - row crop	144	64	53%
Agricultural - pasture/grass	243	22	18%
Rural residential	91	11	9%
Forest	817	16	13%
Wetlands	110	2	2%
Direct to lake surface	54	2	2%
Septic loads		3	3%
Total	1498	120	100%

2. Numeric Water Quality Criteria

2.1 Designated Uses and Applicable Criteria Limits

Ticklenaked Pond is a Class B waterbody. Class B waterbodies are to support at minimum consistently good aesthetics, no undue adverse impacts to aquatic life use and habitat, and supported primary and secondary contact recreation. These uses are impaired by phosphorus in Ticklenaked Pond. The current Vermont water quality standards do not provide a numeric criterion for phosphorus in Class B inland lakes. Rather, they state:

> *(…)*
> *All waters - general policy*
> *In all waters, total phosphorous loadings shall be limited so that they will not contribute to the acceleration of eutrophication or the stimulation of the growth of aquatic biota in a manner that prevents the full support of uses. (…)*
>
> *d. Lakes, ponds, or reservoirs that have drainage areas of less than 40 square miles and a drainage area to surface area ratio of less than 500:1, and their tributaries.*
>
> *(1) In addition to compliance with the general policy above, there shall be no significant increase over currently permitted phosphorus loadings. Discharges to tributaries shall not increase in-stream conditions by more than 0.001 mg/l at low median monthly flow. Indirect discharges to lakes, ponds, or reservoirs shall not increase total dissolved phosphorus as measured in the groundwater 100 feet from the mean water level of the lake, pond, or reservoir by more than 0.001 mg/l.*
>
> *(2) Applicable basin plans, other applicable plans, permit limitations, and other measures adopted or approved by the Secretary, may define "no significant increase" so as to allow new or increased discharges of phosphorus, only when the permit for such discharges provides for a corresponding reduction in phosphorus loadings to the receiving waters in question. (…)*

2.2 TMDL Target Concentration

During 2007 and 2008, VTDEC carried out a comprehensive series of analyses aimed at deriving numeric phosphorus criteria for lakes and ponds. This was part of VTDEC's Nutrient Criteria initiative, which is reported in detail by VTDEC (2008). The criterion proposed for total phosphorus in Class B waters to protect aesthetic and aquatic life uses is 24 ppb. This criterion is adopted for the present TMDL.

3. Total Loading Capacity

The total loading capacity is the annual phosphorus load that can be discharged to Ticklenaked Pond waters such that those waters attain the TMDL target concentration. The TMDL target identified here is designed to be protective during the critical conditions of warmer weather periods when excessive algal growth is likely to be the greatest. To estimate the total loading capacity, we used the model as parameterized in Section 1.3.8 to simulate the in-lake annual phosphorus concentration resulting from reductions in total loads under standard water year conditions. The total loading capacities are presented in two components; an external watershed load of 104 kg/yr, and an internal load of zero. Assigning a total loading capacity of zero for the internal loading component essentially establishes the goal of reducing the internal loading in Ticklenaked Pond to the point where the phosphorus retention value is comparable to what would exist in an oxic lake of similar characteristics (Nurnberg, 1984).

Table 6. Total loading capacity based on the Nurnberg (1984) phosphorus model.

		Current load	Loading capacity	
External	kg/yr	120.0	104.0	Capacity for external load
Internal	kg/yr	24	0.0	Capacity for internal load
Phosphorus	ug/l	41	24	Predicted lake P (Nurnberg model)

4. Margin of Safety

The margin of safety in this TMDL is intended to ensure attainment of water quality standards. The margin is established at 10 kg/yr as an explicit additional load reduction goal.

5. Wasteload Allocation

EPA regulations require that a TMDL include a wasteload allocation which identifies the portion of the loading capacity allocated to existing and future point sources, including those permitted under the National Point Source Discharge Elimination System (NPDES). Examples of NPDES-permittable point sources include large and small direct wastewater discharges of municipal and commercial/industrial effluents, and specific NPDES stormwater discharges, namely the construction and the Municipal Separate Storm Sewer System (MS4) permitted discharges. There are currently no existing permitted point source discharges to Ticklenaked Pond. Given the uncertainty as to the types and number of NPDES point source discharges that may exist in the future, as well as the difficulties of quantifying loads from such discharges, if any, the Agency has decided not to quantify a WLA in this TMDL. Issuance of a NPDES permit for any direct wastewater proposed point source discharge would require the re-opening of this TMDL.

By contrast, for future construction activities that require a Vermont NPDES construction permit, construction activities will be considered consistent with the provisions of this TMDL if construction permit coverage is obtained and if all BMPs required by the permit are properly installed and maintained, or if local construction stormwater requirements that are more restrictive than the VT NPDES construction permit are met. The Ticklenaked Pond watershed is currently not within a MS4 permitted region of Vermont and due to its relatively sparse population it is highly unlikely that it ever will be.

Any stormwater discharges associated with industrial activities that require a stormwater multi-sector permit will be considered consistent with this TMDL if the conditions of that permit are met. At this time, there are no such discharges to the lake.

6. Load Allocation

Since the WLA is zero, the non-point load allocation for phosphorus is established as the total loading capacity, minus the margin of safety. The total loading capacity is sub-allocated to watershed and internal components:

External Allocation + Internal Allocation + Margin of Safety = Total Loading Capacity
94 kg/yr +0 kg/yr + 10 kg/yr = 104 kg/yr

7. Total Maximum Daily Load

This total maximum daily load is expressed as an annual load, rather than a daily load, which is the most reasonable approach for a small lake if this type, where no wasteload is present, and no wasteload allocation is envisioned. The target total phosphorus load identified in this TMDL has been calculated to produce an in-lake target concentration of 24 ppb, as measured in Spring total phosphorus, based on average annual loading. This is a typical protocol when describing in-lake algal response to nutrient loading which is based more on annual dynamics such as hydraulic residence time, stratification, internal phosphorus cycling and climate rather than daily loadings from nonpoint sources. Nutrient loading on any given day has a much less significant impact than the overall annual load. The algal response to the overall annual load is expressed during the critical conditions of seasonally warm weather, primarily summer, when the air and water temperatures and sunlight act to spur algal growth. This deviation from daily loading in TMDLs is permissible under the decision of the U.S. Court of Appeals for the Second Circuit per NRDC v. Muszynski, 286 F 3d.91 (2^{nd} Cir. 2001). The annual TMDL summary is presented in Table 7.

Table 7. Ticklenaked Pond TMDL Summary

TMDL Category	Kg	%
Current Load	144	
Wasteload Allocation	0	
Load Allocation-External	94	
Load Allocation-Internal	0	
Margin of Safety	10	
Total Loading Capacity	104	
Load Reduction Required	40	28

8. Annual and Seasonal Variation

It is anticipated that on certain days and/or at certain times of year, daily loads will exceed values that, when multiplied by 365, would exceed the TMDL. This variation is considered allowable, so long as the annual allocations are met or exceeded, as outlined above. As projects to control non-point sources become implemented, follow-up monitoring can be used to ensure that actual loads are declining. This monitoring can take the form of in-lake monitoring to track improvement in conditions, or watershed monitoring to track reductions in loadings.

9. Reasonable Assurances

When a TMDL is developed for waters impaired by both point and nonpoint sources, and the wasteload allocation is based on an assumption that nonpoint source load reductions will occur, EPA Guidance states that the TMDL should provide reasonable assurances that nonpoint source control measures will achieve expected load reductions in order for the TMDL to be approvable. This information is necessary for EPA to determine that the TMDL, including the load and wasteload allocations, has been established at a level necessary to achieve water quality standards. However, since this TMDL only has a load allocation for nonpoint sources, no statement of "Reasonable Assurance" is required. For further information pertaining to the type and magnitude of projects necessary to attain Water Quality Standards in Ticklenaked Pond, see Section 10.

10. Public Participation

A public comment period was established upon the release of the draft Ticklenaked Pond Phosphorus TMDL that ran from September 9th through October 9th, 2009. The comment period, draft TMDL and supporting documents were noticed on the VTDEC website. In conjunction with the web notification, members of the Ticklenaked Pond Lake Association and local agricultural interests were notified directly via email. At the close of the public comment period, VTDEC had received no comments.

11. Implementation - Phosphorus Reduction Action Plan

The minimum total load reduction necessary to achieve this TMDL is 40 kg, or a 28% reduction of the current load. One important approach to reliably reduce loads by 24 kg/yr involves inactivation of sediment phosphorus recycling mechanisms. In lakes where internal phosphorus cycling exists but is not addressed, water quality responses to external load reductions are often delayed (e.g., St. Albans Bay, Lake Champlain). Inactivating sediment phosphorus recycling mechanisms in the lake by means of an appropriate treatment would have the added benefit of ensuring that watershed reductions would improve water quality in a short timeframe. However, it is necessary to reduce the external watershed loads first before conducting an in-lake phosphorus inactivation treatment, in order to ensure treatment longevity. VTANR and the partners listed in the following action items suggest that the phosphorus reductions shown in Table 8, which would exceed the minimum necessary, are realistically achievable.

Table 8. Proposed phosphorus reductions by class to achieve the Ticklenaked Pond TMDL.

Class	Current P loading (kg)	Proposed reduction (kg)	Proposed % reduction by class	Percent of total reduction sought	Final load (kg)
Agricultural - row crop	64	13	20%	27%	51
Agricultural - pasture/grass*	22	7	32%	14%	15
Rural residential**	6	2.5	42%	5%	3.5
Roads and driveways	5	2.5	50%	5%	2.5
Forest	16	0	0%	0%	16
Wetlands	2	0	0%	0%	2
Precipitation	2	0	0%	0%	2
Septic loads	3	1	33%	2%	2
Internal nutrient recycling	24	24	100%	49%	0
Total	144	50		100%	94

*) Includes reductions from farmsteads and barnyards
**)Not including roads and driveways.

The proposal shown in Table 8 provides one pathway to reduce total phosphorus discharge to the lake to levels that will support water quality standards. To achieve these reductions, the Ticklenaked Pond Phosphorus Action Plan envisions three phases: 1) planning activities to identify and implement controls on non-point discharges in the watershed; 2) implementation of watershed controls, planning of in-lake controls on internal phosphorus recycling, and implementation of other lakeshore problems; 3) execution of an in-lake treatment to control internal nutrient recycling.

VTANR, through the Basin Planning Process, is committed to ensuring the successful implementation of this TMDL. Following these four general principals is necessary for Ticklenaked Pond to meet water quality standards:

1) Execution of the Ticklenaked Pond Phosphorus Action Plan.

2) Adherence of watershed residents and businesses to applicable State regulations pertaining to septic design and maintenance, and State enforcement of these regulations.

3) Enforcement of Accepted Agricultural Management Practices, implementation of certain best management practices, and comprehensive nutrient management planning.

4) Enforcement of Accepted Management Practices for Logging jobs in Vermont, and permitting of heavy forest cuts as required by 10 V.S.A. 83 §2625.

12. References

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Figures

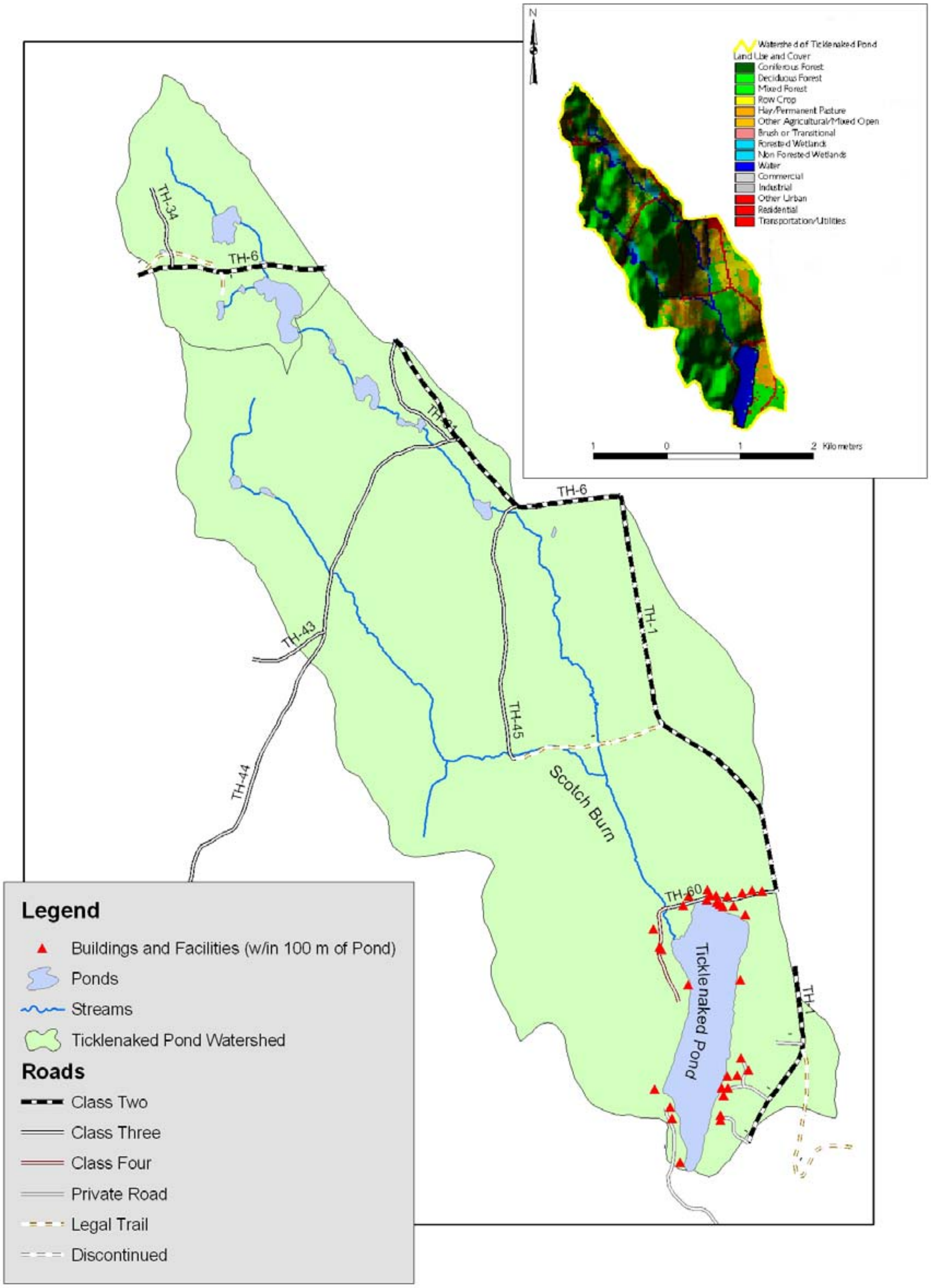

Figure 1. Watershed of Ticklenaked Pond, Franklin, VT. Inset shows land use distribution.

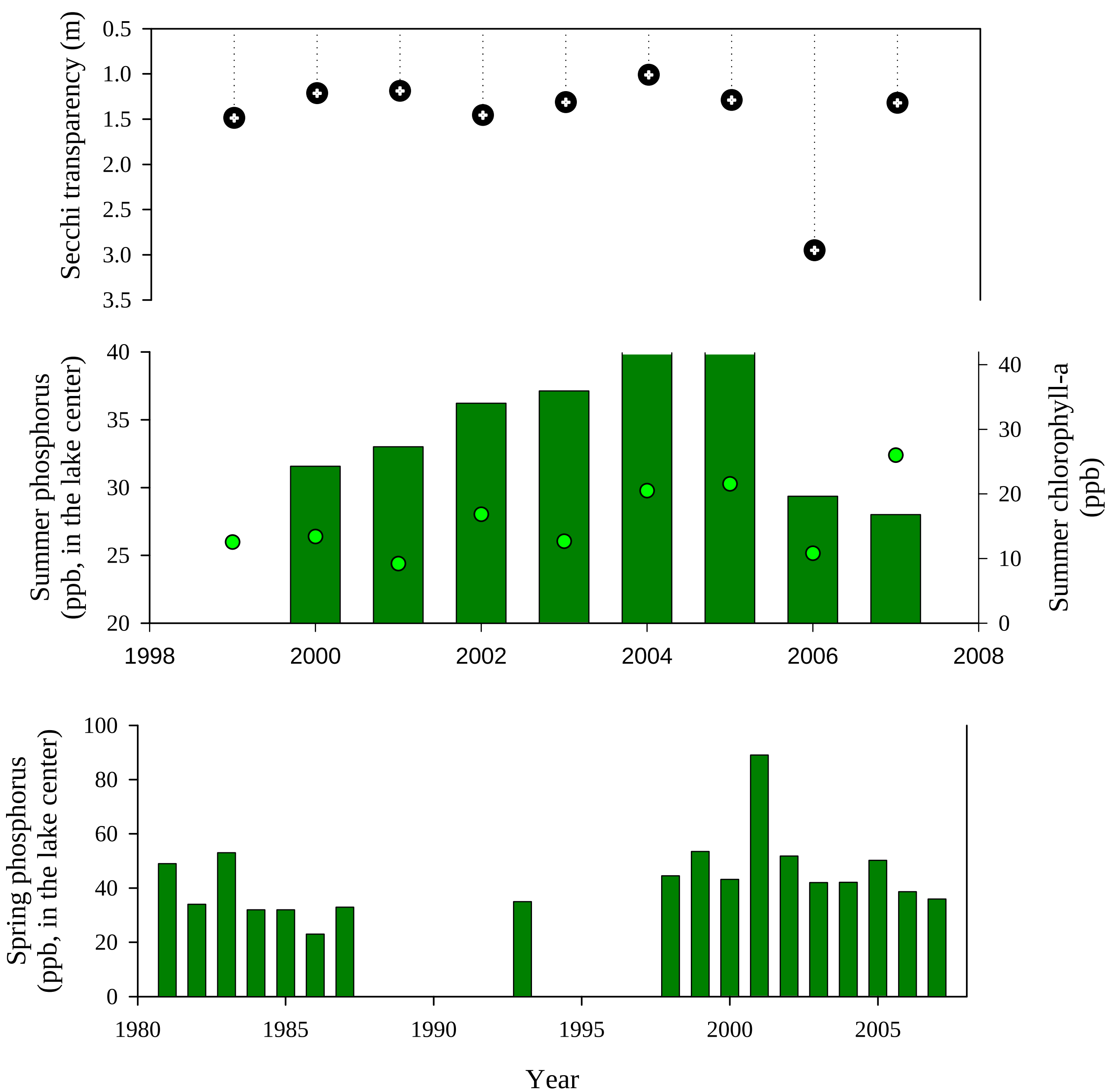

Figure 2. Trends in total phosphorus (bars), chlorophyll-a (points), and Secchi transparency, from the Spring Phosphorus and Lay Monitoring Programs.

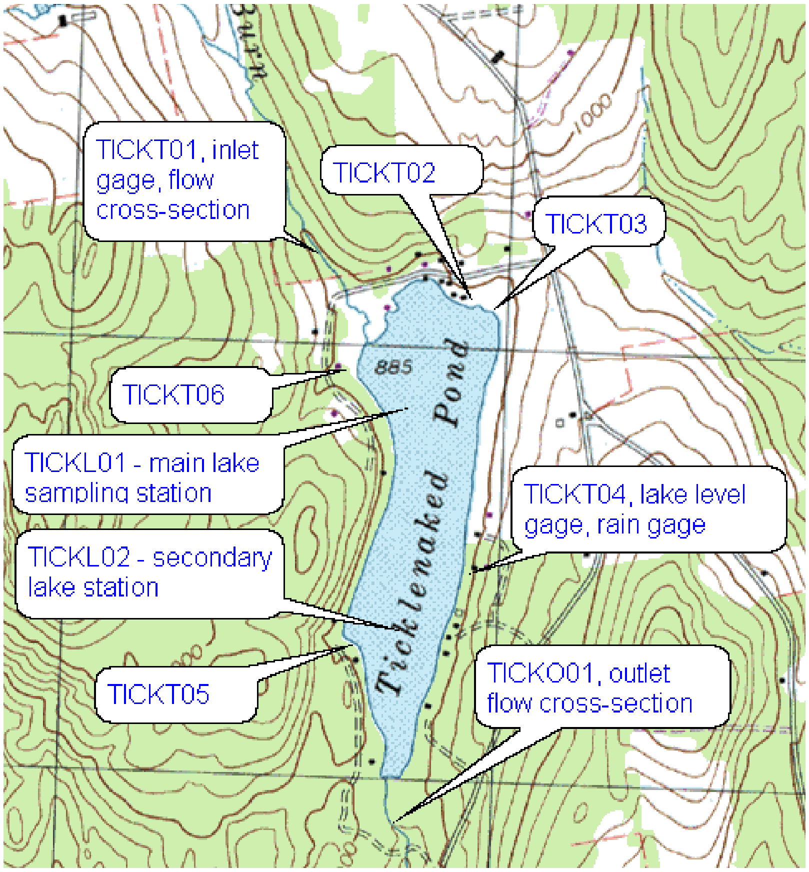

Figure 3 Map of sampling locations for the Ticklenaked pond diagnostic study.

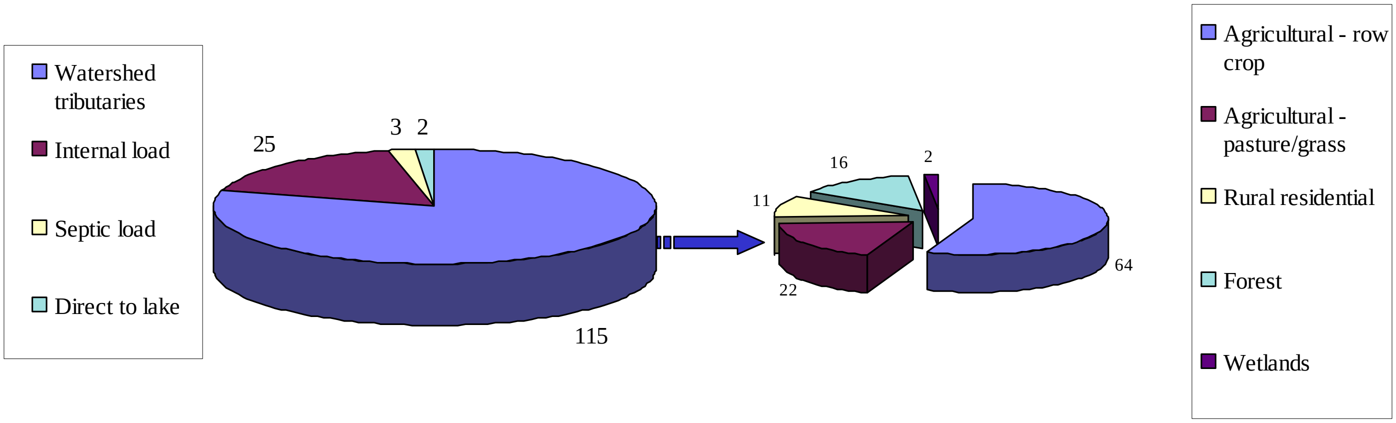

Figure 4. Apportionment of total phosphorus loads to Ticklenaked Pond.

Appendix A. Ticklenaked Pond TMDL. Technical details underlying watershed load measurements

This Appendix provides methodological details behind the calculation of water and phosphorus loads used to support this TMDL analysis. Annual watershed phosphorus loads were estimated using a mass balance approach combining stream gauging, flow measurements, and phosphorus measurements. In brief, to calculate water inflows, a rating curve predicting inflow volume from river stage was calculated. To calculate water outflows, a rating curve was calculated predicting outflow volume from lake level. For ungauged areas, the mean observed residual in water outflows relative to inflows of 15.8% was attributed to loads from the very small ungauged tributaries 02 through 06, plus groundwater flow. This residual water inflow was allocated to tributaries 02 through 06 by pro-rating the tributary contributing areas relative to the total ungauged area.

To calculate nutrient loads, total phosphorus concentrations measured from each of the tributaries and the outlet were related to simultaneously-measured water-stage, to generate stage-concentration relationships. Resulting predictions (and errors) for total phosphorus concentrations and measurement errors were estimated on an hourly basis from the stage measurements, and multiplied by water load. The resulting phosphorus loads were summed across the project period to derive annual loads.

Finally, since water-year 2006 was quite wet, the 2006 phosphorus load was adjusted to the mean water year load. This conversion was based on the long-term mean water year flow at the Wells River gauge in Wells River (148 CFS) relative to the 2006 mean flow (232 CFS).

Water load - Scotch Burn

Stage measurements

To calculate water loads to Ticklenaked Pond from the Scotch Burn, a gauging station was established at Station TICKT01 (Figure 3). Stage was measured using a YSI LS_600 tide-sonde that was hard-mounted to the stream bedrock in a small pool exhibiting natural stage control across the range of stage heights examined. This sonde monitored stage on a 15-minute basis, and was checked for calibration on a weekly or bi-weekly basis. As needed, data were corrected for stage calibration drift by linear interpolation of the pre- and post-calibration stages. The sonde was deployed for the period 7/22/2005 to 12/01/05, and from 3/14/06 to 11/10/06 (Figure A1).

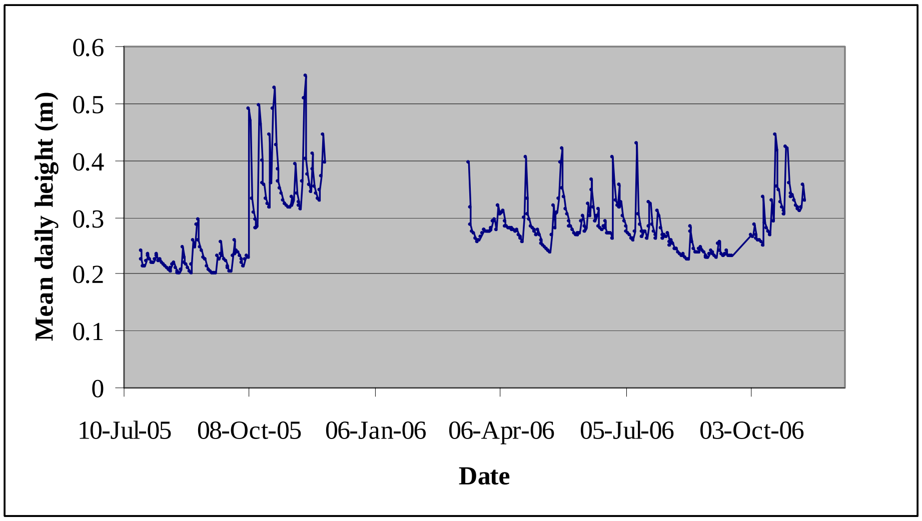

Figure A1. Mean daily stage record at TICKT01. Note the effect of extreme rain events in the fall of 2005.

In order to fill the winter data gap in the Scotch Burn record between 12/02/05 and 3/13/06, the relationship between the mean daily stage at TICKT01 and the daily USGS flow at the nearby USGS Wells River gauge (gauge 01139000) was calculated (Eq. 1):

$$\text{Stage (m)} = 0.22 + 0.00037 \times \text{USGS (cfs)} - 2.0669\text{e-}7\,(\text{USGS (cfs)}-195.763)^2 \qquad \text{Eq. 1}$$

where:
Stage (m) is the mean daily height of the Scotch Burn gauge in meters, and,
USGS (cfs) is the mean daily flow gauged at Wells River.
$R^2 = .867$, $p<0.0001$, RMSE = 0.026m

Where winter conditions resulted in ice formation precluding gauging measurements at the Wells River gauge, the flow from the period of ice-onset to ice-breakup was linearly interpolated. The final flow record estimated for the Scotch Burn at TICKT01 is shown in Figure A3.

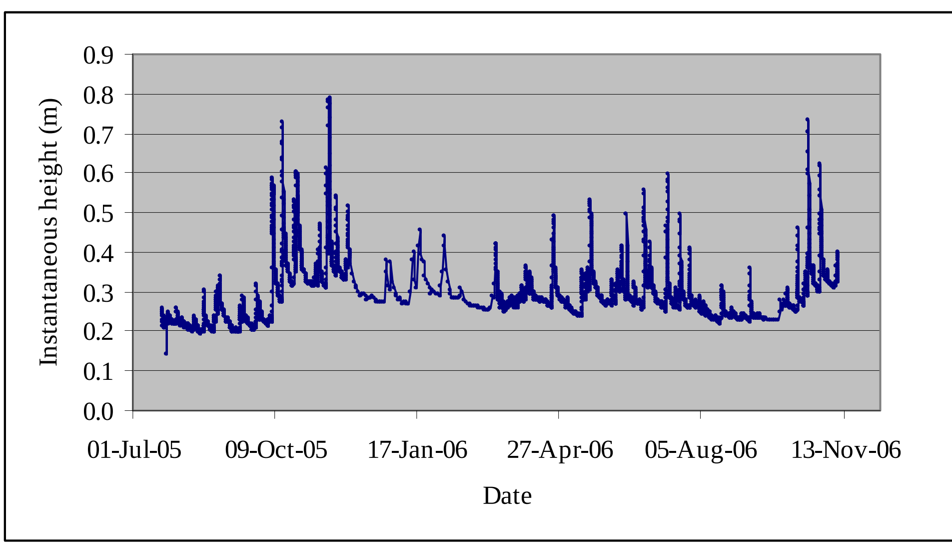

Figure A4. Final instantaneous stage record for TICKT01. Measurements for the period 12/2/05 to 3/14/06 are daily mean heights estimated using data from USGS gauge 01139000.

Discharge and rating curve development

To calculate a rating curve, flow measurements were made across a continuum of stages, at a stream cross-section just downstream of TICKT01. All flow measurements were made using a Sontek Flowtracker acoustic doppler current meter, using USGS method TWRI-A8 on a minimum of 10 points per cross section. While no major control shifts were evident in the stage-discharge relationship, we omitted two flow measurements that reflected excessive error in the calculation of the stage-discharge regression (Figure A3, Eq. 2).

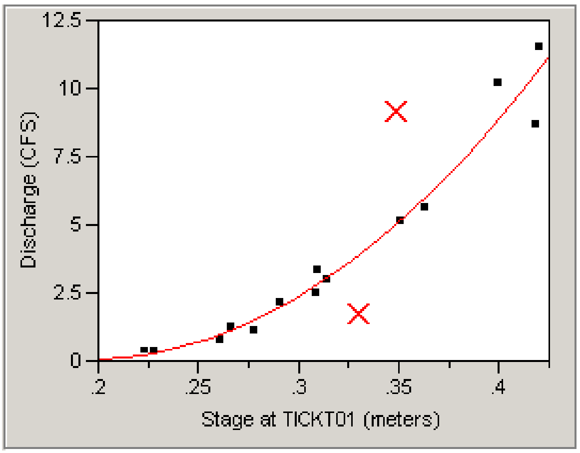

Figure A3. Stage-discharge relationship at TICKT01. Note two datapoints shown by X were considered outliers.

The stage-discharge relationship for TICKT01 is:

$$\text{Flow (cfs)} = -12.98 + 51.009 \times \text{stage (m)} + 209.34826\,(\text{stage(m)} - 0.31664)^2 \qquad \text{Eq.2}$$

where:
Flow (cfs) is the instantaneous measured flow of the Scotch Burn gauge in CFS, and,
stage (m) is the instantaneous stage measured at the Scotch Burn gauge, in meters.
$R^2 = .964$, $p<0.0001$, RMSE = 0.77 cfs.

Water loss – lake outlet

Stage measurements

To calculate water loss from Ticklenaked Pond from the Scotch Burn, a gauging station was established at along the eastern shore of the lake, in the vicinity of station TICKT04 (Figure 3). Stage was measured using a YSI LS_600 tide-sonde deployed vertically in a secure 6" PVC stilling well. This sonde monitored stage on a 15-minute basis, and was checked for calibration on a weekly or bi-weekly basis. As needed, data were corrected for stage calibration drift by linear interpolation of the pre- and post-calibration stages. This sonde was deployed for the period 7/22/2005 to 12/01/05, and 4/20/06 to 11/10/06 (Figure A4).

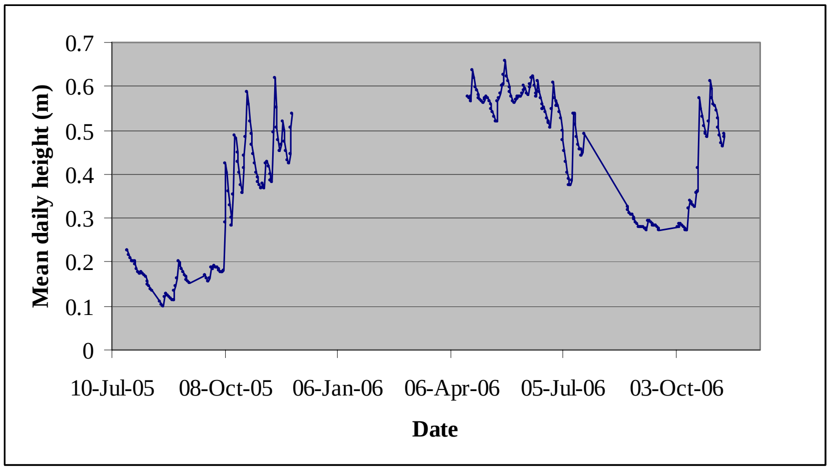

Figure A4. Mean daily lake stage.

In order to fill the winter data gap in the Scotch Burn record between 12/02/05 and 4/20/06, we relied on the relationship between the mean daily tributary stage at TICKT01 stage and the mean daily lake stage (Eq. 3):

$$\text{Lake stage (m)} = -0.262 + 2.017 \text{ trib stage (m)} - 5.2582795 (\text{trib stage(m)} - 0.285)^2 \qquad \text{Eq.3}$$

where:

Lake stage (m) is the mean daily height of the lake gauge in meters, and,
trib stage (m) is the mean daily height of the TICKT01 gauge.
$R^2 = .878$, $p<0.0001$, RMSE = 0.051m

Discharge and rating curve development

To calculate a rating curve, flow measurements were made across a continuum of stages, at a stream cross-section just upstream of TICKO01. All flow measurements were made using a Sontek Flowtracker acoustic doppler current meter, using USGS method TWRI-A8 on a minimum of 10 points per cross section. The rating curve was calculated relating lake stage to outlet flow (Figure A5, Eq. 4). As can be seen in Figure A5, a considerable control shift occurred during spring 2006 due to uncontrollable beaver activity in the lake outlet. This severely compromised our ability to construct a suitable rating curve, necessitating the following steps:

1) All lake stage data for 2006 were omitted from the dataset;
2) A stage-discharge relationship was calculated using 2005 data;
3) The relationship shown by Eq. 2 was used to calculate the most likely lake stage throughout 2006, which provides a dataset that is corrected for the control shift;
4) Outlet flows were calculated using the 2005 stage-discharge relationship.

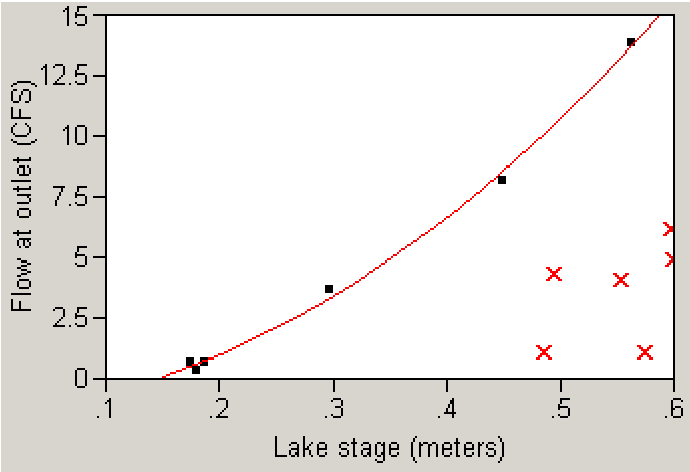

Figure A5. Stage-discharge relationship for TICKO01. All points shown by x were measurements taken after the 2006 control shift, and were not used in the calculation of a stage-discharge equation.

The stage-discharge relationship for TICKO01 is:

$$\text{Flow (cfs)} = -5.276 + 28.87 \times \text{stage (m)} + 42.35\,(\text{stage(m)}-0.308)^2 \qquad \text{Eq.4}$$

where:

Flow is the instantaneous measured flow of the Scotch Burn outlet in CFS, and,
stage (m) is the instantaneous stage measured in the lake, in meters.
$R^2 = .997$, $p<0.0001$, RMSE = 0.36 cfs.

The final corrected lake-level stage record is shown in Figure A6. The influence of the low-precipitation summer of 2005 is evident in this figure.

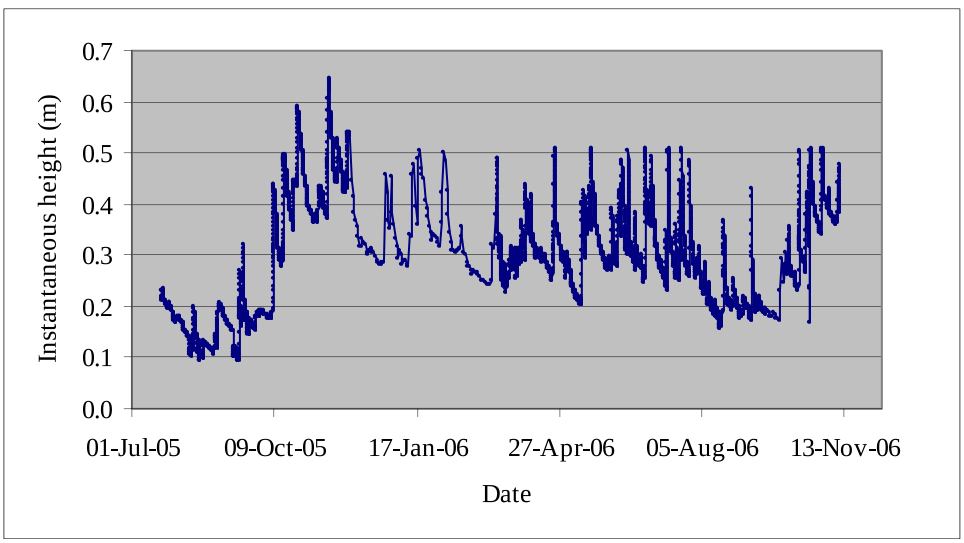

Figure A6. Final instantaneous stage record for TICKO01. Measurements for the period 12/2/05 to4/20/06 are daily mean heights estimated using data the inlet gauge.

Ungauged areas

To calculate water loads from ungauged areas, the mean observed residual water inflow relative to outflow was attributed to loads from the very small ungauged tributaries 02 through 06, plus groundwater flow. This residual water inflow of 15.8% (Table A.1) was allocated to tributaries 02 through 06 by pro-rating the tributary watershed areas relative to the total ungauged area (Table A.2).

Table A.1. Calculation of water balance for the project period.

Year	Monitored inlet water load (m3)	Monitored outlet water load (m3)	% residual	Monitoring period
2005	1,319,539	1,549,349	14.8%	July to December
2006	2,385,756	2,864,543	16.7%	March to November
Mean	1,852,648	2,206,946	15.8%	

Table A.2. Proportion of the Ticklenaked Pond watershed allocated to each subtributary area, and mean measured total phosphorus concentration

Tributary	Percent of water load	Mean total phosphorus (ppb), ± std. err.
Scotch Burn	84	Proportional to flow - see Eq. 5
Trib 2	2	28 ± 3.0
Trib 3	2	26 ± 2.0
Trib 4	4	11 ± 2.0
Trib 6	8	11 ± 2.0

Note): Tributary 5 identified as “TICKT05” on Figure 3 has at best infrequent, intermittent flow. This location was essentially a minor groundwater seep. Very few phosphorus measurements were obtainable from this location. The potential water and nutrient loads associated with this tributary are contained within the estimates for tributaries 2, 3,4, and 6.

Total water load

Water loads were summed by month. The total water load for water-year 2006 (October, 2005 to September, 2006, was 3.06×10^6 m^3.

Phosphorus loads

To calculate nutrient loads, water quality samples collected from each of the tributaries and outlet were related to simultaneously-measured water-stage, to generate a stage-concentration relationship. Water quality samples were obtained using an ISCO sampler that was electronically programmed to acquire discrete samples during high-flow events. This approach yielded a more precise estimation of the phosphorus – stage relationship than would have been obtained using traditional, fixed-interval sampling.

The stage-phosphorus relationship was then used to estimate the likely phosphorus concentration for each measured interval. Predicted total phosphorus concentrations and measurement errors were estimated on an hourly basis from the stage data, and these were summed across the project period to derive annual loads.

For the ungauged tributaries, stage-concentration relationships were developed using the pro-rated flows described above. Where a statistically significant relationship was evident, this relationship was used to estimate hourly TP concentrations. Where no relationship was evident, the tributary mean concentration and error were simply multiplied by the estimated flow. In both cases, TP concentrations and measurement errors were estimated on an hourly basis, and summed across the project period to derive annual loads.

Stage-concentration relationships

Total phosphorus concentration at TICKT01 was positively related to stage (Figure A7, Eq. 5). For the remaining small tributaries, there were no statistically significant relationships between measured stage and total P concentration in tributaries TICKT02 thru TICKT06, nor for the lake outlet.

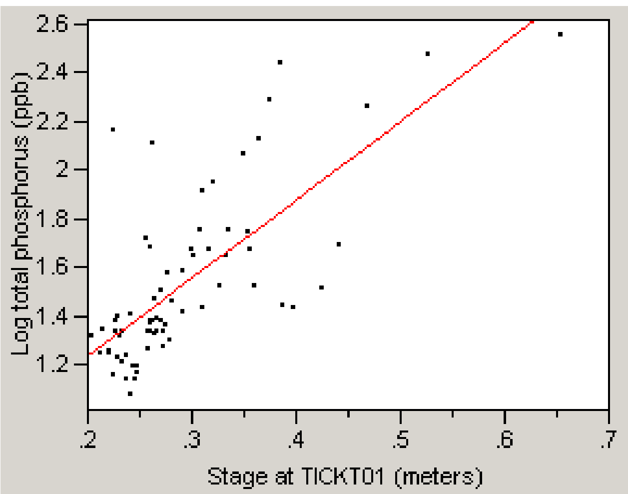

Figure A7. Stage-concentration relationship for the Scotch Burn

The stage-concentration relationship for TICKT01 is:

$$\text{Log TP} = 0.594 + 3.214 \text{ Stage (m)} \qquad \text{Eq.5}$$

where:
Log TP is the Log_{10} of the instantaneously-measured total phosphorus concentration, and,
Stage (m) is the simultaneously measured stage in the stream, in meters.
$R^2 = .529$, $p<0.001$, RMSE = 1.8 ppb TP.

Calculation of instantaneous and cumulative loads and losses

For TICKT01, total phosphorus concentrations and standard errors were estimated for each hourly (or daily) flow interval, and multiplied by the total flow for that interval, to provide a total load. For tributaries TICKT02 through TICKT06, the mean total phosphorus and standard errors were multiplied by the estimated hourly (or daily) flow to provide a total load for that interval. For the lake outlet, the mean total phosphorus concentration and standard error for the lake surface at Station TICKL02 were calculated by sampling period. These values were multiplied by each hourly (or daily) flow interval measured for the outlet. In all instances, the hourly total phosphorus load estimates were summed across the project period to provide an annual from, expressed for the 2006 water year (Table A.2).

Table A.2. Summary of total phosphorus loads from tributary streams to Ticklenaked Pond, Ryegate, VT, for water year 2006 and the mean water year. The water year is defined as Oct 1 to Sept 30.

Period		Phosphorus loads, in kilograms					
Year	Month	Trib_1_Load	Trib_2_Load	Trib_3_Load	Trib_4_Load	Trib_6_Load	Outlet_Load
2005	7	0.72	0.02	0.01	0.01	0.03	0.77
2005	8	2.33	0.07	0.04	0.05	0.09	1.06
2005	9	2.68	0.07	0.05	0.05	0.10	0.94
2005	10	48.59	0.25	0.15	0.17	0.33	10.64
2005	11	51.46	0.25	0.16	0.17	0.33	23.89
2005	12	11.01	0.17	0.10	0.11	0.22	9.99
2006	1	16.11	0.20	0.12	0.13	0.25	10.90
2006	2	10.38	0.15	0.09	0.10	0.19	7.83
2006	3	7.08	0.13	0.08	0.09	0.17	5.71
2006	4	9.11	0.15	0.09	0.10	0.20	6.00
2006	5	10.89	0.15	0.09	0.10	0.20	6.48
2006	6	12.40	0.17	0.10	0.11	0.22	8.62
2006	7	11.28	0.15	0.09	0.10	0.20	7.09
2006	8	3.81	0.10	0.06	0.06	0.13	2.91
2006	9	3.01	0.08	0.05	0.06	0.11	5.19
2006	10	23.45	0.18	0.11	0.12	0.24	12.44
2006	11	4.43	0.06	0.04	0.04	0.08	6.75
Total for water year 2006 (kg)		195.13	1.95	1.19	1.29	2.54	105.25
Error for water year 2006 (kg)		27.30	0.07	0.03	0.08	0.15	7.11

The mean water year relative to the 2006 water year

Water-year 2006 was considerably wetter than average. The USGS gauge at Wells River has operated since 1940. The mean annual flow at that gauge is 148 CFS (http://waterdata.usgs.gov/vt/nwis/uv/?site_no=01139000). The mean flow measured for the 2006 water year was 232 CFS, or a 57% difference. The Ticklenaked Pond TMDL is being based on the average water year in order to more accurately capture long-term conditions. Accordingly, the load estimates provided by Table A.3 were reduced by this proportion to derive long-term annual phosphorus load estimates for the lake, upon which the TMDL was calculated (see Table 1 of the Ticklenaked Pond TMDL).