Phosphorus Total Maximum Daily Load (TMDL)

for

Lake Carmi

Waterbody VT05-02L01

October 2008

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with guidance from:

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1. Background

1.1 Introduction

Lake Carmi in Franklin, Vermont, has experienced high phosphorus concentrations and the resultant water quality problems for several decades. Late summer algae blooms, reduced water clarity and heavy aquatic plant growth persist. The Department of Environmental Conservation lists Lake Carmi as "impaired" by phosphorus, i.e. the lake does not meet Vermont Water Quality Standards. Excessive amounts of phosphorus in the lake feed algae growth to such an extent that problem conditions are present. Recently the Franklin Watershed Committee has worked within the watershed to reduce nonpoint sources of phosphorus. This report presents data and estimates regarding sources of phosphorus and provides detail about the level of non-point source phosphorus reduction needed to bring the lake into compliance with the Water Quality Standards, and more importantly, meet the recreational needs of lake users.

What is a TMDL?

Section 303(d) of the Clean Water Act requires waters that do not meet state water quality standards to have a Total Maximum Daily Load analysis prepared. A "TMDL" identifies a daily amount ("load") of phosphorus that can enter the lake without causing water quality problems. Lake Carmi exceeds such a daily load currently and the TMDL will provide guidelines as to how much the load needs to be reduced. If followed, the TMDL should result in the correction of water quality problems.

Lake Carmi would most likely be somewhat nutrient-rich under entirely natural conditions, as compared to deeper lakes in Vermont because it is in an area of fairly rich soils. Nevertheless, lake conditions are documented to have changed considerably in the past 200 years, due to changes in land uses and farming practices. The current reduced water clarity is likely limiting aquatic plant growth, even given there are places in the lake where people find the plants a problem. If phosphorus (and algae growth) were reduced beyond a certain point, plant growth would very likely increase due to an increase in the depth to which light can penetrate. There is a consensus amongst stakeholders that the target phosphorus concentration for this TMDL eliminates algae blooms, but is not so low that aquatic plant growth dramatically increases. The water quality targets and load allocations developed in this TMDL are defined so as to eliminate severe algae blooms in Lake Carmi and are consistent with a lake condition that will meet water quality standards.

The TMDL portion of this report articulates this phosphorus concentration goal in terms of maximum allocation of the annual loading of phosphorus to the lake from the watershed that will permit the lake to attain the target concentration of 22 ppb phosphorus.

1.2 Description of Lake Carmi

Lake Carmi is a large relatively shallow lake located in northwestern Vermont in the town of Franklin. It is 1,402 acres in size and has a watershed area of 7,710 acres. Its maximum depth is 33 feet. The lake's long axis runs north-south and measures approximately three miles. Lake Carmi has extensive wetlands in its watershed, most notably Franklin Bog at its southern end. Somewhere within the Franklin Bog lies the divide between the Pike River and Missisquoi River watersheds. The watershed is made up of low hills, with only a 485 foot difference between the lake elevation (435 feet) and the highest point in the basin. A small, wetland-edged pond, Little Pond is located within the watershed on the eastern side, and its outlet, Marsh Brook, is the largest tributary to the lake (Figure 1).

The lake is located in an agricultural region of the state and 44% of its watershed is tilled or untilled farm land. There are five dairy farms in the watershed, as well as many acres of hay, corn, and pasture fields leased by farms located outside of the Carmi watershed. Forty-five percent of the watershed is wooded or wetland, including a large portion of Franklin Bog. Apart from fairly intensive shoreline development, low-density residential development is spread throughout the watershed.

Lake Carmi State Park is located on its shores and is one of the most used state parks in the state. In addition to a large swimming beach, 2.9 miles of undeveloped shore (38% of the total shoreline) are included in the park, and comprise the bulk of the undeveloped shore lake-wide. The remaining shore is fairly heavily developed, including 206 camps and 3700 feet of road within 50 meters of the shore. Many of the shoreline camps are located within 50 feet of the shoreline, and most do not have significant vegetation other than lawn between the camp and driveway and the lake. In addition to a boat launch ramp in the State Park, there is a Department of Fish and Wildlife Access at the northern end directly on Route 120. Many town residents park along Route 120 and swim off the shore adjacent to the boat ramp during the summer.

The lake is natural, but a dam controls the water level and elevates the water about 2 feet over its natural level. The dam is located at the north end of the lake and drains north into the Pike River which flows into Canada and eventually into the Missisquoi Bay of Lake Champlain. The dam, originally constructed in the mid 1800s to provide power for a sawmill, was rebuilt in the early 1970s and is now owned by the VT Department of Environmental Conservation. The Lake Carmi dam is actually located about 2400 feet from the lake itself, having been built downstream on the outlet. Therefore, the outlet stream leaves Lake Carmi and passes under Dewing Shore Road and through Mill Pond before reaching the dam. The culvert that passes under the road can have lower capacity than the dam itself, so at times of high flow it determines the water level in the lake.

1.3 Background on Water Quality Issues

Lake Carmi has a history of late summer algae blooms, resulting in conditions that residents find objectionable and will not swim in. Anecdotally, there was a period in the 1990s when conditions improved, but they have since worsened. Currently, residents report that a bloom can occur anytime during the summer, with late summer still being the time of most intense algae growth.

The Franklin Watershed Committee was formed in 1994 (originally as the Carmi Watershed Committee) to investigate and address sources of phosphorus to the lake. The group has accomplished many projects since then and received funding through the Vermont Watershed Grants Program, US EPA Section 319 – Nonpoint Source Pollution, the Lake Champlain Basin Program, the Town of Franklin and the Carmi Campers Association. Below is a partial list of the projects:

1. **Nutrient management of Lake Carmi watershed farms** – The Committee provided financial support to three watershed farmers since 1998 to enable their participation in an Integrated Crop Management assessment that focuses on nutrient needs and manure management of crop and hay fields. As part of a five year project, soils and manure are tested, and a plan to maximize the efficiency of manure spreading and minimize the need for chemical fertilizers is developed for each farmer's use. Currently, about half of the farms in the watershed are operating under nutrient management plans.

2. **Steam assessments -** In 1994-5 and in 2005 volunteers and VTDEC staff assessed the conditions along the major tributary streams (Alder Run, Marsh Brook, King Farm Watershed) to observe problems and rank tributaries for pollution reduction action. In 2006, Marsh Brook and Dewing Brook (Fig.1, "Trib 4") were again assessed, this time with Phase 2 Stream Geomorphic methods.

3. **Septic tank pumping cost share –** Since 2002 the Franklin Watershed Committee has given 78 shoreland camp owners partial funding toward maintenance pumping of septic tanks as a means to promote the necessary practice and provide septic system maintenance tips to owners.

4. **Septic survey** – During the summer of 2004, 63 camp owners were surveyed as part of an effort to understand the relative suitability of existing septic systems and the extent to which camp owners knew about their septic systems and how to take care of them.

5. **Tree planting** on public beach – In 1997, trees and shrubs were planted along the shore between the lake and Route 120 at the north end of the lake to stabilize the shoreline. Unfortunately the trees were later accidentally mown down during roadside maintenance.

6. **Stabilize ditches and slopes** at Dewing Farm – In 2005, volunteers seeded and mulched unstable slopes and ditches on the Dewing Farm. In addition, they installed drainage tile in an existing eroding ditch so that it could be covered over and seeded.

7. **Roadside stabilization** The Town of Franklin received a Better Backroads grant to stabilize the road/lake bank along 500 feet of Dewing Shore Road.

8. **Removed two truck loads of trash** from Marsh Brook.

9. VT Youth Conservation Corp **graded and seeded ditches** along Patton Shore Road.

10. **Lay Monitoring Program** – Lake Carmi has been sampled annually by volunteers through the Lay Monitoring Program since prior to 1980. This data is incorporated into the phosphorus loading analysis later in this report.

11. **Shoreland Planting -** During the summer of 2006, four camps along the north shore were offered plants and labor via the Vermont Youth Conservation Corps to revegetate the lakeshore bank on their property. The majority of participants chose to plant a strip of cedars to maintain bank stability.

12. **Streambank stabilization –** Three projects were carried out in 2007 aimed at reducing sediment delivery to Lake Carmi.

1.4 Current Water Quality Conditions

1.4.1 History of cyanobacteria (blue-green algae) blooms

During the summer of 2006 and 2007, algae blooms tested positive for cyanobacteria. Cyanobacteria are known to produce toxins, although the timing and concentrations of toxin production do not necessarily track with bloom density. The increasing incidence of cyanobacteria in Lake Carmi corresponds with increased occurrences in other lakes in Vermont; this may be the result of a regional or larger increase in blue-green algae blooms and not indicative of worsening conditions on Carmi. Despite these recent increases, cyanobacteria have been measured in Lake Carmi as far back as 1976 (VT Department of Water Resources, 1976).

1.4.2 Long-term water quality trends

Water quality monitoring in Lake Carmi has been carried out by the Vermont Lay and Spring Phosphorus Monitoring Programs since 1980. The Vermont Lay Monitoring Program trains citizen volunteers to collect summertime weekly measurements of total phosphorus, chlorophyll-a (a measure of algal growth in the openwaters of the lake), and Secchi transparency (a standard measure of lake water clarity). The mean total phosphorus, based on a 23-year record, is 28 parts-per-billion (+/- 0.9). The mean chlorophyll-a is 17 ppb, and the mean Secchi transparency is 2.0 meters (+\- 0.07). 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 provides long-term trends of these three parameters.

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, Lake Carmi has an 18-year record since 1980 (Figure 2). The mean spring total phosphorus is 25 ppb (+/- 0.84), which is only slightly lower than the summer mean measured by citizen monitors. There is no trend evident in the long-term pattern of spring total phosphorus in Lake Carmi.

Measurements from both these programs are made in the central portion of the lake. In nearshore areas, phosphorus and chlorophyll-a are significantly higher, and transparency is significantly poorer. Paradoxically, while summertime water quality conditions appear to be improving in the center of the lake (Figure 1, CARMI01), watershed residents indicate that the quality of waters in the lake margins has declined in recent years, particularly in the lakes' northeast corner (Figure 1, CARMI03), where cyanobacteria blooms are consistently observed. This TMDL is therefore adopting the precautionary approach of specifying the TMDL compliance location at CARMI03.

1.4.3 Intensive water quality investigations

1994-1996

Intensive water quality investigations have also been carried out in Lake Carmi since 1994. From 1994 to 1996, the lake was intensively monitored on a bi-weekly basis to develop an understanding of the internal phosphorus dynamics in the lake. The goal of that sampling campaign was to determine the relative importance of watershed-based vs. internal sources of phosphorus to the lake. The results of these studies are described in VTDEC (1997). In brief, water column profiles of phosphorus and other constituents were collected at the main lake station (CARMI01, Figure 1). These data were plotted using "isopleth" diagrams to visualize the potential for sediment nutrient resuspension. In addition, measured total phosphorus concentrations in the lake were related to modeled total phosphorus loads. This analysis used simple land-use export models to predict the proportion of phosphorus in the lake that could be attributed to watershed losses vs. internal phosphorus recycling. Total phosphorus discharges to the lake, based on land use characteristics, were estimated to range from 1,221 to 1,887 kg/year, based on 1993 land-use data.

The summer mean concentration throughout the water column was 30 ppb in 1994 and 1995, but ***42*** ppb in 1996. During 1996, an internal "pulse" of phosphorus from the lake sediments following a turnover event explains the increased phosphorus, which resulted in a major cyanobacteria bloom. No data were collected during that project period from the tributary streams, precluding the development quantitative estimates of phosphorus loads from streams. This means that the proportion of watershed vs. internal phosphorus loading could not be estimated on an annual basis with certainty. That study concluded that while internal loading was not a major factor under most conditions, under conditions of peak and persistent summer stratification followed by a "mixing event," internally-derived phosphorus could influence algae blooms in the lake.

1998

In 1998, Lake Carmi was included in a study that was designed to assess contamination of mercury to waters statewide. While that study had little relevance to the present TMDL, one element involved collecting ^{210}Pb-dated sediment cores from several lakes, including Lake Carmi, with the goal of analyzing historic and current levels of mercury contamination. In addition to estimating historical mercury contamination, three more relevant indicators of lake condition were measured within these cores (methods are described by Kamman and Engstrom, 1998): sediment accumulation rate; carbon:nitrogen ratio (C/N); and, isotopic ratios of ^{13}C : ^{12}C (also called stable ^{13}C). These latter "proxies" were measured by the University of Vermont, Department of Geology as part of a collaborative VTANR-UVM research initiative.

Sediment accumulation rate is simply the vertical accumulation of sediments in the lake, per unit area, over time. In most Vermont lakes, sediment accumulation rates range from <0.01 to 0.04 mg dry sediment m^{-2} yr^{-1} (Kamman and Engstrom, 1998). Increases in sedimentation rate result from land clearing, which delivers sediments from the watershed. Sedimentation increases also result from enhanced in-lake productivity, whereby decaying and settling algae can add considerably to background accumulation. The C/N and stable ^{13}C ratios assess the importance of the algal contribution to the sediments in the lake. When C/N ratios are significantly below a value of 10:1, the sediments are typically of algal origin. Declines in C/N are indicative of increasing algal contributions in sediments. Precipitous increases in stable ^{13}C relative to background levels are commonly an indicator of highly accelerated eutrophication in lakes (Lini et al., 2007).

In combination, these three indicators describe the history of eutrophication in Lake Carmi (Figure 3). Ratios of C/N below a value of 10:1 even prior to 1860 suggest that the lake has always been somewhat nutrient enriched. From ~1860 to ~1900, water quality became increasingly dominated by algae, even while sediment delivery from the watershed was stable and low. This is likely reflective of intensifying, but non-mechanized agriculture. Sedimentation rate increased from 1900-1940, but the other proxies indicate this to be a period of relative stability in the lake waters. Between 1940 and 1960, the sediment proxies suggest that eutrophication accelerated, and beginning ~1980, this increase in the rate of eutrophication became more pronounced. This eutrophication may be the result of increased mechanization and the amount of lands in agriculture, increased development of lakeshore camps and residences, and the enhanced use of federally-subsidized "super-phosphate" fertilizers. Super-phosphates were provided to farmers at low or no-cost until late in the 20th century, and the legacy of super-phosphate-charged soils presents a challenge when remediating water quality. In summary, while the evidence suggests that Lake Carmi has always been somewhat enriched, it is presently at a historic eutrophication peak.

2006 - 2007

During this period, the sampling regimen implemented in 1994-1996 was repeated, with several enhancements. First, owing to public concern over clear gradients in water quality between the main lake station and the northeast cove, water quality profiles were also collected at CARMI03. In addition, automated stream height gauges and sampling stations were established in the Marsh Brook at the Lake Carmi State Park, and at the dam below the Mill Pond, at the lake's outlet to the Pike River. This sampling was initially carried out to relate measured total phosphorus at the Marsh Brook and outlet culvert to discharges. These data were collected to calculate annual phosphorus load estimates for the Marsh Brook, and to assist in calculating a phosphorus mass-balance for the lake. This monitoring was not completely successful, owing to late station establishment in 2006, and a probe malfunction in 2007. While the data collected proved insufficient to accurately calculate annual loads to and exports from the lake, the data nonetheless provide an indication of total phosphorus concentrations at these sites in relation to water stage.

The average water column total phosphorus concentrations for CARMI01 and CARMI03 were 37 and 41 ppb, respectively, for late May to early November, 2006, and 28 and 29 ppb, respectively, for the same period in 2007 (Figure 4). These levels are comparable to those measured during the 1994-1996 period, reflecting considerable inter-annual variation. Total phosphorus concentrations in the lake increased steadily at both stations throughout the season in both years (see Figure 4), highlighting the influence of algal production on the nutrient regimen of the lake. An examination of the available flow records suggests that 2006 was a considerably wetter year than 2007, which explains the considerably higher measured phosphorus concentrations for that time period. This

TMDL is being calculated based on measured in-lake concentrations for the 2007 monitoring year, which are consistent with long-term average conditions.
In addition, and in order to more appropriately target streams for remediation, volunteer monitors from the Franklin Watershed Committee collected samples on a weekly basis during the summer of 2007 in locations of the Marsh Brook watershed, as well as at the mouths of Tributaries 4, 5, 6, and the Alder Run (Figure 1). Results, provided in Figures 5 and 6, indicate that concentrations of phosphorus from these streams are considerable, despite the small relative flows. On the Marsh Brook, location 5, 6, and 8 displayed particularly elevated concentrations when flowing, with minimum values in excess of 150, 60, and 500 ppb, respectively. In other watershed locations, the highest P concentrations were noted in the Tributary 5 subwatershed, followed by Tributary 4, Tributary 6, and the Alder Run. The flow records captured at the USGS monitoring gauges located at the Pike River at the VT-PQ border, and on the Missisquoi River in Swanton, VT, indicate that 2007 was within 20% of an average year with respect to total water loads in this area, and therefore, the measurements in these tributaries should be indicative of average conditions for the watershed.

1.4.4 Approach to modeling

The general approach to modeling phosphorus in Lake Carmi used estimates of watershed phosphorus loads, and robust estimates of septic and internal loads, to model the in-lake phosphorus concentrations that result from these loads. Watershed loads were calculated using export coefficients as described in Section 1.4.5. These, along with septic and internal load estimations and in-lake modeling, relied on the Wisconsin Inland Lakes Modeling Suite (WILMS). WILMS (WIDNR, 2001) offers several approaches to estimating in-lake phosphorus concentrations from loads, relying on well-used, published lake phosphorus models including those of Reckhow, Walker, Vollenweider, Nurnberg and others (references in WILMS).

1.4.5 Land uses and phosphorus export estimates

Annual phosphorus loading estimates to Lake Carmi were derived using land use information and an export coefficient-based load estimation procedure. Detailed land use information was compiled for the Lake Carmi watershed using a Geographic Information System, relying on the data provided by Troy et al (2007). This land use dataset can be considered the best available. It was corrected for potential misclassifications in transportation and agricultural lands, using a robust validation process involving high-resolution digital orthophotography and ground-truthing.

By the export coefficient load estimation procedure, the annual phosphorus loss per unit land area (in kg P/Ha/yr) is identified for each land use type. These coefficients are multiplied by the area of their respective land use types, resulting in an annual phosphorus load estimate for each type. Loads from each land use category are then summed to estimate total loading (kg/yr) to the lake. This method of estimating phosphorus loading is easy to implement and widely used. As part of their land-use mapping, Troy et al. (2007) also recalculated land-use coefficients generically for the Lake Champlain Basin, and more specifically for the watershed of the Missisquoi Bay. Initially, both sets of coefficients were used to estimate phosphorus loss to Lake Carmi from the watershed.

Modeling analyses were used to determine the accuracy of watershed phosphorus export estimates (see Section 1.4.9). When this was done, it was evident that the generic export coefficients published by Troy et al. for the Lake Champlain Basin underestimated actual losses by 31%. By contrast, when the Missisquoi Bay coefficients were used, loads were overestimated 40%. For this TMDL, the export coefficients calculated specifically for Missisquoi Bay were employed, but resultant loads were reduced by 40% to provide the most accurate possible estimate of actual phosphorus loads to the lake (Table 1).

Table 1. Total phosphorus export, by land use, from the Lake Carmi watershed.

Land Use	Acres	Export coefficient kg/ha/yr	Initial load (kg/yr)	Corrected load kg/yr	Loading %
Agriculture	2,748	1.78	1979	1188	85%
Urban – lakeshore	100	2.52	102	61	5%
Urban – low density	62		63	38	2%
Forest	2,090	0.04	34	20	1%
Wetlands[1]	722	0.15	44	26	2%
Other water[2]	586	0	0	0	0%
Lake Surface[1]	1,402	--	88	88	5%
Total	7,710	--	2,310	1,421	100%

1) Direct deposition of phosphorus to contiguous wetlands and the lake surface was calculated using the approach of the Lake Champlain TMDL (VTDEC and NYSDEC, 2002).
2) Direct deposition of phosphorus to non-contiguous ponds and tributaries was considered negligible.

1.4.6. 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 loss to septic systems, a factor relating to septic system integrity, and a factor relating to soil phosphorus retention. The latter two factors were derived from a set of studies conducted on lakes by the State of Wisconsin, and provided in a WILMS module, and should be considered suitable for application in the Lake Carmi watershed. Specific to Lake Carmi, 209 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 three persons per camp, and an occupation of ½ year per camp, leading to the following estimate: 206 camps x 3 persons/camp x 0.5 yrs occupancy/camp = 309 person-years usage. Septic phosphorus discharges to the lake ranged from 2 kg/yr (assuming adequate soil retention and adequate septic system design), to 49 kg/yr (assuming poorly-functioning systems and poor phosphorus retention in soils). WILMS provides a most-likely value of 15 kg/yr, which was used for this TMDL.

1.4.7. Internal phosphorus loading

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

Method 1 relies on a mass phosphorus budget to estimate internal loading (mass phosphorus in inflows – mass phosphorus loss to sediments = Mass phosphorus in outflows). Here, if outflow phosphorus exceeds inflow phosphorus on an annual mass basis, the overage is attributed to internal loading. Method 2 uses growing season phosphorus 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 phosphorus release rates (low, most likely, and high) and applies them to the average anoxic sediment area over the period of anoxia.

Since loads are expressed annually, the estimates from method 1 are typically small. This is because on an annual basis, most of the P that is recycled from the sediments will settle back to the sediments. By contrast, method 3 relies on observations of in-lake P prior to and following the period during which internal loading would occur (the summer, peak stratification period). A significant difficulty of relying entirely on this method is that the increase in P loading from internal loads is in this case confounded with the watershed load that results from fall rains (see Figure 4 for 2006). Accordingly, methods 1, 2, and 4 provide the most appropriate internal loading estimates, providing guidance on the magnitude of internal P cycling in Lake Carmi (Table 2). The average of these estimates, or 97 kg/yr is carried through the remainder of the analyses in this TMDL.

Table 2. Internal P load estimates for Lake Carmi derived using WILMS.

Method	Kg P/yr
1. From a complete mass budget	-154 kg
2. From growing season in situ phosphorus increases	254
3. From in situ phosphorus increases in the fall	1011
4. From phosphorus release rate and anoxic area, using most likely p release rates	191
Mean for methods 1,2, and 4	97

1.4.8 Lake Carmi State Park Wastewater Treatment Facility

The Lake Carmi State Park wastewater treatment facility utilizes a recirculating textile filter for effluent treatment, storage in a lagoon, and spray disposal. The maximum discharge is 15,500 gallons per day. There are strict requirements within the facility's State-issued indirect discharge permit for spray effluent and down-gradient groundwater sampling. As this is an indirectly-discharging facility, phosphorus removal is not required, since significant downstream P removal occurs from groundwater percolation. While the spray effluent itself has TP concentrations in parts-per-million range, groundwater monitoring data indicate that maximum soil-P levels achieve only ~0.215 mg/L. Accordingly, the effluent infiltration and groundwater transport has a profound phosphorus removal effect.

The facility is a seasonal one, in operation during the summer months. In order to estimate the annual contribution of P from the facility, we simply multiplied the daily flow, the groundwater P concentrations, and the number of operation-days.

$$\mathbf{15{,}500\ gal/day \times 120\ days \times 215\ \mu g/L\ P \times 3.81x10^{-9} = 1.5\ kg/yr}$$

(where $3.81x10^{-9}$ is a conversion constant)

This estimate is a highly conservative overestimate in that: 1) it is assumed that there is no further reduction in groundwater P levels from the downstream-most sampling point to the lake, and therefore all P measured in the groundwater is assumed to discharge to the lake; and, 2) the maximum measured groundwater P concentration was used in the calculation, which overestimates the summertime average concentration considerably.

1.4.9 Modeling in-lake phosphorus concentrations from total loads

In order to qualify the total loading estimates for Lake Carmi, we ran a series of modeling exercises in WILMS to predict measured in-lake phosphorus concentrations based on a set of 14 published lake models. Initially, the models were run using the initial load of 2,424 kg/yr, which comprises the initial watershed (Table 1, Missisquoi Bay-specific export coefficients), internal (Table 2), septic, and wastewater loads. WILMS provides diagnostic information to aid in the selection of an appropriate subset of models that accurately portray in-lake conditions. These models were evaluated for accuracy based on two factors; conformance to model assumptions, and concurrence of modeled and measured in-lake phosphorus concentrations.

Two initial modeling runs were carried out. The first used watershed loads calculated from Missisquoi Bay-specific coefficients, while the second used Lake Champlain Basin generic coefficients. Using the generic coefficients, the predicted in-lake phosphorus concentrations were considerably underestimated. Using the Missisquoi Bay coefficients, the predicted in-lake phosphorus concentrations were considerably overestimated in all models. Therefore, a series of modeling iterations was conducted that sequentially reduced the magnitude of the Missisquoi Bay land-use export coefficients until measured in-lake concentrations were accurately predicted. Based on the model runs, and using the four models shown in Table 3, a 40% reduction in phosphorus export was found to be necessary for the four most accurately performing models to predict the measured in-lake concentrations.

Table 3. WILMS model output based on total phosphorus (TP) loads to Lake Carmi. Input total phosphorus concentrations are shown.

Lake phosphorus model Mean 2007 GSM* TP: 28 ppb Mean ANN** TP: 26 ppb	Mean TP (predicted), ppb	Predicted TP range	Model prediction type
Nurnberg, 1984 Oxic	27	12-43	ANN
Vollenweider, 1982 Shallow Lake/Res.	29	12-49	ANN
Rechow, 1977 water load < 50m/year	35	17-51	GSM
Vollenweider, 1982 Combined OECD	35	15-60	ANN

*GSM: Growing season mean phosphorus
**ANN: Annual mean phosphorus, calculated by WILMS as the average of spring total phosphorus and GSM

1.4.10 Summary of phosphorus sources and estimated loads to Lake Carmi

The information provided in Sections 1.4.3 to 1.4.9 provides the following summary of phosphorus loads to Lake Carmi (Table 4, Figure 7). The total estimated annual load of phosphorus to Lake Carmi is 1,535 kg. This value will be carried through the remainder of this TMDL analysis.

Table 4. Estimated annual phosphorus loads to Lake Carmi by source category.

Source of phosphorus load	Value used to calculate this TMDL (kg/yr)
Watershed tributaries[1]	1,421
Septic loads	15
Internal loads	97
Load from Lake Carmi State Park WWTF[2]	2
Total annual load	1,535

[1)] Includes 88 kg phosphorus delivered directly to the lake surface from atmospheric deposition
[2)] This WWTF is permitted as an indirect discharge using a leachfield design. As such, it is being treated as part of the non-point source load in the TMDL.

2. Numeric Water Quality Criteria

2.1 Applicable water quality standards

Lake Carmi is a Class B waterbody. Class B waterbodies are to support consistently good aesthetics, no more than a moderate impact to aquatic life use and habitat, and primary and secondary contact recreation. These uses are impaired by phosphorus in Lake Carmi. 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

Since the VT Water Quality Standards do not provide a numeric phosphorus concentration applicable to this lake, a target concentration must be selected for the purpose of this TMDL that serves to meet designated uses. The selection of this concentration must balance articulated desire amongst stakeholders to eliminate algae blooms while also limiting the proliferation of littoral aquatic plants.

The monitoring history of the lake is instructive in this regard. There have been years during which phosphorus has been relatively low in the lake, with lower mean chlorophyll-a concentrations resulting. During 1997, 1998, and 2002, the mean summertime total phosphorus was ≤ 23 ppb, and mean chlorophyll-a was < 10 ppb. During this period, watershed stakeholders expressed satisfaction with water quality, and uses appeared met (Figure 2). The recovery of the lake during the early 2000s was, unfortunately, short-lived, with considerable increases in phosphorus beginning in 2003. In order to consistently achieve concentrations viewed as satisfactory to watershed stakeholders, this TMDL is defining 22 ppb as the TMDL target concentration, measured as summertime average concentration to be attained at both the CARMI01 and CARMI03 monitoring locations.

3. Total Loading Capacity

The total loading capacity is the maximum phosphorus loading rate that can be discharged to Lake Carmi waters and still attain the TMDL target concentration. To estimate the total loading capacity, we used the same phosphorus models presented in Section 1.4.9 to simulate the in-lake annual phosphorus concentration resulting from reductions in total loads. In this exercise, the four models highlighted in Table 4 were used to predict the loads necessary to achieve the target concentration of 22 ppb (Table 5). Total loading capacities estimated in this manner ranged from 924 to 1,168 kg/yr, resulting in necessary load reductions of 367 to 611 kg. The average of the four modeled total loading capacities (1,027 kg/yr) is taken as the final total loading capacity.

Table 5. Total loading capacity and calculated load reduction required, based on four lake phosphorus response models.

Lake Phosphorus Model	Modeled starting concentration (ppb)	Current load (kg/yr)	Total loading capacity (kg/yr)	Load reduction required (kg)	Final concentration (ppb)
Nurnberg, 1984 Oxic	27	1,535	1,168	367	22
Vollenweider, 1982 Shallow Lake/Res.	29	1,535	1,056	479	22
Rechow, 1977 water load<50m/year	35	1,535	960	575	22
Vollenweider, 1982 Combined OECD	35	1,535	924	611	22
Average			1,027	508	

4. Margin of Safety

A margin of safety is being incorporated into this TMDL to account for any uncertainty that the recommended total loading capacity will bring about the necessary in-lake phosphorus concentration of 22 ppb. An explicit margin of safety of 10% of the total loading capacity, or 103 kg/yr is established under this TMDL. Under full implementation, this additional loading reduction from the total loading capacity will better ensure that the lake will attain the annual target of 22 ppb and the applicable water quality standards.

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 Lake Carmi. 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 in compliance 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 Lake Carmi 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 in compliance with this TMDL if the conditions of that permit are met. At this time, there are no such discharges to the lake.

6. Non-point Source Load Allocation

As no WLA is established, the non-point load allocation (LA) for phosphorus is therefore the total loading capacity, minus the margin of safety:

$$LA = 1{,}027 \text{ kg/yr} - 103 \text{ kg/yr} = 924 \text{ kg/yr}$$

7. Total Maximum Daily Load

This total maximum daily load is expressed as an annual load, which is the most reasonable approach for a lake of this type, where no wasteload is present and no WLA is envisioned. This 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 6.

Table 6. Lake Carmi TMDL Summary

TMDL Component	**kg/yr**	
Current load	1,535	
Wasteload allocation	0	
Load allocation	924	
Margin of safety	103	
Total loading capacity	1,027	
Load reduction required	611	40%

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 because these allocations are consistent with meeting the in-lake phosphorus target concentration. As projects to control non-point sources become implemented, follow-up monitoring can be used to determine whether 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 WLA 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 has no wasteload allocation, no statement of "Reasonable Assurances" is required.

10. Public Participation

A public comment period was established upon the release of the draft Lake Carmi Phosphorus TMDL that ran from August, 8, through September 26, 2008. The comment period was noticed in a regional newspaper and on the VTDEC website. In conjunction with the release of the draft TMDL, VTDEC hosted a well attended informational public meeting within the Lake Carmi watershed on September 11, 2008 to present the TMDL and to answer questions. Additionally, notification of the public informational meeting was posted to the Vermont Department of Libraries website.

At the close of the public comment period, VTDEC had received comments from one party. This comment was a general letter of support for the development of the TMDL received from the Franklin Watershed Committee. No VTDEC response was deemed necessary.

11. Implementation - Phosphorus Reduction Action Plan

The implementation plan for this TMDL identifies projects that, once implemented, are expected to result in the lake meeting its in-lake phosphorus concentration target of 22 ppb. The watershed of Lake Carmi contains a wide variety of land uses, including residential development (year-round and seasonal), agriculture, roads, and forest. The Lake Carmi Phosphorus Reduction Action Plan (Appendix A) was written to encompass improvements needed in all land use types since all are sources of phosphorus. The Franklin Watershed Committee and the Vermont Agency of Natural Resources promote the view that phosphorus reductions are needed across the board to address all possible sources as well as encourage the responsibility and involvement of all land owners and users.

Some of the Action Items recommended in the Action Plan are ones which can be undertaken by the existing structure of the Franklin Watershed Committee with its existing annual budget, while others will necessitate significant additional funds. As of this writing, VTDEC has awarded a Clean Water Act §319 grant to the Franklin Watershed Committee to begin implementation of the Action Plan.

VTANR, through the Basin Planning Process and other programs, is committed to ensuring the successful implementation of this TMDL following these four general elements:

1) Complete execution of the 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 Practices, requirements for best management practice implementation, 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.

5) Adherence of watershed residents and businesses to applicable State regulations pertaining to stormwater construction permits, and State enforcement of these regulations.

6) Monitoring to assess progress in meeting this TMDL.

12. References

Chapra and Reckhow. 1983. Engineering Approaches to Water Quality Modeling. Butterworth Publishers.

Kamman and Engstrom. 1998. Historical and Present Fluxes of Mercury to Vermont and New Hampshire Lakes Inferred from 210Pb-dates Sediment Cores. *Atmos. Environ*. 36:1599-1609.

Troy A., Wang D. and Capen D. 2007. Updating the Lake Champlain Basin Land Use Data to Improve Prediction of Phosphorus Loading. LCBP Technical Report #54.

Vermont Department of Water Resources, 1976. "Lake Carmi Water Quality Report, 1976" Lake Eutrophication Series Report No. 11. Montpelier, VT.

VTDEC and NYSDEC, 1994. Lake Champlain Diagnostic-feasibility Study. Waterbury, VT.

Vermont Department of Environmental Conservation, 1997. An Analysis to Determine the In-Lake Phosphorus Distribution and Estimate Phosphorus Loadings to Lake Carmi, Franklin, VT. Waterbury, VT.

Vermont Department of Environmental Conservation, 1997. Lake Carmi Watershed Project Accomplishments to Date, January, 1997. Draft. Waterbury, VT.

Vermont Department of Environmental Conservation, 2005. Vermont Lay Monitoring Report. Waterbury, VT.

VTDEC, 2008. Lake Carmi Phosphorus Reduction Action Plan.

WIDNR, 2001. Wisconsin Inland Lakes Modeling Suite, v. 3.3.18.1. Wisconsin Department of Natural Resources. Madison, WI, USA

Figures

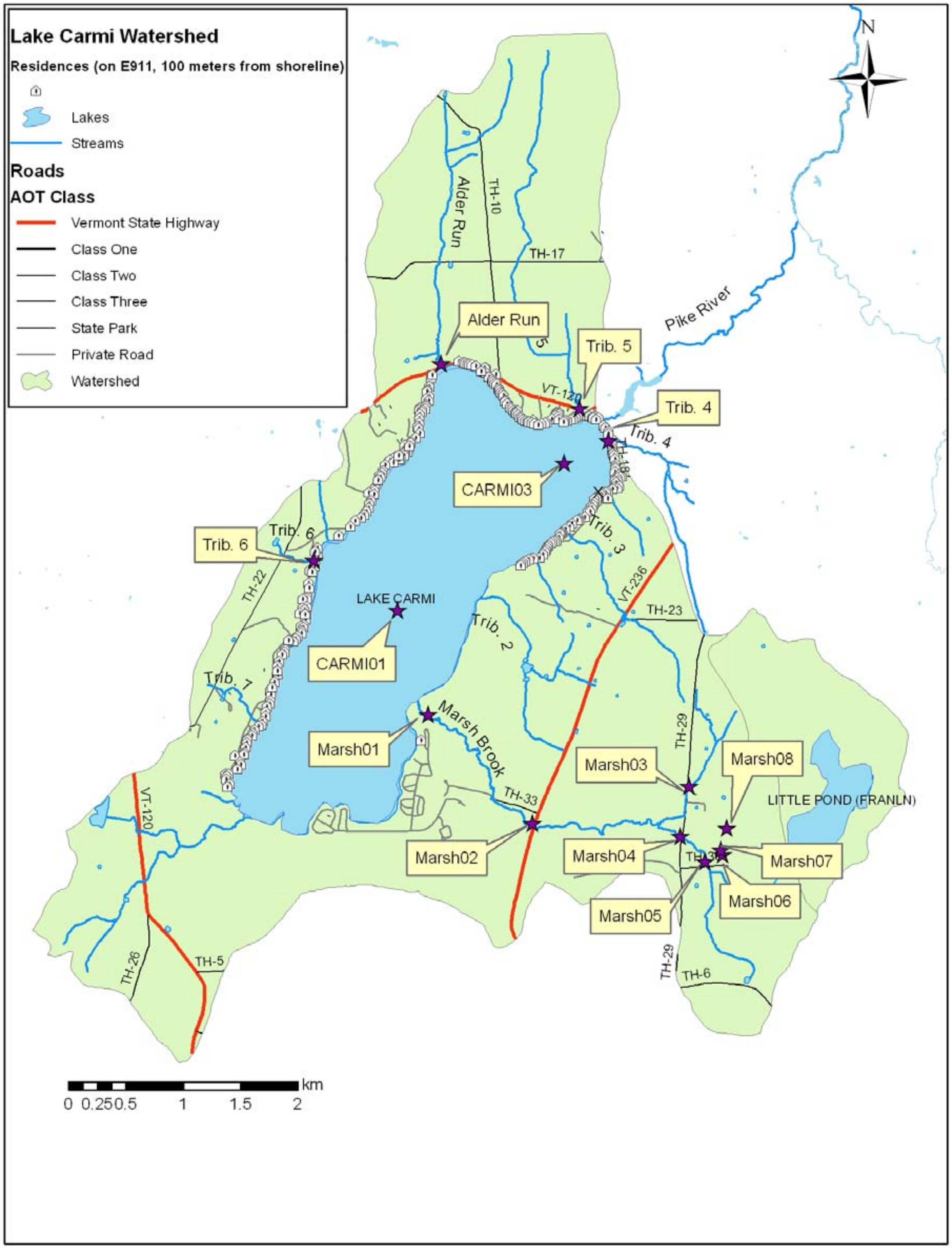

Figure 1. Watershed of Lake Carmi, in Franklin, VT. Monitoring locations shown by star symbols.

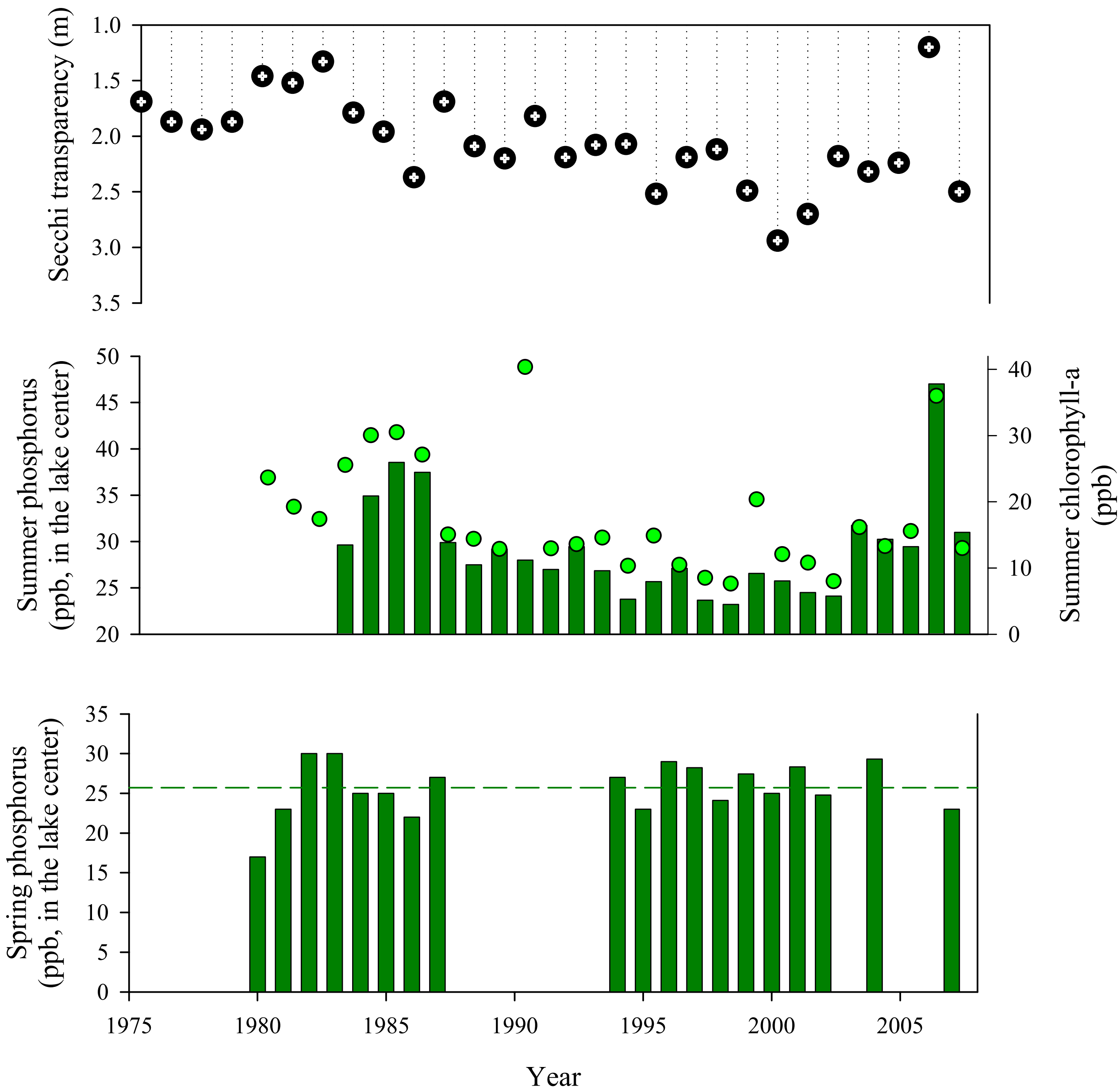

Figure 2. Trends in total phosphorus (bars), chlorolhyll-a (solid points), and Secchi transparency (crosshair points), from the Spring Phosphorus and Lay Lakes (summer) Monitoring Programs.

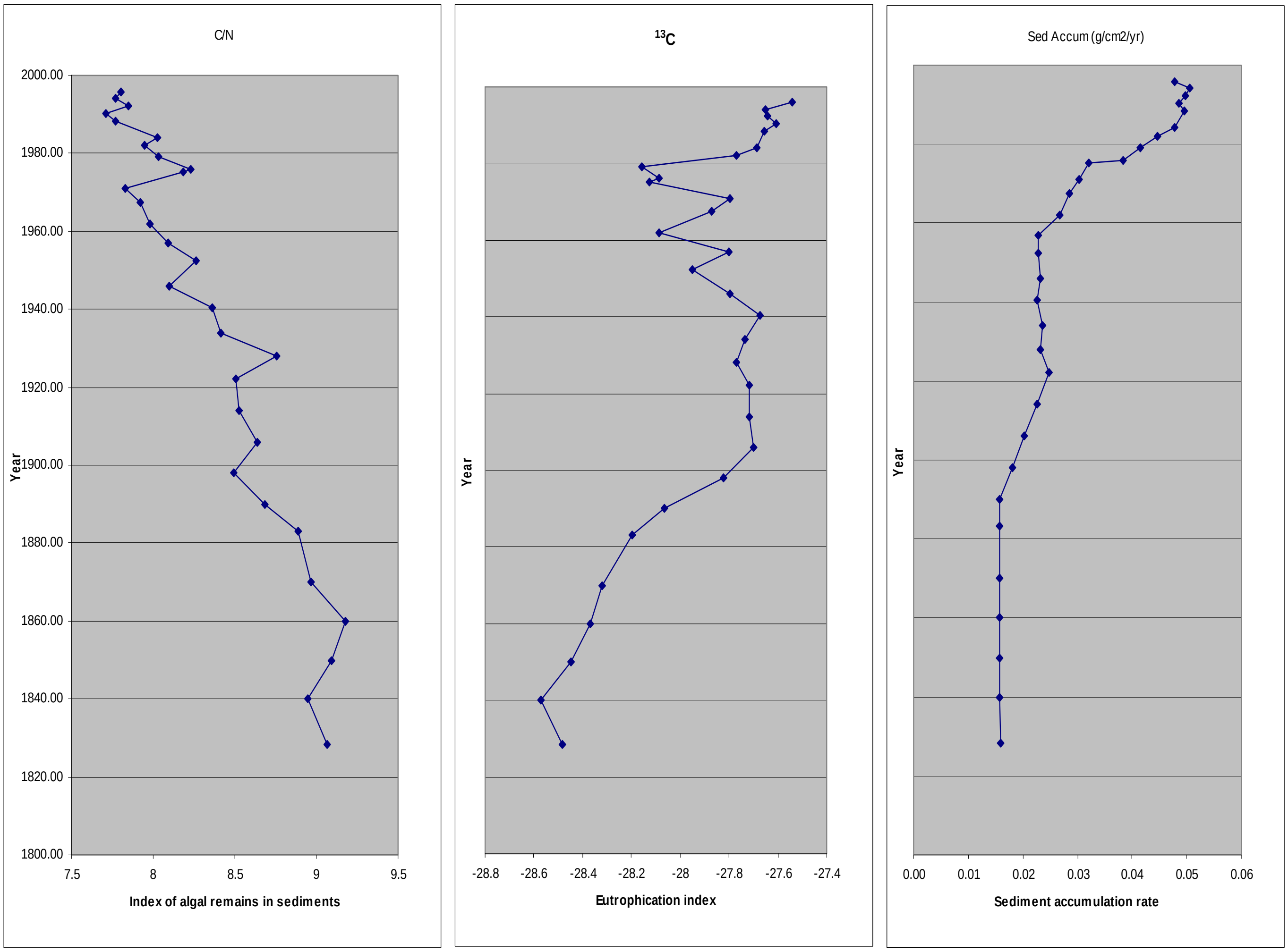

Figure 3. Profiles of carbon-nitrogen ratios ("Index of algal remains," in %), ^{13}C isotopic ratios (a.k.a. "Eutrophication index," in $^{o}/_{oo}$), and sediment accumulation rates (in μg/m^2/yr), from the Lake Carmi sediment core.

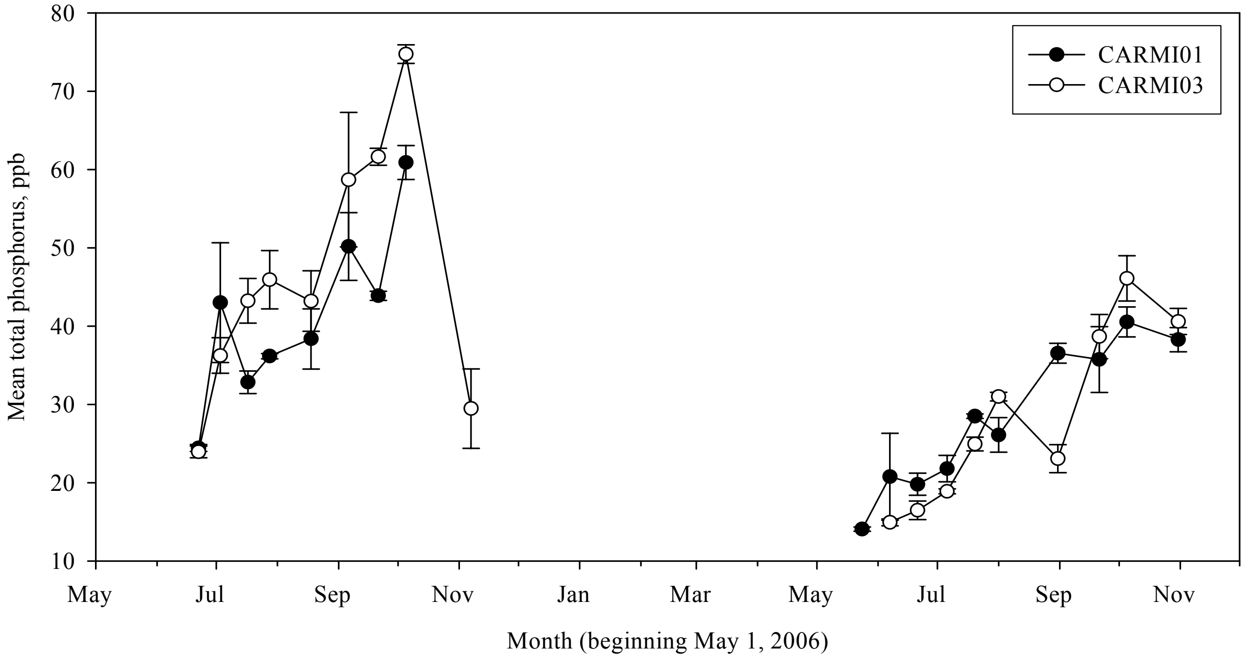

Figure 4. Mean whole-water column total phosphorus concentrations in 2006 and 2007. Bars represent standard errors.

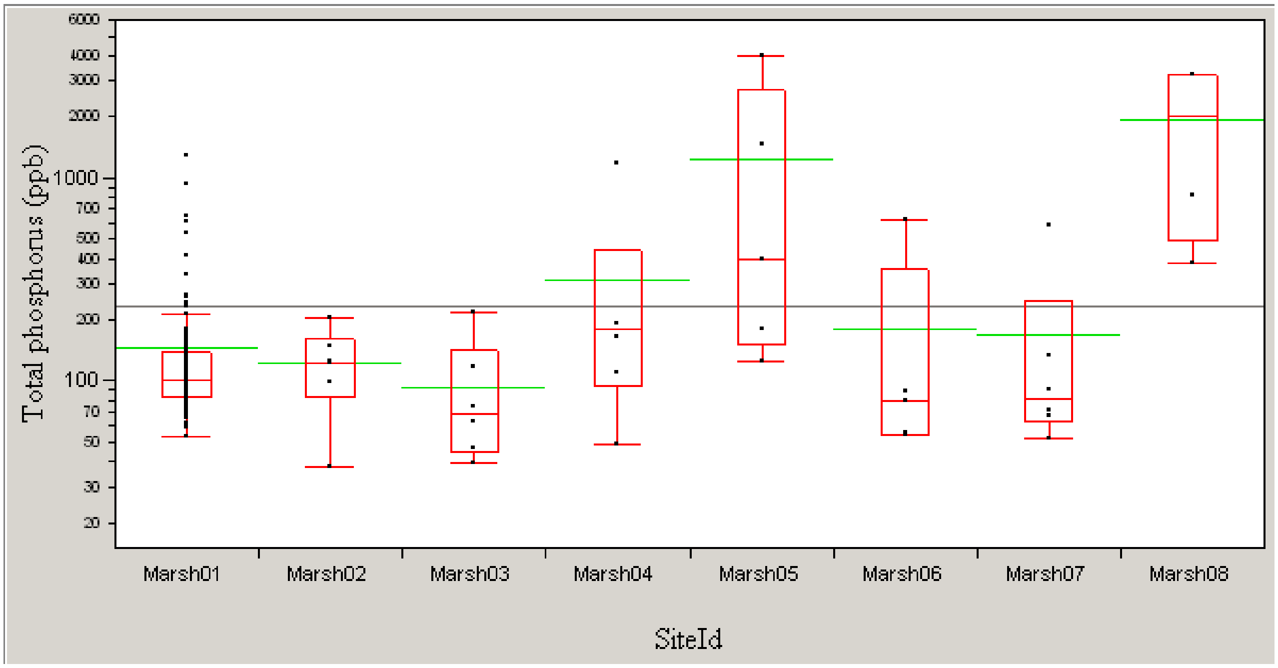

Figure 5. Box plot showing distribution of total phosphorus concentrations sampled in 2007 within the Marsh Brook watershed. Green lines show arithmetic means of each station. Grey line shows the mean for all stations. See Figure 1 for tributary site locations.

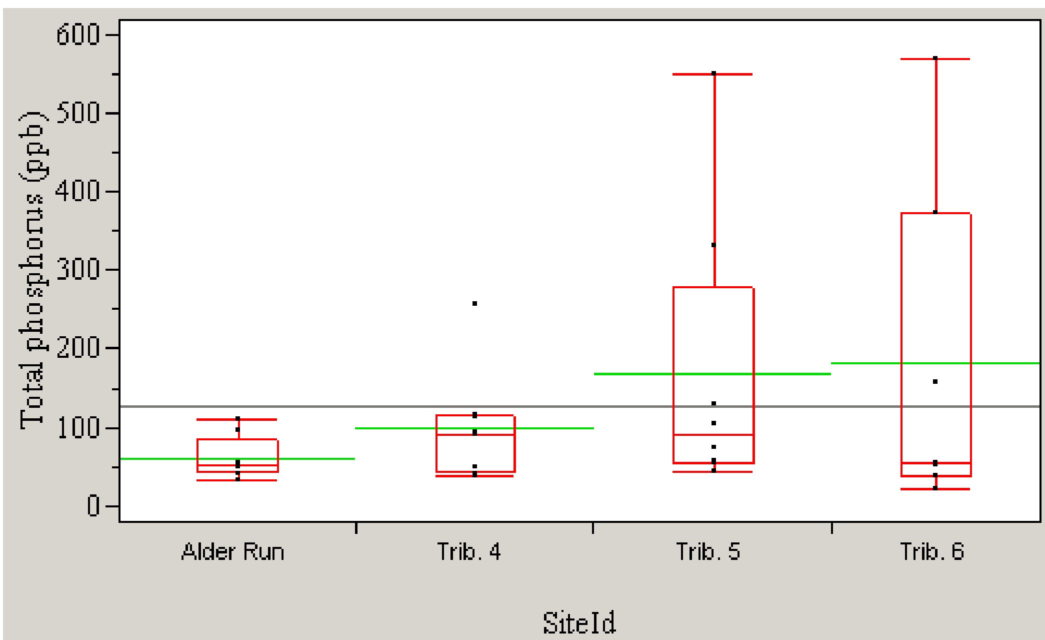

Figure 6. Box plots showing distribution of total phosphorus concentrations sampled in 2007 within the Lake Carmi watershed. Green lines show arithmetic means of each station. Grey line shows the mean for all stations. See Figure 1 for tributary site locations.

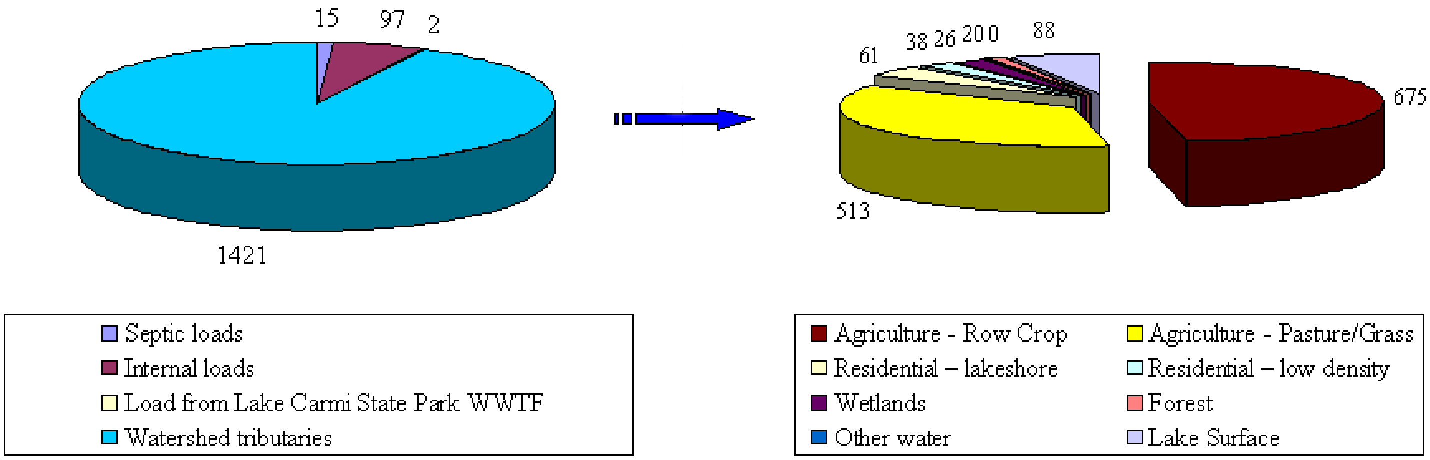

Figure 7. Apportionment of estimated annual phosphorus loads to Lake Carmi, showing the breakout of loads from various components of the watershed tributaries. Values are in kilograms per year.