Analysis of Internal Phosphorus Loading in Newport Water Reservoirs

Executive Summary

Based on information collected in 2014 and 2015, each of the nine reservoirs, serving the Newport Water System, has exhibited some indirect evidence of internal loading (the release of phosphorus from lake sediments). The indirect evidence includes hypoxic bottom waters, elevated levels of phosphorus in the bottom waters, increases in chorophyll-a concentrations after fall turnover, elevated lake sediment-phosphorus concentrations, and/or increases in reservoir phosphorus mass during the growing season.

Internal loading for Newport's nine reservoirs was estimated using two well-established methodologies: (1) assessing in-situ increases in reservoir phosphorus, and 2) estimating a sediment-phosphorus release rate based on sediment-phosphorus concentrations. The in-situ method appeared to be the better method for quantifying the internal load from these particular reservoirs, since the in-situ method assumptions more closely match reservoir water quality conditions (i.e. the occurrence of harmful algal blooms). The data used to estimate internal loading for the reservoirs consisted of single sediment cores collected in each of the reservoirs in 2014, and water quality data (including phosphorus and DO data) collected biweekly from May through October, 2015.

The in-situ method quantifies the internal load by subtracting a lesser reservoir phosphorus mass recorded during the spring from the maximum mass recorded during the late summer or fall. The increase in mass is assumed to be the result of internal loading. Application of this method to Newport's reservoirs had to take into consideration intra-reservoir water transfers, tributary inflow and hypolimnetic water withdrawals, which are expected to cause significant changes in reservoir phosphorus mass. To reduce estimation error resulting from intra-reservoir water transfers, reservoir phosphorus mass increases were assessed only during periods when there were no water transfers. The abbreviated time period used for assessment of phosphorus increases, likely resulted in an underestimation of the internal load of four of affected reservoirs (Lawton Valley Reservoir and St. Mary's, North Easton, and South Easton Ponds). These same four reservoirs were also subjected to hypolimnetic withdrawals (the withdrawal of bottom water utilizing pipes that are located near the reservoir bottom). Because hypolimnetic withdrawals pull potentially phosphorus rich bottom waters, the internal load estimate of these four reservoirs is likely further depressed. The internal loads of North Easton, Paradise and Nonquit Ponds may have been overestimated due to tributary inflow. An estimation of the internal load of Watson Pond was not possible using this method, because the phosphorus mass actually decreased in this reservoir during the growing season. Watson Pond was heavily utilized, during the summer of 2015. The lack of an increase in phosphorus mass may have been the result of hypolimnetic withdrawal, which as noted above could have obscured evidence of internal loading.

The internal phosphorus load was also calculated following the method that uses sediment phosphorus concentrations in which an estimated sediment release rate is multiplied by an anoxic factor (Nurnberg, 2009). One sediment core was taken in each of the nine reservoirs. Sediment release rates were estimated using literature regressions of measured TP release rates (RR) and sediment-phosphorus concentrations (Nurnberg, 1988). The anoxic factor represents the number of days that a sediment area, equal to the whole-lake surface area, is overlain by anoxic water. The sediment-phosphorus concentrations, associated with most of the reservoirs, were below the threshold concentration indicative of sediment-phosphorus release. Negative release rates for these reservoirs were generated, indicating that the reservoir is a sink and not a source of internal phosphorus. Using this method, internal loading was indicated only for North Easton, Gardiner, and Paradise Ponds. However, the prediction that internal loading is not occurring in the remaining reservoirs is not consistent with results of the in-situ method or other evidence of internal TP

release including the trend of increasing mean whole water column TP concentrations during the growing season, and visual observations (i.e. severe algal blooms) of these reservoirs.

The following analysis and quantification of the internal load of the Newport Water Reservoirs was conducted in support of the Newport Water Reservoirs TMDL (publication pending). The analysis documents evidence of internal phosphorus cycling within Newport's Water Reservoirs, however, because of the confounding influence of intra-reservoir water transfers, tributary inflow and hypolimnetic water withdrawals, the estimations of internal load are only approximate in nature. A more accurate estimation of internal loads would require flow measurements and phosphorus sampling of intra-reservoir water transfers, major tributaries, and water withdrawals into the North Easton and Lawton Valley Water Treatment facilities.

Introduction

Internal loading, the release of phosphorus from lake sediments, can be a significant source of phosphorus in eutrophic lakes. Internal phosphorus loading originates from a pool of phosphorus accumulated in the lake sediment. The ultimate source of most of the sediment-bound phosphorus is external (i.e. watershed sources such as stormwater). Under certain conditions this sediment-bound phosphorus can be released into the water column resulting in elevated phosphorus concentrations that can generate algal blooms and subsequent low DO conditions. Internal loading is generally more significant in deeper, stratified lakes, where the potential for anoxic conditions favor the release of sediment-bound phosphorus.

In deep lakes (>5 m), phosphorus concentrations at the surface and at depth are typically similar in the spring, reflecting the physical mixing that occurs in the spring. After deep ponds become thermally stratified in the summer and early fall, oxygen at depth can become very depleted because of the decay of organic matter in the sediment and also from the decay of recent algal die-off. The bottom waters of deep ponds are typically isolated from aerobic surface waters in the summer and early fall, with little occurrence of vertical mixing with the oxygenated upper layer. Under aerobic conditions, phosphorus is typically retained in the lake sediment, bound to metal oxides such as iron and manganese. When the bottom waters become anoxic in the summer, the chemical state of iron and other metal oxides changes, resulting in release of phosphorus into the water column. Phosphorus concentrations at depth tend to increase dramatically in the summer and early fall, in deep eutrophic ponds. Søndergaard et al. (1993) found that in a Danish lake phosphorus release mainly occurred from April to October, with little or no phosphorus release occurring during the winter.

While shallow lakes are generally well mixed, they may become weakly or intermittently stratified, resulting in anoxic conditions in the bottom waters. Riley and Prepas (1984) studied two shallow intermittently-stratified lakes in Alberta and found that during periods of stratification water directly overlying sediments was anoxic and total phosphorus increased in deep water, with the sediments being the major source of total phosphorus. After eight of nine mixing events that immediately followed stratified periods, total phosphorus in the surface water increased by 3-52%.

Although the release of sediment-bound phosphorus is enhanced by anoxic bottom conditions, phosphorus is also released from lake sediments to well aerated water more typical of shallow lakes. Holdren and Armstrong (1980) per Fricker (1981) quoted literature values of sediment phosphorus release rates from several lakes in the United States for aerobic (0 to 13 P mg/m^2/day) and anaerobic conditions (0 to 50 [max. 150] mg P mg/m^2/day). Welch and Cooke (1995) reported very high internal loading rates (20-50 mg/m^2/d) in shallow lakes characterized by wind mixing/resuspension. Søndergaard et al. (1999) measured the seasonal phosphorus concentrations of 265 shallow, mainly eutrophic Danish lakes and found that total phosphorus concentrations during summer were two to four times higher than winter values in lakes with a mean summer total phosphorus concentration above 200ug/l. Søndergaard et al. (1992) reported that the rate of phosphorus release from the undisturbed sediment of a shallow eutrophic Danish lake during the summer was 4-12 mg/m^2/day. This rate increased to 150 mg/m^2/day during simulated resuspension events. Phillips et al. (1994) recorded sediment phosphorus release rates as high as 278 mg/m^2/d, in very shallow lakes in the United Kingdom.

Pore water chemistry, especially the Fe:P ratio, can have a significant effect upon the mobility of sediment-bound phosphorus. Jensen et al. (1992) found that internal cycling from aerobic sediments from fifteen Danish lakes was suppressed by Fe:P ratios above 15 (by weight). No correlation was found between the water column total phosphorus concentration and sediment phosphorus concentration alone. Conversely, very high internal loading rates (20-50 mg/m^2/d) have been observed in shallow lakes with low Fe:P ratios (Welch and Cooke, 1995). Phillips et al. (1994) measured higher phosphorus release rates during periods when sulfide from sulfate reduction removed iron [FE(II)] from the sediment pore water.

The level of phosphorus concentrations in the water column influences the length of time that phosphorus is released from the sediment. Søndergaard et al. (1999) found that in shallow eutrophic Danish lakes, with total phosphorus concentrations below 100 ug/l, phosphorus was retained in lake sediments for most of the year, except July and August when mean internal loading accounted for 10-30% of external loading. In lakes with total phosphorus above 100 ug/l, phosphorus was retained in lake sediments during the winter but released from April to September.

Experience gained in various lake restoration projects suggests that the history of accelerated eutrophication, that is, the length of time the lake has been eutrophied, has an important bearing on lake behavior with respect to internal loading and phosphorus retention in the sediments. Sediments remain P sinks only gradually become P sources, long after the water mass becomes highly eutrophic (Schindler et al, 1976). Conversely, the highly P enriched sediment would remain a P source to the lake long after the external load is reduced and would thus delay the recovery of the lake. In some shallow lakes, with high sediment-phosphorus concentrations and a long history with eutrophication, 22 to 400% of the external phosphorus load was released from the sediments after reduction of the external load (Ryding and Forsberg, 1976).

The contribution of internal loading to the total phosphorus load has been quantified in several studies. In 14 of 17 Washington lakes, where phosphorus budgets were available and internal loading was measurable, internal loading averaged 68% of the total phosphorus loading during the summer (Welch and Jacoby, 2001). Internal phosphorus loads accounted for between 56 and 66% of the total phosphorus load to Spring Lake in southwestern Michigan (Steinman and Rediske, 2003). For 23 stratified lakes with anoxic hypolimnia, internal load contributed an average of 39% of the total phosphorus load (Nurnberg and Peters, 1984).

The importance of addressing internal phosphorus loading should be clear. The focus of TMDL implementation sections is the control of identified external sources of phosphorus discharged to the reservoirs. However, it must be understood that even if external loading is significantly reduced, little improvement may be seen in water quality for decades, in lakes or reservoirs experiencing continued internal loading. For example, after wastewater treatment was installed reducing 80% of the external load to Shagawa Lake in Minneapolis, Minnesota, modeling indicates that it would take 80 years to achieve a 90% reduction in summer lake phosphorus, due to internal cycling (Chapra and Canale, 1991). Søndergaard et al. (1993) estimated that, even after an 80–90% reduction in external phosphorus loading to a shallow hypereutrophic Danish Lake, phosphorus would continue to be released from the sediment for approximately 20 years. One year after the drastic reduction in external phosphorus loading in 1982, net internal phosphorus loading was 8 g/m^2/y. This rate decreased slowly to 2 g/m^2/y in 1990, 15 years after the reduction in external phosphorus loading.

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Even if the internal load to the Newport Water Reservoirs may comprise only a fraction of the external load, the release of phosphorus from lake sediments may have an outsized effect on water quality (ie. harmful algal blooms), relative to a similar external load, at least over the short term (the relative importance of internal loading is discussed in the paragraphs below). Although the release of internal phosphorus may have a more immediate effect on water quality, the primary driver of internal loading, and the ultimate cause of long term adverse water quality impacts remains external loading, which is derived from the watershed. Phosphorus from phosphorus-rich tributary discharge, has been accumulating in reservoir sediment for many decades. Once enough phosphorus has accumulated, the sediment's ability to adsorb it permanently, is overcome and the phosphorus is released into the water column, on a seasonal basis. The problem of internal loading becomes more serious and protracted the longer the watershed load of phosphorus-rich water continues. The primary focus of any lake management plan should be the control of identified external sources of phosphorus. Mitigation of internal phosphorus should occur only after loading from identified external sources have been reduced, or concurrently with the mitigation of the watershed load.

Sediment-released phosphorus (dissolved or soluble reactive phosphorus), is in a form that is readily available to algae. External phosphorus, by contrast is largely in particulate form and only partially available to algae (Peters, 1978; Schaffner and Oglesby, 1978). In anoxic ponds, with hypolimnetic total phosphorus (TP) concentrations greater than 100 ug/l, 70% of the sediment-released phosphorus can be utilized by epilimnetic plankton, following turnover or even partial thermocline decay (Nurnberg and Peters, 1984). Hypolimnetic phosphorus can also be positionally available to metalimnetic plankton at the oxic/anoxic boundary (Konopka, 1983). Some species of cyanobacteria can also adjust their buoyancy, sequester hypolimnetic phosphorus and transport it into the epilimnion (Barbiero and Welsh, 1992; Petersson et. al. 1993; Head et al., 1999). This phosphorus can then be available to other algae species via leakage or mortality.

The timing of phosphorus release from lake sediments (June through September) largely coincides with the occurrence of algal/cyanobacteria blooms. In other words, phosphorus is released from the sediment at a time that is critical for algal metabolism and growth. In contrast, much of the external TP load, enters the reservoirs during a period of relative algal quiescence (algal blooms do occur from late fall through early spring, however they are much less frequent and problematic). However, phosphorus from external loading, entering the reservoirs during the colder months, may remain in the water column during warmer months (depending on reservoir's retention time), when the problem algal growth may be more acute. In addition, external phosphorus entering the reservoirs during the colder months, may become entrained in reservoir sediments, only to be released during the season of more problematic algal growth. However, it is likely that at least some portion of the external load passes through the reservoirs during the colder months, without having a significant effect on algal growth.

Newport Water Reservoir TMDL

This estimation of the internal phosphorus load has been conducted in support of the Newport Water Reservoir TMDL (in preparation). In support of the TMDL, staff from RIDEM collected water chemistry and phytoplankton samples, and other physical data in all nine reservoirs on a bi-weekly basis from early May through early October 2015. In total, 12 surveys were completed. A single sediment sample was collected in each of the nine reservoirs at the deepest location in May, 2014.

The study design is described in detail in the EPA-approved Quality Assurance Project Plan (www.dem.ri.gov/pubs/qapp/newpresv.pdf). All surface water data referenced in the remaining portion of this document are available online in the Newport Water Supply Data Report at: www.dem.ri.gov/programs/benviron/water/quality/rest/pdfs/nptdata.pdf. Reservoir sediment data are on file at RIDEM's Office of Water Resources, and are available upon request.

Indirect Evidence of Internal Phosphorus Loading in Newport Reservoirs

Indirect evidence of internal loading (the release of phosphorus from lake sediments) includes the following (Nurnberg 1988; Nurnberg et al, 2012; Nurnberg et al, 2013):

- hypoxic bottom waters (< 2 mg/l DO) in stratified lakes;
- elevated TP and dissolved P in the bottom water in stratified lakes
- increase in euphotic zone P and chlorophyll concentrations during fall turnover in stratified lakes
- decrease in water clarity during fall turnover in stratified lakes
- high TP concentrations in anoxic lake sediments (52-85 ug/g on a wet-weight basis and 1.1 mg/g on a dry-weight basis)
- increase in TP in late summer and early fall in unstratified lakes.

Available Newport reservoir data for each of these conditions are reviewed below.

Hypoxic Bottom Waters

Six of the Newport Water reservoirs were seasonally or weakly stratified in 2015, and were characterized by hypoxic bottom waters, during at least one sampling event (Table 1). Watson and Lawton Valley Reservoirs are the deepest (>5 m) reservoirs in the Newport Water system, however the Lawton Valley Reservoir has several aerators which prevented it from stratifying on a consistent basis, as evidenced by the bi-weekly bottom DO data. Paradise Pond is the only reservoir, other than Watson Reservoir, that was stratified on a consistent basis. Both reservoirs were stratified for approximately 3 months, and were the only reservoirs with anoxic (DO < 1 mg/l) bottom waters. South Easton, North Easton Pond, Gardiner Pond, and Lawton Valley Reservoir were weakly stratified (hypoxic bottom waters were recorded for periods of about 2-6 weeks). The remaining ponds (St. Mary's, Sisson and Nonquit Ponds) were polymictic (well mixed), and did not exhibit thermal stratification or low hypolimnetic DO. The hypolimnetic DO of these polymictic reservoirs remained above 2 mg/l during all 12 sampling events.

Elevated Total and Dissolved Phosphorus in Bottom Waters

Most of the stratified and weakly stratified reservoirs were characterized by elevated TP in their bottom waters during hypoxic periods, an indication of the release of phosphorus from the sediments (Table 2). South Easton and Paradise Ponds and Lawton Valley and Watson Reservoirs all displayed elevated TP in their bottom waters. Paradise Pond had the most elevated bottom water TP concentrations, while Watson Reservoir had hypolimnetic TP concentrations that were only slightly above the criteria value (25 ug/l). This RIDEM phosphorus criteria applies to lakes, ponds, and reservoirs. The introduction of phosphorus into the hypolimnion, from the sinking of inorganic particulates and organic material could also result in a steady increase in dissolved phosphorus in the hypolimnion. This potentially false indication of internal loading can be avoided by assessing the change in the whole water column TP value over the growing season, instead of comparing bottom and surface concentrations (discussed in more detail below). North Easton and Gardiner Ponds do not have elevated TP concentrations in their hypolimnion, probably because these ponds were only weakly stratified for a period of about two weeks. The thermocline may not have been sufficiently established to retain phosphorus in the hypolimnion.

Table 1. Stratification Status of Newport Water Reservoirs.

	Lake Surface Area (Acres)	Maximum Recorded Depth (m)	Aeration	Seasonally Stratified	Weakly Stratified	Polymictic
South Easton	132	3.0	No		✓	
North Easton	113	3.6	No		✓	
Paradise	28.9	3.8	No	✓		
Gardiner	92.4	2.7	No		✓	
St. Mary’s	112	3.2	Yes			✓
Sisson	69.1	3.0	No			✓
Lawton Valley	81.4	8.2	Yes		✓	
Nonquit	196	3.5	No			✓
Watson	371	7.1	No	✓		

Table 2. Mean TP at Surface and Depth when Bottom Waters are Hypoxic (DO < 2 mg/l).

	North Easton	South Easton	Paradise	Gardiner	St. Mary’s	Sisson	Lawton Valley	Nonquit	Watson
Surface TP (ug/l)	73	17	81	97	N/A*	N/A	51	N/A*	15
Bottom TP (ug/l)	68	44	214	62	N/A*	N/A	77	N/A*	28

*DO in bottom waters >2 mg/l during all 12 sampling events.

With the exception of Paradise Pond, hypolimnetic dissolved phosphorus (DP) concentrations were low in all the stratified and weakly stratified reservoirs (Table 3). This is unusual in lakes characterized by sediment phosphorus release, since phosphorus is released in the dissolved form. It is possible that once released from anoxic sediments into bottoms waters with relatively higher DO (1-2 mg/l), that the dissolved phosphorus is readsorbed onto iron, another metal, or organic compounds. Some algal and cyanobacteria species are also able to adjust their buoyancy and sequester phosphorus below the thermocline (Barbiero and Welch, 1992; Salonen and Jones, 1984). It may be that these organisms depleted any potential hypolimnetic pool of dissolved phosphorus.

Table 3. Mean DP at Surface and Depth when Bottom Waters are Hypoxic (DO < 2 mg/l).

	North Easton	South Easton	Paradise	Gardiner	St. Mary's	Sisson	Lawton Valley	Nonquit	Watson
Surface DP (ug/l)	5	3	10	14	N/A*	N/A	4	N/A*	3
Bottom DP (ug/l)	5	3	44	13	N/A*	N/A	8	N/A*	2

*DO in bottom waters >2 mg/l during all 12 sampling events.

Increase in Euphotic Zone Phosphorus and Chlorophyll Concentrations and Decrease in Water Clarity during Fall Turnover

Certain changes in surface conditions, pre- and post- fall turnover, can also be an indication of internal loading in stratified lakes. As previously discussed, Paradise Pond and Watson Reservoir are the only reservoirs that are stratified on a consistent basis. When phosphorus-rich bottom waters mix into the surface during fall turnover, it often results in an increase in surface TP and a concomitant increase in chlorophyll-a and decrease in clarity. Neither reservoir exhibited a significant increase in TP in its surface waters after fall turnover (Table 4), perhaps because the volume of phosphorus-rich bottom water is small compared to the lower phosphorus waters above the thermocline or because the released phosphorus recombined with iron, another metal, or organic compounds, and settled out of the water column. Chorophyll-a concentrations increased in Paradise Pond after fall turnover (Table 5), however there was no decrease in water clarity (Table 6). Watson Reservoir did not exhibit an increase in chorophyll-a concentrations nor a decrease in water clarity after fall turnover.

Table 4. Surface TP Concentrations (ug/l) before and after Fall Turnover.

	North Easton	South Easton	Paradise	Gardiner	St. Mary's	Sisson	Lawton Valley	Nonquit	Watson
Before Turnover	N/A*	N/A*	117	N/A*	N/A	N/A*	N/A*	N/A*	15
After Turnover	N/A*	N/A*	119	N/A*	N/A	N/A*	N/A*	N/A*	12

*Not seasonally stratified.

Table 5. Surface Chlorophyll-a Concentrations (ug/l) before and after Fall Turnover.

	North Easton	South Easton	Paradise	Gardiner	St. Mary's	Sisson	Lawton Valley	Nonquit	Watson
Before Turnover	N/A*	N/A*	43	N/A*	N/A*	N/A*	N/A*	N/A*	20
After Turnover	N/A*	N/A*	62	N/A*	N/A*	N/A*	N/A*	N/A*	15

*Not seasonally stratified.

Table 6. Water Clarity (Secchi Depths) Before and After Fall Turnover (m).

	North Easton	South Easton	Paradise	Gardiner	St. Mary’s	Sisson	Lawton Valley	Nonquit	Watson
Before Turnover	N/A*	N/A*	0.5	N/A*	N/A*	N/A*	N/A*	N/A*	1.1
After Turnover	N/A*	N/A*	0.6	N/A*	N/A*	N/A*	N/A*	N/A*	1.4

*Not seasonally stratified.

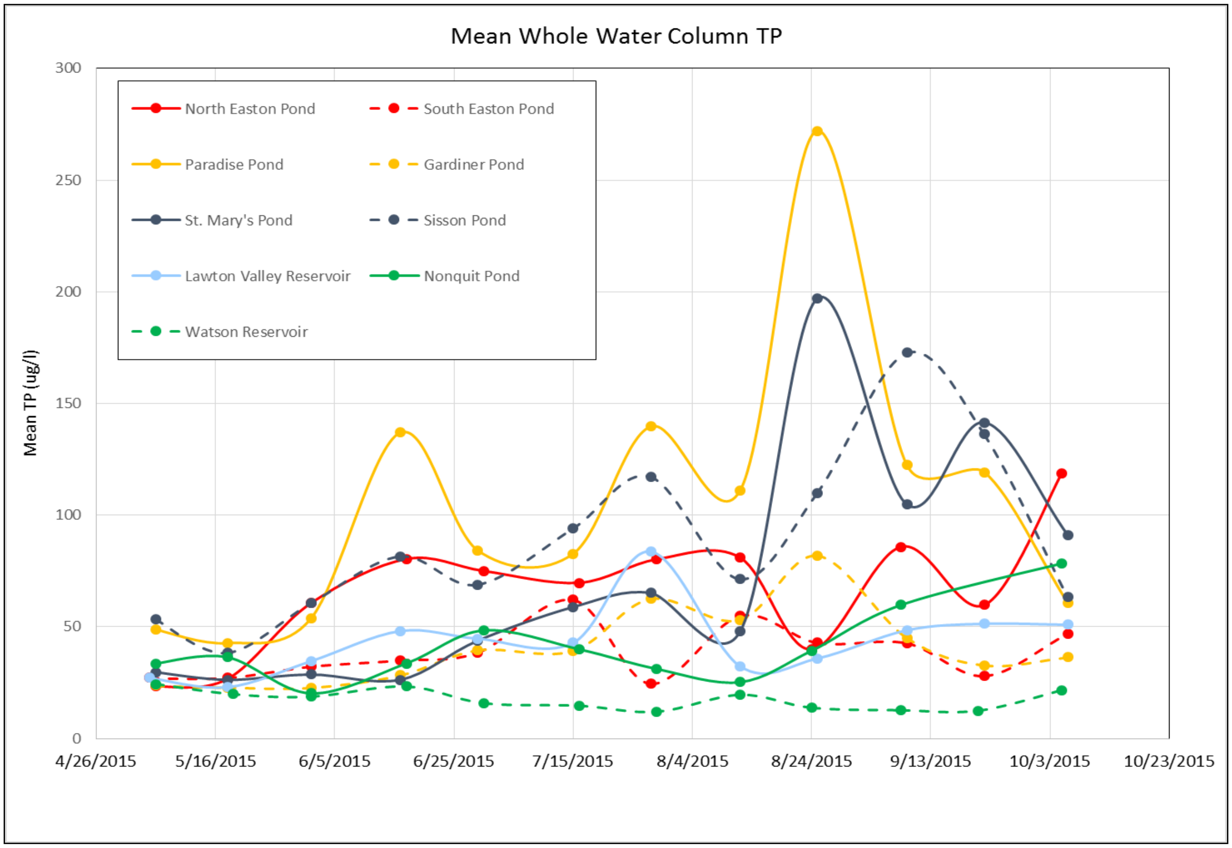
<u>High Total Phosphorus in Anoxic Lake Sediments</u>

As will be discussed in greater detail later in this document, Nurnberg (1988) developed regressions relating lake sediment phosphorus concentrations to measured TP release rates. Only three of the Newport Water reservoirs had sediment-P concentrations indicative of the release of internal phosphorus. North Easton Pond had the highest sediment-P concentration on a wet-weight basis (246 ug/g), followed by Gardiner Pond (101.6 ug/g). The sediment-P concentration of Paradise Pond (53 ug/l) is just barely above the threshold value where the release of sediment phosphorus is indicated.

<u>Increase in Total Phosphorus in Late Summer and Early Fall in Unstratified Lakes</u>

With the exception of sediment-TP concentrations, all other indications of internal loading discussed above, are associated with stratified or at least weakly stratified ponds. As previously discussed, the release of sediment phosphorus can also occur in shallow polymictic (well mixed) ponds. An increase in mean water column TP, occurring from late spring through late summer and early fall is perhaps the strongest and most direct indication of internal loading, not only in polymictic lakes but also in stratified lakes. As phosphorus is released from the sediment, concentrations in the water column increase throughout the growing season. During the summer and early fall, many of the tributaries to the reservoirs dry up and others are characterized by minimal flow. If the mean water column TP concentration increases throughout this period, when the external load is minimal, there is a strong indication of the internal release of phosphorus from lake sediments. With the exception of Watson Reservoir, all reservoirs are characterized by a trend of increasing TP, during the growing season (Figure 1).

Figure 1. Mean Whole Water Column TP.



All of the reservoirs have at least some indication of internal loading (summarized in Table 7). However, the strongest indication of internal loading (a trend of increasing water column TP during the summer and early fall) is absent in Watson Reservoir. In fact, there is a general trend of decreasing phosphorus in Watson Reservoir. This would appear to indicate that phosphorus is settling out of the water column, and is adsorbed onto lake sediment, which is acting as a sink. Another explanation is the hypolimnetic withdrawal of water. Several of the reservoirs have multiple intakes at varying elevations and most reservoirs have intakes close to the bottom of the reservoir. The lower intake of Watson Reservoir is located only 2 ft. off the bottom. If phosphorus was released from the sediment, into the hypolimnion of this stratified pond, and the lower intake was consistently extracting this phosphorus-rich water, there may be no signature increase in TP concentrations. In this case internal loading would be occurring, however it is not possible to quantify it by the methods employed below.

Table 7. Summary of Indirect Evidence of Internal Loading.

	North Easton	South Easton	Paradise	Gardiner	St. Mary's	Sisson	Lawton Valley	Nonquit	Watson
Hypoxic Bottom Waters	Yes	Yes	Yes	Yes	No	No	Yes	No	Yes
Elevated TP in Hypoxic Bottom Waters	No	Yes	Yes	No	N/A[1]	N/A[1]	Yes	N/A[1]	Yes
Elevated DP in Hypoxic Bottom Waters	No	No	Yes	No	N/A[1]	N/A[1]	No	N/A[1]	No
Increase in Surface P during Fall Turnover	N/A[2]	N/A[2]	No	N/A[2]	N/A[2]	N/A[2]	N/A[2]	N/A[2]	No
Increase in Surface Chlorophyll Concentrations during Fall Turnover	N/A[2]	N/A[2]	Yes	N/A[2]	N/A[2]	N/A[2]	N/A[2]	N/A[2]	No
Decrease in Water Clarity during Fall Turnover	N/A[2]	N/A[2]	No	N/A[2]	N/A[2]	N/A[2]	N/A[2]	N/A[2]	No
Sediment-TP Concentrations Indicative of P Release	Yes	No	Yes	Yes	Yes[3]	No	No	No	Yes[3]
Increase in Whole Water Column TP Mass during the Growing Season	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No

1. DO in bottom waters >2 mg/l during all 12 sampling events.
2. Not seasonally stratified.
3. Based on data collected by Fuss & O'Neil in 2015 for the City of Newport (sediment-P concentrations reported by Fuss & O'Neil were significantly higher than sediment-P concentrations recorded by RIDEM).

Methods for Estimating the Internal Phosphorus Load

There are three different ways to estimate internal phosphorus load for a lake (Nurnberg, 2009): 1.) compare in-situ end-of-summer hypolimnetic or whole-water column P masses with masses at the beginning of the season; 2.) measure or estimate sediment release rates and an anoxic factor determined from the anoxic sediment area and the duration of anoxia; and 3.) perform a complete P budget or mass balance.

Method 3 (mass balance approach) was not used because all of the necessary data were not available. An extensive phosphorus budget requires a mass balance of inflows, outflows and internal fluxes on an annual basis. This requires at least monthly measurements of P entering the waterbody, P leaving the waterbody and the P concentration and volume of each lake strata (epilimnion, metalimnion and hypolimnion). Although the necessary in-lake data were collected, inflow and outflow data were not collected.

Method 1: In Situ Phosphorus Increases

Methodology

In situ summer increases in water-column TP concentrations can be used to estimate net internal load (Nurnberg, 2009). In seasonally stratified lakes, the internal load is the difference between the end-of-summer hypolimnetic or whole water column TP mass and the respective TP mass at the beginning of the anoxic period. Loads are expressed in terms of mass/lake surface area, to facilitate comparison between the internal loads of different lakes, in addition to comparing internal loads with certain external loads, which are often expressed in the same terms. In polymictic and weakly stratified lakes, the maximum summer whole water column TP mass may be more appropriate to calculate loading, rather than the mass at the end of the summer (Nurnberg, 2009). For polymictic and weakly stratified lakes the internal load is the difference between maximum summer whole water column TP mass and the minimum springtime whole water column TP mass, both normalized for the lake surface area. For some reservoirs, the lowest springtime TP mass was not used to calculate the internal load, to avoid the influence of intra-reservoir transfers (discussed in greater detail below). Instead the lowest growing season TP mass, which was measured when there were no water transfers, was used to estimate the internal load. Since there was only one stratified reservoir (Paradise Pond) that showed strong evidence of internal loading, whole water column TP (rather than hypolimnetic TP concentrations) were used to calculate the internal loads for all the reservoirs. The **general formula** used to calculate the internal load by the in situ method is shown below:

$$\mathbf{L_{int} = TPt_2 \times Vt_2/A_ot_2 - TPt_1 \times Vt_1/A_ot_1}$$

where;

L_{int} = internal load (mg/m^2)

t_1 = date of minimum spring TP concentration;

t_2 = date of maximum summer TP concentration;

TP = average water column TP concentration;

V = lake volume; and

A_o = lake surface area.

Nurnberg (2013) employed the following method of calculating the **average water column TP concentration** when TP samples were available at discrete depths:

$$\mathbf{TP_{avg} = (TP_e \times V_e + TP_1 \times V_1 + TP_2 \times V_2 + TP_3 \times V_3)/V_o}$$

where;

TP_{avg} = average water column TP concentration;

TP_e = TP concentration in euphotic zone;

V_e = volume corresponding to euphotic sample;

TP_1, TP_2, TP_3 = TP concentration at three discrete depths in the hypolimnetic zone;

V_1, V_2, V_3 = volume associated with each discrete depth of the hypolimnetic sample; and

V_o = total lake volume at the time of sampling.

The Newport Water Reservoirs were sampled approximately every two weeks from the beginning of May, 2015 through the beginning of October, 2015. TP was sampled 1-2 ft. below the surface and approximately 2 ft. off the lake bottom. A YSI-Pro Plus was used to measure DO at intervals of 0.25 - 0.50 m intervals. If the DO profile showed anoxia in the bottom waters, then a third TP sample was taken near the middle of the oxycline. Reservoir volumes corresponding to 0.5-1 ft depth intervals were supplied by Newport Water.

The internal load was calculated for each of the Newport Water reservoirs using the general formula to calculate internal load, shown on the previous page. The volume-weighted mean whole water column TP concentration was calculated for each sampling event (this calculation is described in greater detail below). The mean TP concentration was then multiplied by the total lake volume to derive the TP mass present in the water column during each sampling event. This mass was then divided by the lake surface area, to normalize the result.

The volume-weighted mean TP concentrations of the reservoirs were calculated using the same methodology described in the previous page. However, instead of utilizing only TP concentrations that were collected at 2-3 discrete depths in the water column, and weighting each value with a corresponding volume of one half or one third of the reservoir volume, concentrations were interpolated in 0.5-1 ft. increments of the water column, and multiplied by the corresponding water volumes. The latter method resulted in a more accurate estimation of the mean TP concentration. Use of the latter method was especially critical in estimating the mean TP concentration in stratified lakes, when the TP concentration can change dramatically with depth, especially below the thermocline.

TP concentrations at discrete depths were calculated by interpolating between the measured surface and bottom TP concentrations. In the event that three TP samples were taken, two linear interpolations were used to calculate TP concentrations. This simple method approximates the phosphorus profile typical of stratified lakes, with a curve inflection point at the oxycline. The water volume associated with each discrete depth was then multiplied by the interpolated concentration to yield the mass of TP, corresponding to each depth interval, or each layer of the water column. The masses of TP, corresponding to each discrete depth, were then summed to yield the mass of TP in the entire reservoir. The mean whole water column TP concentration was derived by dividing the summed masses by the total lake volume, at the time of sampling. The mean TP value was multiplied by the total volume and the product was then divided by the lake surface area at the time of the sampling event (lake surface areas sometimes fluctuated significantly as water was withdrawn and transferred between reservoirs). Lake surface area was calculated by dividing the incremental volume of the surface layer (0.5-1 ft interval) with the corresponding depth interval. The lowest early spring (or lowest growing season) whole water column TP load (mg/m^2) was subtracted from the highest summer TP load (mg/m^2). When this result is multiplied by the average lake surface area (mean of surface areas corresponding to the highest and lowest load estimates), the result is a seasonal load expressed in terms of mass (e.g. kg of TP).

Method Limitations

The in situ method reportedly overestimates internal loading (Nurnberg, 2009) because it does not account for all settling and sediment sequestering that will occur after the sediments become oxic. However, adverse effects (e.g. algal blooms) resulting from the sediment-released phosphorus may occur even when the dissolution of phosphorus into the water column is only temporary.

The in situ method assumes steady state conditions (i.e. the external phosphorus load is equal to the phosphorus load outflow from the reservoirs), and that any external load into the reservoirs is equal to any outflow load. In other words, the in situ method assumes that any increase in reservoir TP mass is due solely to the release of phosphorus from reservoir sediments. However, incoming water transfers and tributary inflow could also cause an increase in in-lake TP concentration and mass, resulting in an inflated estimation of internal load. In contrast, hypolimnetic withdrawals of phosphorus-rich bottom waters, could cause an in-lake decrease in phosphorus mass, resulting in an underestimation of internal load. This is discussed in detail below.

Incoming Intra-Reservoir Water Transfers

The Newport Water reservoir system has infrastructure enabling the transfer of water between reservoirs. Reservoir water can be transferred into any of the seven reservoirs on Aquidneck Island. Water is not transferred into Nonquit Pond and Watson Reservoir (water can only be transferred out of these reservoirs).

The Newport Water Division provided RIDEM with records of intra-reservoir water transfers, as well as water withdrawals to the two water treatment plants (located at north Easton Pond and Lawton Valley Reservoir), and diversions of the Maidford River into both Paradise and Gardiner Ponds, for 2015. The record included the names of the contributing and receiving reservoirs, and the dates that the transfer was initiated and terminated. Phosphorus concentrations, measured during periods of incoming water transfers, were not utilized to calculate internal loads. By excluding these data, observed changes in TP concentration and mass could be solely attributed to internal load alone (assuming there was no influence from tributary sources).

There were no water transfers into five of the nine reservoirs (Paradise, Gardiner, Sisson, and Nonquit Ponds and Watson Reservoir), during the period when the lowest and highest phosphorus concentrations were recorded. Because of this, changes in phosphorus mass within these reservoirs are attributed solely to internal loading (again barring any influence of any tributary inflow).

For the remaining four reservoirs (Lawton Valley Reservoir and St. Mary's, North Easton, and South Easton Ponds), the highest and/or lowest TP concentrations were recorded during periods of incoming water transfers. These data were not utilized. Instead only the high and low TP concentrations, which occurred during periods of no incoming water transfers, were used to calculate internal loads. Because changes in TP concentrations and mass were assessed over an abbreviated time period, and not the entire growing season, the calculated internal load, for these four reservoirs, was likely underestimated.

Influence of Tributaries

During the summer and early fall, many of the tributaries to the reservoirs dry up and others are characterized by lesser flows, relative to flows during the wet season. Bailey's Brook (a tributary to North Easton Pond), the Maidford River (a tributary to both Paradise and Gardiner Ponds), Paradise Brook (a tributary to Paradise Pond) and Borden Brook (a tributary to Nonquit Pond) are the most perennial of the tributaries, however even these streams can dry up during the summer.

The reservoirs located in Portsmouth (St. Mary's and Sisson Ponds and Lawton Valley Reservoir) each have tributaries less than 0.5 miles in length. These tributaries appear to be manmade swales and are apparently ephemeral. Summertime inflow to the reservoirs appears to be insignificant.

Of the four reservoirs on lower Aquidneck Island (North Easton, South Easton, Paradise and Gardiner Ponds), two had no significant tributary inflow, during the summer of 2015. There are no tributaries to South Easton Pond (it is bermed around its entire perimeter). Although water from the Maidford River can be diverted to Gardiner Pond (as well as Paradise Pond), the valve from the Maidford River diversion structure was closed until October 2015, because work was being done in Paradise Pond. Therefore, there was no tributary inflow into Gardiner Pond, during the time period when the internal load was calculated. Bailey's Brook and Paradise Brook discharged significant summer tributary inflow to North Easton and Paradise Ponds, respectively.

Concerning the remaining two reservoirs (Nonquit Pond and Watson Reservoir), located to the east of the Sakonnet River, tributary inflow into Nonquit Pond was significant and may have influenced the estimation of internal load. As will be discussed in greater detail in the section below, the internal load of Watson Reservoir was not calculated and therefore no assessment of tributary inflow was necessary. Three of the eight reservoirs, which were evaluated for internal load, had significant tributary inflow during the late summer and early fall. As previously discussed, these reservoirs include North Easton, Paradise and Nonquit Ponds. Some portion of the quantified increase in TP mass, within these reservoirs, may have been the result of tributary inflow. Therefore the calculated internal load, associated with the three reservoirs, may have been overestimated.

Water Withdrawals

Although there were no incoming water transfers into the reservoirs, during the critical period, there were water withdrawals from four of the eight reservoirs, for which an internal load was calculated (North Easton, South Easton, and Saint Mary's Ponds and Lawton Valley Reservoir). These withdrawals not only resulted in a loss of reservoir volume, but also a reduction in TP mass in these reservoirs. This loss in TP mass was compounded by the fact that most, if not all, withdrawals were conducted by pipes located near the reservoir bottom. In the event that phosphorus, released from the sediment, was trapped in the bottom waters, these hypolimnetic withdrawals likely removed much of this phosphorus-rich water from the system. Loss of water volume and phosphorus mass, caused by withdrawals to the treatment stations, makes accurate estimation of internal loading difficult and likely results in an underestimation of the internal load. The subject reservoirs are the same reservoirs that were assessed during a restricted time period, because of incoming transfers, further compromising the accurate estimation of internal load.

Summary

A summary of reservoir tributary status and incoming water transfers is shown in Table 9. St. Mary's Pond, Lawton Valley Reservoir, and North and South Easton Ponds all had both internal loads assessed during an abbreviated time period, and were also the subject of hypolimnetic water withdrawals. Paradise Pond was partially dewatered in the summer of 2015. Therefore, the calculated internal load for all of the above reservoirs was likely underestimated. Nonquit Pond had a high in-lake TP concentration similar to the mean dry-weather in-stream TP concentration of its major tributary (Borden Brook). It is therefore possible that the internal load of Nonquit Pond may have been overestimated. The calculated internal loads of the remaining reservoirs (Sisson and Gardiner Ponds), appear unaffected by confounding factors.

Results

Watson Reservoir is the only reservoir for which an internal load estimate was not possible. Although Watson Reservoir had some indications of internal loading (a hypoxic hypolimnion and slightly elevated phosphorus concentrations in the bottom vs surface waters), as previously discussed the mean whole water column TP concentration generally decreased as the growing season progressed. In addition, the TP mass, present in the reservoir at any given time, was highest in the spring and lowest in the summer and early fall. Internal loading may be occurring in Watson Reservoir but its signature effects of increasing trends in mean TP and TP mass may have been masked by hypolimnetic withdrawal. The lowest intake pipe is located only 2 ft. off the bottom of Watson Reservoir. It's possible that phosphorus was released from the sediment and collected in the hypolimnion of this stratified lake. However, if water was withdrawn from the lowest intake, much of this phosphorus would have been removed from the reservoir. It was therefore not possible to quantify the internal load to Watson Reservoir, using the methods employed above.

Table 10 shows the parameters that were used to calculate the internal TP load (mean whole water column TP, reservoir volume and surface areas). As previously discussed, the load (expressed as mg/m^2) was computed for each sampling event, by multiplying the volume-weighted mean TP concentration by the lake volume, and dividing the result by the lake surface area at that time. The minimum load was then subtracted from the maximum load to yield the internal TP load, again expressed in mg/m^2. This load was then multiplied by the mean lake surface area (average of surface areas calculated for the 12 sampling events) to express the load in terms of kg.

Table 9. Summary of Reservoir Tributary Status and Incoming Water Transfers.

	Incoming Water Transfers during Period of Max. Increase in TP[1]	Significant Summer Tributary Inflow	Water Withdrawals from Reservoir
Nonquit Pond	No	Yes	No
Lawton Valley Reservoir	Yes	No	Yes
St. Mary's Pond	Yes	No	Yes
Sisson Pond	No	No	No
North Easton Pond	Yes	Yes	Yes
South Easton Pond	Yes	No	Yes
Paradise Pond	No	Yes	Yes[2]
Gardiner Pond	No	No	No

1. Maximum and/or minimum TP masses were recorded during a period of incoming water transfers. Therefore, this data was not utilized, and only TP masses that occurred during a period without incoming transfers were used.
2. Water was withdrawn to affect work on reservoir infrastructure.

Internal phosphorus loads, relative to lake surface areas (expressed in mg/m^2), are shown in Figure 2. Paradise Pond had the highest load, relative to its lake surface area (445 mg/m^2). However, the internal loading estimate for Paradise Pond may have been overestimated, due to tributary inflow. Gardiner Pond, Lawton Valley Reservoir and Nonquit Pond had moderate areal TP loads (110-158 mg/m^2) (the internal load of Lawton Valley Reservoir was calculated during a two-week time frame, when there were no water transfers. It is therefore likely that the internal load of this reservoir was significantly higher). The internal load estimation of Nonquit Pond could have been slightly overestimated, due to tributary inflow from Borden Brook. South Easton, Sisson, North Easton, and St. Mary's Ponds had the lowest areal internal load. The internal load for Sisson was probably the most accurate estimation for this group, since there were no water transfers into this reservoir, no was there any significant tributary inflow. The internal loads for the remaining reservoirs in this group were calculated during restricted time periods and therefore likely underestimated (although there was significant tributary inflow into North Easton Pond, which could counter the underestimation of the internal load).

Internal TP loads expressed as mass (kg) are summarized in Figure 3. Nonquit Pond had the largest internal phosphorus load of the Newport Water Reservoirs (122 kg). Nonquit watershed is by far the largest watershed of any of the reservoirs for which an internal load was calculated. North Easton Pond, Lawton Valley Reservoir, and Gardiner and Paradise Ponds had moderate internal phosphorus loads (32-43 kg). Sisson, St. Mary's and South Easton Ponds had the lowest internal phosphorus loads (10-20 kg).

Table 10. Method 1 (In Situ Increase) Results.

	Highest Growing Season TP Loads[1]					Lowest Growing Season TP Loads[1]					Internal TP Loads		
	Date	Mean Whole Water Column TP (ug/l)	Volume (MG)	Lake Surface Area (A)	Areal TP Load (mg/m^2)	Date	Mean Whole Water Column TP (ug/l)	Volume (MG)	Lake Surface Area (A)	Areal TP Load (mg/m^2)	Areal TP Load (mg/m^2)	Mean Lake Surface Area (A)[2]	Total TP Load (kg)
North Easton Pond	9/9/15[3]	86	212	105.6	160.9	8/25/15[4]	40	258	108.8	88.6	72.3	108.9	31.9
South Easton Pond	7/14/15	62	268	146.2	106.5	6/29/15[5]	39	299	146.8	73.5	33.1	145.8	19.5
Paradise Pond	8/25/15	272	46	21.3	549.0	5/18/15	43	67	25.8	104.5	444.5	24.0	43.1
Gardiner Pond	8/25/15	82	186	94.4	151.3	6/2/15	23	182	94.3	41.2	110.1	94.1	41.9
St. Mary's Pond	7/28/15[6]	65	130	89.2	89.0	6/2/15	29	170	96.9	47.1	89.0	92.7	15.7
Sisson Pond	9/9/15	173	17	26.1	103.7	6/2/15	61	26	34.4	43.6	60.2	42.5	10.4
Lawton Valley Reservoir	7/28/15	84	239	66.6	280.8	7/14/15[7]	43	268	69.9	153.8	127.0	73.1	37.6
Nonquit Pond	10/6/15	78	542	192.4	206.8	6/2/15	20	495	190.1	49.2	157.6	191.9	122.3

1. Actual highest and lowest loads were not included, if they occurred during periods of intra-reservoir water transfers. By excluding high and low TP loads, occurring during intra-reservoir transfers, these transfers could be excluded as the cause of TP load increases.
2. Mean surface area of all 12 sampling events.
3. The highest mean TP concentration (119 ug/l) in North Easton Pond occurred on 10/6/15.
4. The lowest mean TP concentration (23 ug/l) in North Easton Pond occurred on 5/5/15.
5. The lowest mean TP concentration (27 ug/l) in South Easton Pond occurred on 5/5/15.
6. The highest mean TP concentration (197 ug/l) in St. Mary's Pond occurred on 8/25/15.
7. The lowest mean TP concentration (23 ug/l) in Lawton Valley Reservoir occurred on 5/18/15.

Figure 2. Newport Water Reservoirs' Internal Load Expressed in Terms of Lake Surface Area (mg/m^2).

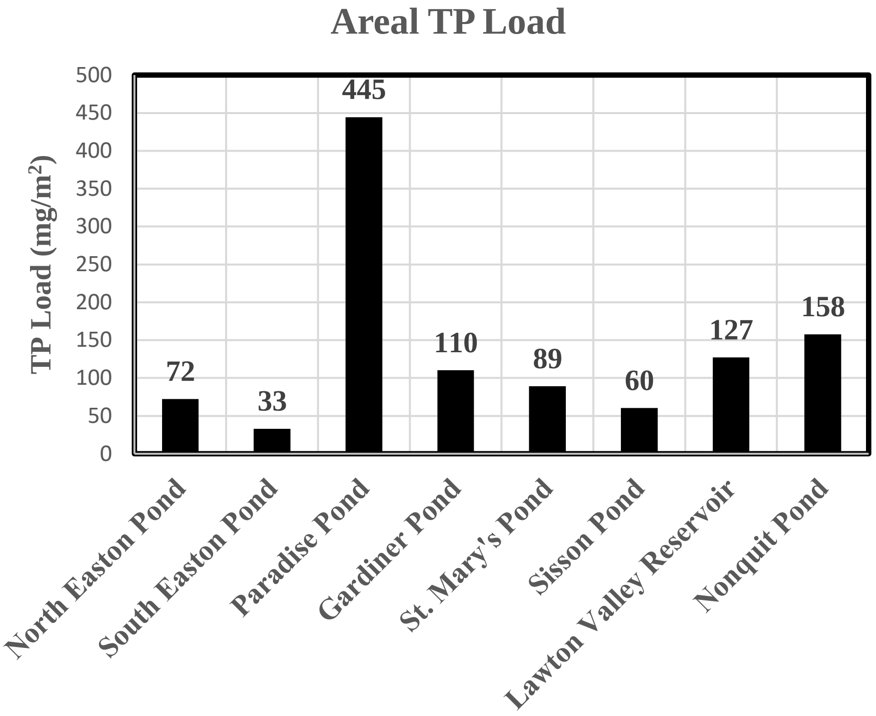
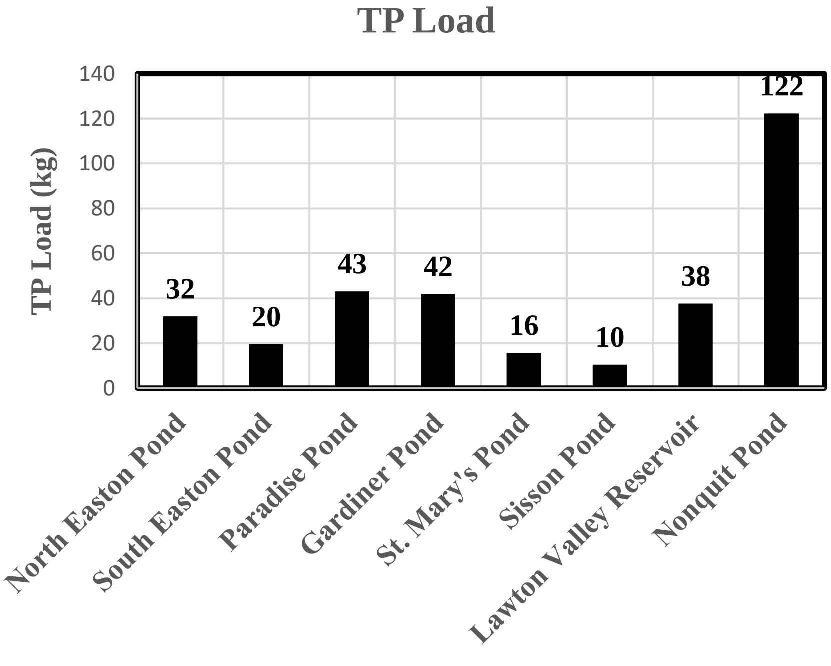


Figure 3. Newport Water Reservoirs' Internal Load Expressed as TP Mass (kg).



Method 2: Measured Anoxia and Sediment Phosphorus Release Rate

The internal phosphorus load can also be calculated for stratified lakes by multiplying the sediment release rate by the anoxic factor (Nurnberg, 2009).

$$\mathbf{L_{int} = AF \times RR}$$

Where:

AF = anoxic factor (days); and

RR = sediment release rate ($mg/m^2/d$).

The anoxic factor (AF) is computed from the duration of anoxia, the anoxic area, and the lake surface area. The anoxic factor represents the number of days that a sediment area, equal to the whole-lake surface area, is overlain by anoxic water. For instance, if the anoxic period spanned 21 days, yet the anoxic sediment area is only one third of the total lake surface area, then the anoxic factor would be 7 days.

To compute the AF, the depth to the oxycline was determined from the oxygen profiles previously discussed. The criterion for anoxia was 2 mg/l DO, with the assumption that bottom waters, with a DO below this value, were underlain by anoxic lake sediment. Since the depth to the oxycline fluctuated between each sampling event, the period of anoxia was consistently 14 days (the reservoirs were sampled every two weeks). The number of days of anoxia was multiplied by the surface area at the oxycline (a surrogate for the anoxic sediment area), and divided by the lake surface area. The surface area at the oxycline as well as the lake surface area, were computed by dividing the incremental volume by the corresponding incremental depth, as previously discussed. This computation was repeated for each distinct measured oxycline depth (the number of times when hypoxic conditions were recorded). The individual calculations were then summed to derive the AF. The method used to calculate the AF is shown below (Nurnberg, 2002):

$$\mathbf{AF = \sum_{1}^{n} (t_i \times a_i)/A_o}$$

where:

AF = anoxic factor (days);

t = period of anoxia (days);

a = anoxic sediment area (m^2);

A_o = lake surface area (m^2); and

n = number of periods with different oxycline depths.

Regressions of measured TP release rates (RR) and sediment total phosphorus concentrations (TP_s), were used to calculate the release rates of the reservoir sediments. Over 70 sediment cores from 7 North American lakes were used for the regression (Nurnberg, 1988). Different regressions were developed for both dry and wet weight core samples and for different core thicknesses. The formula below is the regression applicable to wet-weight sediment core from 0-5 cm. This regression equation was selected for the Newport Water reservoirs, because the reservoir sediment sampling regime was most similar to the 0-5 cm to wet-weight sediment core associated with the regression formula below (in 2014 RIDEM’s Office of Water Resources collected a single sediment core at the deepest area of each of the Newport Water reservoirs and the top 2 cm of the cores were analyzed for wet-weight sediment TP).

$$\mathbf{RR = -3.97 + 0.076TP_s}$$

Where:

RR = release rate (mg/m^2/d); and

TP$_s$ = sediment TP (ug/g) (ug TPs/g sediment, wet weight).

Method Limitations

The sediment release rate method is based on a linear regression of cores from only seven North American Lakes (Nurnberg, 1988). Using an estimated release rate, instead of one that was measured either in the field or laboratory, may be problematic. The relationship between sediment-P concentrations and release rates associated with Newport Water's reservoirs, may be significantly different than the relationship in the seven study lakes.

The sediment samples that were collected from the Newport Water Supply reservoirs were of the top 2 cm of sediment. Nurnberg (1988) used cores at least 5 cm in thickness, to develop sediment-P/internal loading relationships. Although sediment TP concentrations generally increase towards the sediment surface, this may have not been the case with the reservoir sediments. It's possible that the top layer of reservoir sediment, which was often flocculent, had a lower TP concentration than the sediment directly below. A thicker sediment sample (5-10 cm) may have been more representative of the actual sediment-P concentration.

Results

The hypoxic periods of the only two stratified reservoirs (Watson Reservoir and Paradise Pond) were in excess of thee months long. Some of the remaining reservoirs, including North Easton Pond, South Easton Pond, Gardiner Pond, and Lawton Valley Reservoir, were weakly mixed, and had hypoxic periods lasting between approximately two and six weeks. St. Mary's, Sisson, and Nonquit Ponds are polymictic (well mixed) lakes and the bottom DO remained above 2 mg/l, during the entire length of the study.

The anoxic factor represents the number of days that a sediment area, equal to the whole-lake surface area, is overlain by anoxic water. Given a specified hypoxic period, the larger the anoxic sediment area, relative to the lake surface area, the greater the anoxic factor. Paradise Pond and Watson Reservoir had the highest anoxic factors (48 and 52 days, respectively). The remaining hypoxic ponds, had anoxic factors of less than one week (Table 8).

North Easton Pond had the highest concentration of TP in its lake sediment (246 ug/g), followed by Gardiner Pond (101.6 ug/g) (Table 8). As a consequence, North Easton and Gardiner Ponds had the highest computed sediment release rates (14.7 and 3.8 mg/m^2/day, respectively). Sediment TP values of less than 52 ug/g generate negative release rates ($RR = -3.97 + 0.076TP_s$), indicating that the sediment is a sink, rather than a source. Paradise, St. Mary's and Sisson Ponds had sediment TP concentrations only marginally greater than this threshold concentration. However, both St. Mary's and Sisson Ponds never displayed hypoxic bottom waters, so this method suggests that the internal load in these ponds is zero (the internal load of Paradise Pond is estimated to be negligible). The remaining reservoirs (South Easton Pond, Lawton Valley Reservoir, Nonquit Pond, and Watson Reservoir) all had sediment-P concentrations below the 52 ug/l threshold, suggesting that internal loading is not a factor in these lakes.

The calculated sediment release rates are not consistent with the trophic status, the trend of increasing mean whole water column TP concentrations during the growing season, and visual observations of the reservoirs. The calculated release rates, for most of the reservoirs are less than 1 mg/m^2/d, which is consistent with oligotrophic lakes (Nurnberg,1988). Only Gardiner and North Easton Ponds would be classified as mesotrophic and eutrophic, respectively, based on sediment release rates. Based on mean whole water column TP concentrations, most of the reservoirs would be classified as eutrophic (Carlson and Simpson, 1996). The only exceptions were Watson Reservoir (mesotrophic) and Paradise Pond (hypereutrophic). In addition, all of the reservoirs were classified as either eutrophic or hypereutrophic, based on chlorophyll-a concentrations and secchi depths. It appears that this method is not appropriate for the reservoirs, since the estimated sediment release rates are inconsistent with increasing mean TP concentrations during the growing season, as well as clear visual indications of eutrophy (frequent and severe algal blooms, including cyanobacteria blooms).

Table 8. Method 2 (Anoxic Factor and Sediment Release Rates) Results.

	Hypoxic Period (days)	Anoxic Factor (days)	Sediment TP (Wet Weight) (ug/g)	Sediment Release Rate (mg/m^2/d)	Internal Load (kg)
North Easton Pond	14.5	6.9	246.0	14.7	45.0
South Easton Pond	28	4.6	21.0	- 2.4	N/A[2]
Paradise Pond	98.5	47.6	53.4	0.09	0.4
Gardiner Pond	14	3.2	101.6	3.8	4.6
St. Mary’s Pond	N/A[1]	N/A[1]	52.7	0.04	N/A[1]
Sisson Pond	N/A[1]	N/A[1]	53.6	0.10	N/A[1]
Lawton Valley Reservoir	43	5.4	29.4	- 1.7	N/A[2]
Nonquit Pond	N/A[1]	N/A[1]	23.8	-2.2	N/A[12]
Watson Reservoir	97.5	51.8	23.7	- 2.2	N/A[2]

1. DO in bottom waters >2 mg/l during all 12 sampling events.
2. Negative release rate.

Conclusions

The in-situ method appeared to provide a better estimation of the internal load than the calculation based on sediment-phosphorus concentrations. The in-situ method was more consistent with trophic status and with indirect evidence of internal loading. Sediment cores, may not have been of sufficient thickness and/or the flocculent nature of the cores may have resulted in inaccurate results, using the second method.

The analysis and quantification of the internal load of the Newport Water Reservoirs was conducted in support of the Newport Water Reservoirs TMDL (publication pending). The analysis documents evidence of internal phosphorus cycling within Newport's Water Reservoirs, however, because of the confounding influence of intra-reservoir water transfers, tributary inflow and hypolimnetic water withdrawals, the estimations of internal load are only approximate in nature.

A more accurate estimation of internal loads would require a mass balance approach, involving load estimations of intra-reservoir water transfers, major tributaries, and water withdrawals into the North Easton and Lawton Valley Water Treatment facilities. In order to estimate flows (and ultimately loads) associated with intra-reservoir water transfers and water withdrawals, flow meters would be required to be installed within the piping systems. Frequent (weekly or biweekly) sampling of transfers and withdrawals would also be required to predict loads. To predict loads associated with the major tributaries (Bailey's, Paradise and Borden Brooks, as well as the Maidford River), frequent flow measurements as well as phosphorus sampling would be required. Stream sampling stations should be located as close as possible to the reservoirs.

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