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REPORT

Modeling the Watershed of Russell Lake

CLAYTON DEVELOPMENT

REPORT NO. SD19184.

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REPORT TO **Clayton Developments**

FOR **Modeling the Watershed of Russell Lake**

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EXECUTIVE SUMMARY

In accordance with Section 3.1 of the Russell Lake West Development Agreement between the Halifax Regional Municipality (HRM) and Clayton Developments Limited a water quality monitoring program is currently being conducted to establish baseline conditions for the Russel Lake, Dartmouth (MPS Policy ML-30). One of the intended outcomes of the program is to “establish eutrophication threshold levels for the lakes which would be used as a basis for re-evaluating watershed management controls and future development potential within the area.” To assist in this aim, Clayton Development Limited has contracted Jacques Whitford Limited, in collaboration with Dr. Walton Watt, to undertake phosphorus modeling for Russell Lake.

The objectives of the phosphorus modeling exercise are twofold:

1) To estimate how the mean total phosphorus concentration in Russell Lake will be affected by the Russel Lake West Development; and
2) To suggest ways to mitigate the potential increase in the lake’s total phosphorus (TP) concentration that will be brought about by this change in land use.

Water quality sampling was conducted on a seasonal basis, along with supplementary sampling as needed, to collect necessary information on phosphorus loading as well as general water chemical characterization. This report provides the predictive modeling methodology and resulting effects of an increase in phosphorus loading to Russell Lake that will be attributed to the Russell Lake West Development.

In most Canadian lakes, high levels of algal production are the most obvious sign of pollution problems. Algal blooms were reported from Russell Lake in the 1970's and 80's. With freshwater algal blooms, the nutrient phosphorus is usually the controlling factor, and by limiting the amount of total phosphorus (TP) that enters the lake it is usually possible to control the level of algal and other plant growth. Phosphorus concentration in Russell Lake water declined between 1980 and 2005 to the point where the lake was thought to be free of algal blooms.

Monitoring of the water chemistry in Russell Lake in 2005-06 indicated that the lake appears to be undergoing rapid seasonal nutrient concentration changes. During a one year period of sampling in 2005-06, the lake progressed from oligotrophic (low) nutrient levels in the spring to mesotrophic (moderate) levels in the fall. The lake appears to be responding to siltation loading from previous projects in its drainage area. Unusually high phosphorus levels were observed entering the lake from the south-west inlet, possibly due to sewage contamination.

The mathematical model of TP in the watershed of Russell Lake described in this report was constructed primarily to forecast how much additional TP would be entering the lake as the result of changing the land use on the west side of the lake from undeveloped (forest, scrub growing in old farm fields, and wetland) to an urban residential area with sport fields and parkland. The model uses TP export coefficients estimated from data collected at inlets to the lake.

The TP export coefficient for undeveloped drainage was estimated by running the Russell Lake model 'backwards' until the predicted TP concentration matched the April 1980 mean TP level in lakes Lamont, Topsail and Major. These are nearby drinking water lakes with similar geochemistry but undeveloped, protected drainage areas. It is recommended that these lakes be used as undeveloped controls for Russell and other urbanized lakes in the vicinity.

The model predicts that the land use changes accompanying the Russell Lake West Development will cause an additional TP loading to Russell Lake of about 9 kg/y, which, under 2005-06 conditions would increase the TP concentration in the lake by about 1.5 mg/M^3 (µg/L). This potential increase is unlikely to change the trophic status of the lake.

Since sewage contamination contributed about 25 kg/y of TP to the lake in 2005-06, it is suggested that the TP increase contributed by Russell Lake West Development can be more than adequately mitigated by reducing or stopping the input of sewage to the lake.

Table of Contents

List of Tables

1.0 INTRODUCTION

In accordance with Section 3.1 of the Russell Lake West Development Agreement between the Halifax Regional Municipality (HRM) and Clayton Developments Limited a water quality monitoring program is currently being conducted to establish baseline conditions for the Russell Lake, Dartmouth (MPS Policy ML-30). One of the components of the program is to "establish eutrophication threshold levels for the lakes which would be used as a basis for reevaluating watershed management controls and future development potential within the area." Data and information are provided in this report to assist the Dartmouth Lakes Advisory Board and HRM staff with establishing the threshold level and providing a recommendation to the Harbour East Community Council.

Clayton Development Limited contracted Jacques Whitford Limited, in collaboration with Dr. Walton Watt, to conduct phosphorus modeling in Russell Lake. Water quality sampling was undertaken on a seasonal basis, along with supplementary sampling as needed, to collect necessary information on phosphorus loading as well as general water chemical characterization. This report provides the predictive modeling methodology and resulting effects of an increase in phosphorus loading to Russell Lake that will be attributed to the Russell Lake West Development.

2.0 OBJECTIVES OF THE STUDY

The objectives of the phosphorus modeling exercise are twofold:

1) A housing development is now under construction on the west side of Russell Lake in Dartmouth, Nova Scotia. A computer model of the lake and drainage area was thought to be the best way to estimate how the mean total phosphorus concentration in Russell Lake will be affected by the conversion of an area that was regrowth forest and old farm fields into an urban residential area.
2) It was also hoped that the study would be able to suggest ways to mitigate the anticipated increase in the lake's total phosphorus (TP) concentration that will be brought about by this change in land use.

3.0 URBAN LIMNOLOGY

A watershed area is all the area inside the line that divides the direction of flow between different lakes or streams. A drainage basin is all of the land and water areas that drain toward a particular lake. The area of the drainage basin plus the area of the lake constitutes the watershed area. Thus, a watershed is defined in terms of the selected lake (or river). There can be sub-watersheds within watersheds. For example, a tributary to a lake has its own watershed, which is part of the larger total drainage area to the lake.

The water quality in a lake is a reflection of the quality of the water coming from its drainage basin. More specifically, a lake reflects the drainage basin's size, topography, geology, land use, soil fertility and erodibility, and vegetation. Typically, nutrient loading increases with an increasing ratio of watershed area to lake area. This is obvious when one considers that as the watershed to lake area increases there are additional sources and volumes of runoff to the lake.

Land use has an important impact on the quality and quantity of the water entering a lake. In urban areas the high proportion of impervious surfaces prevents rainwater from penetrating into the soil and so increases the volume of surface water flow directly to the lake. This is especially so when the flow is in underground storm sewers. The high flow rates from urban areas can increase erosion and provide sufficient force to carry particles of soil to the lake. Soil particles, especially clays, can carry large quantities of adsorbed phosphorus with them. Thus, water quantity and velocity also affect water quality.

As water flows over streets, parking lots and rooftops, it accumulates nutrients and contaminants in both dissolved and particulate form. The nutrient phosphorus is particularly important because in fresh water systems it is the availability of phosphorus that usually controls the amount of algal growth and the overall aesthetic aspect (trophic level) of a lake. The influence of soil type and slope are also important because finer particles and steeper slopes mean higher phosphorus inputs to the lake. Phosphorus occurs in several chemical forms that are readily interchangeable, so the commonly accepted best practice is to measure total phosphorus (TP).

Water in lakes has a tendency to stratify. In summer water forms a top layer called the epilimnion and a deep water layer which is lower in temperature called the hypolimnion. When precipitation falls on a lake surface the TP that accompanies it promotes algal growth, and if sufficient additional TP enters the lake from other sources the algal growth will proliferate and eventually die and sink through the water column. As it sinks it decays and as it decays it consumes oxygen from the water. If enough of the organic matter accumulates on or near the bottom of the lake it can consume all of the oxygen in the layer of deeper water, the hypolimnion.

HRM soils are naturally high in iron and aluminum hydroxides, both of which readily bind to organic and inorganic phosphorus. When such soils are eroded into a river or lake they carry this bound phosphorus with them in particulate form. Once in the lake, a good proportion of the soil and other particles sink to the bottom, carrying the phosphorus with them. As long as the water in the lake contains dissolved oxygen, the phosphorus is likely to remain sequestered in the lake sediments. However, if the water at the bottom of the lake becomes anoxic (no oxygen) as a result of the decay of organic matter sinking through the water column, then the chemistry changes and the metals release the inorganic phosphorus into the anoxic water. In this way high concentrations of phosphorus can accumulate in the hypolimnion of the lake. When the lake’s water is mixed, which occurs each spring and fall, the released phosphorus is distributed throughout the entire lake and becomes available in the surface waters where it promotes further algal growth. This phenomenon is called internal phosphorus loading, and it is generally accepted as an undesirable sign of eutrophication.

Lakes can be classified according to their ‘trophic’ (a Greek root meaning food) status. Oligotrophic lakes have low food production and eutrophic lakes have high food production. Mesotrophic is in the middle. Although the lake and its biosystem is indifferent, most nearby human residents and fishers object when their lake becomes eutrophic, because eutrophic lakes support less desirable fish species and the algae and other plants may be considered unsightly and can sometimes smell bad. In general oligotrophic and mesotrophic lakes are more pleasant to live beside.

Trophic status in lakes is roughly related to mean TP concentration. Lakes with a mean TP concentration less than 10 mg/M^3 are usually oligotrophic and this is the natural (pre-development) status of most HRM lakes. Lakes in the 10 - 20 mg/M^3 range are usually mesotrophic. HRM’s lakes in urbanized drainage areas are not likely ever to be restored to their original oligotrophic state, but urban communities need to strive to keep their lakes at least at the mesotrophic level. Controlling the TP input to a lake is one of the most practical and proven ways of controlling its trophic status.

4.0 PHOSPHORUS EXPORT COEFFICIENTS

Each type of land use causes different amounts of phosphorus to be released into the lake. In an undisturbed system the phosphorus input is largely supplied by deposition with precipitation, and also dry deposition as dust. For modeling purposes the Nova Scotia bulk (wet and dry) TP deposition from the atmosphere was taken to be 25 mg/M^2/y (Vaughan Engineering Assoc., 1993) (i.e., the atmospheric deposition of TP on water or ground is providing 25 mg/M^2/y of phosphorus).

When this falls on undeveloped land such as a forest, much of the phosphorus (for example, about 60%) is cycled through the biological system and eventually winds up in plants or chemically bound to metals in the soil. The other 40% of the phosphorus that falls on the forest remains dissolved in the rainwater which drains into the lake. Thus the forest, while receiving 25 mg/M^2/y of TP would only be releasing 10 mg/M^2/y to the lake, and for modeling purposes the value 10 mg/M^2/y is called the TP export coefficient for the land use category ‘forest’. Typical TP export coefficients for Nova Scotia forests might range from about 5 mg/M^2/y for undisturbed old-growth forest up to about 25 mg/M^2/y when a forest growing on a steep slope has been logged.

In a residential area the opportunity for the phosphorus that falls with the precipitation to become bound in plants and soil is somewhat limited by impermeable surfaces like roofs, driveways, sidewalks and streets, so we would expect more than the 40% of our previous example to escape to the lake. In addition, more phosphorus will have been added in the form of lawn and garden fertilizer and dog and cat urine and faeces. Typical TP export coefficients for low density urban residential land use areas are usually in the range 15 - 30 mg/M^2/y. Higher density residential areas, like apartment blocks, will have even higher export coefficients, similar to commercial areas.

Commercial areas have high export coefficients because they are usually completely paved over and since the precipitation has virtually no contact with soil, all of the 25 mg/M^2/y TP falling from the atmosphere runs directly off in storm sewers to the lake. In addition, the precipitation falling on the roofs, streets and parking lots of commercial areas comes into contact with dust, food waste, pigeon faeces, automotive emissions, fly-ash and other sources of TP. Typical export coefficients for commercial areas can range from 30-300 mg/M^2/y, or even higher.

Establishing accurate TP export coefficients is a difficult task: ideally one chooses an area where one can sample the runoff from a single land use category and takes multiple samples from every precipitation event for at least one year. Usually one has to settle for much lower sampling rates. Alternatively, one can select from many published values (see Table 4.1).

TABLE 4.1 Published Phosphorus Export Coefficients (mg/M^2/y) (from Reckhow *et al.*, 1980)

	High	Mid	Low
Commercial	500	80-300	50
Urban Residential	270	56-110	19
Forest	83	14-40	2
Precipitation	60	20-50	15

The problem with the published values is that they are seldom applicable to the watershed of interest, and with such a wide choice available it is possible to produce a model that will give almost any answer that might be desired.

Although only limited sampling is available for the Russell Lake watershed, the author has opted to use this on-site data to estimate export coefficients for each of the lake's sub-drainages. These data are very specific to the Russell Lake drainage area and as such should yield higher accuracy than the generalized published values even though the coefficients are estimated from a very small data series. Using local data gives the advantage that, if a lake (like Russell) shows signs of undergoing rapid changes in trophic status, then the watershed can be modeled for one specific data year only.

5.0 LAKE WATERSHED MODELING

What follows is a description of the modeling methodology that has been used to estimate the TP loading and the mean TP concentration in Russell Lake for the annual period 15 March 2005 to 14 March 2006.

The area of the watershed in square metres (M^2) was multiplied by local rainfall (1.46 M in this period) and by 0.67 which is the mean annual runoff coefficient for Nova Scotia (the proportion of the precipitation that actually reaches the lake outlet - the rest is lost to evaporation and transpiration) to estimate the total amount of water (M^3/y) that exited the lake over the year. The total volume of water that exited the lake divided by the volume of the lake gives the **flushing rate** in times/year.

Next the estimated TP export coefficient in milligrams per square metre per year (mg/M^2/y) for each sub-drainage was multiplied by the area to give the total input of TP (mg/y) for that particular sub-drainage. All TP inputs were then summed (not forgetting the precipitation directly on the lake) to get the **total TP loading** (kg/y).

Phosphorus retention by the lake is a function of the TP settling velocity (M/y) and the total depth of water relative to a reference surface which is usually taken as the surface area of the lake. This is called the **areal water loading rate**. It is calculated as the total volume of water exiting the lake (M^3/y) divided by the surface area of the lake (M^2) to give areal loading rate in M/y. The proportion of TP retained by the lake should be directly proportional to the ratio of the settling velocity to the sum of settling velocity plus areal loading rate. However, TP settling rates are notoriously difficult to estimate directly. The best approach is to do it empirically by measuring the total amounts of TP entering and leaving a lake for several years, and then back calculate for the mean settling velocity. This was done by Dillon *et al*. 1986 using several years of data on small Precambrian Shield lakes which are geochemically similar to the Nova Scotia lakes on the Meguma Group rocks. Thus, the settling rates are not really settling rates at all, but rather empirically derived values that make the function fit.

Different (lower) settling velocities are used for modeling lakes which develop anoxic hypolimnia. The alternative would be to use a two layered limnological model, but it has been shown that single layer models with empirically derived lower settling velocities (to reduce the amount of TP predicted to be retained in the lake) are just as accurate as two layer models and much less complicated.

The theoretical TP concentration in the lake is then calculated as:

$$\frac{\text{Total TP loading} \times (1 - \text{proportion of phosphorus retained})}{\text{lake volume} \times \text{flushing rate}}$$

The model uses an estimate of lake discharge, after phosphorus precipitation on the lake and after phosphorus retention by the lake; hence the TP concentration calculated is actually the one at the outlet of the lake. In some data sets there may be a significant difference between TP concentrations in the main lake and at the outlet. This can be corrected by dividing the output of the above function by the mean ratio of TP concentration at the outlet to TP concentration at the lake station. It is best to use paired data (collected on the same day) for this.

6.0 GEOPHYSICAL SETTING

Russell Lake lies on quartzite bedrock, part of the Goldenville Formation in the Meguma Group, which also includes the Halifax Formation of slates (Keppie, 2000). The rock is overlain by a 2-5 metres thick layer of reddish Lawrencetown till, which has a relatively high clay and fine silt content. The east and west sides of the lake are bordered by steep sided drumlins composed of the same till though with lesser rock inclusion. As the reddish colour implies, Lawrencetown till includes material transported from the Carboniferous rock region to the north (Prime, 2001); and, especially on the drumlins, it produces Wolfville soils with moderately good agricultural potential and is rated as “good crop land” by MacDonald *et al*., 1963.

Precipitation falling on the sides of the drumlins drains directly into the lake. The steep slopes and fine textured soil mean that any surface disturbance will result in a high turbidity runoff. Fine soil particles, especially clays, can carry a lot of chemically bound phosphorus with them into the lake. The slope on the east side is the site of a recent residential development built about the turn of the century. It is steeper than that on the west side which is presently undergoing development.

There is a relatively large wetland behind (west of) the west drumlin. The wetland drains into a small brook which flows south and then east to empty into the lake in the southwest corner. Another small brook (seasonally intermittent) entering from the southeast drains a small area of undeveloped wetland and forest. The north end of the lake is bordered by wetland and the main inlet from the northwest has been blocked by a soil and rock berm, forcing the water to pass through the adjacent wetland before entering the main lake. This wetland also receives the drainage from the northeast. The lake’s outlet is in the northeast corner, not far from the current north inlet.

7.0 THE RUSSELL LAKE BYPASS ISSUE

A moderate problem in modeling Russell Lake is the extent to which water flowing into the lake under the north boardwalk (the primary north inlet to the main body of the lake) goes directly to the adjacent outlet, bypassing the main lake. Griffiths Muecke, 1998 assumed a virtual 100% bypass in modeling the routing of water from Russell to Morris lakes, but there appears to be no documented evidence of this.

The best data set found for studying this issue was Dr. Donald Gordon's data from June - August 1993 (reported in Griffiths Muecke, 1994) on the water chemistry of Russell Lake, its inlets and the outlet. From these data five variables were chosen that were at substantially higher concentrations in the North Pond than in the main body of the lake. The variables were selected because of the likely precision in the methods of their analyses. It was reasoned that if a bypass existed then these variables should be higher at the outlet than in the middle of the main lake. The three stations in the main lake were not significantly different for any of these variables. Three of the variables (Na^+, Cl^- and turbidity) showed no significant difference (paired data 't' tests) between the mid lake station and the outlet. For the other two, pH was significantly lower at the outlet and colour was significantly higher. There is, thus, no evidence of an operating bypass in the summer of 1993. It is tentatively concluded that this is not a quantitatively significant phenomenon.

Further resolution of this issue has not been assigned a high priority because at the present time it seems obvious that summer trophic conditions in Russell Lake are largely controlled by the quantity of TP entering the lake from the south. The 2005-06 water chemistry data indicate that in April the water quality in the lake was controlled by the quality of the (much larger) drainage from the north, but that this changed as the seasons progressed.

A series of seasonal samples from water flowing into the main lake from the north wetland (under the boardwalk, after the mixing of NW and NE drainages), at mid lake and at the outlet would probably resolve the issue. A bypass feature would be most significant when the water entering from the north is less dense (warmer or less saline) than the surface water of the main lake and there is a wind from the south or southwest.

8.0 THE EXCESS PHOSPHORUS ISSUE

Previous investigators have noted high levels of total phosphorus entering the lake from the southwest inlet. Over the years various sources have been proposed, including an industrial chemical leaching in from Imperial Oil lands, continuing contamination from a large pig farm that ceased operations about 1980 and sewage input from a trailer park. It has also been noted (Griffiths Muecke, 1994) that the trophic status of the lake appears to be declining, with fewer algal blooms in evidence in recent years. The April levels of total phosphorus in the lake appear to reflect the trophic decline with total phosphorus concentrations for April 1980, April 1991 and April 2005 of 22, 11 and <5 mg/M^3 respectively (Gordon *et al*., 1981; Keiser *et al.*, 1993; and the current study).

It should be noted that the apparent lowering of the trophic status of Russell Lake in recent years has two possible causes. One possibility is a reduction in TP input. The other is increased silt loading (which has been noted) from construction activity in the drainage area. Excess silt would bury the high phosphorus sediments on the bottom of the lake, and the reduction in internal phosphorus loading would lower the trophic status. If this is the case, then the situation will reverse itself as the silt load declines.

TP concentrations entering the lake via the southwest inlet in 2005-06 were consistently much higher than those in the lake or in any other inlet. Identifying the source of the phosphorus in the drainage of the SW inlet was considered a priority. The 2005 data show TP concentrations of about 44 mg/M^3 in April, June and August, about 90% of which was in orthophosphate form (in other inlets only about 10% was orthophosphate). Total nitrogen (TN) of about 400 mg/M^3, giving a N/P ratio of about 9/1, which is quite normal. The ratio in biological organisms is usually 7/1 by weight and ratios from there up to 30/1 are common in aquatic environments because inorganic nitrogen is much more mobile than phosphorus. However, when the TP concentration at the SW inlet went up to 88 mg/M^3 (still 90% orthophosphate) in November of 2005, the TN did not go up at all, bringing the N/P ratio down to about 4/1. Biological processes do not produce 4/1 ratios. Even pig manure, which is high in phosphorus, would not do that. The data suggest a source of inorganic phosphorus somewhere in the drainage.

In an effort to resolve this issue, two water samples were collected from the ditch on the trailer park side of the Circumferential Highway culvert on 11 October 2005 and analyzed for faecal coliform bacteria and total phosphorus.[i] The faecal coliform counts were high (>200.5) in both samples, suggesting the presence of sewage. Total phosphorus concentrations were also extremely high at 243 and 257 mg/M^3.

It was then decided to do soil (actually peat) analyses from the wetland, below the Circumferential Highway (111) culvert. This wetland is part of the headwaters of the SW inlet. It consists of a small treeless cattail swamp and, downstream of that, a larger forested bog. On 8 February 2006 one peat sample was taken from the cattail swamp, six samples from the downstream bog and a control sample from forested wetland in the completely undeveloped drainage of the SE inlet. The results showed 11 g/kg (dry wt.) of total phosphorus (1.1% phosphorus) in the cattail swamp, an average of 2.3 g/kg in the six samples from the wooded wetland downstream of the swamp and 1.3 g/kg in the control sample.

The peat in the cattail swamp contains 8.5 times more TP than the control sample, and the six peat samples from the wooded downstream wetland contain about double the TP content of the control sample. The phosphorus in the swamp is 86% inorganic, and is probably orthophosphate adsorbed onto metals in the peat. The peat is particularly high in calcium, aluminium and iron, all of which bind readily with orthophosphate. The N/P ratio in the swamp is 3/1, in the wooded wetland it is 9/1 and in the control it is 14/1. If the original source is sewage (as seems likely from the high calcium in the peat and high faecal coliform in the water at the other end of the culvert), then considerable nitrogen loss has taken place in the swamp. Denitrification is to be expected since swamps generally have low oxygen levels. A period of low oxygen in the swamp followed by heavy rain would flush out large amounts of orthophosphate.

The cattail swamp is almost certainly the penultimate source of the excess phosphorus that has been plaguing Russell Lake. The swamp is upstream from the pig farm site and immediately downstream from the highway culvert that drains the trailer park. It would appear that raw sewage is somehow entering from the trailer park (perhaps from the sewer overflow pipe) and is being broken down biologically in the swamp. The wetland is providing primary through tertiary treatment since high levels of faecal coliform bacteria have not been found at the mouth of the inlet and most of this TP enters the lake in the inorganic orthophosphate form. The high TP concentration gradient between the cattail swamp and the downstream bog suggests that sewage input is still occurring.

9.0 ESTIMATING PRE-DEVELOPMENT TP

There are three nearby lakes (Topsail, Lamont and Major) that have similar geological conditions and whose watersheds have been protected from development because these lakes are used to supply drinking water. Of course, the lakes are not strictly "pristine" with regard to total phosphorus because present day rainfall and windblown dust almost certainly contain higher concentrations of phosphorus than they did in pre-settlement days, and the drainage areas do contain some construction of water control and treatment facilities. However, these lakes can be used as reference sites to estimate what

[i] This sampling took place after two days of very heavy rain so the ditch was flowing vigorously. The samples were taken on either side of the sewage overflow pipe, which was not spilling at the time of sampling. A tank truck was busy pumping out the adjacent sewage collection tank and workers volunteered the information that this had to be done after every heavy rain.

the concentration of total phosphorus could have been, with undeveloped drainage areas, for those Dartmouth lakes whose drainage areas are currently urbanized.

The Dartmouth drinking water supply lakes Topsail and Lamont are on Meguma Group bedrock that is covered with a layer of Lawrencetown and Halifax tills. Lamont and Topsail also have adjacent drumlins with Wolfville soils. Lake Major is also on Meguma quartzite, and has primarily Halifax (quartzite) till. The earliest known determinations of total phosphorus in these lakes was in 1980 (Gordon *et al.*, 1981). A second survey done in 1991 (Keizer *et al.*, 1993) is suspect because the authors felt that there was a problem with the analyses for total phosphorus.

Using just the 1980 survey data for the Dartmouth water supply lakes Topsail, Major and Lamont, there are seven analyses from the three lakes, and the overall mean and standard error are 7.4 ± 2.5 mg/M^3.[ii] It is suggested that 7 mg/M^3 be used as the pre-development reference level for mean total phosphorus concentration in Russell Lake.

10.0 THE YEAR IN RUSSELL LAKE

Russell Lake was sampled in the northern portion over the deepest part of the lake. A data series was collected in 1993 (Griffiths Muecke, 1994) in which, from June to September, five water samples were analyzed from each of three stations down the length of the lake. It showed that all three lake stations, including one at the north end over the deepest part, were chemically almost identical. So, the 2005-06 data series for this station are considered to be representative of the entire main body of the lake. There were also sampling sites at all inlets and at the outlet. Not all sites were sampled each time.

For the inlet with the largest drainage (NW inlet at culvert) the data series (n=4) showed little variation with a mean and standard error of 29 ±3 mg/M^3. For the Russell Lake station and the SW inlet, however, that was definitely not the case (see Table 10.1). On 22 April the main lake station actually had a TP concentration of <5 mg/M^3 (the detection limit), but at the same time the concentration at the nearby outlet was 7. It was clear that if the actual concentration at the lake station was less than 5 it could not be very much less, so 4 was assumed. The concentration apparently remained low for the early part of the summer, from which we can conclude that there was no spring release of large amounts of excess TP from the contaminated wetland behind the west drumlin even though the rainfall in May was very high[iii]. However, by the end of August lake stratification had set in, the hypolimnion had become anoxic and internal loading had produced high TP concentrations in the deeper water. The value of 16.4 mg/M^3 in the table for August is a mean whole lake concentration arrived at by calculating the TP contained within each subsurface layer of the lake and combining them. Later that fall, the SW inlet whose TP concentration had hitherto been in the 40's (substantially higher than at any other inlet) increased to near 90 mg/M^3 as it released mainly inorganic phosphate. This was probably prompted by the exceptionally high rate of precipitation in October which flushed out phosphorus that had been released by summer anoxic conditions in the contaminated wetland. As a result of this and the internal loading, the TP concentration in Russell Lake in November had climbed to 25 mg/M^3 and an algal bloom ensued.

[ii] There are three other local drinking water supply lakes (First Chain, Second Chain and Long) on the west side of Halifax. These lakes have had similar watershed protection but are on very different geology – granite bedrock with thin granite derived till and virtually no soil. There are five analyses available from 1980 and the mean and standard error are 3.2 ±0.4 mg/M^3 of TP. The three Halifax drinking water lakes have a naturally lower total phosphorus concentration than the Dartmouth lakes because of the geochemical differences in the watersheds.

[iii] This probably reflects a lack of anoxic conditions in the wetland during winter and spring.

TABLE 10.1 TP Concentrations (mg/M^3) for Russell Lake and the Southwest Inlet in 2005-06

Sample Date	Main Lake	SW Inlet
22 Apr 05	4	42
29 Jun 05	7	46
29 Aug 05	16.4	43
21 Nov 05	25	88
09 Mar 06	15	31
14 Mar 06		39
MEAN	**13.5**	**48.2**

By March the TP concentration in the SW inlet was back down to normal (for it) but the late winter concentration of TP in the main lake was still high and may result in a spring bloom and other eutrophic phenomena in Russell Lake in 2006.

11.0 RESULTS OF RUSSELL LAKE WATERSHED MODELING

The modeling approach is as described for "export coefficient modeling" in Environment Canada, 2004. Total phosphorus export coefficients (except for undeveloped drainage) have been calculated using local data (n=4 except 6 for the SW inlet) for three types of sub-drainage to Russell Lake, and then rounded to the nearest 5 mg. The coefficients estimated in this manner are presented in Table 11.1.

TABLE 11.1 Estimates of Total Phosphorus Export Coefficients for the Russell Lake Drainage Area

Drainage	Export Coefficient (mg/M^2/y)
Undeveloped Drainage	10
Southwest Inlet (TP Source)	45
Northwest Inlet (Culvert)	30
Residential Area (Russell L East)	25

The procedure was to take the mean concentration and multiply by the total precipitation and the runoff coefficient: thus for the northwest inlet (culvert at the intersection of Baker and Norman Newman drives) the mean TP concentration was 28.8 mg/M^3. This was multiplied by 1.46 M of precipitation and by 0.67 (the runoff coefficient) to get 28.1 mg/M^2/y which was then rounded up to 30 mg/M^2/y. The northeast sub-drainage has urban development similar to the northwest, so the same export coefficient was used for both.

The export coefficient for undeveloped drainage could not be derived this way. To get an estimate of this coefficient it was necessary to first build a model of the watershed of Russell Lake. It was then assumed that the hypothetical pre-development Russell Lake would have an entirely forested drainage area like the Dartmouth drinking water lakes do now, and, like them, would have a mean TP concentration of about 7 mg/M^3. The model was then run ‘backwards’ to see what value of export coefficient for undeveloped drainage would give that concentration of TP in the modeled lake. The value was 9.9 mg/M^2/y, so the TP export coefficient for undeveloped drainage was set at 10 mg/M^2/y.

The physical geographic parameters required for watershed modeling are listed in Table 11.2 for Russell and Penhorn Lakes. Because the outlet of Penhorn Lake feeds into an underground storm sewer that is part of the northwest drainage of Russell Lake, it was necessary to model the Penhorn watershed too so as to allow for Penhorn Lake’s phosphorus retention. Other model parameters specific to the period 15 March 2005 - 14 March 2006 are given in Table 11.3.

TABLE 11.2 Physical Parameters for Watershed Modeling of Russell and Penhorn Lakes

	Russell Lake	Penhorn Lake
Lake Area	343,000 M^2	45,000M^2
Lake Volume	1,063,300 M^3	130,000 M^3
Mean Depth	3.1 M	2.9 M
Runoff Coefficient	0.67	0.6
Total Watershed Area	3,484,000 M^2	199,000 M^2
Total Drainage Area	3,096,000 M^2	154,000 M^2
NW Sub-drainage	1,042,000 M^2	
NE Sub-drainage	490,000 M^2	
Russell West Side (Drumlin)	449,000 M^2	
Russell East Side (Drumlin)	202,000 M^2	
SW Inlet (TP Source)	160,000 M^2	
SE Inlet (Intermittent)	160,000 M^2	

TABLE 11.3 Other Modeling Parameters for the Period 15 March 2005 – 14 March 2006

Precipitation at Shearwater Airport	1.46 M
Mean (whole lake) TP conc. in Russell Lake	13.5 mg/M^3
Mean ratio of TP at outlet to TP in main lake	1.25

Outputs from the model, based on various scenarios are provided in Tables 11.4 to 11.8. The watershed model output depicted in Table 11.4 is for the period prior to construction of the Russell Lake West residential development on the drumlin slope on the west side of the lake. The Russell Lake West drainage coefficient is set to undeveloped drainage (10 mg/M^2/y, from Table 11.1). This estimates total phosphorus loading from the lake's drainage area of 87.1 kg/y and predicts a mean whole lake TP concentration of 13.0 mg/M^3, which is gratifyingly close to the observed mean of 13.5 mg/M^3 for the 2005-06 data series at the Russell Lake station.

It was considered instructive to run the same configuration of the model but with the Russell Lake West drainage area (the lake side of the west drumlin) set to the coefficient for residential drainage (25 mg/M^2/y, from Table 11.1). The output (Table 11.5) estimates the post-construction total phosphorus loading from the drainage area at 93.8 kg/y and predicts a mean whole lake TP concentration of 13.9 mg/M^3. This is an increase of about 7 kg in TP loading as a result of the land use change in the west side drainage area, and an increase of about 1 mg/M^3 for the mean TP concentration in the lake. Note that 13.9 mg/M^3 is not a prediction of what will happen to the TP concentration in Russell Lake in the future, but rather what would have happened in 2005-06 if the residential development on the west side of Russell Lake were already built and of the same age as the residential development on the east side of the lake. In actual fact this is a rather conservative estimate of that, because the slope on the west side is not as steep as that on the east side from which the residential TP export coefficient was derived. There is also the fact that present plans call for equipping the storm sewers on the west side with CDS units (for particulate removal) at the outfalls. However, at this stage, the level of TP retention by a CDS unit is uncertain.

Another portion of the Russell Lake West Development will lie in the SW inlet's drainage area, a more complicated sub-drainage area to model. Even without the apparent sewage input, the SW inlet drains the storm runoff from the trailer park and part of the immediately adjacent residential area (the total area involved is about 9.5 ha). A more complex pre-construction version of the watershed model was run with the SW inlet drainage separated out into three categories: undeveloped, residential, and TP loading from the excess TP source. The output has been constrained to match up with the baseline model run (Table 11.4). The model output results are depicted in Table 11.6. The run yields an estimate of 25 kg/y of excess phosphorus released from the contaminated wetland of the SW inlet in 2005-06. That much phosphorus represents the quantity of TP stored in about 2 metric tonnes of dry peat at the concentration found near the surface of the cattail swamp.[v]

By running the model in the absence of the 25 kg identified as coming from the contaminated wetland we can arrive at an estimate of what the 2005-06 nutrient conditions in Russell Lake might have been without the excess TP from the west wetland. This run is shown in Table 11.7. The result is a total TP loading of 62 kg/y (down from 87 kg/y) and a predicted mean TP concentration in Russell Lake of 9.6 mg/M^3. The implication of a predicted mean TP concentration of 9.6 mg/M^3 is that without this source of excess TP the lake would probably have been in a consistent high borderline oligotrophic state, pretty much as it appeared to be in the spring and early summer of 2005.

Current plans call for the portion of the development in the SW inlet sub-drainage to contain an urban park and recreational area (where the west wetland currently is) of about eight hectares, and an additional residential portion also of about eight hectares. Table 11.8 shows the model output with these additions to the SW inlet's drainage. The TP export coefficient for the urban park and recreational area was assumed to be close to that for a residential area. The main development area on the west side of Russell Lake is also included in this run of the model, so this run incorporates the entire portion of the Russell Lake West Development that will drain toward Russell Lake. The total phosphorus loading has gone up to 96 kg/y from a pre-development loading of 87 (Table 11.4). The development has increased the phosphorus loading by 9 kg. The predicted final post-construction TP concentration in Russell Lake is 14.3 mg/M^3. So, the anticipated total increase that would have occurred in the TP concentration in Russell Lake under 2005-06 conditions is about 1.5 mg/M^3.

Given the wide variation that was observed in the TP concentrations in Russell Lake during 2005-06, it is unlikely that an increase of 1.5 mg/M^3 could be noticed. Nevertheless, the Russell West development can be mitigated by reducing or stopping the input of excess phosphorus from the contaminated wetland in the SW drainage. Even if the sewage is stopped, however, there appears to be a backlog of phosphorus stored in the peat. It might be necessary to remove or seal off the peat in the present cattail swamp portion of the wetland. When the final version of the model (Table 11.8) was run with the annual phosphorus contribution from the wetland peat reduced by 10 kg/y (which should be an easily achievable goal) the estimated mean TP concentration in Russell Lake becomes 12.9 mg/M^3, virtually the same as for the pre-construction model run in Table 11.4. Completely eliminating the excess phosphorus input reduces the total phosphorus loading to 71 kg/y and yields a post-construction estimate of 10.9 mg/M^3 for TP concentration in the lake.

[v] The total quantity of peat in the swamp has not yet been determined, neither is it known to what depth the peat is contaminated.

TABLE 11.4 The Russell Lake Watershed Model Baseline Simulation of Pre-Construction TP Inputs and Estimated Mean Lake TP Concentration for the Time Period 15 March 2005 – 14 March 2006

		TP Coef. (mg/M²/y)	TP Loading (kg/y)
NW drainage area(Culvert):			
Export from Penhorn Lake	154,000 M²		1.94
Other urban drainage	888,000 M²	30	26.64
Total NW	1,042,000 M²		
NE drainage area (urban):	490,000 M²	30	14.70
Russell E drainage area:			
Residential	122,000 M²	25	3.05
Forest & wetland	80,000 M²	10	0.80
Total East side	202,000 M²		
Russell W drainage area:			
Scrub, forest & wetland	449,000 M²	10	4.49
SE inlet:			
Forest & wetland	160,000 M²	10	1.60
SW inlet:			
Forest, wetland & TP source	753,000 M²	45	33.89
Total Drainage Area	3,096,000 M²		
Total Watershed Area	3,484,000 M²		
TP in precipitation	25 mg/M²/y	**Total TP Loading**	**87.11**
Model Estimates for Russell Lake			
Precipitation TP	8,575,000 mg P/y		
TP from Drainage	87,107,511 mg P/y		
Total TP input	95,682,511 mg P/y		
Lake discharge	3,408,049 M^3/y		
Areal loading rate	9.9 m/y		
Flushing rate	3.2 times per year		
TP retention coefficient	0.42		
Estimated Mean TP conc.	**13.0 mg/M^3**		
Observed mean TP 2005-06	13.5 mg/M^3		

TABLE 11.5 Russell Lake Watershed Model Output for Post-construction of a Residential Development on the West Side (Drumlin Slope) of the Lake.

		TP Coef. (mg/M²/y)	TP Loading (kg/y)
NW drainage area(Culvert):			
Export from Penhorn Lake	154,000 M²		1.94
Other urban drainage	888,000 M²	30	26.64
Total NW	1,042,000 M²		
NE drainage area (urban):	490,000 M²	30	14.70
Russell E drainage area:			
Residential	122,000 M²	25	3.05
Forest & wetland	80,000 M²	10	0.80
Total East side	202,000 M²		
Russell W drainage area:			
Residential	449,000 M²	25	11.23
SE inlet:			
Forest & wetland	160,000 M²	10	1.60
SW inlet:			
Forest, wetland & TP source	753,000 M²	45	33.89
Total Drainage Area	3,096,000 M²		
Total Watershed Area	3,484,000 M²		
TP in precipitation	25 mg/M²/y	**Total TP Loading**	**93.84**
Model Estimates for Russell Lake			
Precipitation TP	8,575,000 mg P/y		
TP from Drainage	93,842,511 mg P/y		
Total TP input	102,417,511 mg P/y		
Lake discharge	3,408,049 M3/y		
Areal loading rate	9.9 m/y		
Flushing rate	3.2 times per year		
TP retention coefficient	0.42		
Estimated Mean TP conc.	**13.9 mg/M³**		

Notes:
The only input change from Table 11.4 is the substitution of the 'residential' land use TP export coefficient instead of that for 'undeveloped' for the Russell West Drainage Area.

TABLE 11.6 Another Pre-construction Model Run with a More Elaborate Breakdown of the SW Inlet Drainage that Yields an Estimate of 25 kg/y of Phosphorus Flushed into Russell Lake from the Excess TP Source (Sewage Contaminated Wetland) During 2005-06

		TP Coef. (mg/M²/y)	**TP Loading** (kg/y)
NW drainage area(Culvert):			
Export from Penhorn Lake	154,000 M²		1.94
Other urban drainage	888,000 M²	30	26.64
Total NW	1,042,000 M²		
NE drainage area (urban):	490,000 M²	30	14.70
Russell E drainage area:			
Residential	122,000 M²	25	3.05
Forest & wetland	80,000 M²	10	0.80
Total East side	202,000 M²		
Russell W drainage area			
Scrub, forest & wetland	449,000 M²	10	4.49
SE inlet:			
Forest & wetland	160,000 M²	10	1.60
SW inlet:			
Forest & wetland	**658000 M²**	**10**	**6.58**
Residential	**95,000 M²**	**25**	**2.38**
Excess TP source			**24.93**
Total SW	**753,000 M²**		**33.89**
Total Drainage Area	3,096,000 M²		
Total Watershed Area	3,484,000 M²		
TP in precipitation	25 mg/M²/y	**Total TP Loading**	**87.11**
Model Estimates for Russell Lake			
Precipitation TP	8,575,000 mg P/y		
TP from Drainage	87,107,511 mg P/y		
Total TP input	95,682,511 mg P/y		
Lake discharge	3,408,049 M³/y		
Areal loading rate	9.9 m/y		
Flushing rate	3.2 times per year		
TP retention coefficient	0.42		
Estimated Mean TP conc.	**13.0 mg/M³**		

TABLE 11.7 Pre-Construction Run Similar to that in Table 11.6 but with the Phosphorus Loading from the Excess TP Source (Sewage Contamination in the West Wetland) Set to Zero

		TP Coef. (mg/M²/y)	TP Loading (kg/y)
NW drainage area(Culvert):			
Export from Penhorn Lake	154,000 M²		1.94
Other urban drainage	888,000 M²	30	26.64
Total NW	1,042,000 M²		
NE drainage area (urban):	490,000 M²	30	14.70
Russell E drainage area:			
Residential	122,000 M²	25	3.05
Forest & wetland	80,000 M²	10	0.80
Total East side	202,000 M²		
Russell W drainage area			
Scrub, forest & wetland	449,000 M²	10	4.49
SE inlet:			
Forest & wetland	160,000 M²	10	1.60
SW inlet:			
Forest & wetland	**658000 M²**	**10**	**6.58**
Residential	**95,000 M²**	**25**	**2.38**
Excess TP source			**0**
Total SW	**753,000 M²**		**8.96**
Total Drainage Area	3,096,000 M²		
Total Watershed Area	3,484,000 M²		
TP in precipitation	25 mg/M²/y	**Total TP Loading**	**62.18**
Model Estimates for Russell Lake			
Precipitation TP	8,575,000 mg P/y		
TP from Drainage	62,177,511 mg P/y		
Total TP input	70,752,511 mg P/y		
Lake discharge	3,408,049 M³/y		
Areal loading rate	9.9 m/y		
Flushing rate	3.2 times per year		
TP retention coefficient	0.42		
Estimated Mean TP conc.	**9.6 mg/M³**		

TABLE 11.8 Output of the Complete Post-construction Mode Incorporating Both the Residential Development on the West Side of Russell Lake, and the Additional Residential and Urban Park Areas in the Sub-drainage of the SW Inlet

		TP Coef. (mg/M²/y)	TP Loading (kg/y)
NW drainage area(Culvert):			
Export from Penhorn Lake	154,000 M²		1.94
Other urban drainage	888,000 M²	30	26.64
Total NW	1,042,000 M²		
NE drainage area (urban):	490,000 M²	30	14.70
Russell E drainage area:			
Residential	122,000 M²	25	3.05
Forest & wetland	80,000 M²	10	0.80
Total East side	202,000 M²		
Russell W drainage area:			
Residential	**449,000 M²**	**25**	**11.23**
SE inlet:			
Forest & wetland	160,000 M²	10	1.60
SW inlet:			
Forest & wetland	498000 M²	10	4.98
Residential	**175,000 M²**	**25**	**4.38**
Urban Park	**80,000 M²**	**25**	**2.00**
Excess TP source			24.93
Total SW	753,000 M²		36.29
Total Drainage Area	3,096,000 M²		
Total Watershed Area	3,484,000 M²		
TP in precipitation	25 mg/M²/y	**Total TP Loading**	**96.24**
Model Estimates for Russell Lake			
Precipitation TP	8,575,000 mg P/y		
TP from Drainage	96,242,511 mg P/y		
Total TP input	104,817,511 mg P/y		
Lake discharge	3,408,049 M³/y		
Areal loading rate	9.9 m/y		
Flushing rate	3.2 times per year		
TP retention coefficient	0.42		
Estimated Mean TP conc.	**14.3 mg/M³**		

12.0 CONCLUSIONS

1) In recent years Russell Lake has been undergoing a rapid reduction in trophic status, but whether from a reduction in total phosphorus input or from reduced internal loading as a result of siltation is undetermined, though anecdotal evidence favours the latter.
2) During the study period in 2005-06 the lake passed through periods of apparent oligotrophy, then mesotrophy and eutrophy; and then by the end of winter it appeared to be back in a mesotrophic state.
3) In the 2005-06 study period, about 25 kg of excess phosphorus leached out of the contaminated west wetland area below the Circumferential Highway culvert.
4) The excess TP in the west wetland appears to be the result of sewage discharge from the trailer park on the other side of the Circumferential Highway.
5) The Russell West development is expected to increase the total phosphorus concentration in the lake by about 1.5 mg/M^3.
6) This anticipated increase in TP can be mitigated by reducing or eliminating the TP input from the trailer park and contaminated wetland.
7) It is not feasible to restore Russell Lake to its presumed pre-development oligotrophic condition because of the extensive land use changes in the drainage area.
8) Russell Lake can be restored to a stable mesotrophic state and maintained in that state for the foreseeable future. This would require the elimination of the excess TP contamination presently entering from the west wetland.
9) A likely scenario for Russell Lake is that siltation has buried the previous accumulation of high phosphorus sediments on the bottom of the lake. However, if nothing is done to control the excess phosphorus, the continued influx of high TP from the contaminated west wetland will build up a new layer of high phosphorus sediment. As more and more high phosphorus sediment accumulates, the internal loading will drive the trophic status higher and higher until a stable eutrophic state is achieved.

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