Stormwater Pond Maintenance and Anoxic Conditions Investigation
FINAL REPORT

Lake Simcoe Region Conservation Authority

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This project was funded by Environment Canada's Lake Simcoe Clean-up Fund

SUMMARY AND RECOMMENDATIONS

The two objectives of this study were to 1) assess current level of efficiency of select stormwater ponds, and 2) to examine the prevalence and extent of low oxygen conditions in Stormwater Ponds.

With regard to the efficiency of the ponds it was found that of the 98 ponds studied 56 had dropped by 1 or more levels of efficiency, 12 of which had dropped below Level 4 (the lowest level of efficiency). This loss in efficiency translates to an increase of 0.81 t of phosphorus loading to receiving water courses. Interestingly, 37 of the ponds studied were found to have greater volumes than listed in the design information. While the reasons for the greater volumes is uncertain, in some instances, ponds are over excavated when they are first constructed to allow for the collection of excess sediment during the servicing of the subdivision and the house building phase.

Maintenance Recommendations:

- Where it has not already underway, municipalities develop and implement a maintenance program to return stormwater ponds to their design levels. This report provides a starting point for prioritizing pond maintenance (See Appendix C).
- The 12 ponds that have fallen below Level 4 efficiency should be given highest priority for clean out maintenance.
- Policy 4.5-SA of the Lake Simcoe Protection Plan states that municipalities will be required to complete SWM Master Plans for all their settlement areas. Step Ten of the Comprehensive SWM Master Plan Guidelines (LSRCA 2011), indicates that as part of a SWM Master Plan, municipalities will need to establish an ongoing program that assesses the effectiveness of individual stormwater ponds. This program should include routine field inspections of pond volume / design level.
- That enhanced street cleaning be conducted to reduce sediment loads to ponds and thus extend the efficiency of the pond. Priority should be given to stormwatersheds that have highest sediment accumulation rates within the ponds (See Appendix C). Street cleaning should primarily occur in spring to remove sand applied to roads during the winter.
- Municipalities and LSRCA investigate stormwater ponds that apparently have larger current volumes than design criteria. This investigation will help uncover if this is a data management issue / deficiency, operational failing of the pond, or a construction / post construction issue. The information gathered would inform maintenance decisions along with operational / design considerations.
- As-built drawings accompany ponds upon assumption by the Town / Municipality to account for ponds that were over excavated during construction and develop accurate clean out maintenance schedules.
- Municipalities adopt the Yellow Fish Program along with other initiatives aimed at educating the general public and limiting pollutants from entering storm drains and ponds.

Low oxygen conditions were found to be fairly prevalent in stormwater ponds with 42 of the 98 ponds surveyed showing daytime hypoxic / anoxic conditions. Water quality sampling at a select number of ponds yielded strong evidence for nutrient release under these conditions. This has the potential to change what has traditionally been considered a nutrient sink into a nutrient source. Further, the hot and dry weather that was found to promote these low oxygen conditions are predicted to become more frequent under 2050 climate model scenarios. Additional work is required to quantify the amount and impact that low oxygen nutrient release is having on receiving waters.

Anoxia Recommendations:

- Further monitoring of stormwater pond waters and sediment to determine the frequency and duration of low oxygen conditions, quantify the nutrient release, and assess total nutrient loads exiting stormwater ponds.
- Continue to investigate and implement alternative approaches to stormwater management that does not involve potential for standing water to become anoxic. Alternate approaches should include Low Impact Design (LID) and Innovative stormwater management systems.
- Determine significance of low oxygen nutrient release verses overall pond efficiency and implications for use of stormwater ponds as a tool for removing nutrients from urban stormwater runoff.
- Test methods and technologies for preventing stormwater pond anoxia or controlling nutrient release from sediments (i.e. Pond Aeration, Phoslock etc…).
- Incorporate methodologies for monitoring of low oxygen nutrient release into all stormwater pond monitoring plans.

1 BACKGROUND

Urban stormwater runoff is widely recognized as a significant source of pollutants to Lake Simcoe and accounts for an estimated 14% of annual phosphorus (P) loading (Winter 2007). Where the percent of urban land-use in a watershed is high (e.g. Barrie or Aurora-Newmarket) stormwater runoff may be the predominant source of nutrient loading to receiving waters (urban runoff from Barrie exports 120 kg of P per km^2/yr) (LSRCA and MOE 2009). Therefore, interception and treatment of these waters is crucial to maintain the ecological health of receiving streams and lakes. This is most commonly achieved through the use of Stormwater Ponds of which there are 135 quality facilities in the Lake Simcoe Watershed (Figure 1). These ponds work by trapping suspended particulates until they can settle out, thereby removing many pollutants (e.g. phosphorus (P) from the water and preventing travel into the receiving watercourse.

Since 1995, all new development within the Lake Simcoe watershed has been required include Level 1 (the most stringent type of quality control) stormwater management facilities for the treatment of stormwater run-off. Level 1 facilities as defined in the 1995 MOE Storm Water Management Planning and Design Guidelines (or Enhanced as per the 2003 MOE SWMPD Guidelines) are designed to remove approximately 80% of suspended solids and can reduce P runoff by 60% to 90%. By design, these ponds trap sediment, which results in the reduction of pond volume over time. The reduction in pond volume results in reduced particulate and P removal efficiency. Critical to maintaining this efficiency is regular removal of the sediment accumulated in the pond. One of the main goals of this project was to assess the current state of sediment accumulation in SWM ponds in major urban areas of the watershed. The results of this assessment allow current pond efficiency to be calculated and used to estimate the actual phosphorus reduction currently being achieved through the use of stormwater ponds in these urban areas.

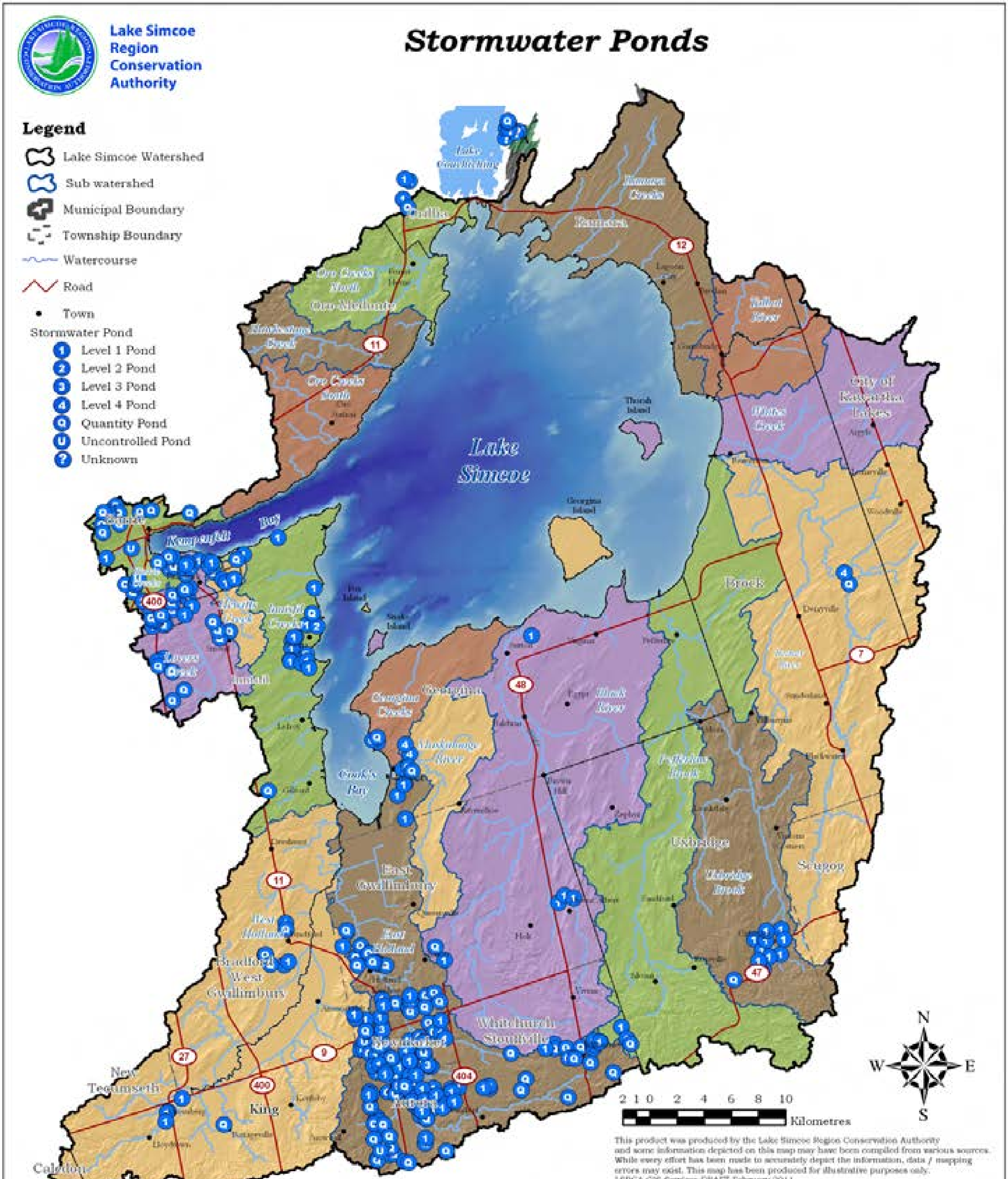
The designed efficiency of a Stormwater pond has been an important variable in calculating the total phosphorus (TP) load to Lake Simcoe as it is this efficiency level that is used to predict the amount of P capture the pond achieves. The efficiency of a SWM pond has a direct relationship to the total phosphorus load from the catchment. If all stormwater ponds in the watershed are functioning as designed, it is estimated that P export is reduced by 4262 kg/yr as compared to uncontrolled conditions (LSRCA 2007). However, as discussed above, the design efficiency of a SWM pond will decline over time as sediment accumulates in the facility. As such it is very likely that P reduction has been overestimated. Accurate pond efficiency estimations are critical for not only calculating phosphorus loads to Lake Simcoe but also for improved and more accurate subwatershed and assimilative capacity modeling and the evaluation of aquatic ecosystem stressors

Under normal conditions dissolved phosphorus has a strong affinity to iron resulting in the incorporation of iron bound phosphorus into sediments such as those captured in Stormwater ponds. However, under low (hypoxic) to no (anoxic) oxygen conditions iron is reduced and the bound phosphorus is released into the water column resulting in an internal source of phosphorus loading to the pond. The potential for pond bottom waters to develop anoxic conditions is well recognized and understood in larger deeper lakes and ponds (Pettersson

1998, Belzile et al. 1996, Søndergaard et al. 2003, Carignan and Flett 1981, deMontigny and Prairie. 1993). To avoid anoxic conditions in stormwater ponds the MOE Stormwater Pond design manual stipulates a maximum depth of 2.5 to 3 meters (MOE 2003). However, a field study by LSRCA staff in 2008 recorded repeated episodes of hypoxia in a stormwater pond with a depth of less than 2 m. The data also suggested that due to the low residence time of the stormwater pond the hypoxic conditions were developing rapidly with storm events causing a mixing of waters and release of the unbound phosphorus to receiving waterbodies. As the vast majority of stormwater pond monitoring has focused on the efficiency of a pond during storm events the development and impact of low oxygen conditions have largely gone unnoticed. Therefore, a second objective of this project was to examine the prevalence and extent of low oxygen conditions in Stormwater Ponds and begin to quantify the significance of the issue.

2 OBJECTIVES

1. **Pond maintenance:** Assess current level of efficiency of select stormwater ponds, and by comparing to design levels, assess:
    - Potential additional, and unaccounted for, loads of phosphorus to Lake Simcoe based actual current pond efficiency
    - Required frequency of maintenance clean out to help ensure ponds operate at design levels
2. **Pond Anoxia**: to examine the prevalence and extent of low oxygen conditions in Stormwater Ponds to:
    - begin to quantify the significance (frequency and duration) of the low dissolved oxygen events
    - assess potential impacts of low dissolved oxygen on release of sediment bound phosphorus to the water column and therefore increased loads to Lake Simcoe



This product was produced by the Lake Simcoe Region Conservation Authority and some information depicted on this map may have been compiled from various sources. While every effort has been made to accurately depict the information, data / mapping errors may exist. This map has been produced for illustrative purposes only.
LSRCA GIS Services DRAFT February 2011.

3 METHODS

3.1 Pond Selection

Stormwater ponds were selected using the Stormwater Ponds GIS point layer which was created for the Lake Simcoe Basin Stormwater Management and Retrofit Opportunities report (2007).The ponds were selected using the following criteria:

- Location – only ponds located in larger urban areas of Aurora, Barrie, Innisfil, Keswick, Newmarket, and Uxbridge were selected.
- Water Quality control pond designed for levels 1-4. Ponds only designed for mitigating water quantity were not included.
- years of age or older so that ponds only in likely need of maintenance are assessed

Initially 114 ponds were identified that met the age and efficiency criteria of the study. However, a number of ponds were eliminated from the study due to issues of safe access and private property access. This brought the total number of ponds examined to 98. While all 98 ponds were assessed for pond maintenance and pond anoxia studies, a subset of ponds was selected for more detailed anoxia measurements, sampling and deployment of multi-parameter water quality loggers. Location of the 98 selected ponds is shown in Figure 1 and pond names are listed in Appendix B.

3.2 Pond Maintenance Evaluation

Pond maintenance assessment was in undertaken by calculating volume of the 98 stormwater ponds selected. Measure volume was assessed by measuring the depth and surface are of each pond. Measured pond volumes were then compared to design volume which was obtained from available reports. The following section details the methods used.

3.2.1 Measured Pond Volume

Measurement of pond volume was undertaken between May and October 2010. During the first site visit at the selected ponds rough sketches were drawn of each pond indicating pond shape, location of inlets and outlets and other identifying features surrounding the pond such as vegetation, houses, trails etc. Photos were also taken at each pond documenting the inlets, outlets and total pond area. Area dimensions of the ponds were taken using a laser level with the exception of ponds N-NW15, N-NW16, N-NW2, N-NW3 and N-NW4, which were measured using a measuring tape.

Water depth was taken a multiple sites within each pond. The number of sites depended on the size of the pond, which ranged from 1 to 7 sites per pond. The water depth measurements were taken with a weighted tape, with the exception of the first two ponds investigated, N-CE2 and N-CE23, which were measured using a depth sounder, but was later abandoned because of interference with heavy vegetation.

The following formulas were used to calculate the areas and volumes of each pond:

- Area of a rectangle = l*w
- Area of an ellipse = π*a*b
- Volume of a truncated rectangle = $1/3((a^2c-b^2d)/(a-b))h$
- Volume of a truncated triangle = $(1/3((a^2c-b^2d)/(a-b))h)/2$
- Volume of a truncated ellipse = $1/3*\pi*((a^2c-b^2d)/(a-b))h$
- Volume of a pyramid = 1/3*Length*Width*Height
- Volume of a truncated cone = $1/3*\pi*(R_1^2+R_1*R_2+R_2^2)*h$

The complete explanations for these formulas can be found in Appendix A. All the ponds were assumed to have a side slope of 3:1; thus necessitating the use of the truncated geometric shapes described above. When multiple depth measurements were recorded over multiple site visits, the lowest recorded depth was used as the permanent water level of the pond (as to not be influenced by rain). Surveyed pond measurements were verified using orthophotos.

3.2.2 Design Pond Volumes

In order to compare the designed pond efficiency with the current measured efficiency the best available design pond volumes were used. Where available these design volumes were taken from the Stormwater Management Reports found in the subdivision files. If there was no information in these reports then if possible they were taken from other reports such as those produced by the Town of Aurora (XCG Consultants Ltd. 2007) and the Town of Newmarket. (AECOM Canada Ltd. 2009). In some instances it would appear that the design volume available does not correspond with the as built conditions of the pond. This makes it difficult to draw conclusions on pond efficiency as in some instances the volumes and depths surveyed in 2010 exceed the design criteria. This is discussed further in the Maintenance Results section.

3.2.3 Calculating changes in pond level and phosphorus loads

Using the MOE Stormwater design manual (2004) combined with catchment area, the stormwater pond volume required to meet Level 1 through 4 efficiency were calculated. These pond efficiency volumes were compared with the design pond volumes and the current measured pond volumes to determine whether or not a pond was still functioning at its design level and if not at what level the pond is currently functioning at.

Phosphorus load per catchment and any associated reduction in load achieved via a stormwater pond were calculated to assess how deviation of pond level from designed to current measured level affects P loads.

A stormwater catchment area is the specific urban area, such as a subdivision, which drains into and is treated by the stormwater pond. These specific catchment areas were taken from the Stormwatersheds GIS polygon.

Phosphorus loads were calculated by catchment based on catchment size, level of imperviousness (residential area = 0.45, industrial / commercial = 0.85), and an average phosphorus load per hectare per year of 1.32 (residential) or 1.82 (industrial / commercial) based on monitoring data from Liang, 1999. Phosphorus reductions for the 4 levels of control were defined as follows:

- Level 1 = 80% phosphorus reduction
- Level 2 = 69% phosphorus reduction
- Level 3 = 54% phosphorus reduction
- Level 4 = 40% phosphorus reduction

These reductions were adopted from available monitoring data in the Southern Ontario area and represent monitoring data on a Level 1 pond (Liang, 1999) and Level 2 pond (LSRCA, 2003). Phosphorus reductions achieved by the ponds vary by season and storm intensity. The numbers adopted for this study represent what is estimated to be the average efficiency of the facility and are applied to the calculation of yearly loadings.

Where the pond volumes determined in this study, indicated that the efficiency of the pond had decreased the new level of efficiency along with the corresponding level of phosphorus was used to estimate the phosphorus load from each catchment. Where the pond efficiency had dropped below Level 4 the pond was assumed to achieve no phosphorus reduction.

3.3 Pond Anoxia - Sampling Procedures

The number of ponds experiencing low dissolved levels was investigated by spot measurements in each of the 98 stormwater ponds at the same time that pond volume measurements were being taken. Detailed sampling and assessment of pond characteristics, to examine the impact of nutrient release under low oxygen conditions, was also completed at 3 ponds. These ponds that were chosen based on results of the spot measurement, with ponds experiencing extreme high and low dissolved oxygen being selected.

Spot measurements in all 98 ponds were taken with a YSI 600 sonde. The multi probe readings were taken at 20cm from the water surface and 20cm from the bottom of the pond for those sites that were deep enough to accommodate two readings. One multi probe reading was taken at 20cm from the water surface at those sites which were approximately 0.65m or shallower. Parameters measured included water temperature, conductivity, dissolved oxygen and pH.

Detailed assessment of pond anoxia and P release was conducted at 4 ponds and involved collection of sediment samples, water quality samples and long-term logging of dissolved oxygen.

Water samples were taken from 33 ponds using a Van Dorn sampler at 20cm from the water surface and 20cm off the bottom of the pond and were filtered through 80 micron mesh. Sediment samples were taken at the sample locations as the water samples. The sediment was taken using an Ekman dredge, with a 10cm cross section of the top sediment used in the sample. Water samples were sent to an accredited lab for analysis of total and dissolved phosphorus, Ammonium, Nitrate, Nitrite and Total Kjeldahl Nitrogen. Sediment samples were analyzed by the Dillon Lab according to the Psenner method for phosphorus fractionation.

Along with these water and sediment samples, a YSI 6600 sonde was deployed at 4 different ponds, (A-EC12, N-CE23, N-CW21 and N-NW3) between June 15, 2010 to October 5, 2010. The sonde logged water temperature, conductivity, dissolved oxygen, pH, turbidity and chlorophyll at 15 minute intervals for 7 to 14 days depending on the pond. These locations were selected upon review of collected data from the spot DO measurements, and ease of access to the pond. The sonde was placed at 20cm from the bottom of the pond as to document the conditions at the bottom layer of the water column.

4 RESULTS AND DISCUSSION

4.1 Pond Maintenance

For the last two decades the primary means of treating urban stormwater runoff has been the construction of Stormwater Management Ponds. Since 1995, all new development within the Lake Simcoe watershed has been required to provide Level 1 (equivalent to Enhanced in the 2003 MOE Guidelines) stormwater management facilities for the treatment of stormwater run-off. Level 1 facilities are designed to remove approximately 80% of suspended solids (MOE 2004) and can reduce P runoff by 60% to 90% (LSRCA 2007). By design, these ponds trap sediment, a feature which results in a reduction in pond volume and thus reduced efficiency by which particulates (and P) are removed. Critical to maintaining this efficiency is regular removal of the sediment accumulated in the pond. In the Lake Simcoe Watershed there are 135 ponds (Figure 1) which are estimated to be removing 4.3 t of phosphorus per year as originally designed (LSRCA 2007). One of the objectives of this study was to examine a large number of ponds to evaluate if the efficiency of ponds has been reduced due to the accumulation of sediment in the pond. This will then allow us to reevaluate the estimated phosphorus reduction that is being achieved by these ponds.

4.1.1 Changes in pond efficiency level

As outlined in the Methods section, each pond was surveyed and this data was used to calculate the permanent pool volume of each pond as of summer 2010. Appendix B displays pond characteristics and volume as originally designed compared with the volumes calculated based on the 2010 survey. Of the 98 ponds surveyed, 77 were originally designed to meet Level 1 criteria, 9 to meet Level 2 criteria, 9 to meet Level 3 criteria and 2 to meet Level 4 criteria. When the ponds were surveyed in 2010, only 36 were still operating at Level 1 efficiency. 27 of the surveyed ponds were found to have dropped by 1 level, 16 that had dropped by 2 levels, and 1 that had dropped by 3 levels. A further 12 ponds had filled with sediment to the point where they no longer had a permanent pool volume or a volume lower than Level 4 efficiency. Figure 2 shows current number of ponds at each level compared to design level. Figure 3 displays only the ponds that have dropped by one or more levels of efficiency. Figure 4 displays the ponds that have not decreased in efficiency but colour coding those that are within 10% of their designed efficiency threshold.

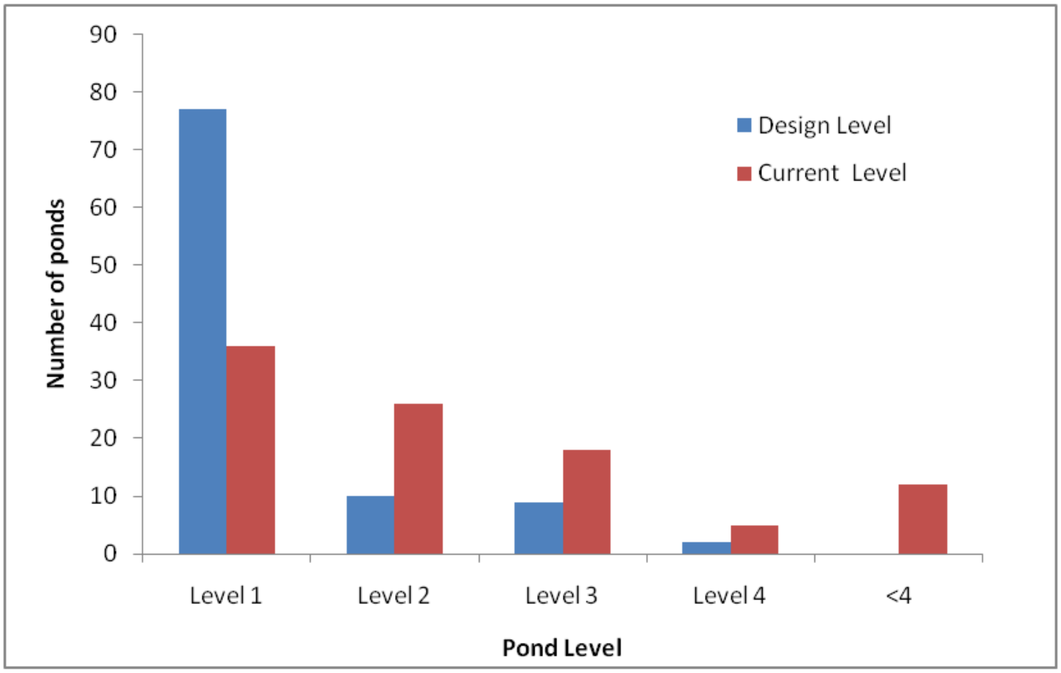
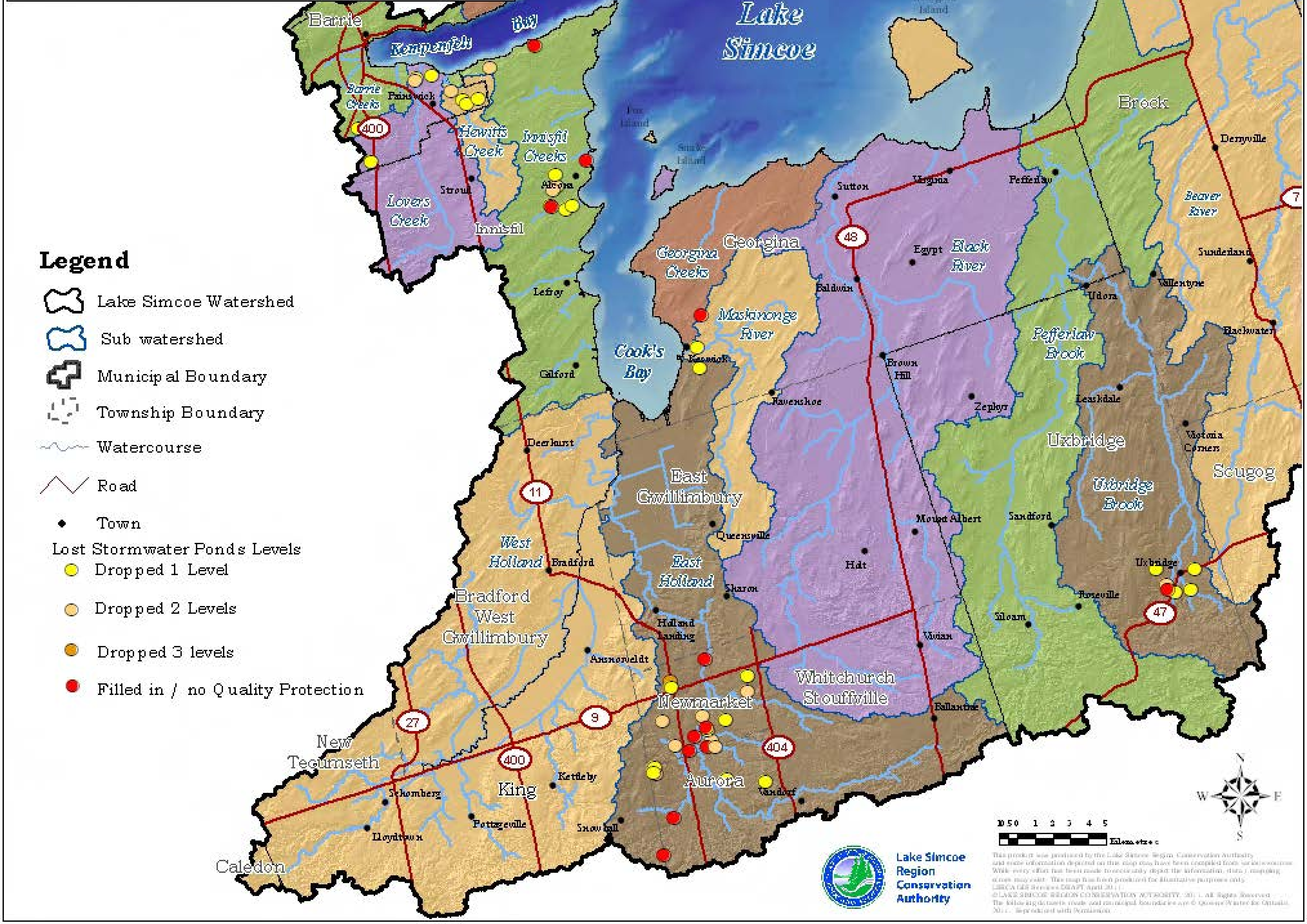


Figure 2: Pond Design Efficiency Level vs. 2010 Surveyed Efficiency Level.

The age of the pond obviously plays a role in the amount of sediment accumulated in the pond and need for maintenance. The older the pond the more time it has had to capture sediment and therefore is more likely to have reduced in efficiency. However, some landuse practices, such as construction, can accelerate the accumulation of sediment and thereby decrease the time between required maintenance activities. In Table 1 the ages of the ponds are compared with the reduction in efficiency. For this table the outliers or ponds with incomplete information, have been removed to allow for a better estimation of the typical time it takes for ponds to drop a given number of levels of efficiency. While it is not possible to give a definitive maintenance schedule from these results, it does provide a range during which maintenance should be considered, approximately 10 years to avoid dropping a level, and more frequently if sediment erosion rates in watershed are high due to activities such as construction. Given the relative ease that pond level can be calculated, and the variance in pond sedimentation rates, it is recommended that routine determination of pond volume / design level be completed in parallel with the routine assessment of facility infrastructure.

Lost Stormwater Pond Efficiency



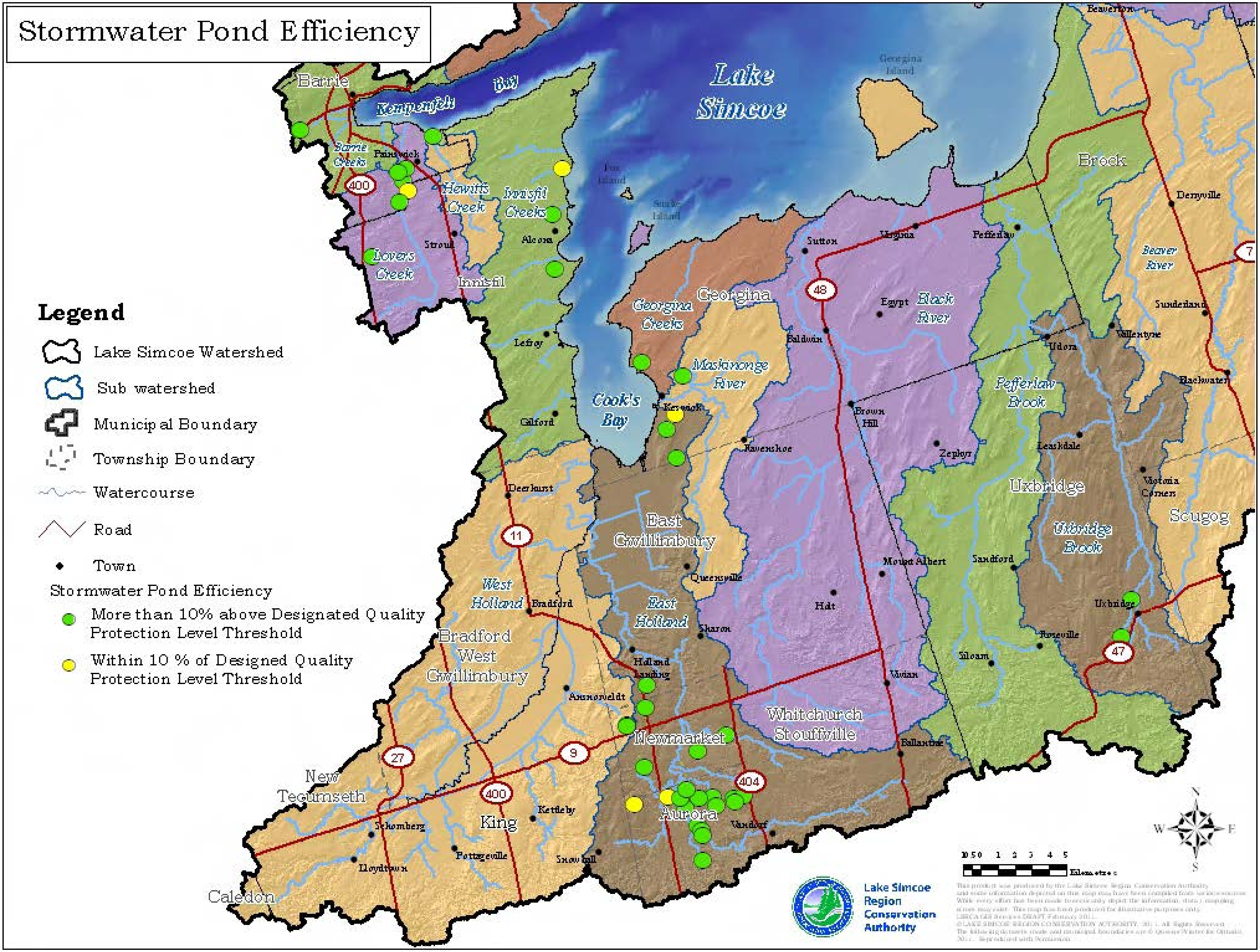

Stormwater Pond Efficiency
Lake Simcoe
Kempenfelt Bay
Georgina Island
Fox Island
Snake Island
Cook's Bay
Barrie
Barrie Creeks
Painswick
Hewitts Creek
Innisfil Creeks
Lovers Creek
Stroud
Alcona
Innisfil
Lefroy
Gilford
Georgina
Georgina Creeks
Maskinonge River
Keswick
Ravenshoe
Sutton
Virginia
Pefferlaw
Egypt
Black River
Baldwin
Brown Hill
Zephyr
Brock
Derryville
Beaver River
Sunderland
Vallentyne
Udora
Blackwater
Pefferlaw Brook
Leaskdale
Uxbridge
Victoria Corners
Scugog
Uxbridge Brook
Sandford
Uxbridge
Roseville
Siloam
Beaverton
Deerhurst
East Gwillimbury
Queensville
Mount Albert
Holt
West Holland
Bradford
East Holland
Sharon
Bradford West Gwillimbury
Holland Landing
Vivian
Ansnorveldt
Whitchurch Stouffville
Newmarket
Ballantrae
New Tecumseth
King
Kettleby
Aurora
Vandorf
Schomberg
Pottageville
Lloydtown
Snowball
Caledon
400
48
7
11
47
27
9
404
Legend
Lake Simcoe Watershed
Sub watershed
Municipal Boundary
Township Boundary
Watercourse
Road
Town
Stormwater Pond Efficiency
More than 10% above Designated Quality Protection Level Threshold
Within 10 % of Designed Quality Protection Level Threshold
N
S
E
W
Kilometres
Lake Simcoe Region Conservation Authority

Table 1: Pond Age Compared with Dropped Levels of Efficiency.

	Dropped 1 Level	Dropped 2 Levels	Dropped 3 Levels	Filled / No Quality
# of Ponds	22	13	1	7
Youngest Pond (years)	6	6		10
Oldest Pond (years)	15	20		20
Median Age (years)	9.5	10	15	14
Outliers – (# Young ponds for level/ # Old ponds for level)	5 (3 / 2)	3 (3 / 0)		5 (3 / unknown)

Note: ponds 3 years old or less were not included in the study.

Outliers, being ponds that are very young or very old for their respective categories, are also very informative. Of the 13 ponds that were outliers, the majority (9) were found to be ponds that were losing efficiency too quickly – i.e. had dropped 1 or more levels within a relatively short period of time. A number of these outliers look to be the result of undersized ponds meaning the pond is receiving runoff from a larger area than it was designed for. This could also be the result of discrepancies in the delineation of the contributing catchment. These would all need to be examined case by case to determine actual catchment size and whether the pond is indeed undersized. Also common to ponds that were quickly filling were ponds servicing areas with active construction or recently completed construction. This highlights the need for the maintenance of onsite sediment controls and pond maintenance upon completion of construction activities.

The majority of outliers that are older ponds are missing information making volume or age calculations suspect. The one exception is a pond that was designed as Level 3 and has dropped to Level 4 after which the only volume threshold is full / dry.

Sediment influx was also calculated (Appendix B) as a product of the volume of sediment accumulated in a pond divided by the size of the contributing catchment and pond age, yielding a measure of m^3 per hectare per year. As the variables used to calculate this are the result of the same assumptions used to calculate efficiency they do not help to explain the rate at which some ponds lose efficiency. However, again removing outliers, the sediment influx ranges from a low of 0.26 m^3/ha/yr to a high of 19.17 m^3/ha/yr with a median value of 3.51 m^3/ha/yr. This median value may be of use for the sizing of ponds or developing maintenance schedules. However, further studies into the reason sediment influx rates vary substantially between ponds could improve the ability to establish appropriate maintenance schedules and undertake appropriate urban Best Management Practices. Implementation of urban best management practices such as street cleaning, sediment and erosion control on construction sites and optimization of road sand application can help to lower the amount of sediment generated by a catchment and lengthen the time between pond maintenance.

Of the 98 ponds surveyed 37 were found to have a current volume greater than the design volume. In some cases it is possible that the volume calculation method employed over estimated volume, particularly if one of our assumptions was not valid for the pond. However, of the 37 ponds, 18 had depths measured in 2010 that were greater than the design depth. Depth was considered to be one of the more robust sets of field data collected. In 6 instances the greater volumes would increase the efficiency of the pond by 1 level. However, as the cause of these discrepancies is not clear these ponds did not receive the increased phosphorus removal associated with a higher level of efficiency. This suggests that alterations to pond design may have occurred during or after pond construction that are not captured with the design information on file. In some instances, ponds are over excavated when they are first constructed to allow for the collection of excess sediment during the servicing of the subdivision and the house building phase. The use of as built drawing would assist in determining over sizing of ponds, associated level of efficiency due to the larger volume, as well as scheduling maintenance relevant to actual pond sedimentation rates.

Other possible explanations of larger volumes may be scour of the ponds due to high flows or post construction cleanout may have removed more material than required. The remaining 17 ponds did not have a conclusive explanation as to why the current volumes were greater as the depths measured n 2010 were approximately equal to those that were designed. In order to develop an accurate maintenance schedule for these ponds it will be important to investigate these volume discrepancies on a case by case basis.

Stormwater ponds achieve a phosphorus reduction by allowing the sediment and nutrients associated with that sediment to settle out of runoff water. This process is also effective at trapping other contaminants such as metals, oil, gas and PAHs (Polycyclic Aromatic Hydrocarbons). As a result, the accumulated sediment in a stormwater pond would most often be considered contaminated fill and require proper disposal. Disposal of contaminated sediment is approximately $380/m3 (B. Piotrowski, Environmental Projects Coordinator LSRCA, personal communication). Using this figure the total maintenance cost to bring ponds back to designed efficiency is approximately $18 million. The most expensive pond maintenance identified is $1.6 million with the median cost being $267,000. Appendix C prioritizes pond maintenance by municipality and cost, Appendix D prioritizes pond maintenance by municipality and loss in phosphorus removal efficiency.

While capture and containment of pollutants is one of the functions of a stormwater pond, implementation of urban best management practices or by-laws can help reduce the contaminant load to these ponds. The provincial ban of the cosmetic use of pesticides will be one step in reducing the contaminant load in ponds. PAHs were identified in the LSRCA Toxic Pollutant Screening Program (2005) as the most prevalent contaminant (of those studied) in the Lake Simcoe Tributaries and are a common contaminant in stormwater ponds. Some towns and municipalities are beginning to consider bans on common sources of PAHs such as driveway sealants, and some have already enacted the ban (http://www.whitebearlake.org/index.asp?Type=B_BASIC&SEC=%7BEE7E830B-377D-4161-BB4B-1B91DA39F7CE%7D). Education, such as through Trout Unlimiteds' Yellow Fish Road Program (http://www.yellowfishroad.org/) raise awareness of pollution entering stormwater ponds and local waterways through stormdrains.

4.1.2 Phosphorus Removal Efficiency

The phosphorus load to Lake Simcoe is approximately 74 t per year and the Lake Simcoe Protection Act is targeting a 30 t reduction to bring the annual load to 44 t per year (LSPP 2010). It is currently estimated that urban areas contribute 22.6 t of phosphorus per year to the Lake and surrounding tributaries through stormwater runoff. This constitutes nearly 1/3 (30.5%) of the annual load to the Lake. The 135 stormwater ponds across the entire Lake Simcoe watershed are estimated to be achieving a 4.3 t (LSRCA 2007) phosphorus reduction without which the load from urban areas would be 26.9 t per year, 36% of the annual load. The 4.3 t reduction achieved by these ponds represents 5.8% of the annual phosphorus load. However, this reduction is based on the assumption that these ponds are still functioning at the level of efficiency they were originally designed. This includes ponds that are over 20 years old that have never been cleaned out (maintained). As discussed above this assumption is incorrect and many ponds are not functioning at their designed efficiency.

As originally designed the 98 ponds in this study would achieve a 3.2 t per year phosphorus reduction. However, at the current level of efficiency determined by the 2010 field surveys these ponds are now achieving a reduction of 2.4 t per year, a difference of 0.81 t per year. This loss in efficiency is ~1% of the yearly phosphorus load. Table 2 shows the phosphorus load by each urban area in the Watershed with and without existing stormwater controls (assuming as designed efficiency). The third column is the reduction achieved through stormwater controls. Compared with the reductions being achieved by stormwater ponds in each urban area the loss of efficiency due to lack of maintenance is significant as it is equal or greater than the reduction achieved by each of these areas with the exception of Newmarket.

For the 98 ponds in this study the loss in phosphorus removal efficiency is approximately 25% less than designed efficiency. Extrapolating this out to all 135 quality ponds brings the 4.3 t per year reduction down by approximately 1.1 ton to 3.2 t per year. This is equivalent to 1.5% of the total annual load.

Table 2: Urban Stormwater Phosphorus Loading by Urban Area.

Location	Phosphorus Loading (kg/yr) Without Existing Stormwater Treatment	Phosphorus Loading (kg/yr) With Existing Stormwater Treatment (as designed)	Difference in Phosphorus Loading (kg/yr)
Aurora	4287.77	3619.08	668.69
Ballantrae	958.23	728.40	229.83
Barrie	6478.37	5781.89	696.48
Beaverton	344.98	344.98	0
Bradford	835.86	733.79	102.07
Cannington	151.79	147.21	4.58
Holland Landing	627.66	625.17	2.49
Innisfil	2918.19	2490.95	427.24
Keswick	1225.48	1036.66	188.82
Mount Albert	215.38	157.25	58.13
Newmarket	4712.80	3309.54	1403.26
Orillia – Lake Simcoe	2064.09	2064.09	0
Pottageville	116.50	116.50	0
Schomberg/Lloydtown	243.12	187.62	55.50
Sharon	327.91	294.93	32.98
Sutton	436.80	397.59	39.21
Uxbridge	971.94	627.56	344.38
Totals	**26,916.87**	**22,663.21**	**4253.66**
Orillia – Lake Couchiching*	1280.96	1280.96	0

** Approximately 1/3 of Orillia drains to Lake Couchiching not Lake Simcoe and was therefore not included in Simcoe totals. Orillia drainage to Couchiching is presented for information purposes.*

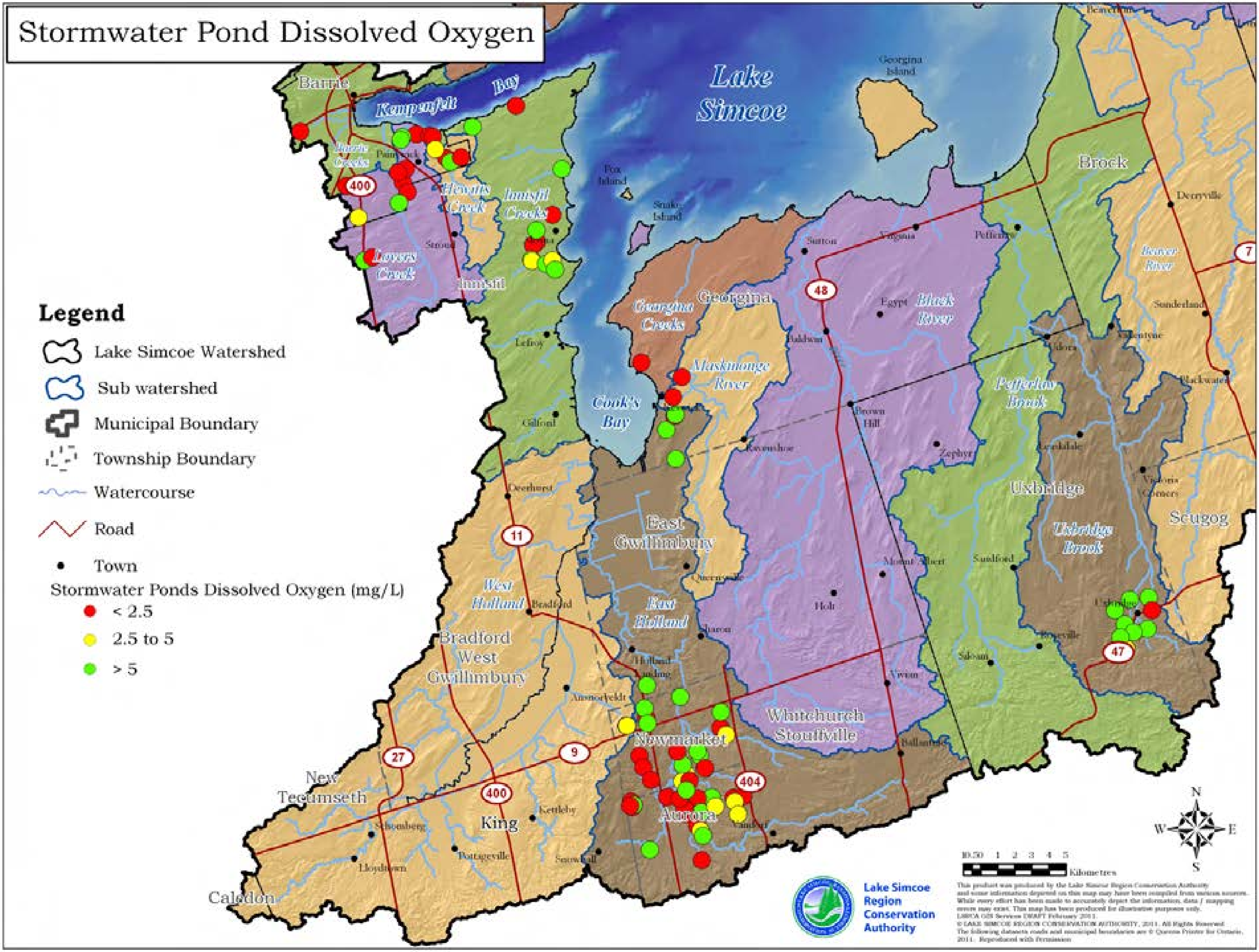
4.2 Stormwater Pond Anoxia Investigation Results

Under normal conditions dissolved phosphorus has a strong affinity to iron resulting in the incorporation of iron bound phosphorus into sediments such as those captured in Stormwater ponds. However, under low (hypoxic) to no (anoxic) oxygen conditions iron is reduced and the bound phosphorus is released into the water column resulting in an internal source of phosphorus loading to the pond. The potential for pond bottom waters to develop anoxic conditions is well recognized and understood in larger deeper lakes and ponds (Pettersson 1998, Belzile et al. 1996, Søndergaard et al. 2003, Carignan and Flett 1981, deMontigny and Prairie. 1993). To avoid anoxic conditions in stormwater ponds the MOE Stormwater Pond design manual stipulates a maximum depth of 2.5 to 3 meters (MOE 2003). However, a field study by LSRCA staff in 2008 recorded repeated episodes of hypoxia in a stormwater pond with a depth of less than 2 m. The data also suggested that due to the low residence time of the stormwater pond the hypoxic conditions were developing rapidly with storm events causing a mixing of waters and release of the unbound phosphorus to receiving waterbodies. As the vast majority of stormwater pond monitoring has focused on the efficiency of a pond during storm events the development and impact of low oxygen conditions have largely gone unnoticed.

In order to determine the prevalence of low oxygen conditions in stormwater ponds, repeated sampling was carried out for dissolved oxygen in the study sites, with hypoxic / anoxic conditions being recorded in 42 of 98 ponds (Figure 5). As these spot dissolved oxygen samples were collected during the day, they do not capture night conditions when ponds are more likely to experience low oxygen conditions. Further some samples were collected into October when the hot conditions that promote anoxic / hypoxic conditions were not as prevalent. This would therefore suggest that the number of ponds identified with low oxygen conditions is conservative and those ponds identified in Figure 5with dissolved oxygen levels between 2.5 to 5 mg/L are likely experiencing anoxic / hypoxic conditions at night.

To further understand the mechanisms driving hypoxic / anoxic conditions and the potential for these conditions to result in nutrient rerelease three ponds (BAR-SE70, N-CW21, and N-NW22) were selected for more detailed study. The water and sediment chemistry of the ponds was sampled on a number of occasions, along with deployment of a YSI sonde to record key water quality variables. While conclusive proof of internal phosphorus loading under low oxygen conditions requires further study, our results strongly suggest a release of sediment bound P during specific weather conditions is occurring in many ponds. During periods of no precipitation, the water columns of these three ponds were observed to stratify on both a temperature and oxygen gradient. Table 3 shows an example an 8 year old, 2 m deep pond sampled July 7th 2010 with a temperature and oxygen gradient as well as a significant total phosphorus and dissolved phosphorus gradient, suggesting sediments as the source of the nutrients. Over several days, as dissolved oxygen concentrations decreased due to respiration of aquatic biota, the concentration of sediment total phosphorus also decreased with increased phosphorus concentrations in the overlying water column, and increases in the concentration of chlorophyll a (a key measure of algal biomass and primary production). All chemistry data is presented in Appendix D.

Figure 6 graphs dissolved oxygen and chlorophyll concentrations over a 13 day dry period in a 9 year old pond, N-CW21, with a depth of 1.5 m. Dissolved oxygen can be seen to dramatically decrease overnight with corresponding increase in chlorophyll concentrations. By July 2nd dissolved oxygen concentrations stay below 2 mg/L and chlorophyll concentrations increase dramatically. With precipitation events, the water column mixes, re-oxygenates, and water column P concentrations and chlorophyll a decreased. Of interest, this same pattern was recorded in six of six study sites in the Holland River, and 12 of 22 study sites in Lake Simcoe (B.K. Ginn, pers. comm.).



Stormwater Pond Dissolved Oxygen
Legend
Lake Simcoe Watershed
Sub watershed
Municipal Boundary
Township Boundary
Watercourse
Road
Town
Stormwater Ponds Dissolved Oxygen (mg/L)
< 2.5
2.5 to 5
> 5
Lake Simcoe
Kempenfelt Bay
Cook's Bay
Georgina Island
Fox Island
Snake Island
Barrie
Barrie Creeks
Hewitts Creek
Innisfil Creeks
Lovers Creek
Innisfil
Georgina
Georgina Creeks
Maskinonge River
Black River
Pefferlaw Brook
Beaver River
Uxbridge Brook
Brock
Uxbridge
Scugog
East Gwillimbury
East Holland
West Holland
Bradford West Gwillimbury
Newmarket
Aurora
King
New Tecumseth
Caledon
Whitchurch Stouffville
400
11
48
27
9
404
47
7
Kilometres
N
E
S
W
Lake Simcoe Region Conservation Authority
This product was produced by the Lake Simcoe Region Conservation Authority and some information depicted on this map may have been compiled from various sources. While every effort has been made to accurately depict the information, data / mapping errors may exist. This map has been produced for illustration purposes only.
LSRCA GIS Services DRAFT February 2011.
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Table 3: Water Quality in Stormwater Pond B-SE78 July 7th, 2010.

	TP (µg/L)	Ortho-P (µg/L)	NH_3 (mg/L)	TKN (mg/L)	Temp (°C)	DO (mg/L)	Sp. Cond (µS/cm^2)
Top Water	14.0	3.0	0.01	0.5	30.8	17.8	313.0
Bottom Water	87.0	15.0	0.39	1.1	18.2	0.8	513.0

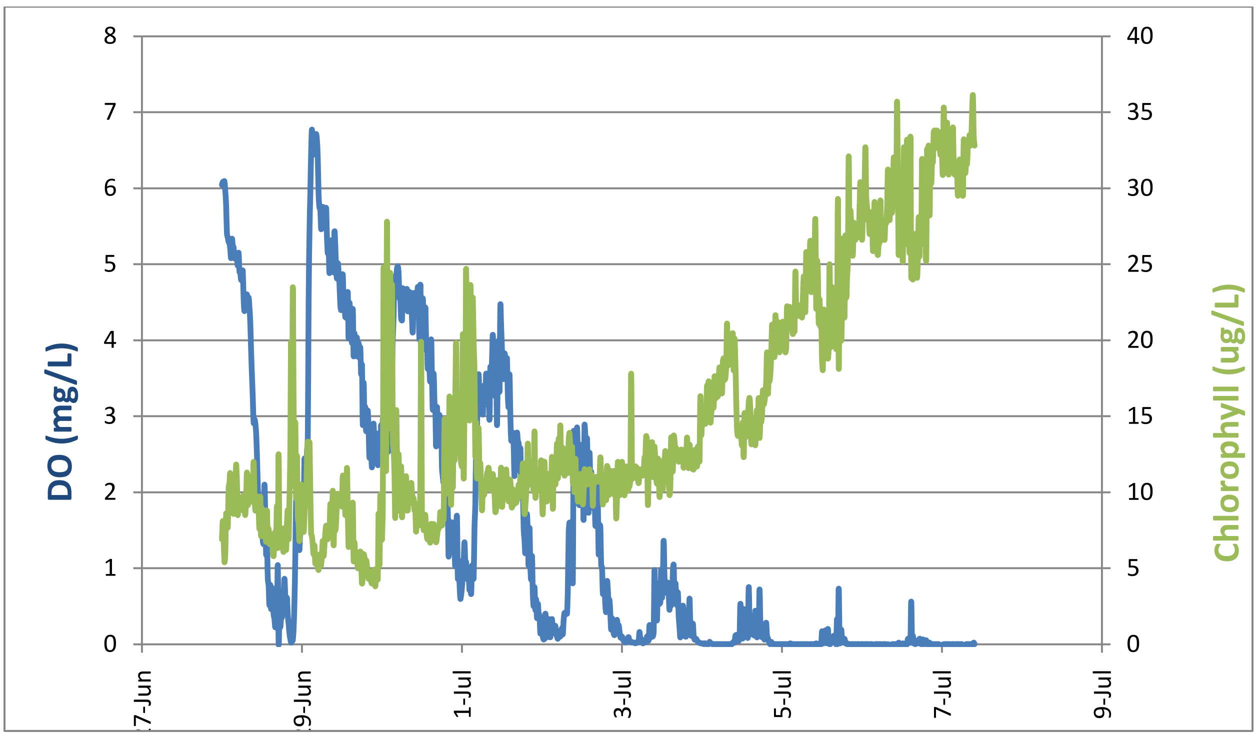

Figure 6: Dissolved Oxygen and Chlorophyll Concentrations in N-CW21, June 27th to July 9th, 2010.

In addition to water chemistry, sediment samples were collected from 36 stormwater ponds in the Lake Simcoe watershed (Table 4). Total Phosphorus (TP) concentrations (mean: 801 µg/g; range: 592 – 1226 µg/g) are similar to that recorded in other studies for Lake Simcoe (range: 340 – 1400 µg/g) and the Holland River (892 – 1233 µg/g) (B.K. Ginn unpublished). In order to gauge the effects of phosphorus, and the potential for release during low oxygen conditions, sediment samples underwent fractionation based on methods described by Lukkari et al. (2007). Fractionation resulted in the determination of several forms: “Loose”, soluble and loosely sorbed P and orthophosphate; “BD”, redox-sensitive P bound to hydrated oxides (mainly Fe); “NaOH”, P bound to remaining oxides of Fe and Al oxides; “HCl” P bound to calcium (e.g. apatite minerals); and “Residual”, sediment total phosphorus minus the sum of fractions. Based on this fractionation, the amount of P available for release to the water column under hypoxic / anoxic conditions is the sum of "loose" "BD" and "NaOH" fractions which represents a mean of 13% (range: 2 – 44%) of P contained in our sediment samples, which is a significant potential source of P loading. When compared with the spot dissolved oxygen readings, the loosely bound phosphorus was found to have a negative correlation (R2 = -0.31) with dissolved oxygen. This is as expected as it suggests that anoxic ponds have lower levels of labile phosphorus and better oxygenated ponds are holding on to the labile phosphorus and have higher levels. As discussed above the spot dissolved oxygen readings did not capture night time conditions and are therefore very likely underestimating the number of anoxic ponds. It is likely that the correlation between labile phosphorus and dissolved oxygen would be much stronger with dissolved oxygen data that included night concentrations.

Implications of these potential internal loading events are a rapid set-up of anoxic conditions with hot, dry weather – conditions which are predicted to become more frequent under 2050 climate-model scenarios. The release of sediment-bound P into the water column also has the potential for increased loading of P into receiving waters with subsequent precipitation turning what we have traditionally thought of as phosphorus sinks into sources of phosphorus. Future work will focus on quantifying the extent of sediment nutrient release in stormwater ponds and the impact on receiving water bodies.

Table 4: Results of phosphorus fractionation procedures on sediment samples from 36 stormwater ponds in the Lake Simcoe Watershed.

#	Site Name	Phosphorus Fraction					TP (µg/g)
		Loose (µg/g)	BD (µg/g)	NaOH (µg/g)	HCl (µg/g)	Residual (µg/g)	
1	A-C22	21	32	33	545	196	827
2	A-C23	33	28	35	447	254	796
3	A-EC12	11	12	18	588	50	679
4	A-NC19	21	33	35	545	132	767
5	A-NC27	21	26	17	404	160	628
6	A-NC28	21	37	40	521	162	780
7	A-NE11	11	16	17	570	56	670
8	A-NE14	8	10	13	619	101	752
9	A-NW1A	22	52	53	551	254	933
10	A-NW1B	25	44	29	305	316	719
11	BAR-SE70	32	195	97	533	58	914
12	BAR-SE77	37	52	103	385	404	981
13	BAR-SE78	28	20	3	564	134	748

#	Site Name	Phosphorus Fraction					TP (µg/g)
		Loose (µg/g)	BD (µg/g)	NaOH (µg/g)	HCl (µg/g)	Residual (µg/g)	
14	BAR-SE79	23	103	70	514	120	831
15	BAR-SE86	22	137	62	588	92	900
16	BAR-SE88	11	9	36	545	113	714
17	BAR-SE89	31	125	83	521	35	794
18	BAR-SW42	11	64	79	422	370	946
19	I-S71	9	29	39	502	33	612
20	K-N17	43	50	32	447	352	925
21	K-N45	58	54	99	594	421	1226
22	K-S19	25	42	38	533	244	882
23	N-CE2	11	18	17	564	75	684
24	N-CE23	7	13	10	557	23	611
25	N-CW21 (SEPT 15)	30	52	46	539	159	826
26	N-CW21 (SEPT 23)	26	48	40	570	274	957
27	N-NW2	33	68	71	521	244	935
28	N-NW3	47	48	66	594	105	861
29	N-NW15	19	20	26	619	131	815
30	N-NW16	11	14	25	570	11	631
31	N-NW22	6	9	14	607	25	661
32	N-SE8	12	14	24	527	15	592
33	N-SW13	16	20	26	539	107	707
34	N-SW18	11	16	24	564	61	676
35	U-NW5	37	38	203	570	289	1137
36	U-NW6	36	40	31	447	283	836
37	U-NW7	21	21	17	539	110	708
38	U-NW21	10	13	37	545	180	785
	Mean	22	42	45	529	162	801
	Minimum	6	9	3	305	11	592
	Maximum	58	195	203	619	421	1226

(Note: Residual = TP – (sum of Loose + BD + NaOH + HCl fractions).

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APPENDIX A: AREA AND VOLUME FORMULAS

<u>Area of a Rectangle:</u>

A = l*w

Where: l = length of rectangle

w = width of rectangle

<u>Area of an Ellipse</u>

A = π*a*b

Where: π = 3.142

a = semimajor axis

b = semiminor axis

<u>Volume of a Truncated Rectangle:</u>

V = 1/3((a2c-b2d)/(a-b))h

Where: a = bottom rectangle side

b = top rectangle side

c = bottom rectangle side

d = top rectangle side

h = height of frustum

<u>Volume of a Truncated Triangle:</u>

V = (1/3((a2c-b2d)/(a-b))h)/2

Where: a = bottom rectangle side

b = top rectangle side

c = bottom rectangle side

d = top rectangle side

h = height of frustum

<u>Volume of a Truncated Ellipse:</u>

V = 1/3*π*((a2c-b2d)/(a-b))h

Where: a = semi=major axis of base (measured at pond surface)

b = semi-major axis of top (calculate off minor axis to maintain proportion of elliptical frustum

as major axis/minor axis of pond surface * minor axis pond bottom)

c = semi-minor axis of base (measured at pond surface)

d = semi-minor axis of top (calculated as 3:1 slope = 6*pond depth – from minor axis at pond

surface)

h = height of frustum (depth of pond)

π = 3.142

<u>Volume of a Truncated Cone:</u>

V=1/3*π*(R12+R1*R2+R22)*h

Where: π = 3.142

R_1 = Radius of the base

R_2 = Radius of the top

h = height of the truncated cone

APPENDIX B: STORMWATER POND DESIGN INFORMATION AND 2010 FIELD SURVEY RESULTS

Pond Name	Pond Age (Years)	Design Volume (m^3)	Design Pond Level	Current Volume (m^3)	Current Pond Level	Accumulated Sediment (m3)	Clean out Cost (@ $380 m3)	Lost Efficiency in P Load per Catchment (kg/yr)	Sediment Influx (m3/ha/yr)
A-C22	17	600.00	2	466.54	2	133.46	$50,716.43	0	1.49
A-C23	17	2400.00	2	1440.29	2	959.71	$364,690.72	0	2.54
A-C25	17	1750.00	1	2042.07	1	-292.07		0	
A-C27	10	2000.00	1	1437.89	1	562.11	$213,602.89	0	6.46
A-EC12	3	5137.00	1	4704.03	2	432.97	$164,529.28	26.21	3.61
A-NC10	22	1100.00	2	628.26	2	471.74	$179,259.77	0	2.09
A-NC18	9	5800.00	3	7578.81	1	-1778.81		0	
A-NC19	9	10474.00	3	11033.66	1	-559.66		0	
A-NC27	15	6600.00	3	8281.86	1	-1681.86		0	
A-NC28	15	24000.00	2	25227.77	1	-1227.77		0	
A-NC3	14	430.00	1	135.07	NA	294.93	$112,072.36	12.1	1.84
A-NC5	14	1600.00	1	461.22	3	1138.78	$432,736.40	4.19	6.67
A-NE10	2	3420.00	1	2542.68575	1	877.31	$333,379.41	0	36.17
A-NE11	3	2746.00	1	3524.04	1	-778.04		0	
A-NE13	4	6580.00	1	7026.75	1	-446.75		0	
A-NE14	4	8790.00	1	8619.57	1	170.43	$64,763.81	0	1.42
A-NE15	4	480.00	1	673.46	1	-193.46		0	
A-NE8	7	7230.00	1	5652.34	1	1577.66	$599,509.43	0	5.87
A-NE9	6	8016.00	1	5471.43	2	2544.57	$966,937.79	8.46	7.28
A-NW1A/B	7	1193.00	1	1824.10	2	-631.10		2.62	
A-NW3	7	580.00	1	402.13	1	177.87	$67,590.14	0	8.32

Pond Name	Pond Age (Years)	Design Volume (m^3)	Design Pond Level	Current Volume (m^3)	Current Pond Level	Accumulated Sediment (m3)	Clean out Cost (@ $380 m3)	Lost Efficiency in P Load per Catchment (kg/yr)	Sediment Influx (m3/ha/yr)
A-NW5	4	NA	1	805.07	3			4.69	
A-SC11	14	750.00	1	849.49	1	-99.49		0	
A-SW2	12	NA	3	NA	NA			26.4	
A-WC4	6	NA	1	212.38	NA			39.3	
BAR-C33	9	19700.00	1	30401.50	1	-10701.50		0	
BAR-SE2	15	2745.00	2	374.63	4	2370.37	$900,741.69	15.62	9.21
BAR-SE70	13	2600.00	1	3144.74	1	-544.74		0	
BAR-SE72	11	5150.00	1	5005.46	1	144.54	$54,926.51	0	0.38
BAR-SE73	12	17470.00	1	15839.67	1	1630.33	$619,526.13	0	2.08
BAR-SE76	12	3656.00	1	1964.06	2	1691.94	$642,935.99	3.85	5.32
BAR-SE77	10	1280.00	1	503.30	3	776.70	$295,146.62	3.68	7.25
BAR-SE78	8	5046.64	1	6257.16	1	-1210.52		0	
BAR-SE79	10	8154.00	1	3830.57	2	4323.43	$1,642,902.49	9.14	6.87
BAR-SE84	12	750.00	1	778.34	2	-28.34		1.27	
BAR-SE86	6	2200.00	1	3029.10	1	-829.10		0	
BAR-SE87	4	3019.00	1	4779.85	1	-1760.85		0	
BAR-SE88	6	2815.00	1	1430.35	2	1384.65	$526,166.22	1.75	19.17
BAR-SE89	7	14325.00	1	14817.22	2	-492.22		18.48	
BAR-SE90	7	425.00	1	315.63	3	109.37	$41,561.80	2.47	2.18
BAR-SW42	12	9737.00	1	6788.89	2	2948.11	$1,120,282.24	11.4	5.97
BAR-SW53	7	2957.00	2	2305.65	3	651.35	$247,513.18	13.51	1.36

Pond Name	Pond Age (Years)	Design Volume (m^3)	Design Pond Level	Current Volume (m^3)	Current Pond Level	Accumulated Sediment (m3)	Clean out Cost (@ $380 m3)	Lost Efficiency in P Load per Catchment (kg/yr)	Sediment Influx (m3/ha/yr)
I-N15	11	1870.00	1	2367.32	1	-497.32		0	
I-N16	15	105.00	2	NA	NA	105.00	$39,900.00	16.02	0.40
I-N2	15	2000.00	1	1370.73	2	629.27	$239,124.00	2.48	2.45
I-N36	11	363.00	1	1068.61	1	-705.61		0	
I-N74	6	566.00	1	1061.68	NA	-495.68		92.64	
I-N83	7	1468.00	1	1153.11	3	314.89	$119,659.24	16.47	0.94
I-NW10	8	1500.00	1	898.16	2	601.84	$228,697.32	1.08	10.09
I-NW9	8	3860.00	2	4300.70	1	-440.70		0	
I-S64	7	353.12	1	275.60	3	77.52	$29,459.19	1.94	1.96
I-S65	3	676.45	1	457.66	3	218.79	$83,141.61	4.26	5.87
I-S68	12	1500.00	1	2333.09	2	-833.09		4.54	
I-S69	12	450.00	1	128.99	NA	321.01	$121,985.11	25.22	1.34
I-S70	8	4860.00	1	5487.11	2	-627.11		9.99	
I-S71	5	453.20	1	1528.35	1	-1075.15		0	
I-S72	5	548.56	1	824.22	2	-275.66		1.73	
K-N17	15	2800.00	3	2059.74	3	740.26	$281,298.38	0	0.93
K-N33	>11	NA	4	NA	NA			18.66	
K-N38	12	1800.00	4	2902.99	3	-1102.99		0	
K-N45	3	2190.00	1	979.03	2	1210.97	$460,167.97	2.13	27.42
K-S1	11	10240.00	1	15227.90	1	-4987.90		0	
K-S19	10	875.00	1	833.03	3	41.97	$15,948.39	5.62	0.26

Pond Name	Pond Age (Years)	Design Volume (m^3)	Design Pond Level	Current Volume (m^3)	Current Pond Level	Accumulated Sediment (m3)	Clean out Cost (@ $380 m3)	Lost Efficiency in P Load per Catchment (kg/yr)	Sediment Influx (m3/ha/yr)
K-S29	10	NA	2	1405.40	2			0	
K-S47	11	5500.00	1	5075.58	1	424.42	$161,278.13	0	9.68
N-CE2	23	NA	1	6529.80	3			56.37	
N-CE20	8	5950.00	1	5316.02	2	633.98	$240,911.10	8.67	3.12
N-CE23	4	3800.00	1	2941.36	1	858.64	$326,282.26	0	12.65
N-CW21	9	NA	1	6103.64	3			36.64	
N-CW6	16	6600.00	1	2973.49	3	3626.51	$1,378,073.05	28.84	3.31
N-NW15	3	3512.00	1	2809.29	1	702.71	$267,029.47	0	11.99
N-NW16	3	3620.00	1	3688.60	1	-68.60		0	
N-NW2	10	12902.00	1	11975.42	1	926.58	$352,099.51	0	1.44
N-NW22	3	2669.00	1	3257.12	1	-588.12		0	
N-NW3	15	NA	1	457.92	4			11.87	
N-NW4	22	NA	3	1026.63	4			10.72	
N-NW6	Unknown	NA	1	211.83	NA			81.24	
N-SE10	14	2547.00	3	362.89	4	2184.11	$829,963.08	2.55	11.33
N-SE11	15	550.00	3	900.01	4	-350.01		6.18	
N-SE8	16	511.00	2	2457.97	1	-1946.97		0	
N-SE9	23	NA	1	3945.73	2			4.59	
N-SW10	14	3500.00	1	1396.95	2	2103.05	$799,160.34	3.24	6.73
N-SW11	15	1428.00	1	1135.76	3	292.24	$111,051.39	6.86	0.97
N-SW12	6	129.40	1	NA	NA	129.40	$49,172.00	4	5.69

Pond Name	Pond Age (Years)	Design Volume (m^3)	Design Pond Level	Current Volume (m^3)	Current Pond Level	Accumulated Sediment (m3)	Clean out Cost (@ $380 m3)	Lost Efficiency in P Load per Catchment (kg/yr)	Sediment Influx (m3/ha/yr)
N-SW13	10	6025.00	1	8675.45	1	-2650.45		0	
N-SW18	6	2200.00	1	467.38	3	1732.62	$658,396.64	5.64	17.57
N-SW4	20	NA	1	NA	NA			63.03	
N-SW5	20	NA	1	NA	NA			12.34	
U-NE11	8	3615.00	1	3339.94	2	275.06	$104,523.10	5.35	0.93
U-NE8	9	5900.00	1	6516.08	2	-616.08		7.81	
U-NE9	15	260.00	1	2094.21	2	-1834.21		4.52	
U-NW11	NA	NA	3	NA	NA			6.57	
U-NW12	3	1949.00	1	2281.24	1	-332.24		0	
U-NW16	7	2016.00	1	1089.01	3	926.99	$352,254.88	8.17	10.62
U-NW21	6	3200.00	1	3654.00	1	-454.00		0	
U-NW5	7	3578.00	1	1836.97	2	1741.03	$661,590.42	2.93	12.34
U-NW6	>10	6200.00	1	6686.03	2	-486.03		11.96	
U-NW7	~20	3172.00	1	859.87	3	2312.13	$878,607.52	16.47	3.71

Sum						**4,879.13**	**$18,431,265.42**	**814.48**	**307.30**
Median						**131.43**	**$267,029.47**	**2.48**	**5.32**
Max						**4,323.43**	**$1,642,902.49**	**92.64**	**36.17**
Min						**-10,701.50**	**$15,948.39**	**0.00**	**0.26**

APPENDIX C: STORMWATER POND MAINTENANCE PRIORITIZED BY COST / SEDIMENT VOLUME

Priority	Pond Name	Pond Age (Years)	Design Volume (m^3)	Design Pond Level	Current Volume (m^3)	Current Pond Level	Accumulated Sediment (m3)	Clean out Cost (@ $380 m3)	Lost Efficency in P Load per Catchment (kg/yr)	Sediment Influx (m3/ha/yr)
Aurora										
1	A-NE9	6	8016.00	1	5471.43	2	2544.57	$966,937.79	8.46	7.28
2	A-NE8	7	7230.00	1	5652.34	1	1577.66	$599,509.43	0	5.87
3	A-NC5	14	1600.00	1	461.22	3	1138.78	$432,736.40	4.19	6.67
4	A-C23	17	2400.00	2	1440.29	2	959.71	$364,690.72	0	2.54
5	A-NE10	2	3420.00	1	2542.68575	1	877.31	$333,379.41	0	36.17
6	A-C27	10	2000.00	1	1437.89	1	562.11	$213,602.89	0	6.46
7	A-NC10	22	1100.00	2	628.26	2	471.74	$179,259.77	0	2.09
8	A-EC12	3	5137.00	1	4704.03	2	432.97	$164,529.28	26.21	3.61
9	A-NC3	14	430.00	1	135.07	NA	294.93	$112,072.36	12.1	1.84
10	A-NW3	7	580.00	1	402.13	1	177.87	$67,590.14	0	8.32
11	A-NE14	4	8790.00	1	8619.57	1	170.43	$64,763.81	0	1.42
12	A-C22	17	600.00	2	466.54	2	133.46	$50,716.43	0	1.49
	Sum						**9,341.55**	**$3,549,788.43**	**50.96**	**83.75**
	Median						**516.92**	**$196,431.33**	**0.00**	**4.74**
	Max						**2,544.57**	**$966,937.79**	**26.21**	**36.17**
	Min						**133.46**	**$50,716.43**	**0.00**	**1.42**
Barrie										
1	BAR-SE79	10	8154.00	1	3830.57	2	4323.43	$1,642,902.49	9.14	6.87

Priority	Pond Name	Pond Age (Years)	Design Volume (m^3)	Design Pond Level	Current Volume (m^3)	Current Pond Level	Accumulated Sediment (m3)	Clean out Cost (@ $380 m3)	Lost Efficency in P Load per Catchment (kg/yr)	Sediment Influx (m3/ha/yr)
2	BAR-SW42	12	9737.00	1	6788.89	2	2948.11	$1,120,282.24	11.4	5.97
3	BAR-SE2	15	2745.00	2	374.63	4	2370.37	$900,741.69	15.62	9.21
4	BAR-SE76	12	3656.00	1	1964.06	2	1691.94	$642,935.99	3.85	5.32
5	BAR-SE73	12	17470.00	1	15839.67	1	1630.33	$619,526.13	0	2.08
6	BAR-SE88	6	2815.00	1	1430.35	2	1384.65	$526,166.22	1.75	19.17
7	BAR-SE77	10	1280.00	1	503.30	3	776.70	$295,146.62	3.68	7.25
8	BAR-SW53	7	2957.00	2	2305.65	3	651.35	$247,513.18	13.51	1.36
9	BAR-SE72	11	5150.00	1	5005.46	1	144.54	$54,926.51	0	0.38
10	BAR-SE90	7	425.00	1	315.63	3	109.37	$41,561.80	2.47	2.18
	Sum						**16,030.80**	**$6,091,702.89**	**61.42**	**59.79**
	Median						**1,507.49**	**$572,846.18**	**3.77**	**5.65**
	Max						**4,323.43**	**$1,642,902.49**	**15.62**	**19.17**
	Min						**109.37**	**$41,561.80**	**0.00**	**0.38**

Priority	Pond Name	Pond Age (Years)	Design Volume (m^3)	Design Pond Level	Current Volume (m^3)	Current Pond Level	Accumulated Sediment (m3)	Clean out Cost (@ $380 m3)	Lost Efficency in P Load per Catchment (kg/yr)	Sediment Influx (m3/ha/yr)
Innisfil										
1	I-N2	15	2000.00	1	1370.73	2	629.27	$239,124.00	2.48	2.45
2	I-NW10	8	1500.00	1	898.16	2	601.84	$228,697.32	1.08	10.09
3	I-S69	12	450.00	1	128.99	NA	321.01	$121,985.11	25.22	1.34
4	I-N83	7	1468.00	1	1153.11	3	314.89	$119,659.24	16.47	0.94
5	I-S65	3	676.45	1	457.66	3	218.79	$83,141.61	4.26	5.87
6	I-N16	15	105.00	2	NA	NA	105.00	$39,900.00	16.02	0.40
7	I-S64	7	353.12	1	275.60	3	77.52	$29,459.19	1.94	1.96
	Sum						**2,268.33**	**$861,966.47**	**67.47**	**23.06**
	Median						**314.89**	**$119,659.24**	**4.26**	**1.96**
	Max						**629.27**	**$239,124.00**	**25.22**	**10.09**
	Min						**77.52**	**$29,459.19**	**1.08**	**0.40**
Keswick										
1	K-N45	3	2190.00	1	979.03	2	1210.97	$460,167.97	2.13	27.42
2	K-N17	15	2800.00	3	2059.74	3	740.26	$281,298.38	0	0.93
3	K-S47	11	5500.00	1	5075.58	1	424.42	$161,278.13	0	9.68
4	K-S19	10	875.00	1	833.03	3	41.97	$15,948.39	5.62	0.26
	Sum						**2,417.61**	**$918,692.87**	**7.75**	**38.29**
	Median						**582.34**	**$221,288.25**	**1.07**	**5.30**
	Max						**1,210.97**	**$460,167.97**	**5.62**	**27.42**

Priority	Pond Name	Pond Age (Years)	Design Volume (m³)	Design Pond Level	Current Volume (m³)	Current Pond Level	Accumulated Sediment (m3)	Clean out Cost (@ $380 m3)	Lost Efficency in P Load per Catchment (kg/yr)	Sediment Influx (m3/ha/yr)
	Min						**41.97**	**$15,948.39**	**0.00**	**0.26**
Newmarket										
1	N-CW6	16	6600.00	1	2973.49	3	3626.51	$1,378,073.05	28.84	3.31
2	N-SE10	14	2547.00	3	362.89	4	2184.11	$829,963.08	2.55	11.33
3	N-SW10	14	3500.00	1	1396.95	2	2103.05	$799,160.34	3.24	6.73
4	N-SW18	6	2200.00	1	467.38	3	1732.62	$658,396.64	5.64	17.57
5	N-NW2	10	12902.00	1	11975.42	1	926.58	$352,099.51	0	1.44
6	N-CE23	4	3800.00	1	2941.36	1	858.64	$326,282.26	0	12.65
7	N-NW15	3	3512.00	1	2809.29	1	702.71	$267,029.47	0	11.99
8	N-CE20	8	5950.00	1	5316.02	2	633.98	$240,911.10	8.67	3.12
9	N-SW11	15	1428.00	1	1135.76	3	292.24	$111,051.39	6.86	0.97
10	N-SW12	6	129.40	1	NA	NA	129.40	$49,172.00	4	5.69
	Sum						**13,189.84**	**$5,012,138.84**	**59.80**	**74.81**
	Median						**892.61**	**$339,190.88**	**3.62**	**6.21**
	Max						**3,626.51**	**$1,378,073.05**	**28.84**	**17.57**
	Min						**129.40**	**$49,172.00**	**0.00**	**0.97**
Uxbridge										
1	U-NW7	~20	3172.00	1	859.87	3	2312.13	$878,607.52	16.47	3.71
2	U-NW5	7	3578.00	1	1836.97	2	1741.03	$661,590.42	2.93	12.34
3	U-NW16	7	2016.00	1	1089.01	3	926.99	$352,254.88	8.17	10.62

Priority	Pond Name	Pond Age (Years)	Design Volume (m^3)	Design Pond Level	Current Volume (m^3)	Current Pond Level	Accumulated Sediment (m3)	Clean out Cost (@ $380 m3)	Lost Efficency in P Load per Catchment (kg/yr)	Sediment Influx (m3/ha/yr)
4	U-NE11	8	3615.00	1	3339.94	2	275.06	$104,523.10	5.35	0.93
	Sum						**5,255.20**	**$1,996,975.93**	**32.92**	**27.60**
	Median						**1,334.01**	**$506,922.65**	**6.76**	**7.16**
	Max						**2,312.13**	**$878,607.52**	**16.47**	**12.34**
	Min						**275.06**	**$104,523.10**	**2.93**	**0.93**

APPENDIX D: STORMWATER MAINTENANCE PRIORITIZED BY PHOSPHORUS REDUCTION

Priority	Pond Name	Pond Age (Years)	Design Volume (m^3)	Design Pond Level	Current Volume (m^3)	Current Pond Level	Accumulated Sediment (m3)	Clean out Cost (@ $380 m3)	Lost Efficency in P Load per Catchment (kg/yr)	Sediment Influx (m3/ha/yr)
Aurora										
1	A-WC4	6	NA	1	212.38	NA			39.3	
2	A-SW2	12	NA	3	NA	NA			26.4	
3	A-EC12	3	5137.00	1	4704.03	2	432.97	$164,529.28	26.21	3.61
4	A-NC3	14	430.00	1	135.07	NA	294.93	$112,072.36	12.1	1.84
5	A-NE9	6	8016.00	1	5471.43	2	2544.57	$966,937.79	8.46	7.28
6	A-NW5	4	NA	1	805.07	3			4.69	
7	A-NC5	14	1600.00	1	461.22	3	1138.78	$432,736.40	4.19	6.67
8	A-NW1A/B	7	1193.00	1	1824.10	2	-631.10		2.62	
	Sum						**4,411.25**	**$1,676,275.83**	**123.97**	**19.39**
	Median						**785.88**	**$298,632.84**	**10.28**	**5.14**
	Max						**2,544.57**	**$966,937.79**	**39.30**	**7.28**
	Min						**294.93**	**$112,072.36**	**2.62**	**1.84**
Barrie										
1	BAR-SE89	7	14325.00	1	14817.22	2	-492.22		18.48	
2	BAR-SE2	15	2745.00	2	374.63	4	2370.37	$900,741.69	15.62	9.21
3	BAR-SW53	7	2957.00	2	2305.65	3	651.35	$247,513.18	13.51	1.36

Priority	Pond Name	Pond Age (Years)	Design Volume (m^3)	Design Pond Level	Current Volume (m^3)	Current Pond Level	Accumulated Sediment (m3)	Clean out Cost (@ $380 m3)	Lost Efficency in P Load per Catchment (kg/yr)	Sediment Influx (m3/ha/yr)
4	BAR-SW42	12	9737.00	1	6788.89	2	2948.11	$1,120,282.24	11.4	5.97
5	BAR-SE79	10	8154.00	1	3830.57	2	4323.43	$1,642,902.49	9.14	6.87
6	BAR-SE76	12	3656.00	1	1964.06	2	1691.94	$642,935.99	3.85	5.32
7	BAR-SE77	10	1280.00	1	503.30	3	776.70	$295,146.62	3.68	7.25
8	BAR-SE90	7	425.00	1	315.63	3	109.37	$41,561.80	2.47	2.18
9	BAR-SE88	6	2815.00	1	1430.35	2	1384.65	$526,166.22	1.75	19.17
10	BAR-SE84	12	750.00	1	778.34	2	-28.34		1.27	
	Sum						**14,255.92**	**$5,417,250.24**	**81.17**	**57.33**
	Median						**1,538.29**	**$584,551.11**	**6.50**	**6.42**
	Max						**4,323.43**	**$1,642,902.49**	**18.48**	**19.17**
	Min						**109.37**	**$41,561.80**	**1.27**	**1.36**
Innisfil										
1	I-N74	6	566.00	1	1061.68	NA	-495.68		92.64	
2	I-S69	12	450.00	1	128.99	NA	321.01	$121,985.11	25.22	1.34
3	I-N83	7	1468.00	1	1153.11	3	314.89	$119,659.24	16.47	0.94
4	I-N16	15	105.00	2	NA	NA	105.00	$39,900.00	16.02	0.40

Priority	Pond Name	Pond Age (Years)	Design Volume (m^3)	Design Pond Level	Current Volume (m^3)	Current Pond Level	Accumulated Sediment (m3)	Clean out Cost (@ $380 m3)	Lost Efficency in P Load per Catchment (kg/yr)	Sediment Influx (m3/ha/yr)
5	I-S70	8	4860.00	1	5487.11	2	-627.11		9.99	
6	I-S68	12	1500.00	1	2333.09	2	-833.09		4.54	
7	I-S65	3	676.45	1	457.66	3	218.79	$83,141.61	4.26	5.87
8	I-N2	15	2000.00	1	1370.73	2	629.27	$239,124.00	2.48	2.45
9	I-S64	7	353.12	1	275.60	3	77.52	$29,459.19	1.94	1.96
10	I-S72	5	548.56	1	824.22	2	-275.66		1.73	
11	I-NW10	8	1500.00	1	898.16	2	601.84	$228,697.32	1.08	10.09
	Sum						**2,268.33**	**$861,966.47**	**176.37**	**23.06**
	Median						**314.89**	**$119,659.24**	**4.54**	**1.96**
	Max						**629.27**	**$239,124.00**	**92.64**	**10.09**
	Min						**77.52**	**$29,459.19**	**1.08**	**0.40**
Keswick										
1	K-N33	>11	NA	4	NA	NA			18.66	
2	K-S19	10	875.00	1	833.03	3	41.97	$15,948.39	5.62	0.26
3	K-N45	3	2190.00	1	979.03	2	1210.97	$460,167.97	2.13	27.42
	Sum						**1,252.94**	**$476,116.36**	**26.41**	**27.68**
	Median						**626.47**	**$238,058.18**	**5.62**	**13.84**
	Max						**1,210.97**	**$460,167.97**	**18.66**	**27.42**
	Min						**41.97**	**$15,948.39**	**2.13**	**0.26**
Newmarket										

Priority	Pond Name	Pond Age (Years)	Design Volume (m^3)	Design Pond Level	Current Volume (m^3)	Current Pond Level	Accumulated Sediment (m3)	Clean out Cost (@ $380 m3)	Lost Efficency in P Load per Catchment (kg/yr)	Sediment Influx (m3/ha/yr)
1	N-NW6	Unknown	NA	1	211.83	NA			81.24	
2	N-SW4	20	NA	1	NA	NA			63.03	
3	N-CE2	23	NA	1	6529.80	3			56.37	
4	N-CW21	9	NA	1	6103.64	3			36.64	
5	N-CW6	16	6600.00	1	2973.49	3	3626.51	$1,378,073.05	28.84	3.31
6	N-SW5	20	NA	1	NA	NA			12.34	
7	N-NW3	15	NA	1	457.92	4			11.87	
8	N-NW4	22	NA	3	1026.63	4			10.72	
9	N-CE20	8	5950.00	1	5316.02	2	633.98	$240,911.10	8.67	3.12
10	N-SW11	15	1428.00	1	1135.76	3	292.24	$111,051.39	6.86	0.97
11	N-SE11	15	550.00	3	900.01	4	-350.01		6.18	
12	N-SW18	6	2200.00	1	467.38	3	1732.62	$658,396.64	5.64	17.57
13	N-SE9	23	NA	1	3945.73	2			4.59	
14	N-SW12	6	129.40	1	NA	NA	129.40	$49,172.00	4	5.69
15	N-SW10	14	3500.00	1	1396.95	2	2103.05	$799,160.34	3.24	6.73
16	N-SE10	14	2547.00	3	362.89	4	2184.11	$829,963.08	2.55	11.33
	Sum						**10,701.91**	**$4,066,727.60**	**342.78**	**48.73**
	Median						**1,732.62**	**$658,396.64**	**9.70**	**5.69**
	Max						**3,626.51**	**$1,378,073.05**	**81.24**	**17.57**
	Min						**129.40**	**$49,172.00**	**2.55**	**0.97**

Priority	Pond Name	Pond Age (Years)	Design Volume (m^3)	Design Pond Level	Current Volume (m^3)	Current Pond Level	Accumulated Sediment (m3)	Clean out Cost (@ $380 m3)	Lost Efficency in P Load per Catchment (kg/yr)	Sediment Influx (m3/ha/yr)
Uxbridge										
1	U-NW7	~20	3172.00	1	859.87	3	2312.13	$878,607.52	16.47	3.71
2	U-NW6	>10	6200.00	1	6686.03	2	-486.03		11.96	
3	U-NW16	7	2016.00	1	1089.01	3	926.99	$352,254.88	8.17	10.62
4	U-NE8	9	5900.00	1	6516.08	2	-616.08		7.81	
5	U-NW11	NA	NA	3	NA	NA			6.57	
6	U-NE11	8	3615.00	1	3339.94	2	275.06	$104,523.10	5.35	0.93
7	U-NE9	15	260.00	1	2094.21	2	-1834.21		4.52	
8	U-NW5	7	3578.00	1	1836.97	2	1741.03	$661,590.42	2.93	12.34
	Sum						**4,328.21**	**$1,996,975.93**	**63.78**	**27.60**
	Median						**1,334.01**	**$506,922.65**	**7.19**	**7.16**
	Max						**2,312.13**	**$878,607.52**	**16.47**	**12.34**
	Min						**275.06**	**$104,523.10**	**2.93**	**0.93**

APPENDIX E: STORMWATER POND WATER AND SEDIMENT CHEMISTRY

SWMP	Date	Top Samples								Bottom samples								Sediment	
		TP (µg·L^{-1})	PO_4 (µg·L^{-1})	NH_3 (mg·L^{-1})	TKN (mg·L^{-1})	Chl A (µg·L^{-1})	Temp (^{o}C)	DO (mg·L^{-1})	Sp. Cond (µS·cm^{-1})	TP (µg·L^{-1})	PO_4 (µg·L^{-1})	NH_3 (mg·L^{-1})	TKN (mg·L^{-1})	Chl A (µg·L^{-1})	Temp (^{o}C)	DO (mg·L^{-1})	Sp. Cond. (µS·cm^{-1})	TKN (µg·g^{-1})	TP (µg·g^{-1})
A-C22	23-09-2010	50	1	<0.01	0.7	n.s.	16.0	8.5	275	50	2	<0.01	0.8	n.s.	15.7	7.5	276	n.s.	827
A-C23	23-09-2010	68	1	n.d.	0.9	50.5	17.3	8.7	430	67	1	0.06	1.2	69.0	16.5	5.7	422	n.s.	796
A-EC12	22-07-2010	17	2	<0.01	0.7	n.s.	27.2	8.6	446	18	2	<0.01	0.6	n.s.	24.0	10.2	466	322	600
	11-08-2010	14	1	<0.01	0.7	n.s.	24.6	8.9	410	25	1	0.01	0.7	n.s.	22.2	7.0	411	749	650
	23-09-2010	26	1	n.d.	0.4	3.6	18.2	9.1	410	26	1	n.d.	0.7	2.3	16.8	9.1	422	n.s.	679
A-NC19	27-09-2010	17	1	<0.01	0.6	n.s.	16.3	8.6	587	17	1	<0.01	1.0	n.s.	15.5	8.9	614	n.s.	767
A-NC27	27-09-2010	21	2	0.03	0.7	n.s.	16.6	8.6	712	31	1	0.07	1.2	n.s.	16.1	6.2	714	n.s.	628
A-NW1-A	06-10-2010	42	13	0.05	0.8	n.s.	12.2	11.8	820	67	43	0.59	1.3	n.s.	12.4	4.8	959	n.s.	933
A-NW1-B	06-10-2010	53	26	0.11	1.0	n.s.	12.0	9.2	483	48	26	0.27	1.1	n.s.	11.5	4.4	513	n.s.	719
B-SE70	13-10-2010	19	2	<0.01	0.8	n.s.	11.7	7.4	275	19	3	<0.01	0.9	n.s.	11.8	7.4	274	n.s.	914
B-SE77	**13-10-2010**	**33**	**<1**	**<0.01**	**0.9**	n.s.	**11.0**	**6.7**	**450**	**149**	**2**	**1.5**	**8.0**	n.s.	**14.3**	**1.8**	**2864**	n.s.	981
B-SE78	**07-07-2010**	**14**	**3**	**0.01**	**0.5**	n.s.	**30.7**	**17.8**	**313**	**87**	**15**	**0.39**	**1.1**	n.s.	**18.2**	**0.8**	**513**	**715**	**660**
	07-10-2010	29	3	<0.01	0.6	n.s.	15.2	12.6	287	31	4	1.0	3.1	n.s.	13.7	2.8	733	n.s.	748
B-SE79	12-08-2010	18	3	<0.05	1.9	n.s.	25.7	14.8	338	19	3	<0.05	0.9	n.s.	22	351	960	2210	960
	13-10-2010	80	<1	<0.01	2.1	n.s.	12.1	11.7	552	33	<1	<0.01	1.1	n.s.	11.6	10.2	569	n.s.	831
B-SE86	21-10-2010	72	2	0.26	1.1	n.s.	9.8	7.5	290	69	2	0.25	1.1	n.s.	9.9	5.9	298	n.s.	900

SWMP	Date	Top Samples								Bottom samples								Sediment	
		TP ($\mu g \cdot L^{-1}$)	PO_4 ($\mu g \cdot L^{-1}$)	NH_3 ($mg \cdot L^{-1}$)	TKN ($mg \cdot L^{-1}$)	Chl A ($\mu g \cdot L^{-1}$)	Temp (^oC)	DO ($mg \cdot L^{-1}$)	Sp. Cond ($\mu S \cdot cm^{-1}$)	TP ($\mu g \cdot L^{-1}$)	PO_4 ($\mu g \cdot L^{-1}$)	NH_3 ($mg \cdot L^{-1}$)	TKN ($mg \cdot L^{-1}$)	Chl A ($\mu g \cdot L^{-1}$)	Temp (^oC)	DO ($mg \cdot L^{-1}$)	Sp. Cond. ($\mu S \cdot cm^{-1}$)	TKN ($\mu g \cdot g^{-1}$)	TP ($\mu g \cdot g^{-1}$)
B-SE88	21-10-2010	79	3	0.05	0.7	n.s.	10.4	11.3	396	75	<1	0.08	0.7	n.s.	10.1	11.3	400	n.s.	714
B-SE89	21-10-2010	118	12	0.31	1.7	n.s.	10.5	10.6	346	117	14	0.30	1.6	n.s.	9.9	9.8	329	n.s.	794
B-SW42	21-10-2010	18	<1	0.17	0.6	n.s.	10.0	11.1	552	14	<1	0.16	0.6	n.s.	10.0	11.1	549	n.s.	946
I-S71	07-10-2010	19	2	<0.01	0.7	n.s.	14.9	11.8	216	31	1	<0.01	0.7	n.s.	14.8	11.9	216	n.s.	612
K-N17	06-10-2010	50	22	0.1	1.2	n.s.	13.1	4.5	861	64	n.s.	0.19	1.3	n.s.	12.8	2.8	919	n.s.	925
K-N45	**07-10-2010**	**129**	**13**	**0.02**	**3.5**	n.s.	**11.8**	**6.0**	**414**	**470**	**184**	**5.2**	**8.4**	n.s.	**12.8**	**1.6**	**1299**	n.s.	**1226**
K-S19	07-10-2010	65	4	0.12	2.0	n.s.	13.6	12.7	787	48	2	0.13	1.9	n.s.	13.0	11.9	800	n.s.	882
N-CE2	17-09-2010	23	1	0.02	0.6	n.s.	14.8	8.6	451	23	2	<0.01	0.5	n.s.	14.0	7.7	456	n.s.	684
N-CE23	05-07-2010	27	7	<0.05	0.5	n.s.	25.4	11.2	289	44	5	<0.05	0.5	n.s.	23.3	20.9	252	1560	680
	17-09-2010	45	1	<0.01	0.5	n.s.	14.4	7.2	251	73	1	<0.01	0.5	n.s.	13.4	6.5	250	n.s.	611
N-CW21	22-06-2010	77	6	n.d.	1.1	21.3	22.5	8.7	1770	74	4	0.32	1.4	18	20.0	109	1900	518	550
	05-07-2010	31	5	<0.05	0.7	n.s.	24.4	9.6	1535	44	5	0.36	1.2	n.s.	21.7	7.1	1578	1690	730
	07-07-2010	25	3	n.d.	0.8	9.2	26.5	7.7	1390	59	4	0.45	1.4	16.9	22.4	3.4	1630	720	1350
	02-09-2010	35	1	0.04	0.7	n.s.	25.2	8.0	941	32	2	0.13	0.9	n.s.	24.5	6.4	1121	n.s.	n.s.
	15-09-2010	9	<1	0.23	1.6	n.s.	17.9	6.8	957	28	1	0.26	1.7	n.s.	17.1	6.5	1012	n.s.	826
	23-09-2010	35	1	0.24	1.1	18.0	19.3	7.1	667	46	2	0.34	1.2	14.1	17.8	5.7	653	n.s.	957

SWMP	Date	Top Samples								Bottom samples								Sediment	
		TP ($\mu g \cdot L^{-1}$)	PO_4 ($\mu g \cdot L^{-1}$)	NH_3 ($mg \cdot L^{-1}$)	TKN ($mg \cdot L^{-1}$)	Chl A ($\mu g \cdot L^{-1}$)	Temp (^oC)	DO ($mg \cdot L^{-1}$)	Sp. Cond ($\mu S \cdot cm^{-1}$)	TP ($\mu g \cdot L^{-1}$)	PO_4 ($\mu g \cdot L^{-1}$)	NH_3 ($mg \cdot L^{-1}$)	TKN ($mg \cdot L^{-1}$)	Chl A ($\mu g \cdot L^{-1}$)	Temp (^oC)	DO ($mg \cdot L^{-1}$)	Sp. Cond. ($\mu S \cdot cm^{-1}$)	TKN ($\mu g \cdot g^{-1}$)	TP ($\mu g \cdot g^{-1}$)
N-NW2	06-07-2010	15	5	<0.05	0.5	n.s.	22.2	10.4	773	58	7	<0.05	1.2	n.s.	23.4	26.6	8434	816	860
	21-09-2010	13	1	0.14	0.8	n.s.	17.1	10.0	927	13	2	0.19	0.8	n.s.	16.6	11.1	1111	n.s.	935
N-NW3	06-07-2010	89	8	0.13	0.8	n.s.	26.2	1.2	981	106	8	0.16	0.9	n.s.	24.3	6.5	3595	1370	940
	11-08-2010	35	9	0.08	0.9	n.s.	23.8	1.1	239	59	10	0.20	1.1	n.s.	23.0	0.2	558	1760	920
	02-09-2010	36	2	<0.01	0.7	n.s.	25.2	3.6	724	36	2	<0.01	0.7	n.s.	24.3	12.8	2537	n.s.	n.s.
	21-09-2010	14	2	<0.01	0.5	n.s.	15.6	4.7	308	16	1	0.02	0.5	n.s.	14.8	5.1	466	n.s.	861
N-NW15	21-09-2010	31	1	<0.01	0.8	n.s.	15.5	8.3	374	28	2	<0.01	0.8	n.s.	15.5	8.3	375	n.s.	815
N-NW16	21-09-2010	14	1	<0.01	0.6	n.s.	15.8	13.5	416	14	1	<0.01	0.6	n.s.	15.8	12.9	417	n.s.	631
N-NW22	21-09-2010	14	2	<0.01	0.4	n.s.	17.7	10.8	777	14	2	<0.01	0.4	n.s.	17.5	10.9	778	n.s.	661
N-SE8	22-09-2010	18	1	0.08	0.8	n.s.	18.2	9.7	375	n/a	1	<0.01	0.8	n.s.	15.8	7.9	537	n.s.	592
N-SW13	22-09-2010	19	1	0.11	1.1	n.s.	18.6	12.4	331	214	1	0.35	2.4	n.s.	17.8	11.5	381	n.s.	707
N-SW18	22-09-2010	33	1	0.1	0.6	n.s.	19.7	8.2	141	10	1	<0.01	0.5	n.s.	15.9	6.1	603	n.s.	676
U-NW5	14-09-2010	38	2	<0.01	0.7	n.s.	17.8	10.1	111	38	1	<0.01	0.8	n.s.	17.1	9.7	111	n.s.	1137
U-NW6	14-09-2010	26	1	<0.01	0.8	n.s.	18.5	12.0	441	24	2	<0.01	0.8	n.s.	18.0	13.0	441	n.s.	836
U-NW7	15-09-2010	19	<1	<0.01	1.4	n.s.	15.8	8.4	406	16	1	<0.01	1.4	n.s.	15.6	8.5	406	n.s.	708
U-NW21	14-09-2010	34	2	<0.01	0.6	n.s.	17.1	8.0	483	31	1	<0.01	0.6	n.s.	16.9	5.5	483	n.s.	785