Evaluation of the Thermal Impact of Stormwater Management Ponds

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Stormwater management ponds (SWMPs) remain a popular option to control flood damage, and for the effective removal of suspended solids and associated contaminants from urban surface runoff (Anderson et al., 2002; Marsalek et al., 2002). However, such ponds can produce diverse potentially negative thermal effects on aquatic habitat (Herb et al., 2009; Lieb et al., 2000; Scheueller and Galli, 1992). The construction and use of SWMPs is increasing in the rapidly developing urban areas of southwestern Ontario, and several municipalities have hundreds of SWMPs within a single watershed. The potential impacts of SWMPs are clearly significant.

This study was developed because of the recognition of the lack of sufficient information and data in Ontario with respect to the potentially adverse thermal enrichment effect of SWMPs on sensitive aquatic habitat. The need for a design of cooling trenches to mitigate the potential adverse effects of SWMPs, and the effectiveness of those cooling trenches which have already been constructed, were other motivators for this study. Furthermore, very few studies and data are available in Ontario on the temperature monitoring of existing ponds and their cooling trenches.

The purpose of this study is to investigate the thermal effects of traditional SWMPs in southern Ontario climate conditions and to evaluate the thermal impact of these SWMPs. The evaluation includes an examination of the effects of upland area characteristics on thermal enrichment and of the effectiveness of current thermal mitigation methods, such as bottom draw outlets and constructed cooling trenches. The preliminary results of the monitoring program are presented in this chapter.

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12.1 Methodology

12.1.1 Introduction

Urbanization causes temperature increases in stormwater runoff. Asphalt and other impervious surfaces absorb heat energy and during rainfall events the stored heat is transferred to the runoff, which eventually discharges to a water body (Thompson et al., 2008). Water temperature is a critical environmental factor for cold water fisheries because most aquatic organisms have a specific temperature range that they can tolerate (Booth and Bledsoe, 2009). Thermal pollution can also affect the ecological functions of aquatic species such as spawning and growth (Selong et al., 2001; Armour, 1991).

Stormwater management ponds remain a popular option to control runoff, total suspended solids (TSS) and pollution, among other practices. However, SWMPs can have a thermal impact. This study has been developed in response to the recognition of the lack of sufficient information and data in Ontario with respect to potential adverse thermal enrichment of SWMPs on sensitive aquatic habitats.

12.1.2 Study Description

In this study, six SWMPs were monitored during three summers (2009 to 2011). The locations of the ponds, in Guelph and Kithcener, Ontario are shown in Figures 12.1 and 12.2 and given in Table 12.1

Figure 12.1 Locations of Guelph ponds.

Figure 12.2 Locations of Kitchener ponds.

Table 12.1 Pond locations.

Pond	City	Location or Major intersection
53	Guelph	York Road and Watson Road
33	Guelph	Edinburgh Road South and Southcreek Trail, next to Preservation Park
81	Guelph	Edinburgh Road South and Gordon Street, East of Carrington Drive
74	Kitchener	The northwest corner of Bleams Road and Fischer–Hallman Road
83	Kitchener	Robert Ferrie SWM (Topper Swamp–West pond), Robert Ferrie Drive
Church	Kitchener	1880 Strasburg Road (private facility)

The Guelph ponds have catchment areas of 79 ha, 19.4 ha and 5 ha for pond 53, pond 33 and pond 81 respectively. The Kitchener ponds are pond 74, pond 83, and Church with drainage areas of 35.8 ha, 10.8 ha, and 5.1 ha respectively. Surface areas and volumes of the ponds are given in Table 12.2. The receiving system for ponds 33 and 81 in Guelph is the Hanlon Creek and for pond 53 is Clyde Creek. Water from pond 74 in Kitchener discharges to the wetland next to it and the receiving systems for pond 83 and Church are Doon South Creek and Strasburg Creek respectively. Furthermore, ponds 53, 81, 74 and Church have had cooling trenches which were monitored during the course of the study.

Table 12.2 Pond information.

Pond	Catchment area (ha)	Volume (m ³)	Surface area (m ²)	Surface area/Catchment area
53	79	6440	8400	0.011
33	19.4	4000	6800	0.035
81	4.9	406	330	0.007
74	35.8	5376	4000	0.011
83	10.8	1300	1387	0.013
Church	5.1	950	2165	0.042

The collected data from sensitive zones (inlet, inside the pond close to outlet, outlet, and inside the cooling trenches) are used to evaluate the performance of the ponds. A PCSWMM model was developed to mimic the existing hydrologic conditions of the catchment areas in Guelph and Kitchener. The land uses within the catchments and the drainage areas vary from pond to pond.

The model was developed from the photogrammetric data and maps representing the studied areas with the use of GIS tools. The pond water level data which have been monitored in the course of study were used to calibrate the PCSWMM model for existing conditions. The inflow and outflow time series generated by PCSWMM was used to calculate event mean temperatures (EMTs) through the system using Equation 12.1 (Picksley and Dectic, 1999). To calibrate the model using the measured water level of ponds, ponds water level time series created by PCSWMM were compared with the measured data to get the best fit as is shown in figure 12.7 below. The Guelph Turfgrass Institute and the Grand River Conservation Authority (GRCA) monitoring stations provided the required climatic data. The Guelph ponds drainage areas are shown in Figures 12.3 through 12.5 opposite.

$$EMT = \frac{\sum_{i=1}^n (QTempdt)}{\sum_{i=1}^n (Qdt)} \quad (12.1)$$

where

Q = the runoff discharge (m³/s),

$Temp$ = the runoff temperature (°C), number of time seps

dt = the time increment of 10 min, and

n = number of time steps.

Figure 12.3 Pond 53 drainage area.

Figure 12.4 Pond 33 drainage area.

Figure 12.5 Pond 81 drainage area.

12.1.3 Monitoring and Data Collection

The water temperatures were measured in sensitive zones of the ponds, such as the inlet, inside the pond, the outlet, and in the cooling trench. The sensors used for temperature and water level were HOBO pendant temperature sensors and HOBO U20 water level loggers respectively. The sensor locations and periods of record for water temperatures and water levels for pond 74 are presented in Table 12.3, as an example. Figure 12.6 shows a typical day's data for pond 74.

Table 12.3 Pond 74 sensor locations and periods of record.

Location	Measured	Period of record 2011	Period of record 2010	Period of record 2009
Inlet	Water level & Temp.	2011 05 11–10 20	2010 04 01–11 09	2009 06 25–10 22
Outlet MH	Water level & Temp.	2011 05 11–10 20	2010 05 26–11 09	2009 06 25–10 22
Inside Pond	Water level & Temp.	2011 05 11–10 20	2010 04 01–11 09	2009 08 18–10 22
Water temp. 0 ft	Temperature	2011 05 11–10 20	2010 04 30–09 26	2009 06 25–10 22
Water temp. 2 ft	Temperature	2011 05 11–10 20	2010 04 30–09 26	2009 06 25–10 22
Water temp. 4 ft	Temperature	2011 05 11–10 20	2010 04 30–09 26	2009 06 25–10 22
Water temp. 6 ft	Temperature	2011 05 11–10 20	2010 04 30–09 26	2009 06 25–10 22
Outlet MH	Temperature	2011 05 11–10 20	2010 05 26–09 26	
Cooling Trench Out	Temperature	2011 05 11–10 20	2010 04 30–09 26	2009 06 25–10 22
Cross street	Temperature		2010 04 30–09 26	2009 06 25–10 22
In manhole	Barometric pressure	2011 05 11–10 20	2010 04 30–11 09	2009 06 25–10 22

Figure 12.6 Pond 74 data 2010 07 11 rain event.

Details on monitoring for the rest of the ponds are not presented here but the data for the sensitive zones were collected as described above. Water level loggers (such as sensor installed inside the pond and outlet manhole) collected the depth of water. The measured depth then used to calibrate the PCSWMM model along with storage curve of the ponds.

12.1.4 PCSWMM Modelling

The collected data were used to establish a PCSWMM model to represent the existing hydrologic conditions of the catchments in the Guelph and Kitchener areas. The land uses within the catchments are varied from pond to pond (residential, parking lot, combination of residential and grassland). The drainage areas also vary in size, being between 5 ha and 79 ha. The model was developed from the photogrammetric data and AutoCAD maps representing the studied areas with the use of GIS tools.

The pond water level data were used to calibrate the PCSWMM model for existing conditions and the inflow and outflow extracted from PCSWMM was used to calculate the event mean temperature in different zones of the system which are inlet, pond water temperature close to outlet, outlet, and cooling trench. Figure 12.7 displays the PCSWMM results for two events versus the observed values for pond water level.

Figure 12.7 PCSWMM result vs observed values for pond 53.

12.2 Results and Discussions

Section 12.2.1 presents results from a comparison of the inlet water temperatures for the Guelph ponds. Some discussion in regard to bottom draw outlet and cooling trenches performance and effectiveness are presented in sections 12.2.2 and 12.2.3

12.2.1 Land Use Effect on Runoff Temperature

Table 12.4 illustrates twelve rainfall events with different durations.

Table 12.4 Comparison of the inlet water temperatures.

Date	Rainfall (mm)	Duration (h)	Pond 53	Pond 33	Pond 81
			20% Imp. DA ¹ 79 (ha) 95m Pipe/ha	50% Imp. DA 19.4 (ha) 62m Pipe/ha	60% Imp. DA 4.9 (ha) 43m Pipe /ha
2009 08 09	11.4	1	16.8	17.5	20.2
2009 08 17	21	1	17.3	18	19.9
2010 06 03	9.2	1	20.2	21.2	21.6
2010 07 15	10.2	2	21.1	25.1	25.3
2010 06 22	12.8	4	16.9	16.9	20.4
2010 06 27	43.8	5	20.3	22.8	22.9
2010 07 02	17.6	7	21	21	21.2
2010 07 09	19.2	7	22.1	24.4	22.9
2010 06 24	13	8	19.2	19.2	19.8
2010 06 06	18.4	9	16.7	19.3	17.4
2010 05 05	16	10	10.7	11.7	10.9
2010 06 26	9.6	10	18.4	20.3	20.3

¹DA = Drainage area; % Imp. = Impervious percentage

The following observations were made after examination of the information in Table 12.4:

- lower inlet water temperature is observed when the percentage impervious cover is less (the drainage area of pond 53, which has 20% impervious area, shows a pronounced lower inlet water temperature in comparison with two other ponds); however, the large amount of pipe/ha may cause the lower inlet temperatures as well;
- lower inlet water temperature is observed when the length of the sewer pipe is longer;
- shorter duration events tend to have more pronounced inlet temperature differences; and
- a buried conveyance system could be designed to mitigate the heating effect of the upland area.

12.2.2 Thermal Enrichment in Ponds

Thermal enrichment of all studied ponds is observed in the positive difference of outlet temperature from inlet temperature as is shown in Tables 12.5 and 12.6, for four ponds. The outlet event mean temperatures (EMTs) differences from inlet EMTs varied between 1.1 °C to 7.0 °C which confirms the negative thermal impact of SWM Ponds.

Table 12.5 Ponds 33 and 53 calculated event mean temperatures.

Date	Rainfall (mm)	EMT rain (°C)	Pond 33 EMTs (°C)			Pond 53 EMTs (°C)		
			Inlet	Outlet	Difference	Inlet	Outlet	Difference
2010 06 08	18.8	12.7	21.4	25.2	3.8	14.6	17.7	3.1
2010 06 16	11.4	13.8	15.1	22.2	7.0	16.0	20.2	4.2
2010 06 27	44.0	22.1	18.0	22.5	4.5	18.5	21.5	3.0
2010 07 23	33.5	25.4	19.5	25.4	5.9	18.4	23.6	5.2

Table 12.6 Pond 74 and Church calculated event mean temperatures.

Date	Rainfall (mm)	EMT rain (°C)	Pond 74 EMTs (°C)			Pond Church EMTs (°C)		
			Inlet	Outlet	Difference	Inlet	Outlet	Difference
2010 07 09	12.8	21.0	22.0	26.4	4.4	20.8	25.1	4.3
2010 07 23	36.2	22.4	20.8	24.7	3.9	19.2	23.8	4.6
2010 08 21	19.2	19.2	21.8	22.9	1.1	20.4	22.9	2.4
2010 09 16	25.8	11.4	14.5	16.7	2.2	15.0	16.2	1.2

12.2.3 Bottom Draw Outlet Effectiveness

Figure 12.8 Water temperature at different depths of pond 74.

Notable points from observed data and calculated event mean temperature (EMT) for some events which are presented in Figure 12.5 above and Table 12.7 are as follows:

- observed data confirm the cooling effect of the bottom draw outlet for pond 74 in Kitchener where all ponds have bottom draw outlets; and
- the significant difference in water temperature observed between the surface water temperature and that recorded at 90 cm (3ft) to 120 cm (4ft). This can determine the minimum depth for bottom draw outlet design.

Table 12.7 Pond 74 calculated event mean temperatures for bottom draw and cooling trench.

Date	Rainfall (mm)	EMT rain (°C)	Inlet	Bottom Draw Outlet	Pond 74 EMTs (°C)		
					Outlet Difference from Inlet	EMT Cooling Trench	Cooling Trench Difference from Outlet
2010 07 09	12.8	21.0	22.0	17.6	-4.4	17.5	-0.1
2010 07 23	36.2	22.4	20.8	21.6	0.8	20.6	-0.9
2010 08 21	19.2	19.2	21.8	21.1	-0.7	20.7	-0.4
2010 09 16	25.8	11.4	14.5	15.8	1.3	16.2	0.4

Air temperature went down after event which may cause the graphs to converge. Also, there was no difference in water temperature at depth for several days which may have been due to groundwater influence to the bottom of the pond which did not measured for this study.

12.2.4 Effectiveness of Cooling Trenches

Pond 33, which has an infiltration trench, does not show any negative thermal impact on the water body. Good shading of the water body (Hanlon Creek) in the monitored areas and the good performance of the infiltration trench are the main reasons for this pond having no pronounced thermal impact.

Pond 53 has a well designed cooling trench. However, the performance of this cooling trench was not as expected since there were no or very few differences in water temperature between the pond outlet and the outlet of the cooling trench (as measured by the installed sensors). The weak performance of the cooling trench was partly due to a missing pipe cap at the very beginning of the pipe leading to the cooling trench and an upward overflow pipe at the end of the cooling trench, which together are supposed to provide the needed water head to help water infiltrate into the trench. Those missing parts caused the pipe to run free, so there was little time to equilibrate.

Pond 81 has an infiltration trench which shows a cooling effect in dry periods or between events, which confirms the effectiveness of contact time between water and rocks inside the trench. However, no cooling effect was observed during the events. The main reasons for no cooling effect during the rainfall events could be (i) no shading and top soil cover for the trench; (ii) the small volume of the trench which could not hold adequate water to provide enough contact time for transferring heat from water to rocks and the surrounding soil; and (iii) the high temperature of the rocks and the initial water in the cooling trench, both of which are exposed.

Pond 74 has a well performing bottom draw outlet structure. It was found that the effectiveness of the bottom draw outlet in driving cooler water to the receiving system is much greater than the effectiveness of the cooling trench during rainfall events. Furthermore, the combination of a bottom draw outlet, the cooling trench and the interaction with the groundwater may help to give greater performance for this pond, with no thermal impact on the receiving system during the warm weather of summer.

Church pond has a very big cooling trench (90 m long) which has an interaction with ground water, and is well shaded. As a result, no negative thermal impact was observed during the course of the study from this cooling trench to the water body.

There are several factors which influence the effectiveness of cooling trenches, such as groundwater interaction and the dimensions of the trench. For instance, the ponds 74 and Church pond cooling trenches have groundwater interactions; the relatively high efficiency of these cooling trenches may partly result from this interaction. Design aspects of cooling trenches are another important factor on cooling trench performance. For example, the dimensions of the Church pond cooling trench are 90 m long and >2 m deep, resulting in the best performance of all the cooling trenches studied. Although pond 74 has a big cooling tunnel (60 m long and 2 m deep), less ground water interaction may result in less cooling effect.

In regard to the monitored receiving systems, water temperature of the Clythe Creek (in Guelph, near pond 53) is mostly >19 °C during the summer (2010) according to data from installed sensors in the creek up and downstream of the pond, and this might have negative impact on the creek habitats.

12.3 Conclusions

This study confirms the influence of impervious percentage cover on inlet water temperature of stormwater management ponds as well as the cooling effect of sewer pipe systems on inlet water temperature; lower inlet water

temperatures are observed when the length of the sewer pipe is greater. Therefore, the presence of a buried conveyance system can partially mitigate the warming effect of the drainage area.

Thermal enrichment of ponds is confirmed (refer to Tables 12.5 and 12.6).

Investigation of the effects of event duration confirms that shorter duration events tend to have more pronounced inlet temperature changes.

Air temperature has a big influence on average runoff temperature increases; and rainfall magnitude has a limited influence on average runoff temperature increases from the pond.

Observed data confirm the cooling effect of the bottom draw outlet; especially when the depth of bottom draw is 90 cm to 120 cm. This can determine the minimum depth for bottom draw outlet design.

There are several factors which have influence the effectiveness of cooling trenches, such as groundwater interaction and the dimensions of the trench. For instance, the pond 74 and Church pond cooling trenches have groundwater interactions. Therefore, the relatively high efficiency of these cooling trenches may partly be a result of this interaction. The design aspects of cooling trenches are another important factor on cooling trench performance. For example, the dimensions of the Church pond cooling trench are 90 m long and more than 2 m deep, resulting in the best performance of all cooling trenches studied. Although pond 74 has a big cooling tunnel, 60 m long and 2 m deep, less ground water interactions may cause less cooling effects from this cooling tunnel. Another important factor in order to get the best result out of designed and constructed facilities is the maintenance of the facilities to make sure they are working properly.

In summary, the cooling trench performance is highly dependent on the following variables:

- flow rate into the cooling trench;
- runoff and cooling trench volumes;
- influent temperature;
- volume of water in the cooling trench before runoff; and
- groundwater interaction.

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