Sustainable Technologies
EVALUATION PROGRAM

TECHNICAL BRIEF

Protecting aquatic ecosystems from the thermal impacts of stormwater ponds: A summary of key technologies and their cooling performance

Thermally enriched runoff from stormwater ponds alters aquatic community composition and activity in freshwater streams, and in some cases, may increase stream temperatures beyond the tolerance threshold of inhabiting species. A number of measures have been devised to help mitigate the impact of thermal pollution from stormwater ponds. This study, prepared for the City of Brampton, assesses the effectiveness of stormwater thermal mitigation measures installed in southern Ontario and provides recommendations on the design and application of the measures for future stormwater infrastructure projects. Thermal mitigation measures evaluated include:

- 18 subsurface draw pond outlets;
- 18 cooling trenches;
- 14 low impact development (LID) technologies; and
- a smaller number of less common techniques such as night time release outlets, floating islands, underground tanks and vegetated channels.

Monitoring data showed that subsurface draw outlets, infiltration practices and underground tanks provided the greatest and most consistent cooling capacity among the different measures investigated. Cooling trenches were found to lack consistency both in terms of sizing and performance, due to the many variables that can influence effectiveness. Other practices such as night time release outlets, floating islands and vegetated channels provided relatively minor cooling benefits, and would normally need to be combined with other practices to produce desired temperature reductions. The analysis also offers insights into the factors influencing performance, and how this understanding can help inform practice selection, sizing and the design of measures.

Urbanized landscapes provide less shade for watercourses than natural areas and supply thermally enriched storm water runoff from heated paved surfaces and roofs. When runoff is drained through stormwater ponds, solar radiation heats the open pond water, resulting in warmer water being released to receiving stream systems.

Stormwater ponds have been shown to increase water temperatures by up to 9°C, and generate outflow temperatures above 30°C.

INTRODUCTION

It has been recognized for many years that stormwater wet ponds increase runoff temperatures to receiving waters through solar heating of ponded water. Mitigating these impacts has become increasingly important in the Greater Toronto Area as urban development expands into cool headwater streams inhabited by aquatic species that are sensitive to temperature and habitat alterations.

In this project, we synthesized existing performance data on several stormwater pond thermal mitigation measures. Based on these data and other relevant information, insights on the design and application of the measures for stormwater infrastructure projects are offered for consideration. The focus of the evaluation was on measures that can be implemented within the stormwater pond block, and in areas upstream of the stormwater pond. Measures suitable for areas draining to existing or recovering habitat for red-side dace and other cool water species were prioritized.

FACTORS INFLUENCING SELECTION AND DESIGN OF THERMAL MITIGATION STRATEGIES

Selection and design of thermal mitigation measures requires an understanding of the factors that may influence performance. Table 1 summarizes some of the important factors that need to be considered and how these may influence the design of thermal mitigation practices.

FINDINGS

Monitoring data from various thermal mitigation projects were analyzed using a consistent and replicable methodology to evaluate the relative benefits each measure provides. The measures evaluated included subsurface draw outlets, night time release outlets, cooling trenches, low impact development measures, and a few less common practices such as underground chambers and floating islands. Results of the analysis for each of these measures are discussed below.

Subsurface Draw Outlets

Installing outlets that draw cooler water from below the pond surface is one of the most common and consistently effective measures for mitigating pond thermal impacts to streams. Although outflow temperature will decrease at outlet invert elevations starting 0.5 m below the normal water level (NWL), more significant cooling requires subsurface draw outlets to be located at least 1.2 m below the permanent pool water level, as this is the level at which significant reductions in the amplitude of diurnal fluctuations in water temperature are observed in most ponds. Maximum summer temperatures of outlets between 1.2 and 1.5 m below the pond normal water level (NWL) were shown to be up to 4^{0}C cooler than surface draw outlets.

Subsurface outlets greater than 1.5 m below the NWL exhibit more constant outflow temperatures, which decrease further as the outlet depth increases. Analysis of over 18 subsurface draw monitoring data sets showed that outlet elevations greater than 2.0 m below the NWL typically generated pond outflows with temperatures less than 24^{0}C at least 95% of the time (Figure 2). These subsurface outlets had 95th percentile temperatures that were approximately 3 to 5^{0}C cooler than surface draw outlets, with variations mostly caused by summer air temperatures.

Since ponds are designed to retain sediment, space below the outlet will be required both for sediment accumulation and to avoid resuspension of previously deposited sediment. Based on MECP guidelines on sediment maintenance frequency and accumulation volumes, it is estimated that a pond with an outlet 2.0 m below the NWL should be at least 3.0 to 3.5 m deep for drainage area impervious covers between 35 and 85%, respectively (TRCA and CH2M Hill, 2015). These depths would allow some clearance between the outlet and pond bottom at the time of maintenance and avoid the requirement for pond cleaning prior to the normal sediment maintenance life cycle.

Anoxic conditions of bottom waters are common in shallow and deep ponds, particularly older ones. Anoxic conditions can result in redox reactions that enhance the release of

Table 1. Factors to consider in designing a thermal mitigation strategy

Influencing Factor	Observation or Effect	Design Implications
Pond Outflow Rates	Pond outflow temperatures are warmest during dry weather when flow rates are low (Figure 1).	Cooling measures may be designed to bypass high flows, resulting in smaller systems with similar cooling potential.
Stream Thermal Regime	Stream temperatures are warmest during dry weather when flow rates are low.	Cooling measures may be designed to provide enhanced cooling benefits during dry weather.
Salt Stratification in Ponds	Salt stratification in ponds persists throughout the summer. Promotes short circuiting of warm water across the pond surface. Helps maintain cool temperature outflows form subsurface draw outlets.	Subsurface draw outlets may be less effective when salt stratification is less pronounced (e.g. in ponds receiving low salt loading).
Pond Turnover Frequency	Fewer water exchanges in ponds increases exposure of water to solar radiation resulting in warmer outflows.	Ponds should be sized to account for reduced runoff volumes from upstream low impact development practices.
Site Runoff Volumes	Lowering discharge volumes through infiltration or evapotranspiration reduces thermal loading to streams. Thermal load is a more direct measure of thermal impacts on receiving waters.	Combine ponds with infiltration measures to reduce thermal loads. Design measures to reduce thermal loads, not just water temperature. Consider stream thermal regime in design.

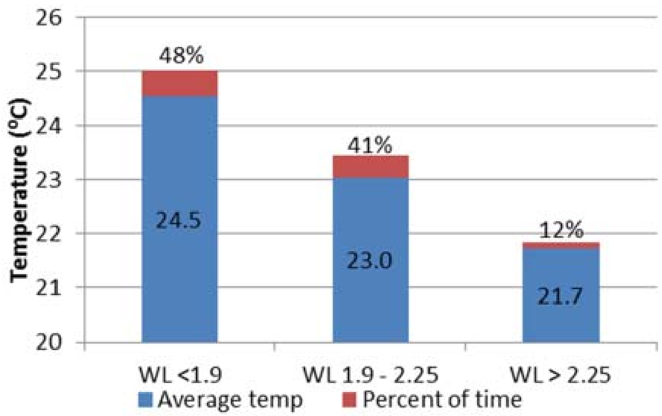

Figure 1. Relationship between water level (WL in metres) and average outlet temperature for the Majorwood pond in Markham. Percentages represent the percent of time between June 15 and September 15 that water levels fell within the indicated water level ranges. Pond water levels are directly correlated with pond outflow rates.

phosphorus and heavy metals from deposited sediments. However, based on the data reviewed, there is insufficient evidence to suggest that anoxic bottom waters and redox reactions in deeper ponds would necessarily result in poorer effluent water quality than that of shallower ponds, or that subsurface draw outlets with sufficient separation (minimum 0.5 m) from the pond bottom would discharge poorer quality water than surface draw outlets. Further study is required to determine the conditions and mechanisms by which subsurface draw outlets may affect pond performance.

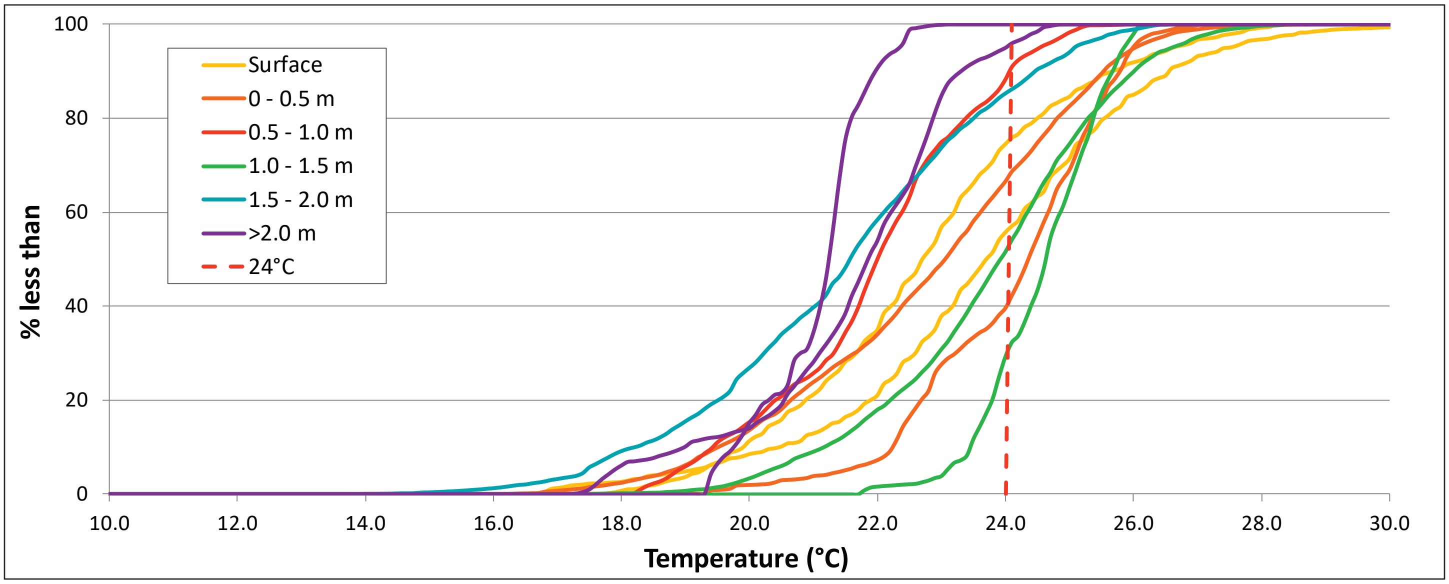

Figure 2. Temperature frequency plots for selected ponds with different outlet elevations below the normal water level (June to Sept, different years). The coolest outlet temperature profile was from a 2.5 m draw pond in Brampton that was monitored from July 8 to August 28 during a year when air temperatures were cooler than normal.

Night-time Release Outlets

Using real time controls on pond outlets to release water at night, when outflow temperatures are cooler, can help mitigate the thermal impacts of ponds, while maintaining appropriate release rates for protection against stream erosion and flooding. Based on data from 4 ponds, the 95th percentile temperature reduction for ponds with night time release outlets was calculated to be approximately 1.6^{0}C for surface draw outlets, and 0.6^{0}C for an outlet 1.4 m below the normal water level. When optimized, these outlets generated temperatures that exceeded 24^{0}C between 20 to 30% of the time over the period between June 15th to September 15th. The thermal mitigation benefit of night time release on deeper outlets (i.e. below 1.2 m) is very small as temperatures from these outlets do not exhibit strong diurnal variations. The optimal 8 hour duration for night time release outlets was found to be between 3 AM and 10 AM inclusive. Robust automation technology with electrical supply is needed avoid excessive repairs and down time.

Cooling Trenches

Rock cribs with perforated pipes at the pond outlet is another common measure used to cool pond outflows. In theory, transfer of heat from water to the stone media and surrounding soils helps cool pond outflows, although thermal sizing calculations suggest that very large trenches would be needed to achieve significant cooling of all pond overflows. Overflows allow high flows to bypass the trench to help enhance thermal function by reducing the volume of water that requires cooling, while also helping to prevent excessive sediment build-up in the trench. Cooling trenches may be installed downstream of the primary pond outlet or draw from a secondary orifice controlled outlet draining water from the pond below the normal water level.

Monitoring data revealed trenches to vary widely in their capacity to cool pond outflows. Nine of the 16 primary outlet cooling trenches reviewed had limited to no outflow cooling benefits (see example in Figure 3), while others showed average summer outflow temperature up to 9^{0}C below the temperature of the pond outlet. Monitoring from two secondary outlet cooling trenches showed 95th percentile temperature

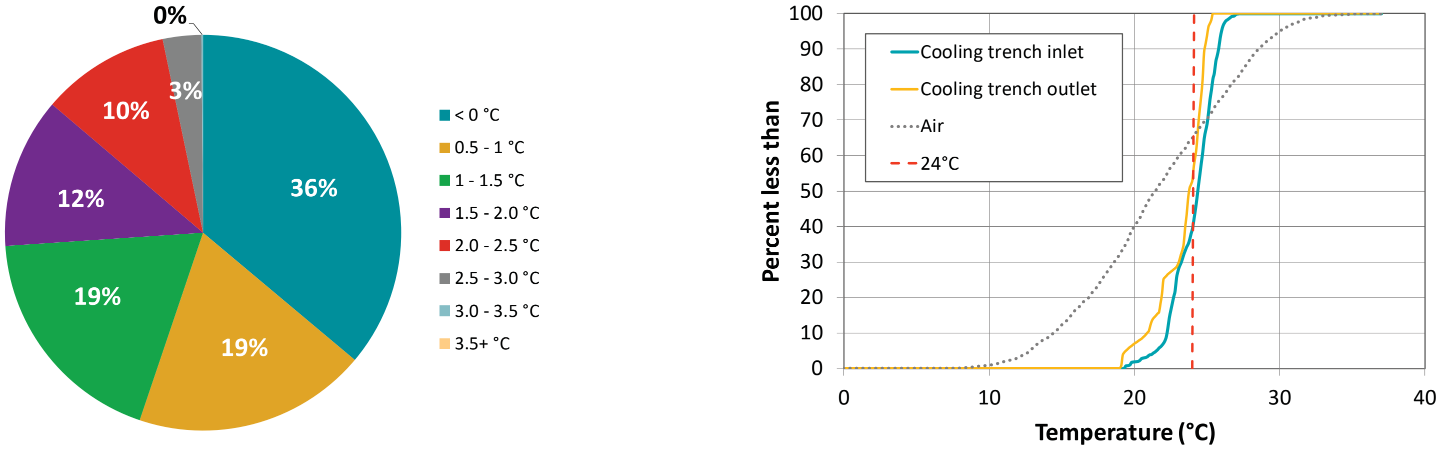

Figure 3: Pond L2, Brampton, cooling trench performance. Left graph shows temperature changes from the inlet to outlet. Right graph shows inlet and outlet temperature frequency.

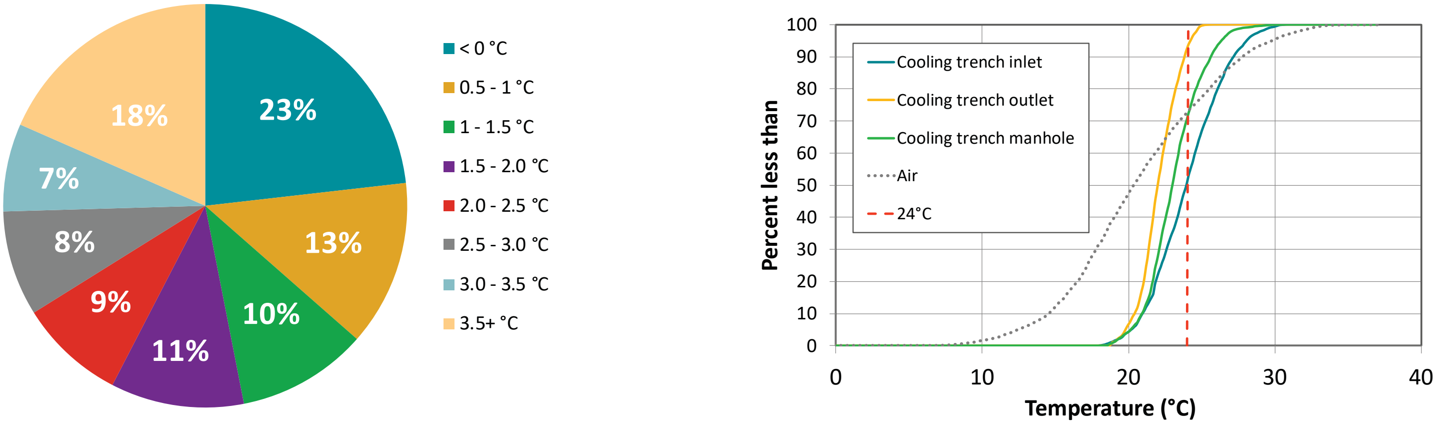

Figure 4. Secondary outlet cooling trench performance from June 15 to Sept 15, 2012, Majorwood Pond, Markham. Left graph shows temperature changes from the inlet to outlet. Right graph shows the temperature frequencies of the air and those within the system at three locations. Pond water drained from a small outlet at 0.5 m below the NWL to a manhole then through a cooling trench (see Van Seters and Graham, 2014 for more information).

reductions in the 4 to 5^{0}C range over the course of the summer (see example in Figure 4). However, these were designed to cool only a small portion of total pond outflows. Variability in cooling trench performance was attributed to several factors, including design, sizing (which varied widely from site to site), interaction of groundwater with water flowing through the trench, and the initial temperature of pond outflows (e.g some ponds combined subsurface outlets with cooling trenches).

As a rule of thumb, and loosely based on the case studies reviewed, primary outlet trenches without groundwater interaction will likely provide summer temperature cooling of the warmest flows by roughly 1 to 3^{0}C if the trench storage volume is equal to or greater than 5% of the runoff volume discharged from the pond during the 25 mm event. Trenches with smaller storage volumes cannot be relied on to provide any cooling benefits, although the monitoring studies suggest that under favourable conditions, these may still provide some cooling.

Low Impact Development (LID) Practices

LID practices can be implemented within the upstream drainage area or pond block to provide cooling. They increase the capacity of streams to assimilate thermal impacts primarily by reducing stormwater volumes through infiltration, evapotranspiration and/or reuse, although several practices also reduce temperatures.

Practices with underdrains more than 0.7 m below the surface, such as bioretention and the infiltration trench, had the coolest outflow temperatures and usually showed the largest reduction in temperatures. Outlet temperatures for these practices were often below 22^{0}C. Green roofs and permeable pavements had drainage layers closer to the surface and as such were more strongly influenced by solar radiation (Figure 5).

Thermal load reductions were higher than for water temperature alone because volume reductions through infiltration and evapotranspiration are taken into account. All but one of the practices had median thermal load reductions above 65%. Even practices such as green roofs and permeable pavements, which increased water temperatures, showed impressive thermal load reductions (Figure 6).

When installed to mitigate the thermal impacts of ponds, LID practices such as trenches, chambers or bioretention are best located within the pond block where the system can draw water continuously form treated pond outflows that often drain for several days after rain events. To facilitate infiltration these systems may need to be located under raised areas such

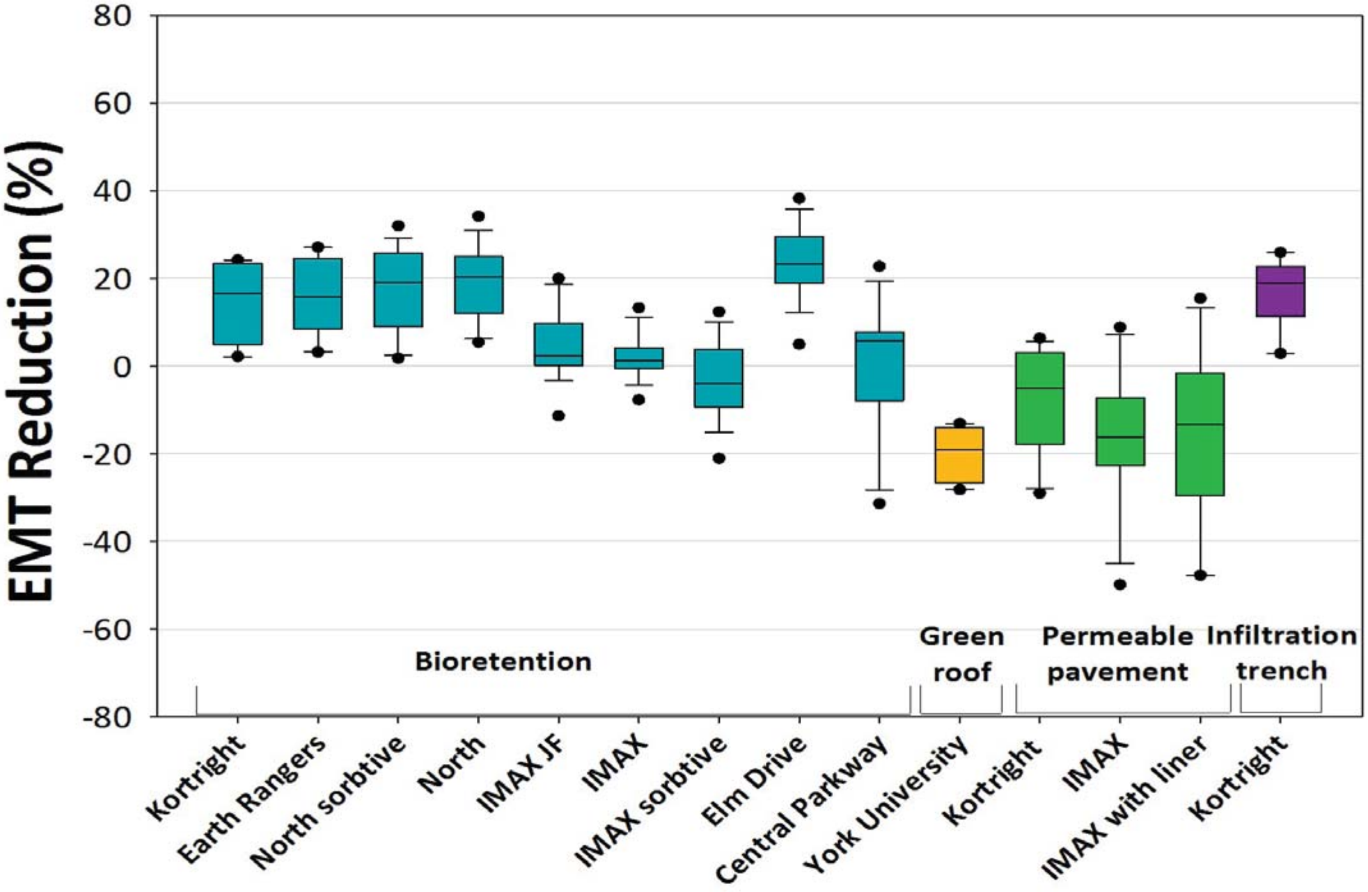

Figure 5. Event mean temperature reduction for LID practices

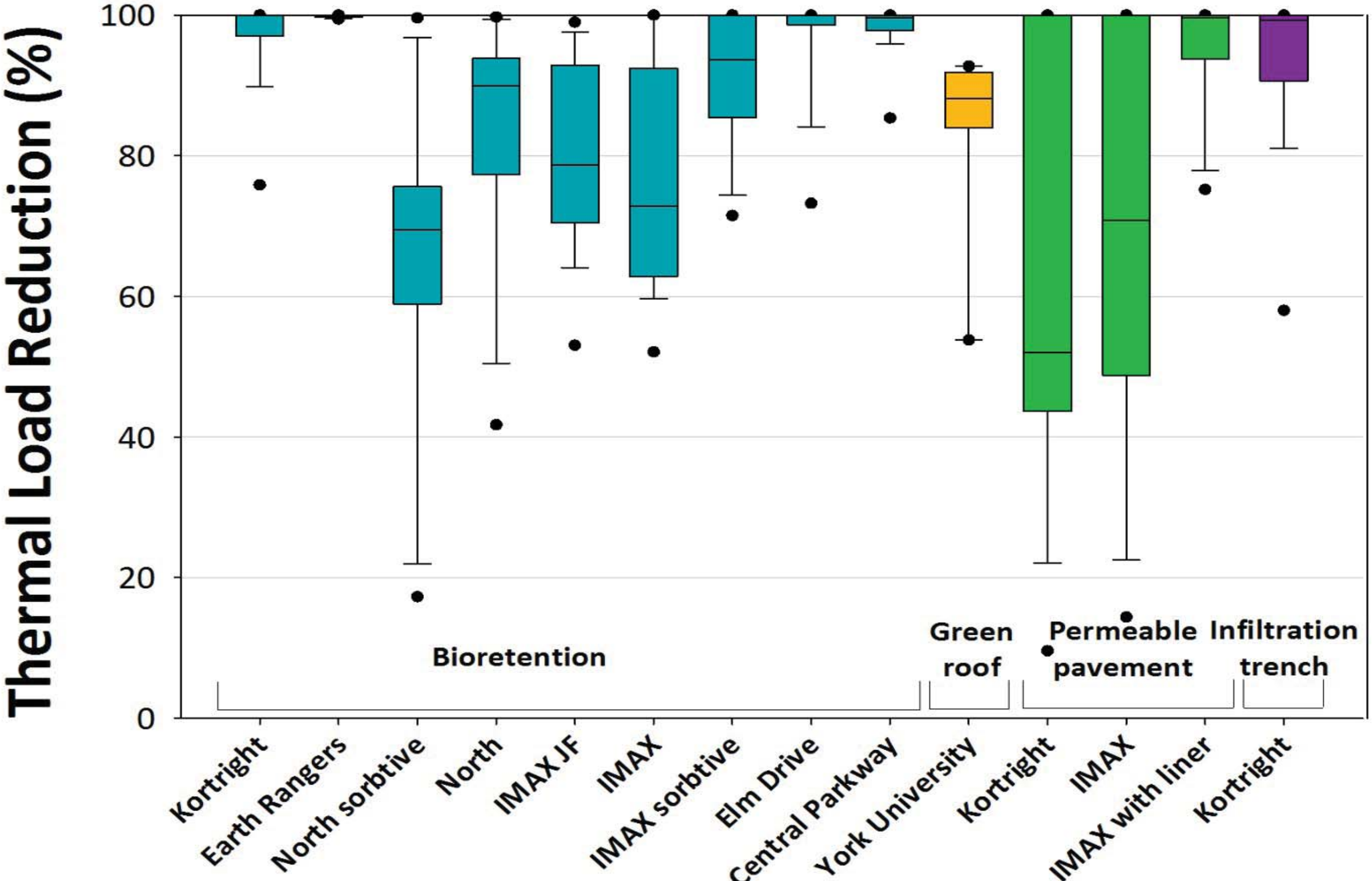

Figure 6. Thermal load reductions for LID practices

as access roads to allow for some separation from the bottom of the system and the seasonally high groundwater table.

Calculations for three ponds with flow and temperature data showed that infiltration systems drawing flows from the pond surface would provide seasonal thermal load reductions equivalent to those of a deep subsurface draw outlet at bottom area sizes of up to 6.6% of the pond surface area in areas with tight native soils (3 mm/hour infiltration) and up to 1.6% of the pond area in areas with loamy and sandy native soils (>12 mm/hour infiltration). In the examples reviewed, achieving this condition required diverting flows from the pond to the infiltration system at maximum flow rates of between 0.22 and 1.01 L/s.

Other Practices

Other practices examined included vegetated channels, an underground detention chamber, and a floating island. A long partially shaded vegetated channel was found to provide cooling of outflows in the 1 to 2°C range. Underground detention chambers, such as the StormTrap system monitored under STEP (Drake et al., 2016), had summer outflows below 22°C, which is sufficient for the protection of most cool water species. A floating island was also investigated, but shown to have limited thermal reduction benefits, likely due to the limited areal extent of cover, which in this case was only 10% of the pond area.

CONCLUSIONS

The available data on thermal mitigation measures implemented in southern Ontario indicates that various approaches may be successfully applied to minimize the thermal impacts of ponds on aquatic ecosystems. However, the effectiveness of these approaches varies considerably, and the capacity to predict performance of measures is limited by the influence of site specific factors, many of which are poorly understood.

Subsurface draw outlets are one of the most predictable measures for mitigating temperatures, as the practice relies strongly on the presence of a thermally stratified layer, which is a common feature of most stormwater ponds. Infiltration systems were also shown to reliably reduce thermal loads, but no data were reviewed for systems installed within the pond block. While simulations were run based on pond flow and temperature data to provide guidance on sizing, further testing of these practices is needed to veryify the modelling assumptions and demonstrate their thermal load reduction capabilities in real world contexts.

Cooling trench performance varied substantially from project to project due to differences in sizing, the presence or absence of groundwater interactions, the initial temperature of pond outflows and other factors. Until more data are available, cooling trenches should be installed in combination with practices such as subsurface draw outlets, infiltration systems, or channel shading where requirements for meeting a specific temperature or thermal load threshold exist.

In future briefs, we will present testing results on various combinations of measures and new approaches involving surface cover or deep geothermal cooling to help increase the range of available thermal mitigation options for implementation in new pond construction and retrofits.

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