Sustainable Technologies
EVALUATION PROGRAM

Evaluation of a Thermal Mitigation System on the Heritage at Victoria Square Pond in Markham

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This final report summarizes key findings obtained during monitoring at the study site, located in the City of Markham, during the summers of 2017 and 2018. The report was prepared by Toronto and Region Conservation Authority with funding support provided by the City of Markham.

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Tim Van Seters
Manager, STEP
Toronto and Region Conservation Authority
101 Exchange Avenue
Vaughan, Ontario
E-mail: tim.vanseters@trca.ca

THE SUSTAINABLE TECHNOLOGIES EVALUATION PROGRAM

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- Carrying out research, monitoring and evaluation of clean water and low carbon technologies;
- Assessing technology implementation barriers and opportunities;
- Developing supporting tools, guidelines and policies;
- Delivering education and training programs;
- Advocating for effective sustainable technologies; and
- Collaborating with academic and industry partners through our Living Labs and other initiatives.

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- City of Markham
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EXECUTIVE SUMMARY

This project is the second of two evaluations of similar cooling trench features installed as part of stormwater management ponds in Markham. The first evaluation was conducted in 2012 on a stormwater pond in the West Cathedral subdivision at Major Mackenzie Drive and Woodbine Avenue (Van Seters and Graham, 2013). The second system, which is the subject of this report, was installed on a pond located at Elgin Mills and Woodbine Avenue in the Heritage at Victoria Square subdivision.

The systems were designed to maintain cool stream discharge from the SWM pond catchment at a level similar to that experienced prior to development. This is accomplished by draining water at a controlled rate from the pond to a cooling/infiltration trench. The cooling trench lowers the temperature of pond water through below ground heat transfer and discharges to the receiving watercourse at a rate and volume mimicking the natural discharge of groundwater. Estimated reductions in groundwater recharge caused by the conversion of land from agriculture and open space to residential use provided the basis for selecting the flow rate discharged from the system to the stream.

Monitoring of the system installed on the Heritage at Victoria Square pond was initiated in mid June 2017, after the pond had been cleaned and the cooling trench system was commissioned. Monitoring continued until mid September, 2017, and again from mid June 2018 to mid September, 2019. Inlet flow rates from the pond to the system were assessed and found to be roughly equivalent to the target design flow of 3.5 L/s, or 1.75 L/s per trench, although rates would be much lower during dry weather as the differential head between the pond and system outlet declines.

Results from the 2017 monitoring season, showed temperatures from the cooling trench outlets fluctuating between 12.9 and 22.7℃, and 12.5 and 21.8 ℃ at the east and west outlets respectively. The maximum temperature of pond water entering the east and west trenches during this period was 28.9℃. In 2018, temperatures from the cooling trench outlets fluctuated between 13.1 and 27.9 ℃, and 10.3 and 23.3 ℃ for the East and West cooling trench outlets, respectively. The maximum inlet temperature over the same period was 31.3 ℃. By comparison, the normal pond outlet had peak temperatures similar to that of the system inlet, which were up to 8℃ higher than peak trench outlet temperatures over the two seasons.

The east trench outlet temperatures were warmer than the west during both monitoring seasons, but particularly in 2018. These differences were attributed to greater interaction with cool groundwater in the west trench, and the presence of ponded water at the east cooling trench outlet, which heats up during the interevent period causing warmer outlet temperatures. The ponded water at the trench outlet was identified as a grading issue that prevented free flow of discharge from the east trench outlet to the main outlet. During some events, the standing water reached a higher elevation than the water in the control manhole, causing flow to reverse from the trench into the manhole, and then through to the west trench. Therefore, the west trench performance data is more representative of how the system should operate with respect to cooling (albeit without flows from the east trench).

The normal outlet of the pond draws water via a reverse slope pipe located approximately 0.7 m above the pond bottom (or roughly 0.5 m below the normal water level). A depth profile of temperature sensors was installed at the outlet in 2017 and 2018 to assess the potential cooling effect associated with drawing water either nearer or further below the permanent pool water surface. The temperature sensors were installed at approximately 0.175, 0.55, 0.925 and 1.3 m meters below the normal pond water level.

Results showed 95th percentile temperature differences between the top and bottom temperature sensors (depth difference: 1.13 m) of 1℃ in 2017 and 4.4 ℃ in 2018, highlighting the potential cooling benefit of drawing water from deeper in the pond. The combination of higher rainfall in 2017, relatively cool weather, and pond cleanout less than a year before monitoring in 2017 may explain why there was less temperature difference with depth in 2017 vs 2018. Thermal and chemical density gradients develop slowly and may not have become fully established until the first or second winter after cleaning. Wet weather can also increase mixing, which reduces thermal stratification.

Recommendations on system design improvements are provided for consideration.

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1.0 INTRODUCTION

Stormwater Management (SWM) ponds have been shown to cause significant warming of water passing through them. Previous studies have shown increases in water temperature from the inlet to the outlet of ponds ranging between 4 and 11°C, with maximum temperatures as high as 31°C (TRCA, 2005). Widespread implementation of ponds for stormwater treatment and flow control has dramatically increased the temperature of water discharged into watercourses, resulting in significant alterations to the structure and diversity of downstream aquatic communities.

Several approaches to mitigating thermal impacts are recommended in The Ontario Ministry of the Environment Stormwater Management Planning and Design Manual (MOE, 2003), including bottom draw outlets, cooling trenches and riparian plantings. Relative to surface draw outlets, subsurface outlets that draw water from 2 m or more below the permanent pool elevation have been shown to reduce 95th percentile water temperatures in Ontario by between 3 and 5°C (Van Seters et al, 2019). The thermal mitigation benefits of cooling trenches vary by size and overall design, but even the best designs do not generally reduce temperatures by more than 1 to 3°C (Van Seters et al, 2019). Other techniques such as riparian plantings likely have important cooling effects, but the magnitude of these benefits has not yet been documented in an Ontario climate setting.

Within the drainage area upstream of the pond, low impact development (LID) technologies can help to reduce thermal loading to watercourses, primarily by reducing the volume of water draining to ponds. If the volume reduction effects of LID practices upstream of the pond are not considered in sizing of the SWM pond, the permanent pool may turnover less frequently, causing water to reside longer in the ponds, which may result in even warmer effluent than would have been the case without the LIDs

This project evaluates an innovative cooling trench feature installed as part of the stormwater pond operation design in the Heritage at Victoria Square subdivision in Markham. It is the second of two such systems implemented in Markham. The first, in the West Cathedral subdivision, was evaluated by STEP in 2012 (Van Seters and Graham, 2013). The technology in both locations, known as the Groundwater Emulation Management System (GEMS), was designed to maintain cool stream discharge from the SWM pond catchment at a level similar to that experienced prior to development. This is accomplished by slowly draining water from the permanent pool to a cooling/infiltration trench. The cooling trench lowers the temperature of pond water through retention and heat transfer with the ground and discharges to the receiving watercourse at a rate and volume mimicking the natural discharge of groundwater.

2.0 STUDY OBJECTIVES

The overall purpose of the monitoring study is to evaluate the effectiveness of the cooling trench system relative to design objectives and document key operational and maintenance requirements. More specifically, the monitoring program will:

- Assess capacity of the systems to cool pond temperatures from the inlet to the outlet of the system over the warm summer months
- Confirm the continuous nature and quantity of the system outflow relative to design flows
- Compare trench outlet temperature to normal pond outflows

Water quality improvements are also likely to occur as pond water passes through the control manhole and filter through gravel media in the cooling trench. These improvements were not assessed as previous monitoring of a similar system on the Majorwood pond demonstrated that the system was effective in this regard.

Data and observations from the monitoring program will help inform recommendations on improvements to the design of the system and provide the knowledge required to consider broader implementation of the system on other stormwater ponds in Markham and other municipalities within southern Ontario.

3.0 STUDY SITE

Two SWM ponds in Markham were built incorporating the cooling trench feature, and are referred to as the Heritage at Victoria Square and Majorwood SWM ponds (Figure 3.1). These ponds were built in 2007 and the SWM pond lands were transferred to municipal ownership at registration as per conditions in the subdivision agreement. The Majorwood facility, also referred to as the West Cathedral Community pond, was evaluated previously in 2012/13 (Van Seters and Graham, 2014) The Heritage at Victoria Square facility is the focus of this report. The pond was cleaned in late 2016 prior to the evaluation in 2017.

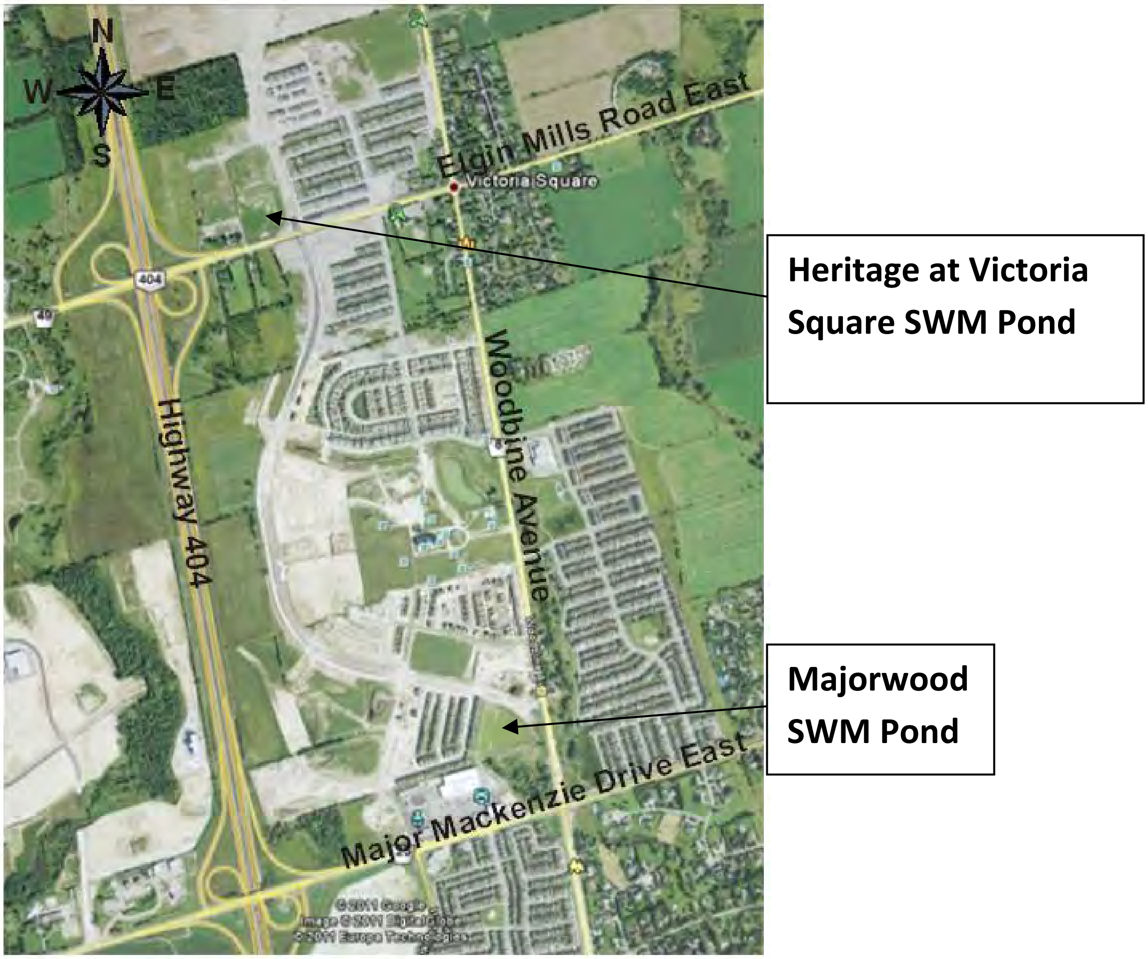


Figure 3.1: Heritage at Victoria Square and Majorwood stormwater management ponds

The Heritage at Victoria Square SWM pond facility is located just northwest of Elgin Mills intersection with Woodbine Avenue Bypass within the City of Markham (see Figure 3.1). The facility was designed in accordance with all applicable City of Markham, Toronto and Region Conservation Authority, and Ministry of Environment design guidelines.

The SWM pond was equipped with a cooling trench (Figure 3.2) that drains the pond water at a continuous rate to compensate for the reduction in infiltration and groundwater discharge to streams caused by conversion of the catchment from agriculture and open space to residential land use. The normal outlet of the pond (Figure 3.3) draws water from approximately 50 cm below the permanent pool water level through a reverse slope 9 m long 300 mm diameter perforated pipe.

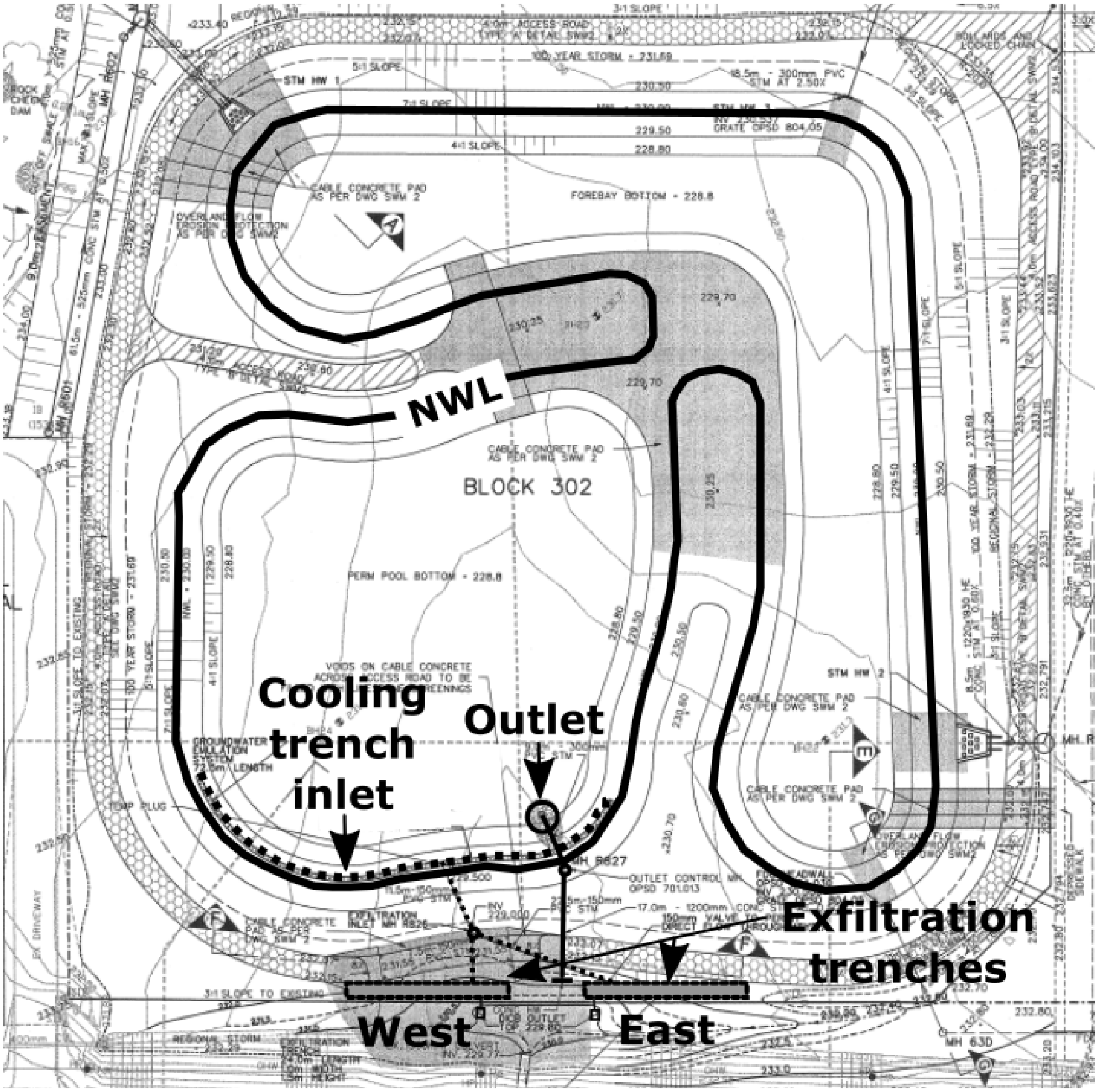


Figure 3.2: Location of the normal outlet and cooling trench system. NWL refers to the normal water level elevation during dry weather when there is no longer flow through the main outlet of the pond.

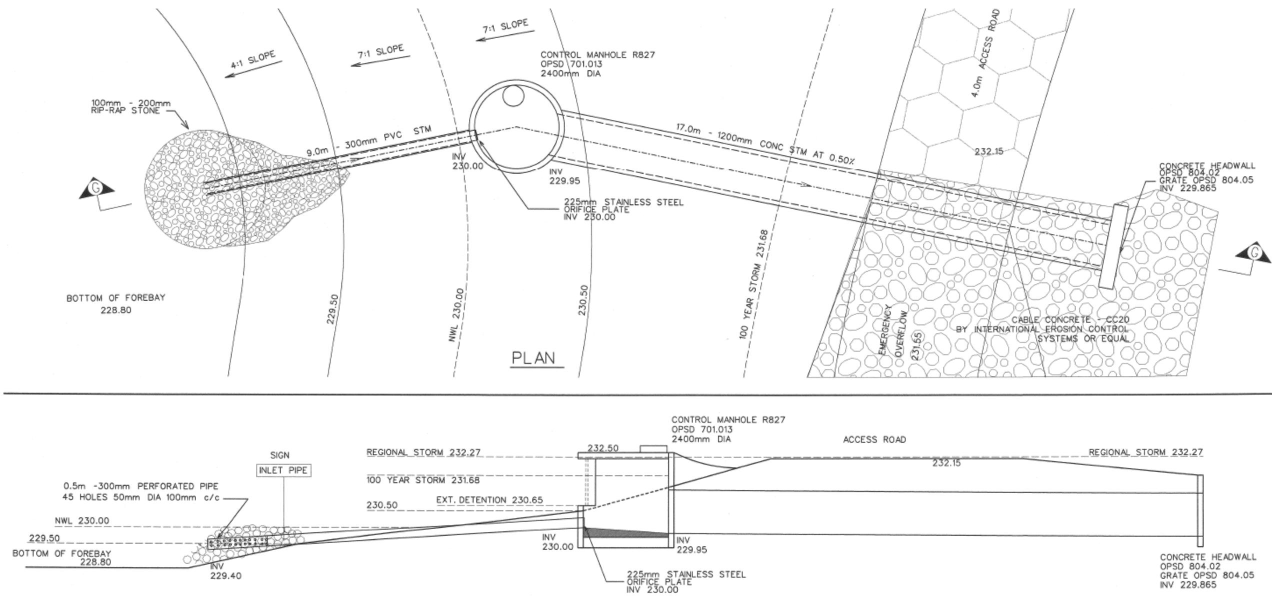


Figure 3.3: Normal outlet of Heritage at Victoria Square Pond

3.1 Design information

The cooling trench drainage system was designed to direct the upper 0.50 m of the pond's permanent pool volume through a sand filter along a portion of the pond bank to the adjacent stream at an average release rate of approximately 3 L/s and peak release rate of 5 L/s, depending on water levels in the pond. The intent was to provide for a continuous base flow with reduced thermal, sediment, and nutrient load impacts in emulation of natural groundwater discharge.

The design of the cooling trench drainage system is presented in Figures 3.4 to 3.7. Flows were conveyed to a control manhole and then split (Figure 3.5) to an east and west cooling trench before discharging through catch basins at the downstream end of each trench. These trenches receive filtered water at a continuous discharge rate from the pond's permanent pool through a 72.5 m long x 0.5 m wide perforated pipe embedded into a gravel/sand jacket within the pond bank 0.5 m below the permanent pool surface (see dashed line in Figure 3.2 and Figure 3.4). The cooling trench consists of two trenches that measure approximately 24 m long by 1 m wide by 1.5 m high. Each trench contains pea gravel and two sets of dual 24 m long 150 mm Ø perforated PVC pipes wrapped in filter fabric.

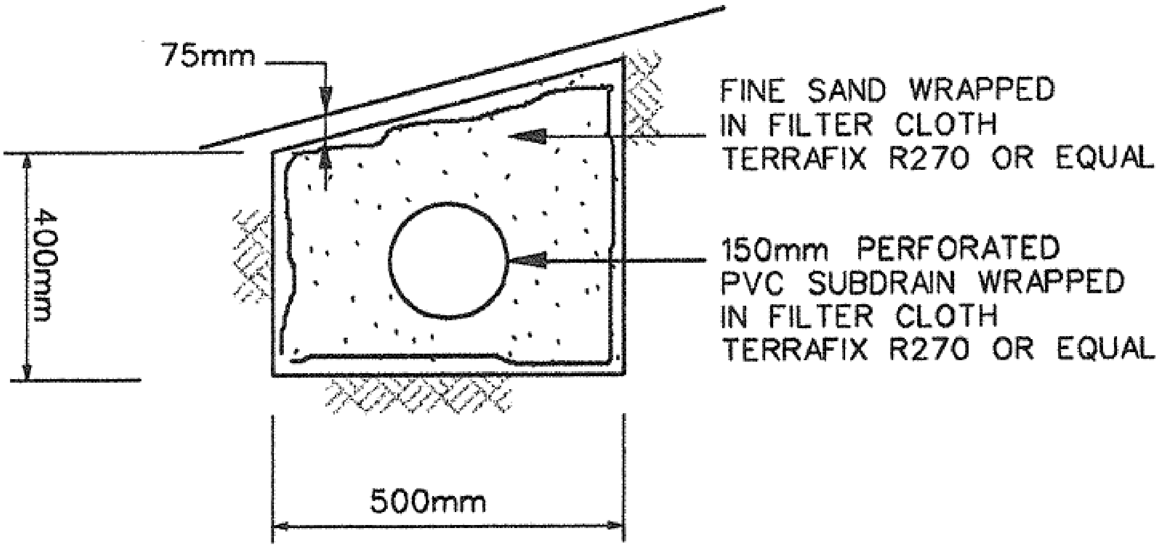


Figure 3.4: Inlet consisting of a filter sock wrapped perforated pipe embedded in concrete sand to improve filtration of suspended solids.

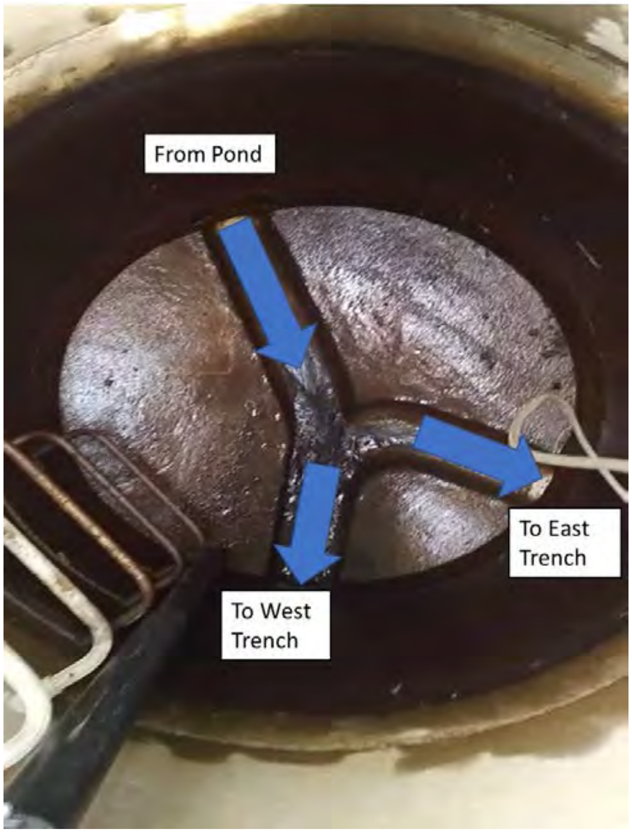


Figure 3.5: Photo of the control manhole looking down. Flows entering from the pond are directed to the east and west cooling trenches via a flow splitter.

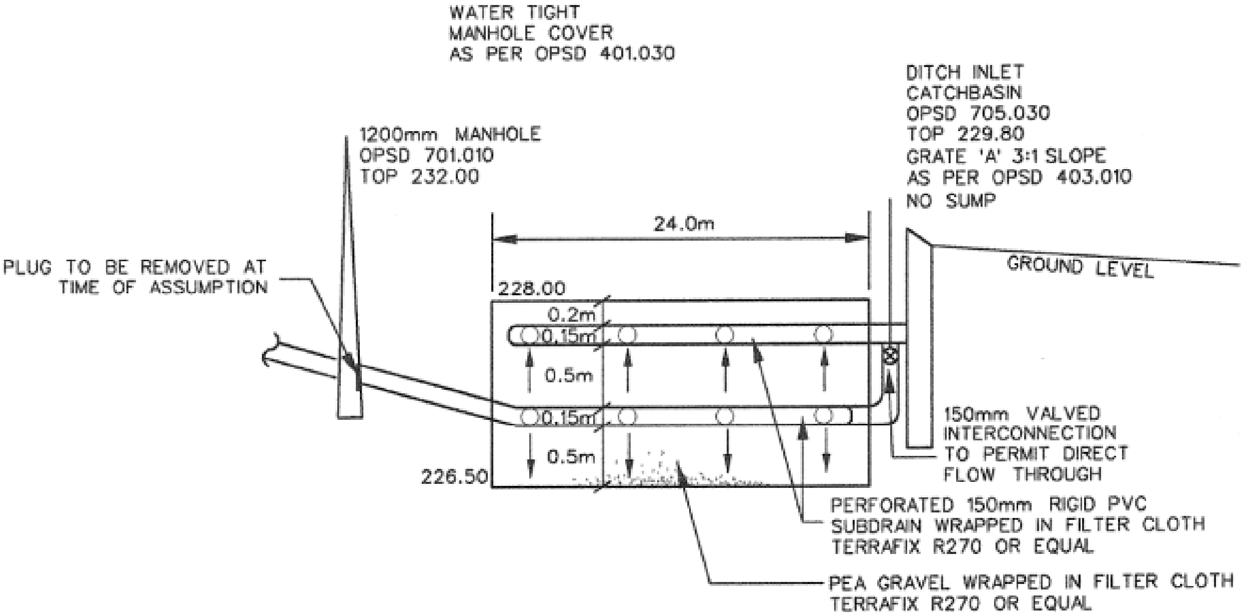


Figure 3.6: Profile view of the exfiltration system

By slowly drawing water out of the pond into the cooling trench, the pond permanent pool could subsequently be lowered to a maximum of 0.20 m below the normal water-level (i.e the difference between the NWL and outlet elevation). Discharge from the pond is collected and conveyed to a manhole via a 11.5 m long 150 mm Ø PVC pipe. Water from the manhole is conveyed separately to the west and east exfiltration systems. One 7.5 m long 150 mm Ø PVC pipe conveys water to the west cooling trench, while a 22.5 m long 150 mm Ø PVC pipe conveys water to the east cooling trench.

Each cooling trench is equipped with a 150 mm Ø valve to permit direct flow through the system. These may be operated together or individually. Each cooling trench is also equipped with a short outlet which conveys flow to a 600 mm x 600 mm catch basin equipped with a grated top that outlets to a concrete pad and ultimately to Otter Tail Creek.

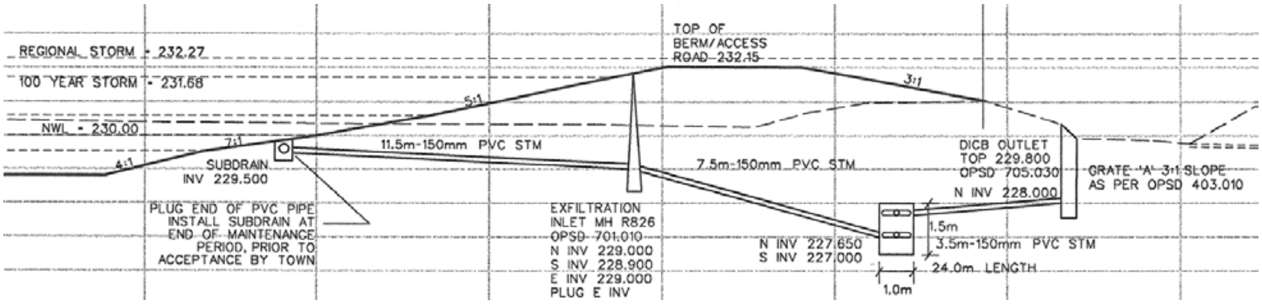


Figure 3.7: Profile view of the cooling trench system flow path

4.0 STUDY APPROACH

The monitoring locations for the subject facility are shown in Figure 4.1. Table 4.1 lists the location and monitoring equipment installed within the cooling trench system, in the stream and at the normal outlet of the pond.

Precipitation and air temperature data are collected from the Town of Richmond Hill's Operations Centre meteorological station roughly 2 km away. Temperature sensors were installed at the inlet, control manhole, cleanouts and outlets of the cooling trenches (Figures 4.1 and 4.2). There was no defined stream channel downstream of the pond outlet.

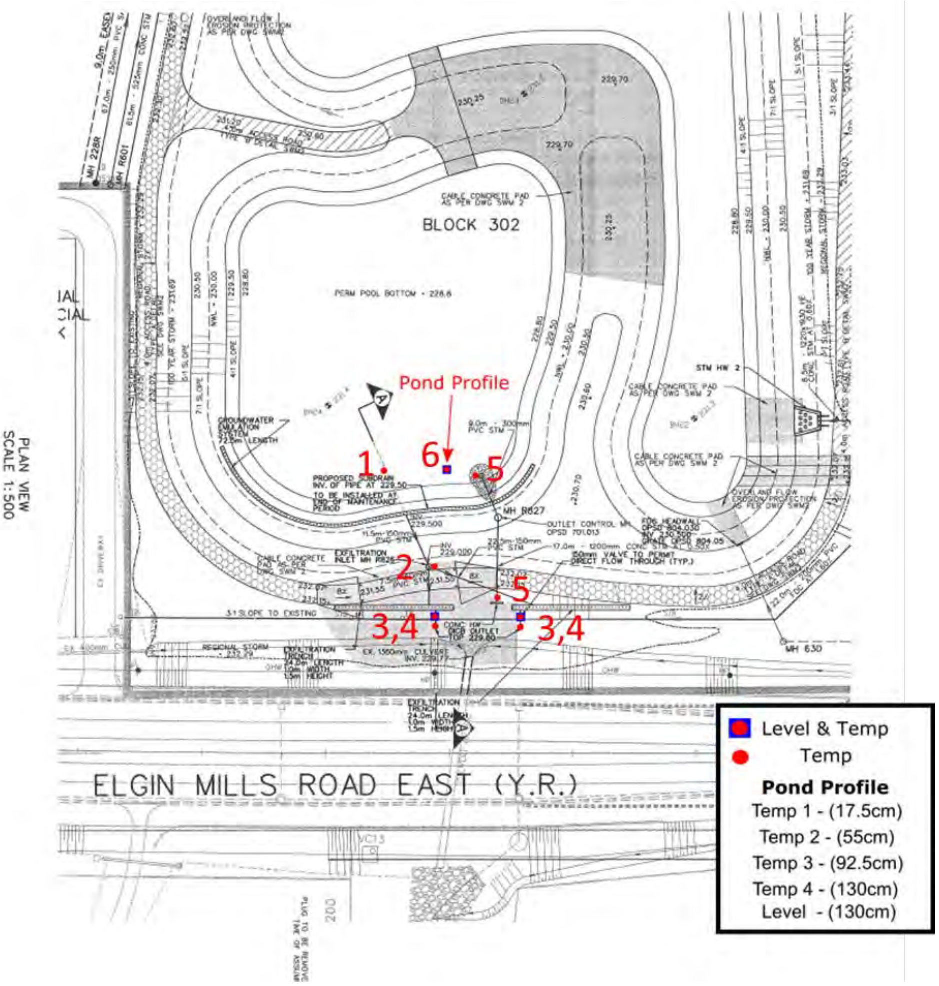


Figure 4.1: Location of sensors. Pond profile depths are expressed in cm below the normal water level. Numbers represent locations referenced in Table 4.1.

A depth profile of four temperature sensors were installed near the normal outlet to characterize the thermal mitigation effects of top versus bottom (or mid) draw outlets, in comparison to the cooling effects of the trench system (Figure 4.1). These sensors were installed at 1.23 m, 0.85 m, 0.48 m and 0.1 m from the bottom of the pond, or approximately 0.175, 0.55, 0.925 and 1.3 m below the permanent pool water level. Since the water level in the pond fluctuates during events, the actual elevation of the sensors below the water surface varies. The pond outlet draws water through perforations along a 0.5 m length at approximately 0.5 m below the permanent pool water level (Figure 3.3).

Table 4.1: Heritage at Victoria Square SWM Pond Monitoring

Sample Locaion	Location	Water Temperature	Water Level	Manual Water-Level
1	A stake adjacent to the system inlet at 0.5 m below the normal water-level.	X		X
2	Manhole between the pond inlet and cooling trench	X		
3	Cleanout pipes prior to cooling trench outlets (East and West)	XX	XX	
4	Catch basin outlets from the system (East and West)	XX		
5	Staked and cabled at conventional outlet location from SWM pond.	XX		
6	A stake adjacent to the outlet with a profile of 4 temperature sensors at 1.23 m, 0.85 m, 0.48 m and 0.1 m from the pond bottom	XXXX	X	

Notes: Each X represents one sensor. Air temperature and precipitation are from the Town of Richmond Hill's Operation centre. Water temperature and water levels are logged continuously at 5 minute recording intervals.

Flow rates from the pond are controlled by an orifice in the control manhole. As mentioned earlier, these were designed to fluctuate between 3 and 5 L/s. To evaluate flow rates the manhole and connected trenches were pumped out and allowed to refill. The recovery rate was determined based on the depth of water in the manhole and trenches after pumping and the depth of water after substantial recovery of the pre-pumping water level. Volumes were determined from manhole and trench areas, accounting for trench porosity at a value of 0.35. Based on this calculation, the flow rate from the pond averaged 3.5 L/s, or roughly 1.75 L/s per trench. These rates were likely considerably slower during dry weather when there was a small hydraulic head differential between the pond and system outlet.

5.0 STUDY FINDINGS

Monitoring of the cooling trench system was conducted between mid June and mid September 2017 and 2018. Monitoring equipment was removed during the cold season. Air temperatures during June to September 2017 were on average 0.4℃ and 0.7℃ warmer than the 30 year Climate Normals (1981 – 2010) from Pearson Airport. Temperatures were considerably hotter in 2018, with 95th percentile temperatures at 30.5℃, versus 95th percentile temperatures of 26.7℃ over the same period in 2017.

5.1 System Temperatures

5.1.1. 2017 Monitoring Season

Results of monitoring in 2017, from June 21st to September 15th, showed temperatures from the cooling trench outlets fluctuating between 12.9 and 22.7℃, and 12.5 and 21.8 ℃ at the east and west catch basin outlets respectively. Ninety five percent of the east outlet temperatures were below 21.5℃, and 95% of the west outlet temperatures were below 20.3℃. The maximum temperature of pond water entering the east and west trenches during this period was 28.9℃ (Figures 5.1 and 5.2).

The results shown in Figure 5.1 show inlet to outlet reductions in the warmest 5% of temperatures ranging between approximately 5 to 6ºC. The west catchbasin was cooler than the east because of more groundwater interaction in this location, and the absence of ponded water at the cooling trench outlet, which heats up during the interevent period causing warmer outlet temperatures in the East trench. Water ponding occurred in this location because of poor surface drainage. As with the Majorwood trench system (see Van Seters and Graham, 2014), significant cooling occurred between the pond surface inlet and the manhole, and flows through the system were relatively slow.

The time series plot in Figure 5.2 further highlights the difference between the two trenches. Water from the pond flows through the Cooling Trench (CT) inlet to a control manhole, then into the trenches and out through a catchbasin outlet that discharges through the surface grate. Temperature increases at the catchbasin outlets occur during rain events when flows through the trench increase. Interevent temperatures are much cooler in the west trench because of mixing with groundwater and the absence of any surface water interactions. Observations of back-flows from the east trench to the manhole indicate frequent bi-directional exchange of water between the pond and trench, which keeps the water in the trench warmer for longer than observed in the west trench.

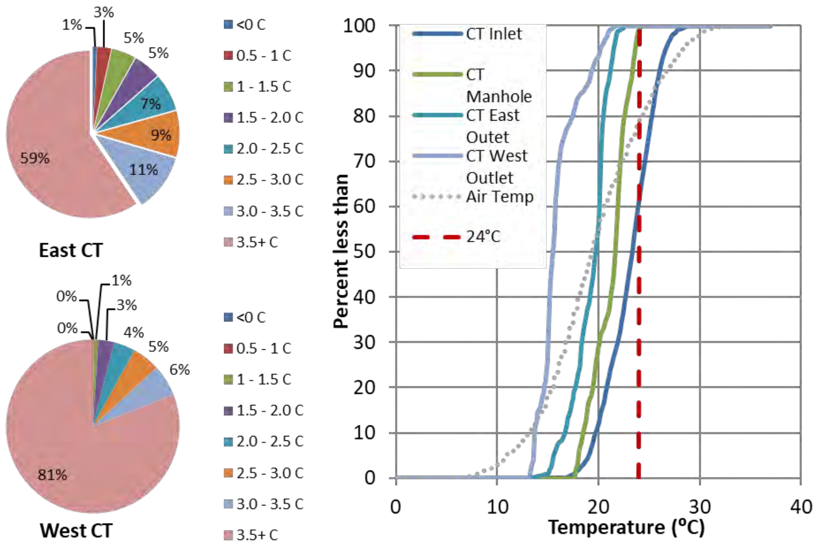


Figure 5.1: Secondary outlet cooling trench performance from June 21 to Sept 15, 2017, Heritage at Victoria Square Pond, Markham. The CT inlet in the pond discharges to a control manhole then to two cooling trenches. Left graph shows temperature changes from the inlet to outlet. Right graph shows inlet and outlet temperature frequency.

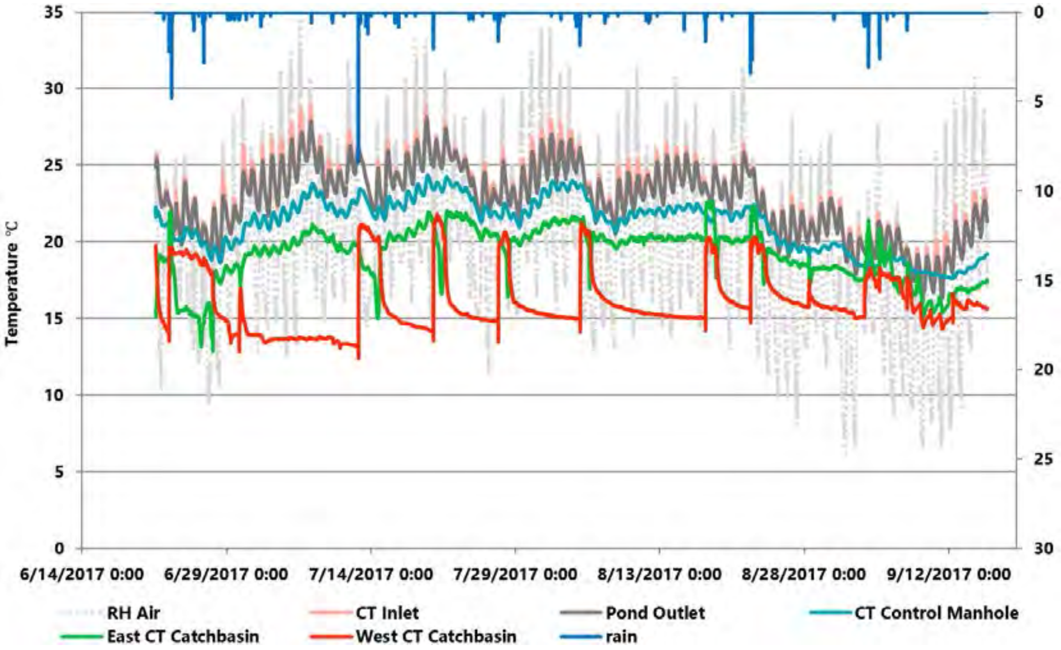


Figure 5.2: Temperature from June 21 to September 15, 2017. Water flows from a secondary outlet (inlet to the CT) to a control manhole and then into the east and west trenches and out to a surface catchbasin outlet (CT catchbasins). The main pond outlet discharges through a larger separate pipe.

5.1.2. 2018 Monitoring Season

Results from the 2018 monitoring season (June 15 – September 15) varied from those observed in 2017. Temperatures fluctuated between 13.1 and 27.9 C, and 10.3 and 23.3 C for the East and West cooling trench outlets, respectively. Approximately 95% of the observed temperatures were below 25.6℃ at the east trench outlet, while 95% of temperatures were below 22.3℃ at the west trench outlet. The maximum inlet temperature over the same period was 31.3 C (warmer than in 2017), and the temperature of the pond outlet lined up closely with the inlet temperature (Figure 5.3 and 5.4).

As mentioned previously, the much warmer east trench outlet temperatures are attributed to backflows at the outlet, which resulted in temporary ponding of water that warmed during the interevent period. Since the system was not designed to produce back-flows, it would stand to reason that the west trench performance data is more representative of how the system should operate with respect to cooling (albeit without flows from the east trench). In this trench, 95th percentile temperatures at the cooling trench outlet were 6.2℃ lower than the pond inlet, but only 1.1℃ cooler than the control manhole, suggesting that most of the cooling occurred as water was transferred from the pond to the control manhole. A possible explanation for the unexpectedly cool manhole temperatures may relate to observed backflows from the east trench. Temperature fluctuations in the manhole and east/west trenches were much more similar in 2018 than in 2017 (compare Figure.5.2 to Figure 5.4)

The cooler interevent temperature in the east trench (Figure 5.4) relative to 2017 may be attributed to the drier weather in 2018. Grading issues at the east outlet created ponded water on the east side that was exacerbated during wet weather. When this ponded water persists into the interevent period, the trench outlet temperatures are affected for longer time periods.

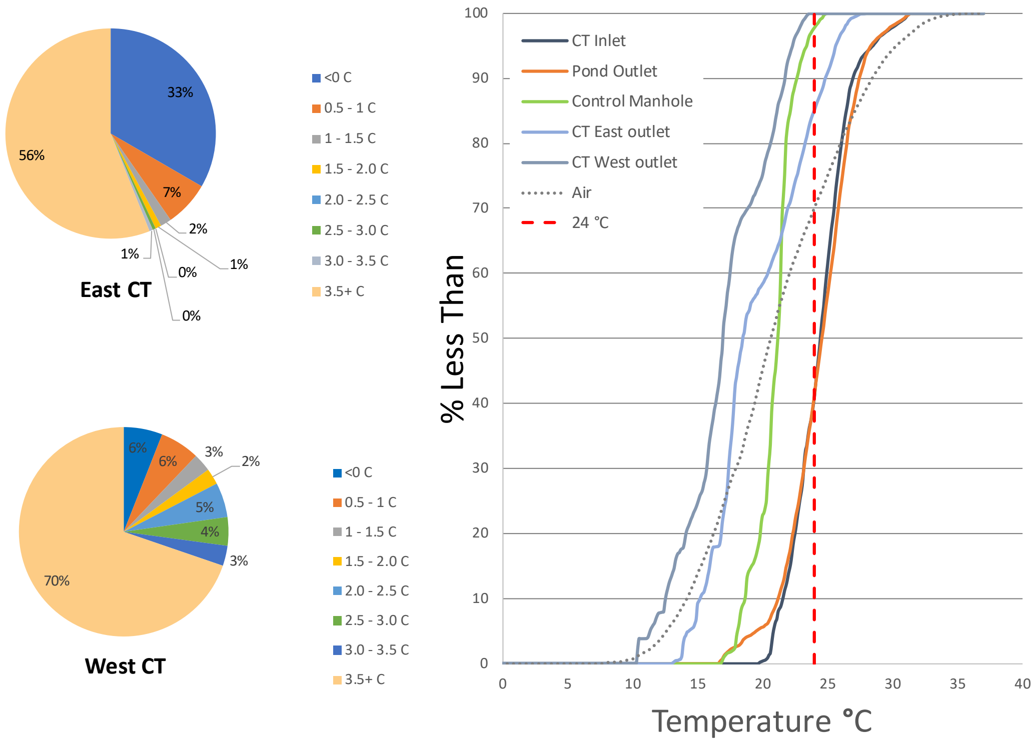


Figure 5.3: Secondary outlet cooling trench performance from June 15 to Sept 15, 2018, Heritage at Victoria Square Pond, Markham. The CT inlet in the pond discharges to a control manhole then to two cooling trenches. Left graph shows temperature changes from the inlet to outlet. Right graph shows inlet and outlet temperature frequency.

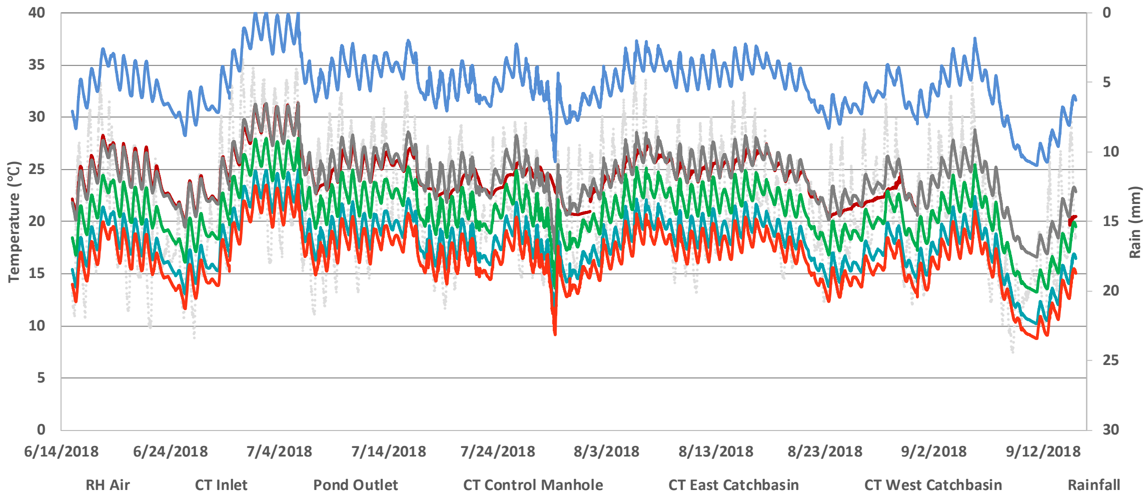
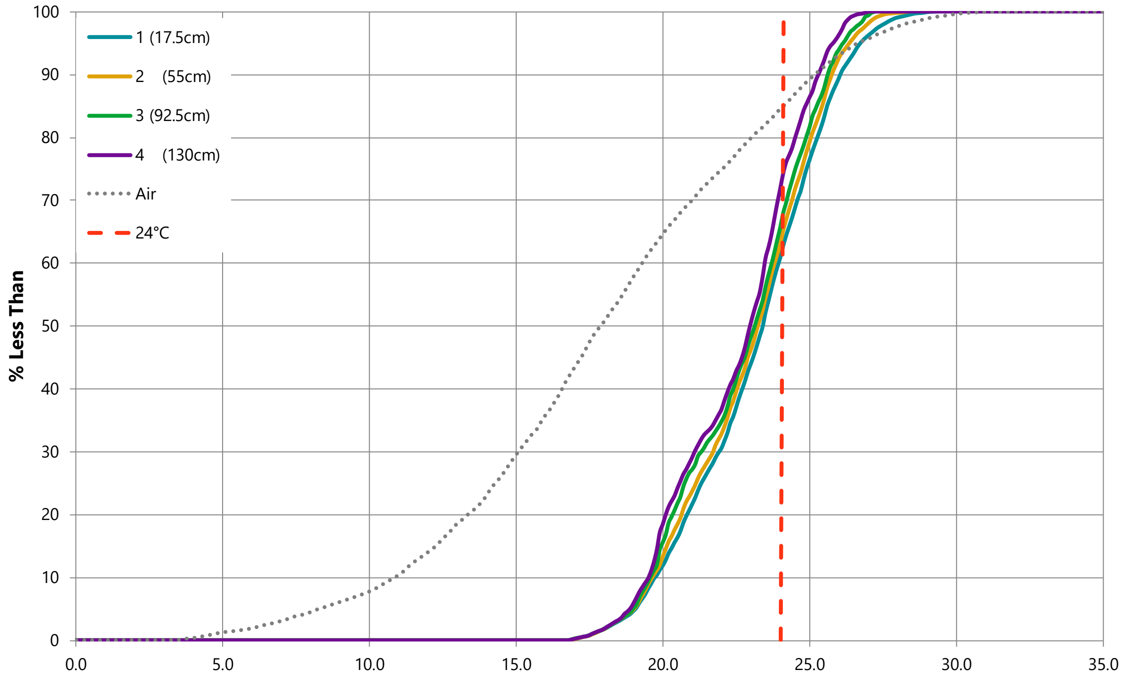


Figure 5.4: Temperature from June 15 to September 15, 2018. Water flows from a secondary inlet (CT inlet) to a control manhole and then into the east and west trenches and out to a surface catchbasin outlet (CT catchbasins). The pond outlet discharges through a separate pipe.

5.2 Pond Water Temperature Profiles

As noted earlier, the normal outlet of the pond draws water via a reverse slope, partially perforated pipe located approximately 0.7 m above the pond bottom (or roughly 0.5 m below the permanent pool elevation). A depth profile of temperature sensors was installed at the outlet in 2017 and 2018 to assess the potential cooling effect associated with drawing water either nearer or further below the permanent pool water surface. Results showed 95th percentile temperature differences between the top and bottom temperature sensors (depth difference: 1.13 m) of 1℃ in 2017 and 4.4 ℃ in 2018. (Figure 5.5)

As noted previously the pond was monitored soon after cleaning. Thermal and chemical density gradients take some time to develop and may not become evident until the first or second winter after cleaning. Large amounts of rainfall can also influence stratification by flushing water out of the pond with greater frequency than usual. The combination of high rainfall amounts in 2017, relatively cool weather, and pond cleanout less than a year before monitoring in 2017 may explain why there was less temperature difference with depth in 2017 vs 2018.



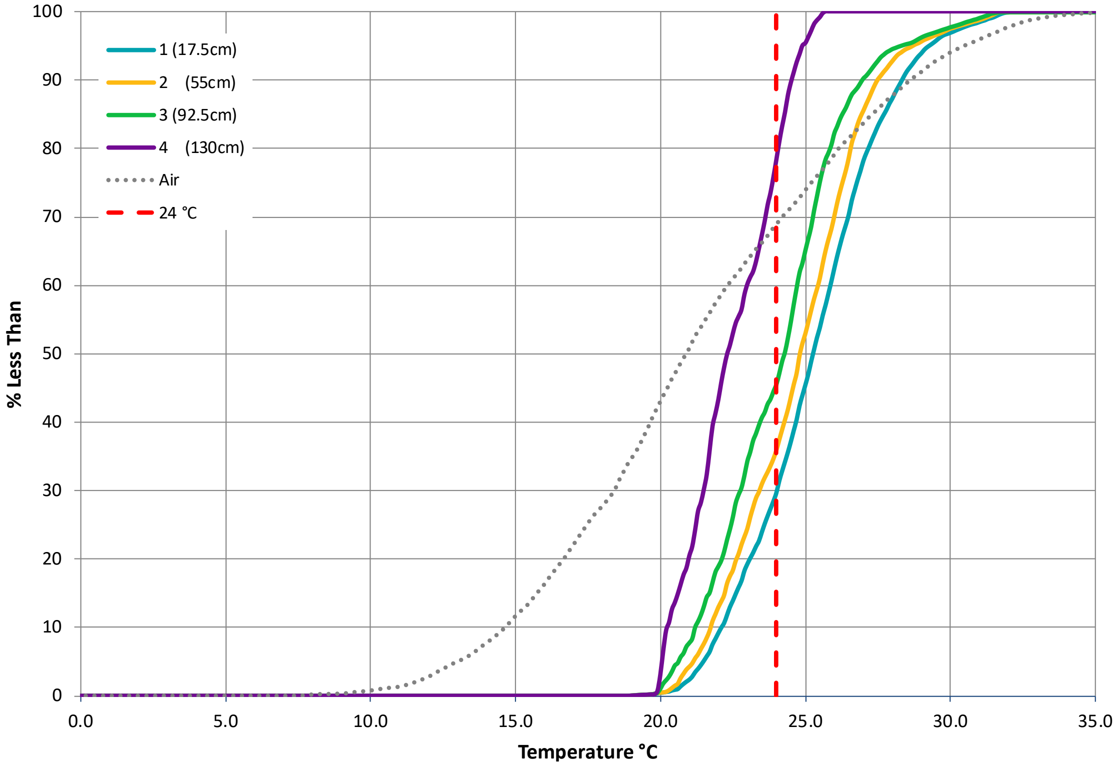


Figure 5.5: Frequency distribution curves for the Heritage at Victoria Square pond in 2017 (top) and 2018 (bottom). Depths are expressed in cm below the normal water level.

6.0 CONCLUSIONS AND RECOMMENDATIONS

The cooling trench system monitored in this study significantly reduced the temperature of outflows and provided a constant source of cool water to the receiving watercourse. The west trench showed exceptional performance, with 95th percentile temperatures over 6℃ lower than pond inlet temperatures in both years, and outlet temperatures consistently below the 24℃ target for the protection of red side dace. Poor drainage between the east trench catchbasin outlet and final outlet below Elgin Mills Road limited the effectiveness of this trench, particularly in 2018 when 95th percentile temperatures at the east outlet were 3.3℃ above those of the west trench and only 2.9℃ lower than inlet temperatures.

Temperature depth profiles were installed in 2017 and 2018 to evaluate thermal stratification in the pond, and assess whether the potential thermal benefit of installing a deeper outlet in the pond. The profiles showed a differential of only 1.1℃ between top and bottom waters in 2017, and a much greater differential of 4.4℃ in 2018. The difference between years was attributed to cooler, wetter conditions in 2017, which promoted greater mixing, and the timing of monitoring soon after the pond was drained for cleaning, which provided less time for thermal gradients to develop.

The following recommendations are provided based on the results of this study:

1. The cooling trench outlets were installed only 20 cm below the normal pond water level. When accounting for pipe head loss, the pond would either not drain or drain very little once the normal water level has been re-established. By design, the cooling system was meant to drain at elevations down to 0.5 m of the normal water level during the interevent period to prevent discharge of warm weather flows from the main outlet and provide additional storage capacity for subsequent rain events. While this may have been difficult to achieve at this site due to grading constraints, in future projects a greater head differential between the system inlet and outlet would be preferred to increase volumes through the system and enhance overall thermal load reductions.

2. The system inlet consists of a 72 m long perforated pipe embedded in a gravel/sand jacket installed along the bank of the pond. This inlet clogged during the construction period and was replaced during the final pond clean-out in 2016. A similar occurrence was noted in a monitoring evaluation of the Majorwood pond, where a GEMS was also installed (see Van Seters and Graham, 2014). In future installations of this system, the perforated pipe inlet should only be installed after final clean-out of the pond. Infrastructure should be installed to provide an option to convert the inlet to a simpler direct inlet pipe with screen in the event that the inlet becomes clogged.

3. The rate of flow through the system is intentionally constrained by the pipe orifice size. This orifice is set to discharge at a flow rate that replaces, on an average annual basis, the theoretical loss of groundwater stream discharge resulting from subdivision construction. Strong performance of this system suggests that the orifice size could be increased to allow more flow

through the system, and less through the main pond outlet. This would reduce warm dry weather flows through the main outlet and enhance overall cooling. However, it should be recognized that increasing the orifice size may result in more cool water discharged to the stream during dry weather periods than occurred prior to development.

4. At a minimum, the overland channel connecting the catchbasin outlet of the system to the receiving water or main outflow channel should have a slope of at least 1.5 to 2% to avoid water ponding and flow restrictions near the outlet. This channel should be inspected periodically to remove debris or obstructions that may be deposited over time.

5. The flow splitter at the control manhole distributes water to each of the two trenches. Although not monitored in this study, very small grading differences and pipe angles can cause one trench to receive more flow than the other. A similar system in the West Cathedral subdivision in Markham had a flow splitter upstream of two parallel trenches. This system was shown to have flow discharging from only one of the two catchbasin outlets. Uneven flow distribution reduces system efficiency and should be avoided where possible. A single larger trench with a single inlet and outlet will provide more optimal conditions for cooling in most instances.

6. Where possible, the cooling trench should be located in an area that maximizes exfiltration potential. Volume losses through infiltration and evapotranspiration enhances the overall thermal load reduction capacity of the system.

7.0 REFERENCES

Toronto and Region Conservation Authority. 2005. *Synthesis of Monitoring Studies Conducted Under the Stormwater Assessment Monitoring and Performance Program*. TRCA, Toronto, Ontario.

Van Seters T. and Graham, C., 2013. *Evaluation of an Innovative Technique for Augmenting Stream Baseflows and Mitigating the Thermal Impacts of Stormwater Ponds*. Sustainable Technologies Evaluation Program, Toronto, Ontario.

Van Seters, T., Graham, C., Dougherty, J., Jacob-Okor, C., David, Y. 2019. *Data Synthesis and Design Considerations for Stormwater Thermal Mitigation Measures.* Sustainable Technologies Evaluation Program. Ontario.