Evaluation of an Innovative Technique for Augmenting Stream Baseflows and Mitigating the Thermal Impacts of Stormwater Ponds

Prepared by: Toronto and Region Conservation **Final Report 2013**

Evaluation of an Innovative Technique for Augmenting Stream Baseflows and Mitigating the Thermal Impacts of Stormwater Ponds

Prepared By:

Tim Van Seters and Christy Graham
Toronto and Region Conservation Authority

April 2013

NOTICE

Photo credit: Photos of cooling trench construction on the front cover are by Doug McGill

PUBLICATION INFORMATION

This report was prepared by Tim Van Seters and Christy Graham. Project management support was provided by Glenn MacMillan. Field monitoring support was provided by Matt Derro, Paul Greck, and Amanda Wilson.

Report citation: Van Seters, T., 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 and Region Conservation Authority, Toronto, Ontario.

Reports conducted under the Sustainable Technologies Evaluation Program (STEP) are available at www.sustainabletechnologies.ca. For more information about this project or the STEP program, please contact:

Tim Van Seters, M.E.S., B.Sc.
Manager, Sustainable Technologies
Toronto and Region Conservation Authority
5 Shoreham Drive,
Downsview, Ontario
M3N 1S4

Tel: 289-268-3902
Fax: 416-661-6898
E-mail: tvanseters@trca.on.ca

THE SUSTAINABLE TECHNOLOGIES EVALUATION PROGRAM

The Sustainable Technologies Evaluation Program (STEP) is a multi-agency program, led by the Toronto and Region Conservation Authority (TRCA). The program helps to provide the data and analytical tools necessary to support broader implementation of sustainable technologies and practices within a Canadian context. The main program objectives are to:

- monitor and evaluate clean water, air and energy technologies;
- assess barriers and opportunities to implementing sustainable practices;
- develop supporting tools, guidelines and policies, and
- promote broader uptake of sustainable practices through education and advocacy.

Technologies evaluated under STEP are not limited to physical products or devices; they may also include preventative measures, alternative urban site designs, and other innovative practices that help create more sustainable and liveable communities.

ACKNOWLEDGEMENTS

Funding support from the following organizations is gratefully acknowledged:

- Great Lakes Sustainability Fund
- City of Markham
- York Region
- Region of Peel
- City of Toronto

We also thank Doug McGill who designed the cooling system evaluated in this study and provided valuable advice and support on monitoring and system commissioning.

EXECUTIVE SUMMARY

This project evaluates an innovative cooling trench feature installed as part of the stormwater management pond operation design in the West Cathedral Subdivision in Markham. The technology, 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 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 setting continuous flow rates released into the system.

Monitoring of the system was initiated in late August 2011, after the system was commissioned and shown to be functioning. Monitoring continued from August until late September, 2011, and again from late May 2012 to the end of September. The flow rate through the system was considerably lower than the target design flow, but sufficient to evaluate the system's cooling potential. The temperature of water discharged from the system fluctuated between 20 and 25°C during the warmest summer months, and was up to 5°C cooler than pond inlet temperatures. By comparison, the normal pond outlet had peak temperatures approximately 3 to 4°C warmer than observed from the cooling system outlet, which resulted in an increase in the average and maximum temperature of Carlton Creek by 0.6 and 1.1°C, respectively. While the cooling trench system helped mitigate the thermal impact of the pond, the outlet temperatures were warmer than groundwater discharge to streams and above the 21°C threshold for the protection of cool water fisheries.

Three grab samples at the inlet and outlet of the system after rain events indicated average total suspended solids (TSS) removal efficiency and effluent concentration of 25% and 37.5 mg/L, respectively. The outlet catchbasin and/or trench were thought to be a potential source of TSS. The inlet, which was modified from its original design, also provided limited opportunity for filtration of pond water.

A depth profile of four temperature sensors was installed at 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. These sensors were installed at approximately 0.31, 0.57, 1.10 and 1.53 meters below the normal pond water level. The pond outlet drew water from just over 0.5 m from the normal pond water level. The depth sensor data showed a peak temperature difference over 1.22 m of between 4.5 and 5.0°C, highlighting the potential thermal benefits of reverse slope outlet configurations that draw water from deep within the pond. The two temperature sensors greater than 1 m below the

normal pond water level showed less pronounced diurnal variations than sensors nearer to the water surface. The deepest sensor showed temperatures varying between 20 and 24°C during the warmest months, which is slightly below that of the cooling trench outlet. These data suggest that significant thermal benefits may be achieved by lowering the invert of the reverse slope outlet pipe to draw cooler water from deeper within the pond.

Recommendations on system design improvements and further research needs are provided for consideration.

TABLE OF CONTENTS

EXECUTIVE SUMMARY iv
1.0 BACKGROUND 1
2.0 STUDY OBJECTIVES..2
3.0 STUDY SITE 3
  3.1 Majorwood SWM Pond Design..3
  3.2 Cooling Trench Design..4
4.0 STUDY APPROACH 7
5.0 STUDY FINDINGS..11
  5.1 Cooling Trench System 11
    5.1.1 System Temperatures 11
    5.1.2 Outlet and Receiving Water Temperatures 14
    5.1.3 System Total Suspended Solids Removal Efficiencies..15
  5.2 Pond Water Temperature 16
6.0 CONCLUSIONS 21
  6.1 Conclusions 21
  6.2 Recommendations..22
7.0 REFERENCES 24

LIST OF TABLES

Table 4.1: Majorwood SWM Pond monitoring.. 9
Table 5.1: System suspended solids concentrations and removal rates.. 16

LIST OF FIGURES

Figure 3.1: Monarch and Majorwood SWM Ponds 3
Figure 3.2: Location of the normal outlet and cooling trench system 4
Figure 3.3: Cooling trench design – plan view.. 5
Figure 3.4: Cooling trench design – cross section 5
Figure 3.5: Original and modified inlet schematics 6
Figure 4.1: Majorwood SWM pond and Carlton Creek monitoring locations.. 8
Figure 4.2: Cooling trench showing the location of temperature sensors.. 10
Figure 4.3: Normal outlet showing location of temperature and water level sensors. 10
Figure 5.1: Monthly time series plots of air temperature, system water temperatures, rainfall and pond water levels.. 12
Figure 5.2: Cumulative frequency plots for the cooling trench system 14
Figure 5.3: Cumulative frequency plots for air temperature, the cooling system outlet, normal pond outlet and stream temperatures upstream and downstream of the pond discharge location 15

Figure 5.4: Monthly time series plots of pond temperatures, water levels and rainfall 18
Figure 5.5: Cumulative frequency plots for air temperatures and water temperatures at different depths in the pond 20

Appendix A: Construction Drawings
Appendix B: 2011 Monitoring Season
Appendix C: Temperature Box Plots

1.0 BACKGROUND

Stormwater Management (SWM) ponds are widely understood to have a warming effect on the 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 (SWAMP, 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. Bottom draw outlets that discharge water from below the permanent pool elevation have been shown to reduce maximum water temperatures in Ontario by between 1 and 5°C depending on the depth of the reverse flow pipe (SWAMP, 2005; Sabouri *et al*, 2013). The thermal mitigation benefits of cooling trenches vary by size and overall design, but generally do not reduce temperatures by more than 1 to 2°C (Sabouri *et al*, 2013; CVC, 2011). 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 the SWM pond design, the permanent pool will 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 West Cathedral Subdivision in Markham. The technology, 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 contact with cool granular surfaces below grade 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 system 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
- Assess the capacity of the system to filter and remove total suspended solids
- Compare flow temperatures at the system outlet to the temperatures of flows exiting the normal pond outlet, and
- Compare discharge temperatures from the cooling trench to temperatures at different depths in the pond to assess the relative thermal mitigation benefits of bottom or mid draw outlets.

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 support broader implementation of the system on other municipally owned SWM ponds 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 Monarch 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. Only the Majorwood facility was complete and ready to be operated at the time of writing.

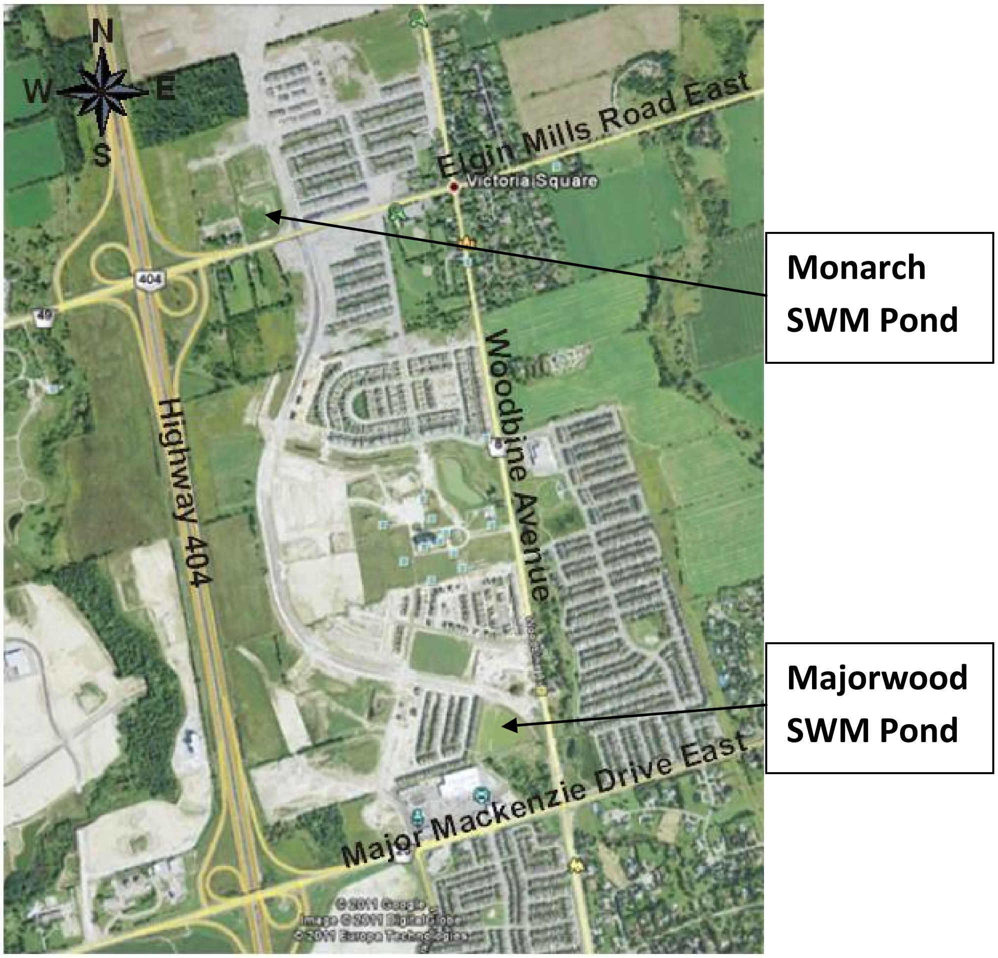


Figure 3.1: Monarch and Majorwood SWM Ponds

3.1 Majorwood SWM Pond Design

The Majorwood SWM pond facility is located just northwest of the Major Mackenzie Drive East and Woodbine Avenue intersection within the City of Markham (Figure 3.1). The SWM pond was constructed during the summer of 2007. The facility is a quantity/quality pond with a minor system drainage area of approximately 100.1 ha and a major system drainage area of approximately 71.2 ha. The facility was designed as a Level 1 (enhanced protection) SWM pond 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 recharge caused by conversion of the catchment from agriculture and open space to residential land use. The normal outlet of the pond (Figure 3.2) draws water from approximately 50 cm below the permanent pool water level through a reverse slope 2 m long 300 mm diameter perforated pipe.

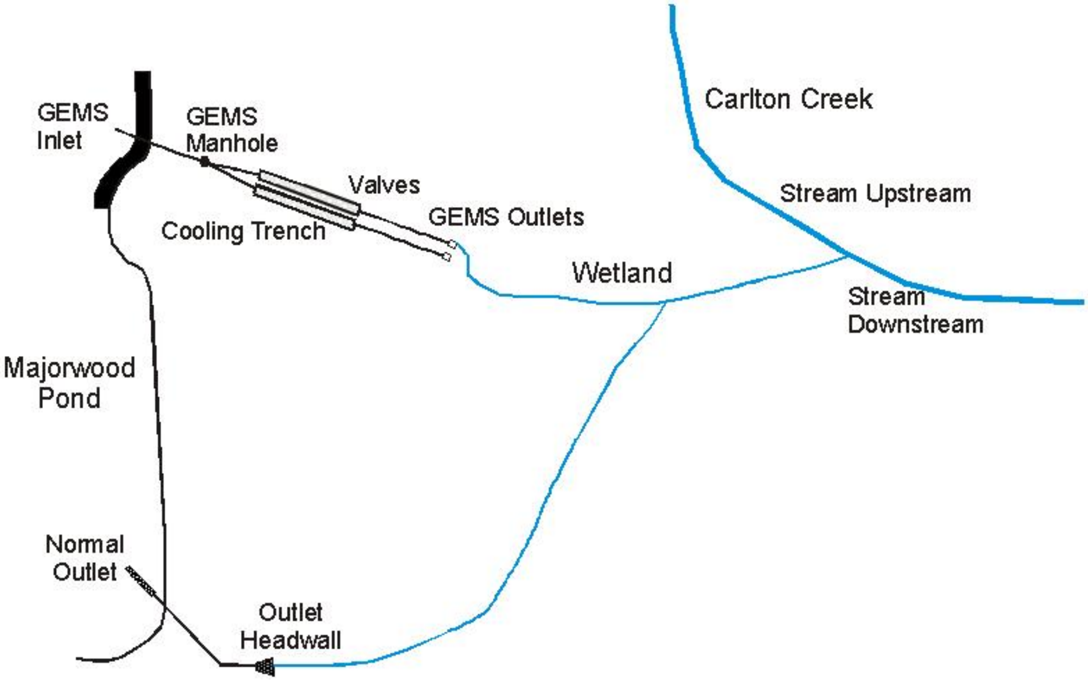


Figure 3.2: Location of the normal outlet and cooling trench system

3.2 Cooling Trench Design

The cooling trench drainage system was designed to direct the upper 0.50 m of the pond's permanent pool volume through a filtering and cooling system to the adjacent stream at an average release rate of approximately 3.6 L/s and peak release rate of 5.4 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 3.3 and 3.4. As shown, the cooling trench consists of two (2) parallel trenches that measure approximately 22 m long by 2 m wide by 1.5 m high. Each trench contains pea gravel and two sets of dual 22 m long 200 mm Ø perforated PVC pipes wrapped in filter fabric. These trenches were originally intended to receive filtered water at a continuous discharge rate from the pond's permanent pool through a 50 m long x 3 m wide infiltration trench along the pond embankment. This trench consisted of coarse sand with a 50 m long 100 mm Ø perforated pipe wrapped in filter fabric (Figure 3.5a). However, upon commissioning, the perforated pipe was found to be clogged with sediment, and was subsequently replaced with a simple 200 mm diameter pipe inlet wrapped in filter cloth that draws water directly from the pond (Figure 3.5b).

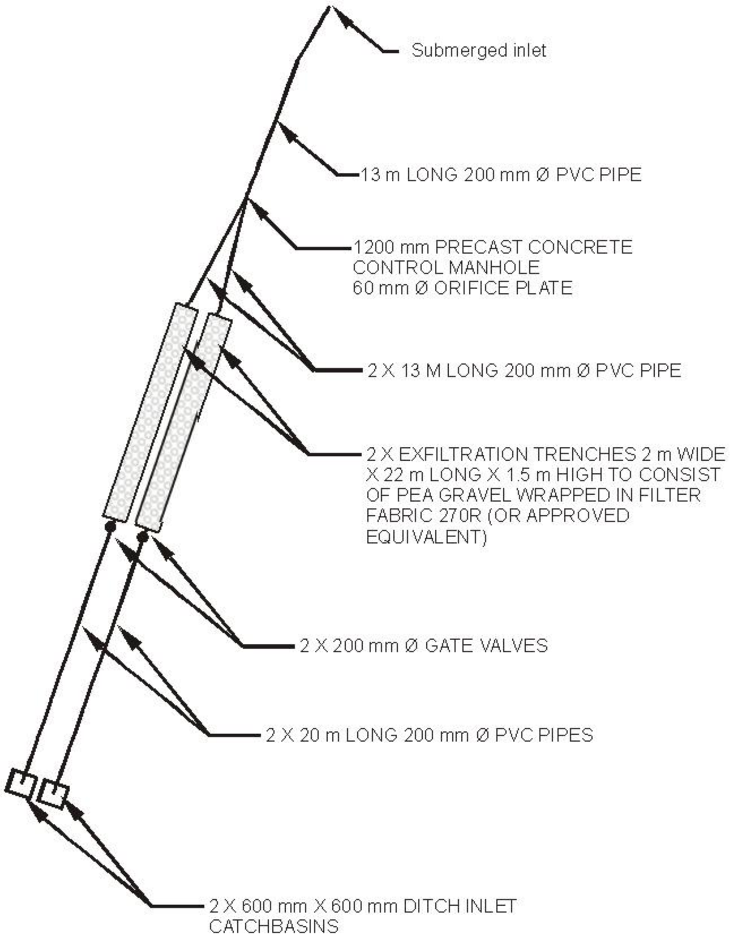


Figure 3.3: Cooling trench design – plan view

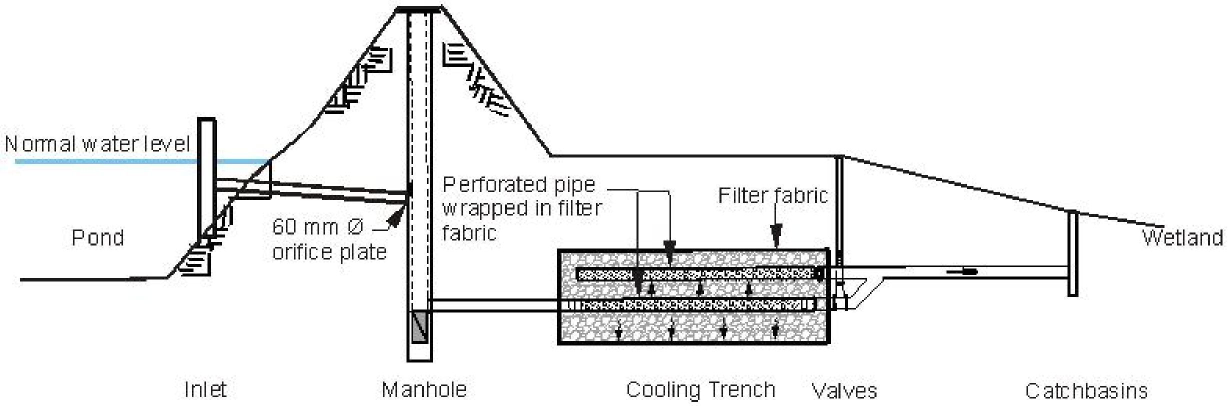


Figure 3.4: Cooling trench design – cross section (see Appendix A for details)

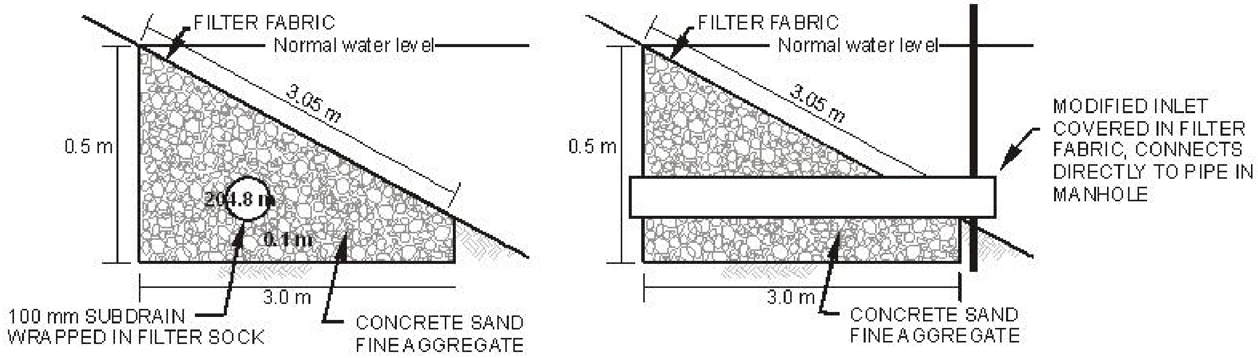


Figure 3.5: Original inlet (left) consisting of a filter sock wrapped perforated pipe wrapped embedded in concrete sand to improve filtration of suspended solids. Modified inlet (right) draws water directly from the pond with minimal filtration of suspended solids.

By slowly drawing water out of the pond into the cooling trench, the pond permanent pool could subsequently be lowered to a maximum of 0.50 m below the normal water-level. Discharge from the pond is collected and conveyed to a 1200 mm Ø manhole via a 13 m long 200 mm Ø PVC pipe that is connected to a 60 mm Ø orifice plate. Dual 13 m long 200 mm Ø PVC pipes convey the water from the manhole to the two cooling trenches.

Each cooling trench is equipped with a “cut-off” at the outlet, which consists of a 200 mm Ø gate valve with valve box. They may be operated together or individually. Each cooling trench is also equipped with an outlet consisting of a 20 m long 200 mm Ø PVC pipe, which conveys flow to a 600 mm x 600 mm catch basin equipped with a grated top that outlets to a grassed swale and ultimately to Carlton Creek. Detailed drawings of the cooling trench are provided in Appendix A.

4.0 STUDY APPROACH

The monitoring locations for the subject facility are shown in Figure 4.1. Table 4.1 below 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 Bruce's Mill and Buttonville meteorological stations roughly 3 km away. Temperature sensors were installed at the inlet, control manhole and outlet of the cooling trench system, as well as at the pond outlet channel and upstream and downstream of the cooling trench discharge location to evaluate the cooling benefits of the system (Figures 4.1 and 4.2).

The flow rate at the cooling system outlet was determined on October 17, 2012 during a dry weather period. The measurement involved pumping out the catchbasin and timing the rate of water recovery. Tests were repeated five times. Results of individual flow tests were within 7.5% of the average test value. Higher flow rates were observed during and after rain events, when pond levels rose, but these were not measured.

A depth profile of four temperature sensors were installed at 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 4.3). These sensors were installed at 1.49 m, 1.23 m, 0.70 m and 0.27 m from the bottom of the pond, or approximately 0.31, 0.57, 1.10 and 1.53 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 2m length at approximately 1.2 to 1.3 m, or between 0.45 to 0.55 m from the normal pond water level (Figure 4.3).

Water quality samples were collected at the inlet and outlet of the system during 3 storm events when the pond water was relatively turbid in order to assess filtering effects of the system. The modified inlet does not incorporate significant filtration, and therefore this component of the system is not expected to provide as significant a benefit in terms of suspended solids removal as was anticipated in the original design.

Figure 4.1: Majorwood SWM pond and Carlton Creek monitoring locations (Google Maps 2011). Monitoring activities at each of the numbered locations are described in Table 4.1.

Table 4.1: Majorwood SWM Pond Monitoring

Sample Location	Location	Water Temperature	Water Level	Manual Water-Level (confirmed at time of grab sample)	Total Suspended Solids (Grab Samples)
1	A stake adjacent to the system inlet at 0.5 m below the normal water-level.	X		X	X
2	Manhole between the pond inlet and cooling trench	X			
3	East catchbasin outlet from the system	X			X
4	Stake and cabled at a location upstream of outflow junction with Carlton Creek.	X			
5	Stake and cabled at a location downstream of outflow junction with Carlton Creek.	X			
6	Staked and cabled at conventional outlet location from SWM pond.	X			
7	A stake adjacent to the outlet with a profile of 4 temperature sensors at 1.49 m, 1.23 m, 0.70 m and 0.27 m from the pond bottom	XXXX	X		

Notes: The Xs represents the number of sensors. Air temperature and precipitation are from Bruces Mill and Buttonville airport. Water temperature and water levels are logged continuously at 5 minute recording intervals.

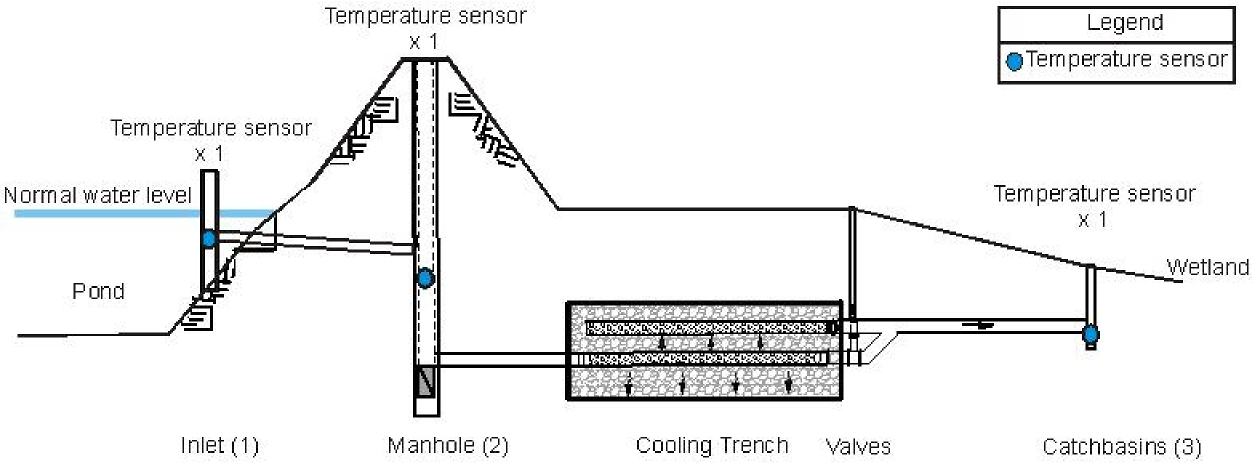


Figure 4.2: Cooling trench showing the location of temperature sensors (not to scale). See Table 4.1 for number references

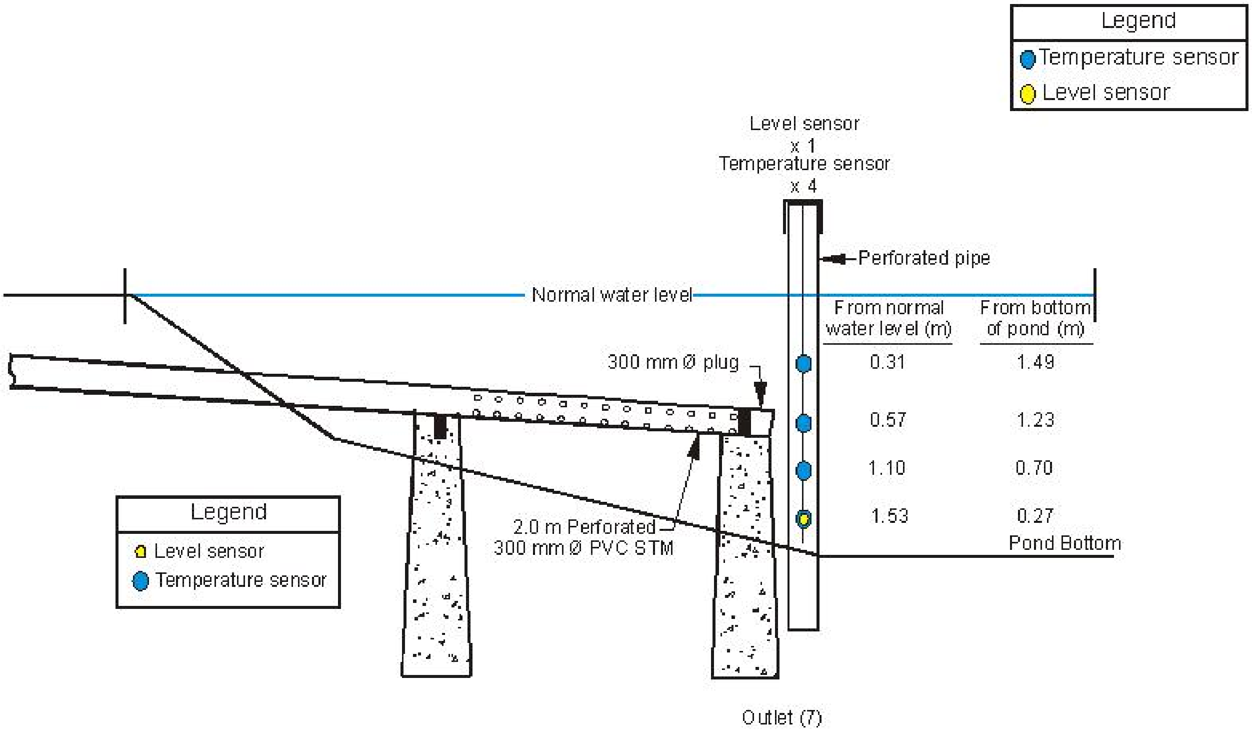


Figure 4.3: Normal outlet showing location of temperature and water level sensors (not to scale). See Table 4.1 for number references

5.0 STUDY FINDINGS

5.1 Cooling Trench System

Monitoring of the cooling trench system was initiated in late August 2011, after the inlet was replaced and the valves had been opened. Monitoring equipment was removed during the cold season, and re-installed in late May 2012. Monitoring continued from May to September, 2012. Air temperatures during the primary monitoring period from June to September, 2012 were on average 0.8°C warmer than the 30 year Climate Normals (1971 – 2000) from Pearson Airport. Over the same period, minimum air temperatures were 5°C lower and maximums were 8°C higher than Climate Normals.

Flow measurements at the outlet catchbasin of the system during a dry period showed the system to be flowing at only 0.23 L/s during dry weather. Higher flow rates were observed visually after rain events, when pond levels were high, but these flow rates would still have been well below the maximum design rate of 5.4 L/s.[1] Infiltration may have reduced flow volumes through the system, although visually, flow through the orifice in the control manhole appeared to be similar to system outflows.[2] During rain events, water levels in the control manhole rose above the system outlet elevation indicating that at least part of the restriction in flow was occurring within the trench itself. Further investigation is required to identify the specific cause(s) of the flow restriction. Despite these deviations relative to design flow rates, however, there was sufficient water passing through the trench to allow for a robust assessment of the overall thermal mitigation benefits of the system.

5.1.1 System Temperatures

Results of monitoring in 2011, from late August to the end of September, showed temperatures from the cooling trench outlet fluctuating between 15 and 17°C (see Appendix B). The maximum temperature of water entering the trench during this period was 29°C.

In late May, 2012, when the system was re-commissioned, similar outlet temperatures were observed. However these temperatures gradually rose in June, and remained between approximately 20 and 25°C until early September (Figure 5.1). As shown in Figure 5.2, the primary benefit of the cooling trench system occurred at higher pond inlet temperatures. When these inlet temperatures rose above 25°C, the outlet discharged water at temperatures that were between 2.5 and 5.0°C lower, mostly due to less pronounced diurnal fluctuations in temperature. Close to half of this temperature drop through the system occurred in the manhole where contact surface area would have been only a small fraction of that available in the trench.

---

[1] Only the east catchbasin was flowing during dry weather, presumably because the dual 200 mm Ø perforated pipes to the east catchbasin were at a lower elevation, causing preferential flow to that side.

[2] Flow rates into the manhole through the orifice could not be accurately measured.

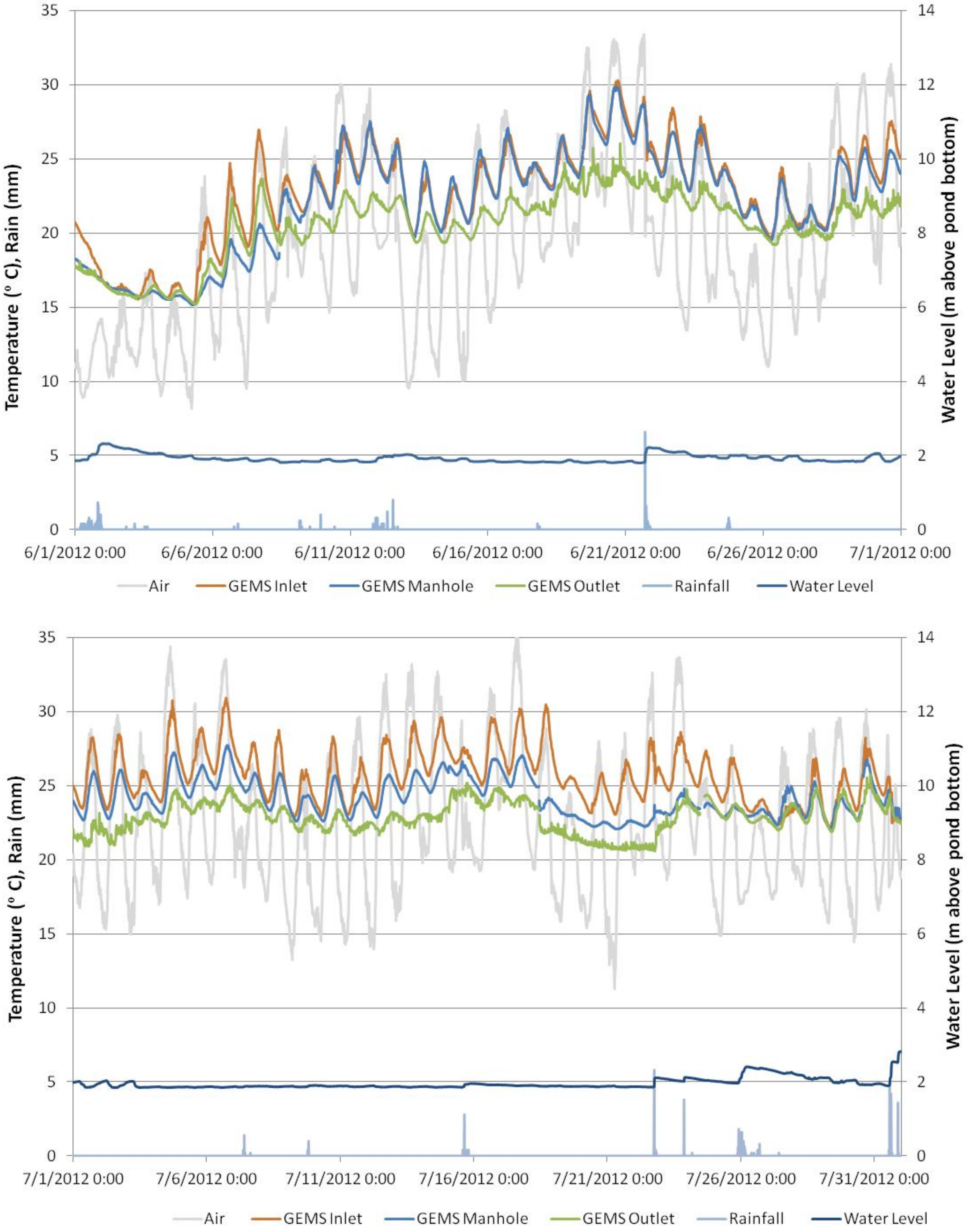
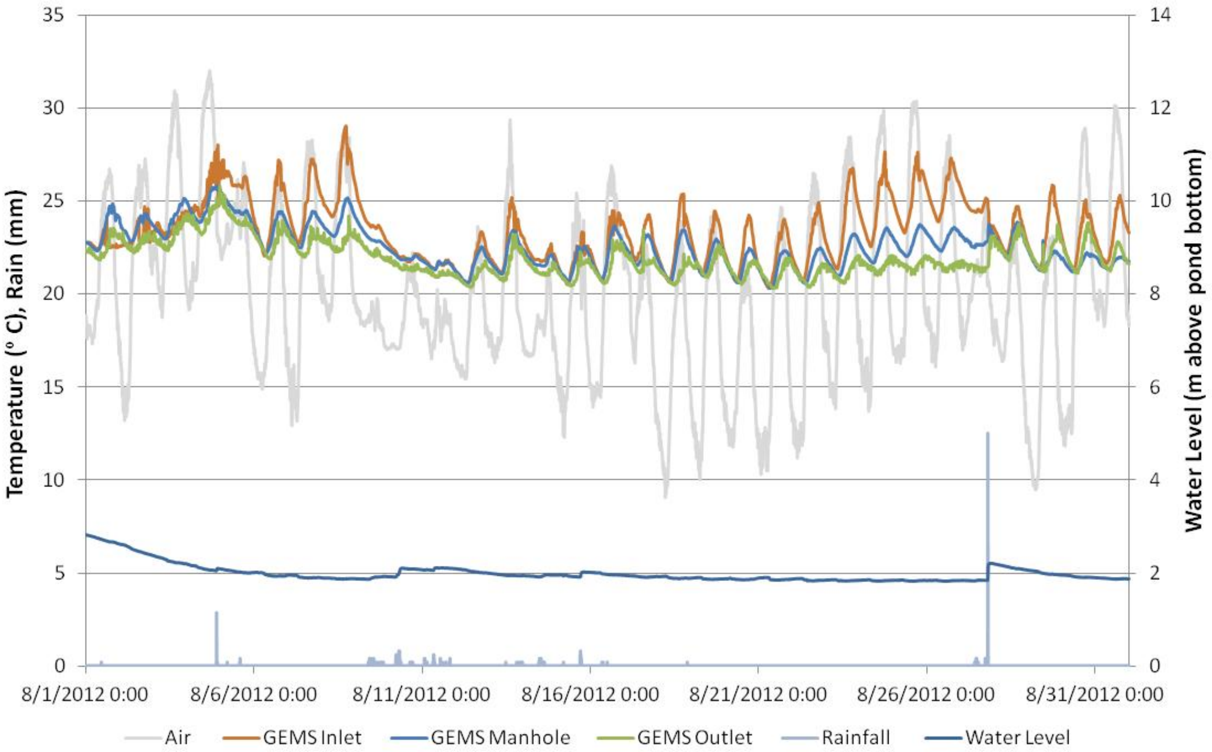


Figure 5.1: Monthly time series plots of air temperature, system water temperatures, rainfall and pond water levels.



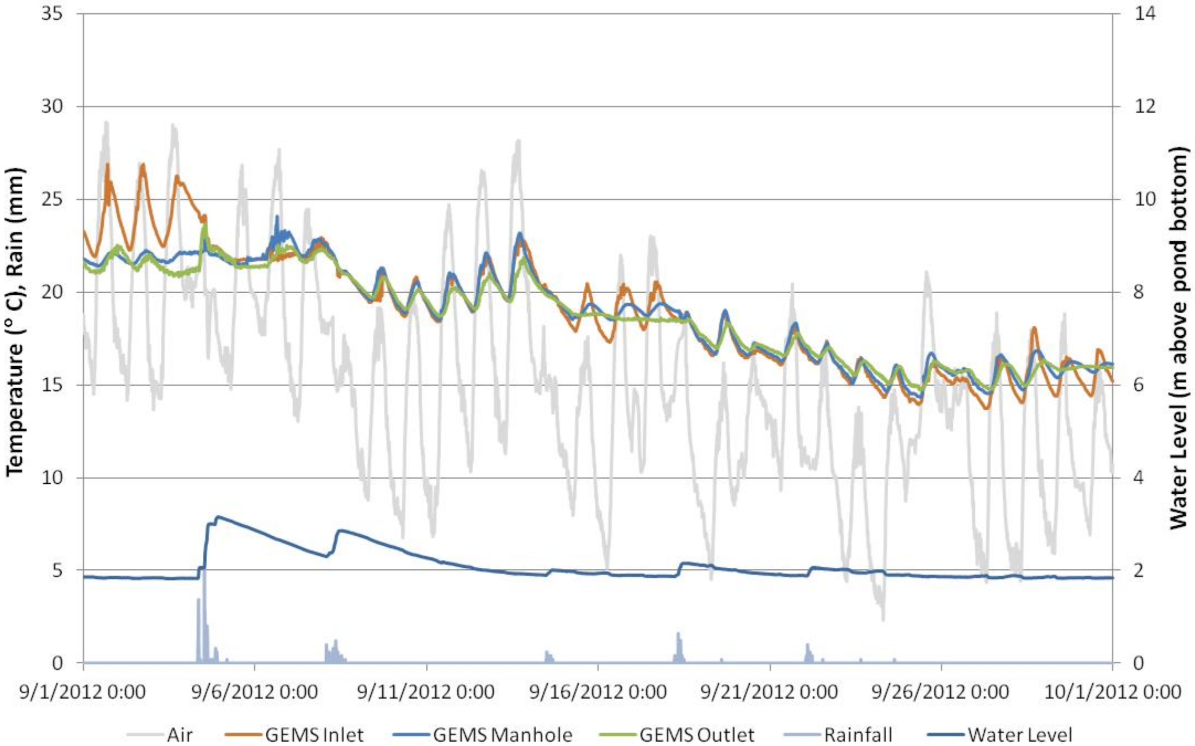


Figure 5.1 (continued): Monthly time series plots of air temperature, system water temperatures, rainfall and pond water levels.

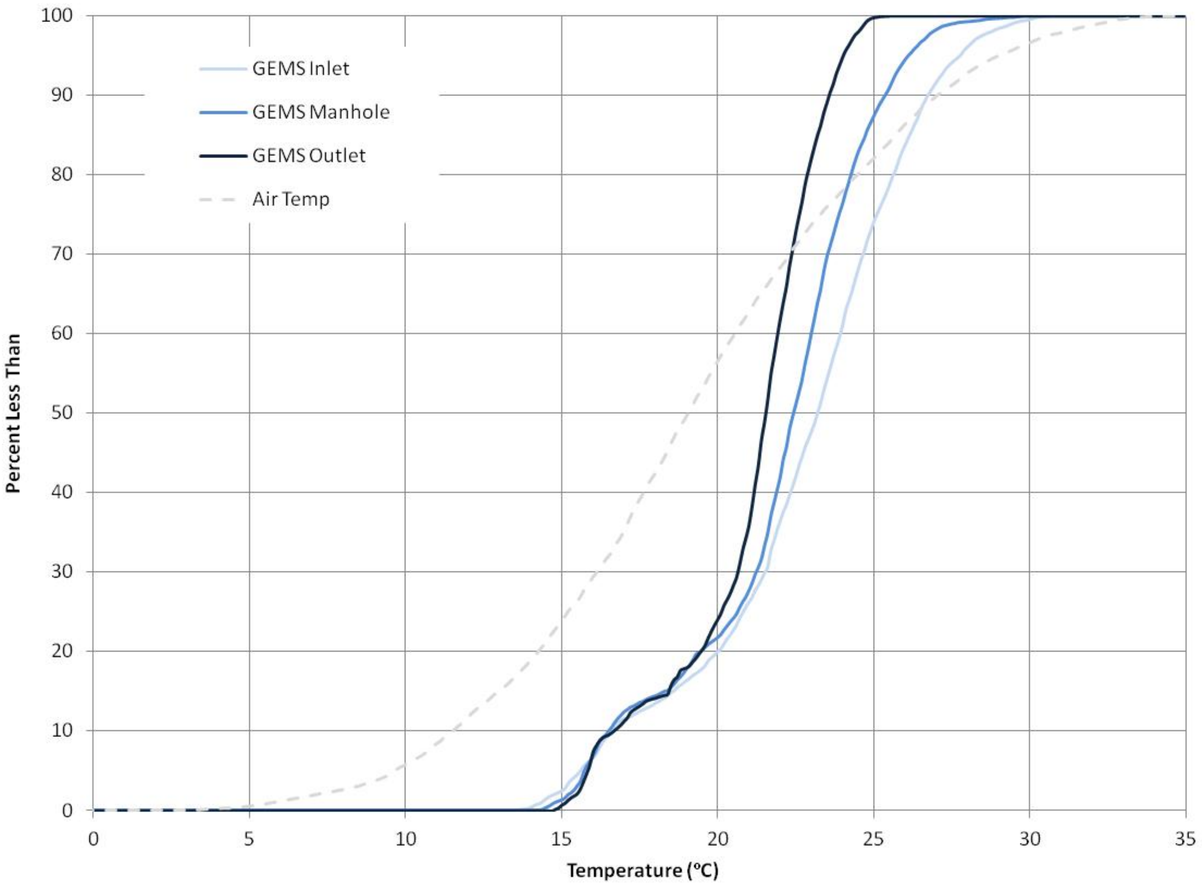


Figure 5.2: Cumulative frequency plots for the cooling trench system (June 1 to Sept. 30, 2012)

5.1.2 Outlet and Receiving Water Temperatures

Figure 5.3 shows the temperature of the cooling system and normal pond outlets relative to the receiving water system upstream and downstream of where the two outlets discharge to the stream. The normal pond outlet had peak temperatures of approximately 3 to 4°C warmer than observed from the cooling system outlet. These warmer pond temperatures resulted in an increase in the temperature of Carlton Creek by approximately 0.7°C during the warmest periods. Although the cooling trench temperatures were slightly warmer than the Creek, discharge volumes were too small to significantly influence stream temperatures.

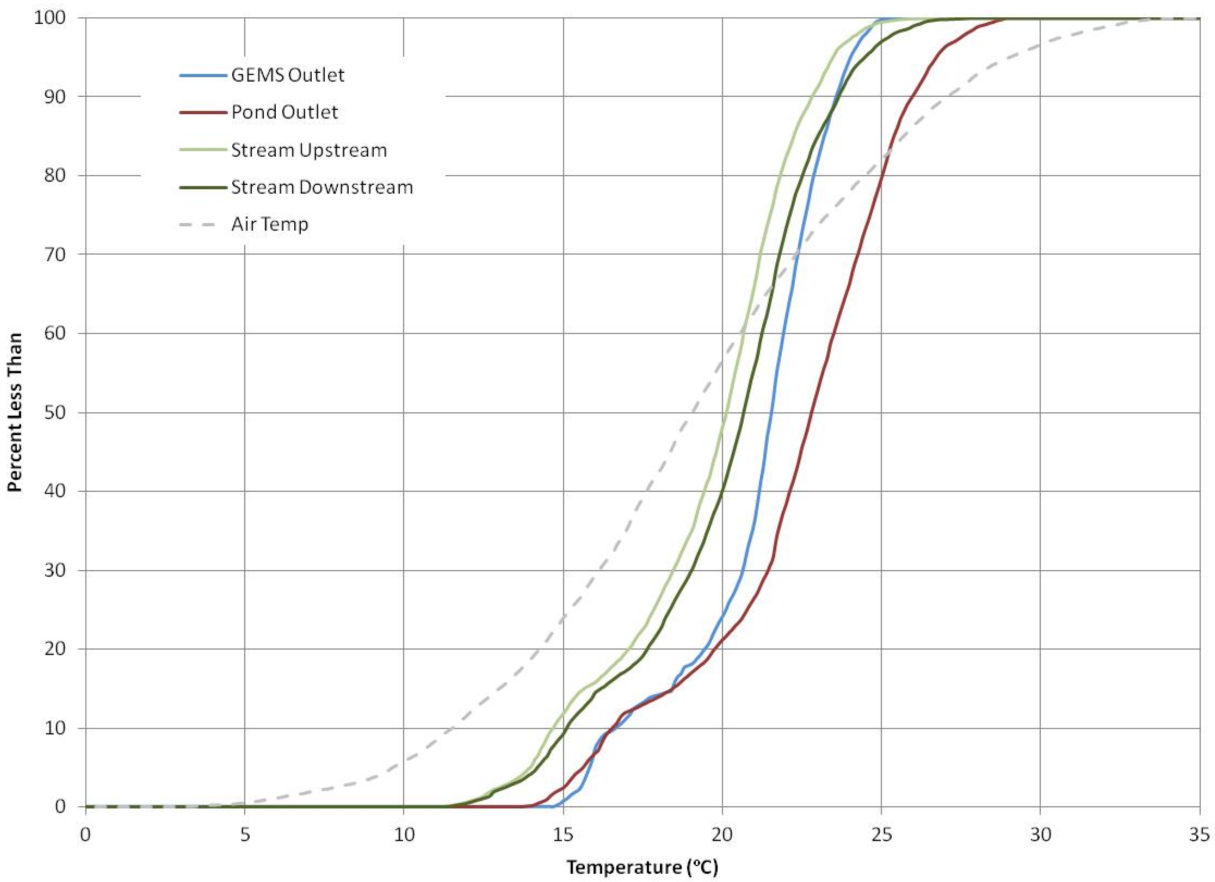


Figure 5.3: Cumulative frequency plots for air temperature, the cooling system outlet, normal pond outlet and stream temperatures upstream and downstream of the pond discharge location (June 1 to Sept. 30, 2012)

5.1.3 System Total Suspended Solids Removal Efficiencies

In November 2011 and September 2012, samples were taken shortly after rain events to assess the capacity of the system to filter total suspended solids (TSS), even though the modified inlet was not expected to provide significant filtration. Results presented in Table 5.1 show relatively low influent concentrations, with an average reduction in TSS of only 25% from the inlet to the outlet of the system. The cause of the decline in TSS removal from November 2011 to September 2012 requires further investigation, but may have been a result of sediment build-up in the outlet catchbasin. TSS in samples consisted primarily of silt and clay sized particles, with d_{50}s of individual samples ranging from approximately 3 to 10 microns. These fine particles remain suspended for long time periods and are not easily filtered from flowing water.

Table 5.1: System suspended solids concentrations and removal rates

Storm Event Date	Total Suspended Solids (mg/L)		TSS Reduction (%)
	Inlet	Outlet	
23-Nov-11	25.5	7.9	69
29-Nov-11	47.6	28.5	40
5-Sep-12	56.6	76.2	-35
Average	43.2	37.5	25

5.2 Pond Water Temperature

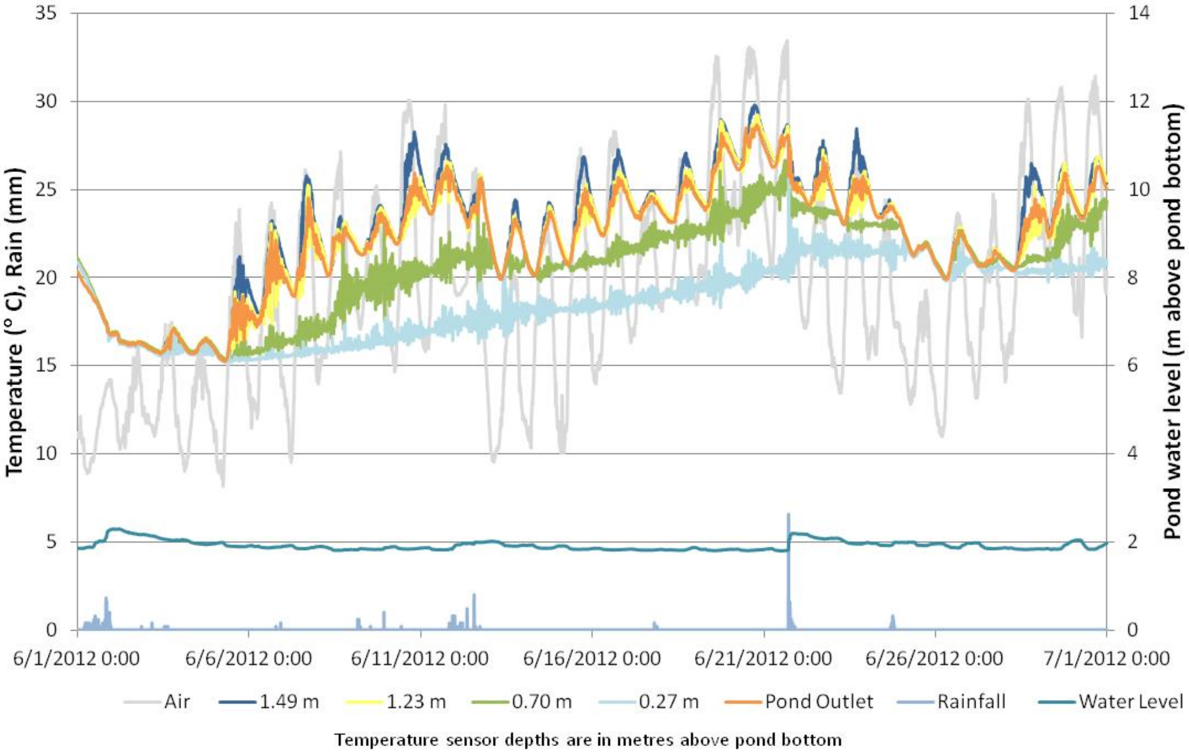
As noted earlier, the normal outlet of the pond draws water via a reverse slope, partially perforated pipe located approximately 1.2 to 1.3 m above the pond bottom (or roughly 40 to 50 cm below the permanent pool elevation). A depth profile of temperature sensors were installed at the outlet in 2011 and 2012 to assess the potential cooling effect associated with drawing water either nearer or further below the permanent pool water surface. Water temperatures were also measured in the stream channel upstream and downstream of the discharge point of the pond (see Figure 4.1 and 5.3).

Results for the shorter 2011 season (June 21 to September 20) are presented in Appendix B. Temperature profile data for the full 2012 season (June to September) are presented in Figures 5.4 and 5.5. Box plots of all temperatures are provided in Appendix C.

The maximum temperature of the mid draw pond outlet in 2012 was 29°C, which is only slightly higher than measured in 2011. The primary benefit of bottom or mid draw outlets is that they avoid extreme diurnal fluctuations caused by direct solar radiation on the pond surface. Figure 5.4 shows this effect during warm dry periods throughout the summer. The two sensors furthest from the bond bottom (1.23 and 1.49 m) and closest to the surface (0.31 and 0.57 below the normal water level) exhibited more pronounced diurnal changes, with temperatures rising during the hot summer day and falling at night. The third deepest sensor at 0.70 m from the bottom (1.10 m below normal water level) was less affected by diurnal temperature changes, varying only slowly with air temperatures. The deepest sensor at 0.27 m above the bottom (1.53 below the normal water level) exhibited the most constant temperatures (typically between 20 and 24°C), and was least affected by changing climate conditions. This sensor had temperatures up to 5.0^{o}C cooler than pond water measured 1.22 m higher, and had a temperature range slightly below that of the cooling trench outlet.

During rain events, pond outlet temperatures usually declined because new water entering the pond promoted mixing of thermally stratified layers, and as pond water levels rose, the fixed outlet drew water from further below the surface (*e.g.* June 25 – 28; July 25 – 30). Cloud cover during and after rain events also reduced air temperatures and solar heating of the pond. This natural cooling effect associated with rain events helps reduce effluent temperatures when pond discharge rates are highest.

The depth profile data indicate that a surface draw outlet would have increased both the maximum and average temperature of outflows. By contrast, an outlet drawing water from deeper in the pond would have discharged significantly cooler water than the current outlet, although maximum temperatures would still have been above the 21°C threshold for the protection of cold water fisheries. There is a practical limit, however, to how deep a bottom draw outlet can be installed as the lower portion of the pond acts as a reservoir for the long term accumulation of sediment. In most instances, this limit lies well below the existing outlet location, particularly if the area around the outlet is dug deeper, as has been done in other ponds (e.g. SWAMP, 2003). In areas with high groundwater tables, however, further excavation around the pond outlet may not be feasible.



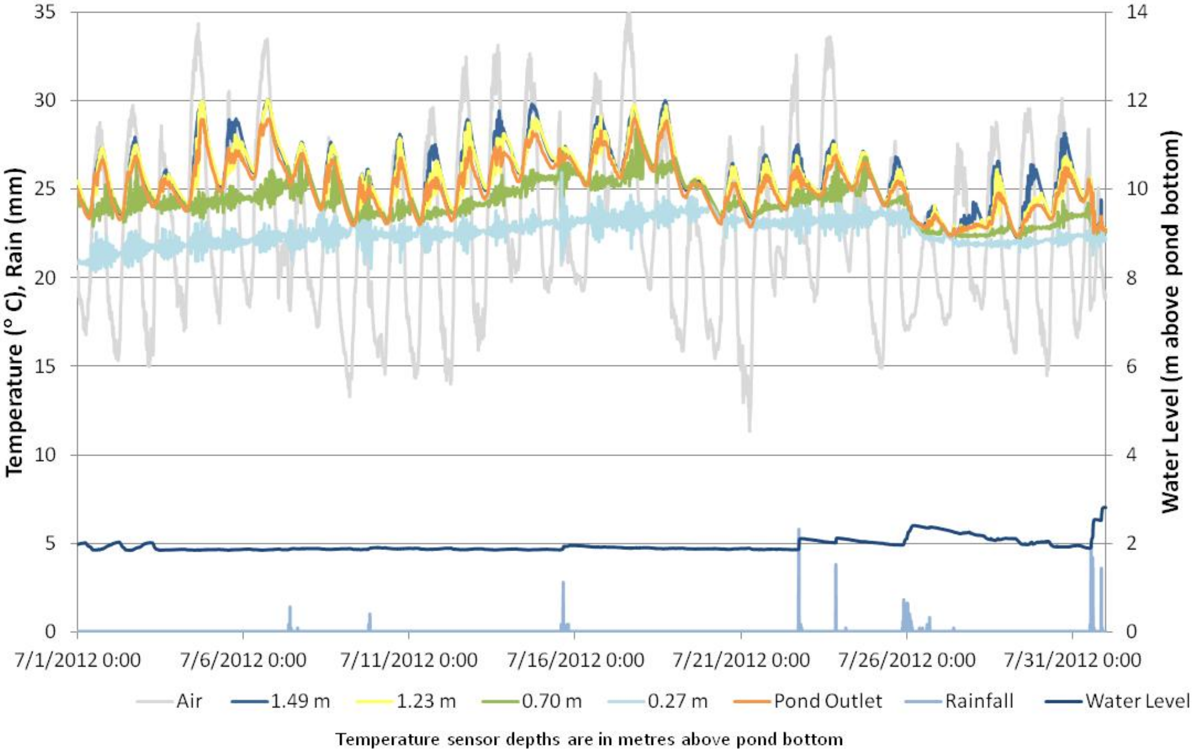


Figure 5.4: Monthly time series plots of pond temperatures, water levels and rainfall. Temperature sensors were 0.27, 0.70, 1.23 and 1.49 m above the pond bottom, or approximately 0.31, 0.57, 1.10 and 1.53 m below the normal pond water level.

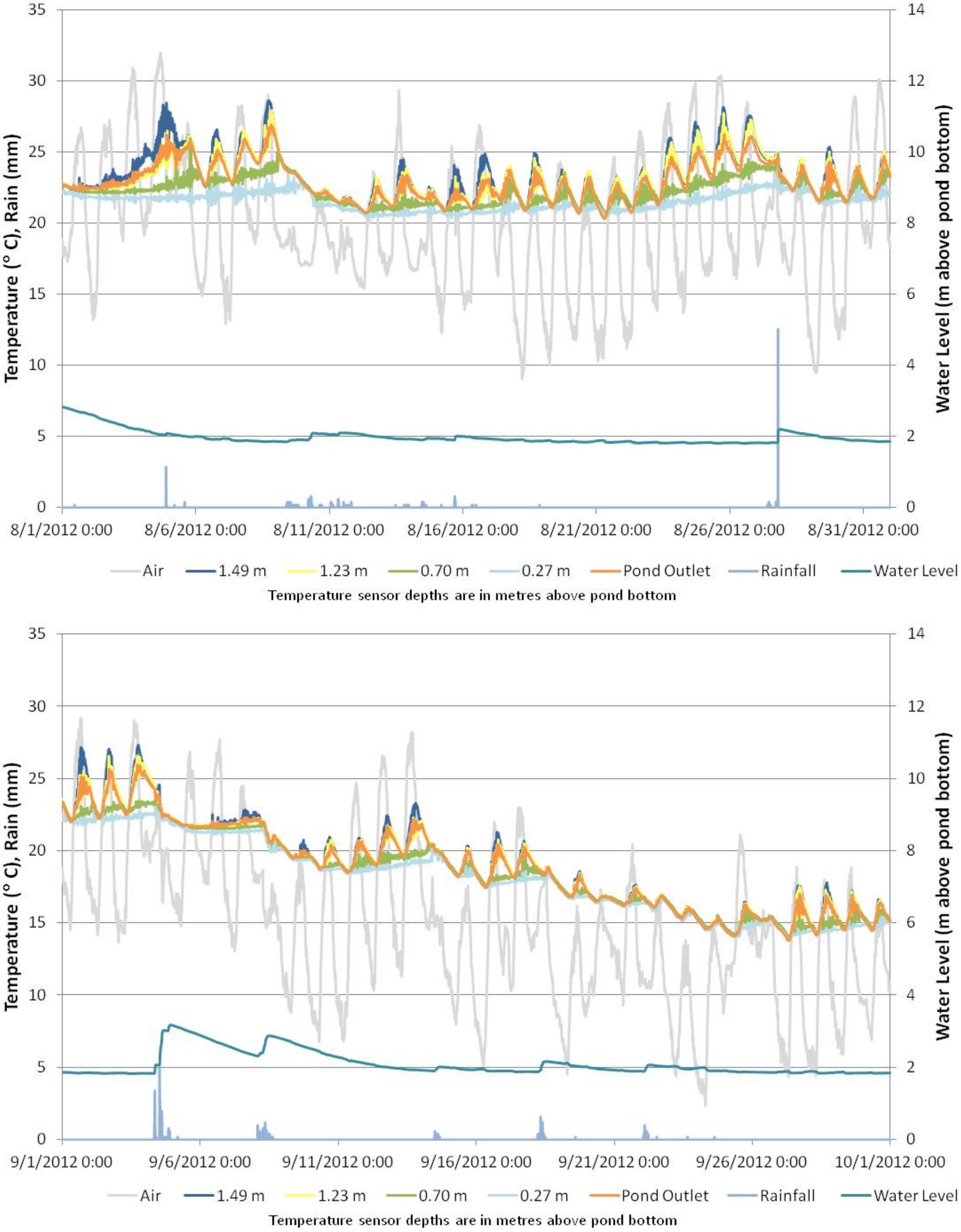


Figure 5.4 continued: Monthly time series plots of pond temperatures, water levels and rainfall. Temperature sensors were 0.27, 0.70, 1.23 and 1.49 m above the pond bottom, or approximately 0.31, 0.57, 1.10 and 1.53 m below the normal pond water level.

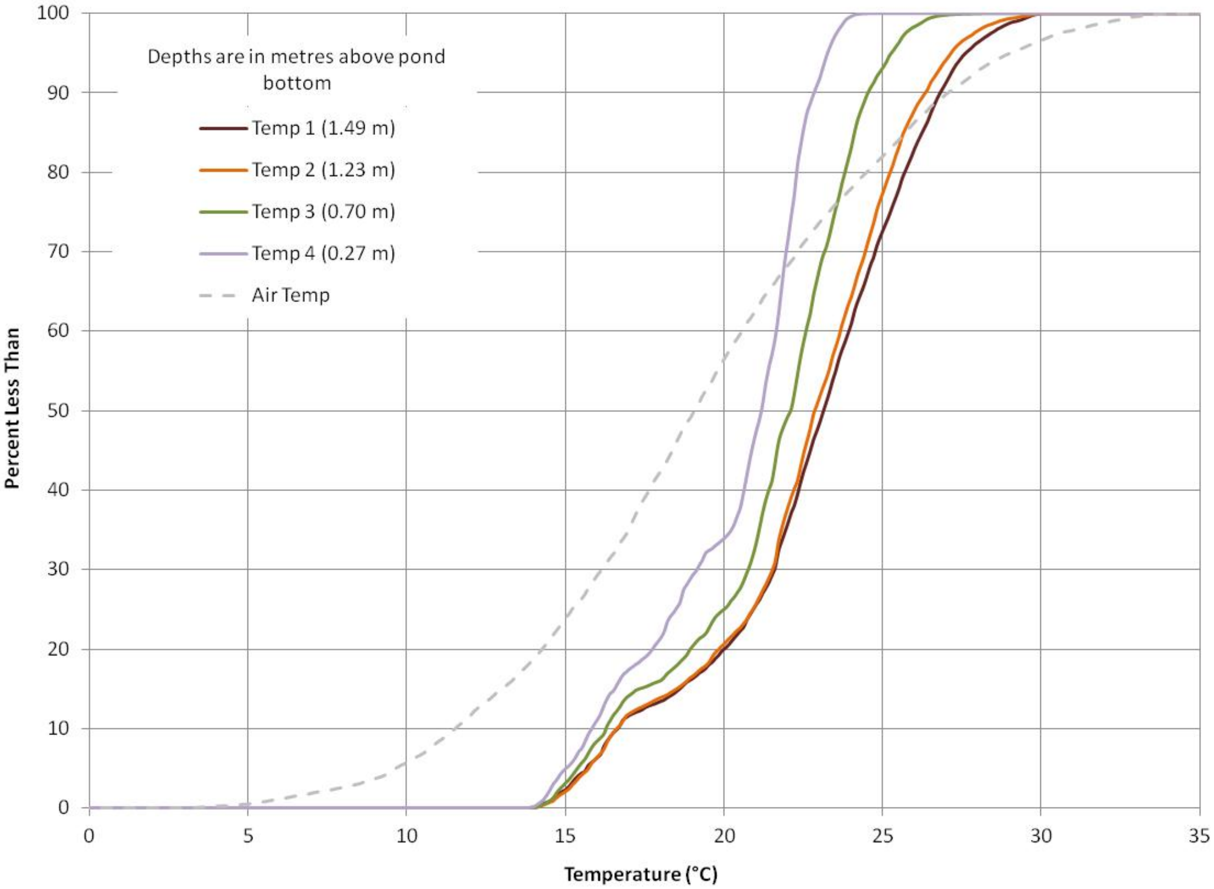


Figure 5.5: Cumulative frequency plots for air temperatures and water temperatures from June 1st to September 30th, 2012, at different depths in the pond. The cumulative frequency plot of pond outflow temperatures over the same time period (not shown) is similar to the pond temperature at 1.23 m above the pond bottom

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

Study results indicate that the cooling trench can mitigate the thermal effects of stormwater ponds and help replace groundwater discharge volumes lost from the reduction in infiltration caused by urban development. The temperature of water discharged from the system fluctuated between 20 and 25°C during the warmest months, and was up to 5°C cooler than system inlet temperatures. Close to half of this cooling benefit occurred as water passed through the control manhole before entering the trench. While the overall reduction in temperatures clearly provided a thermal benefit, the system outlet temperatures were considerably warmer than groundwater discharge to streams and above the 21°C threshold established for the protection of cool water fisheries.

When the system was commissioned in 2011, the 100 mm Ø perforated inlet pipe installed in a 50 m by 3 m infiltration trench along the pond embankment was clogged and needed to be replaced with a modified inlet that drew water directly from the pond through filter cloth. This modification reduced the potential filtering benefits of the system, resulting in relatively low overall TSS removal (average removal 25%; average concentration 37.5 mg/L). It is expected that a portion of the effluent TSS may have been sourced from the outlet catchbasin.

Flow rates through the system were lower than the average design flow rate of 3.6 L/s. The slower flow rates would be expected to enhance temperature reductions by increasing retention times, but the lower volumes of flow through the system may have reduced the overall thermal benefit of the system to Carlton Creek. The system would also have failed to meet its baseflow augmentation objectives, which were based on a flow rate that was sufficient to compensate for the reduction in infiltration and groundwater recharge caused by conversion of the catchment from agriculture and open space to residential land use.

The depth profiles of temperatures in the pond showed a peak temperature difference over 1.2 m of between 4.5 and 5.0°C, highlighting the potential thermal benefits of reverse slope outlet configurations that draw water from deep within the pond. The two temperature sensors greater than 1 m below the normal pond water level showed less pronounced diurnal variations and were less affected by mixing during rain events than sensors nearer to the water surface. The deepest sensor, at roughly 1.5 m below the normal water level, exhibited a temperature range of between 20 and 24°C during the warmest months. This temperature range is slightly below that of the cooling trench outlet, suggesting that similar outflow temperatures may be achieved by lowering the invert of the reverse slope outlet to draw water from deeper within the pond. This may require excavating a deeper sump in a wide area around the outlet to provide a larger area for deposition of settled solids. The baseflow augmentation benefits of the cooling trench could also be achieved through the outlet structure with an orifice that drains water from the pond continuously at a rate similar to the target design flow rate of the cooling trench. However, unlike the cooling trench, this outlet configuration would not provide similar opportunities to reduce thermal and pollutant loads to receiving waters through infiltration.

6.2 Recommendations

The following recommendations on further monitoring and research are provided for consideration.

1. The cooling trench evaluated in this study was originally intended to receive filtered water at a continuous discharge rate from the pond's permanent pool through a perforated pipe installed in a trench along the pond embankment. This inlet became clogged with sediment and was subsequently replaced with a simple direct connection inlet. Further monitoring is needed of similar infiltration trench inlets constructed with coarser clear stone granular material to assess the potential filtration benefits of this type of inlet configuration and their capacity to convey water without clogging.

2. Flow rates through the system were considerably lower than the target design flow rate. These lower flow rates would be expected to improve thermal performance by increasing the time available for heat transfer. The effect of flow rate on system performance requires further study. Experimentation with larger trenches that have longer retention times should also be undertaken.

3. The cooling trench system monitored in this study was located in a wet area adjacent to the pond. Monitoring programs of cooling trenches in wet areas should include measurements of groundwater levels and temperatures to assess the potential effects of groundwater interactions on system performance.

4. The cooling trench has the potential to significantly enhance the baseflow and thermal mitigation objectives of the system through infiltration. In this project, however, the system's infiltration potential was inhibited by its location in a low lying wet area with high water table. Where feasible, the trench should be constructed at a higher elevation above the water table to enhance its capacity to infiltrate stormwater.

5. Experimentation with cooling trenches constructed from large void chambers or tanks is recommended as other researchers have shown that stone media contributes very little to the thermal cooling benefits of trenches.

6. This study showed that water temperatures near the bottom of ponds were similar to the temperature of water discharged from the cooling trench. Bottom draw outlets have been shown in previous studies to be an effective method for reducing the thermal impacts of stormwater ponds. Different optimized bottom draw outlet structure designs with baseflow augmentation capabilities need to be monitored to quantify their thermal mitigation benefits more precisely, and document other potential adverse effects on water quality and operational requirements.

7.0 REFERENCES

CVC, 2011. *Thermal Impacts of Urbanization Including Preventative and Mitigation Techniques*. Credit Valley Conservation

Ministry of the Environment (2003). *Stormwater Management Planning and Design Manual*. ISBN-0-7794-2969-9.

Sabouri, F, Gharabaghi, B., Perera, N., Mc Bean, E. 2013. Draft. *Evaluation of the Thermal Impact of Sstormwater Management Ponds*.

SWAMP, 2002. *Performance Assessment of a Pond-Wetland Stormwater Management Factility – Markham, Ontario*. Toronto and Region Conservation Authority.

SWAMP, 2003. *Performance Assessment of a Highway Stormwater Quality Retention Pond – Toronto, Ontario*. Toronto ad Region Conservation Authority

SWAMP, 2005. *Synthesis of Monitoring Studies Conducted under the Stormwater Assessment and Monitoring Performance Program*. Toronto and Region Conservation Authority

APPENDIX A: Construction Drawings

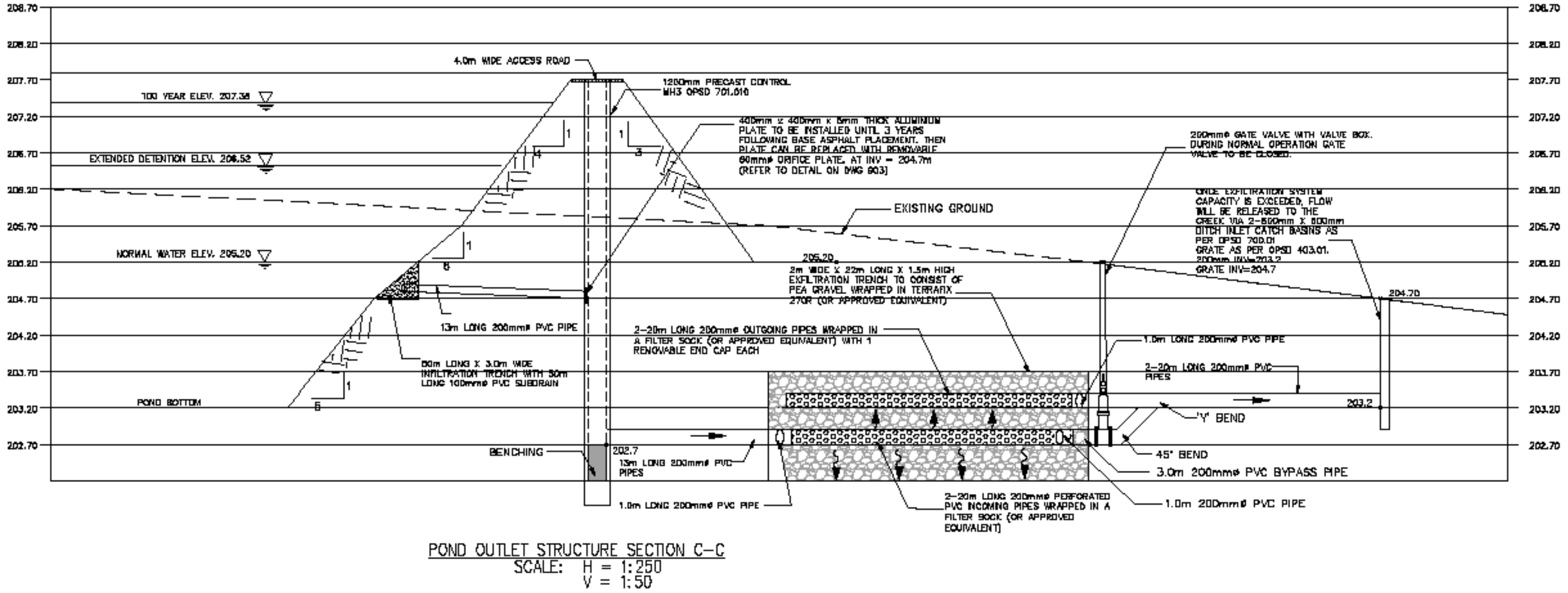


Figure A1: Cooling Trench System Details

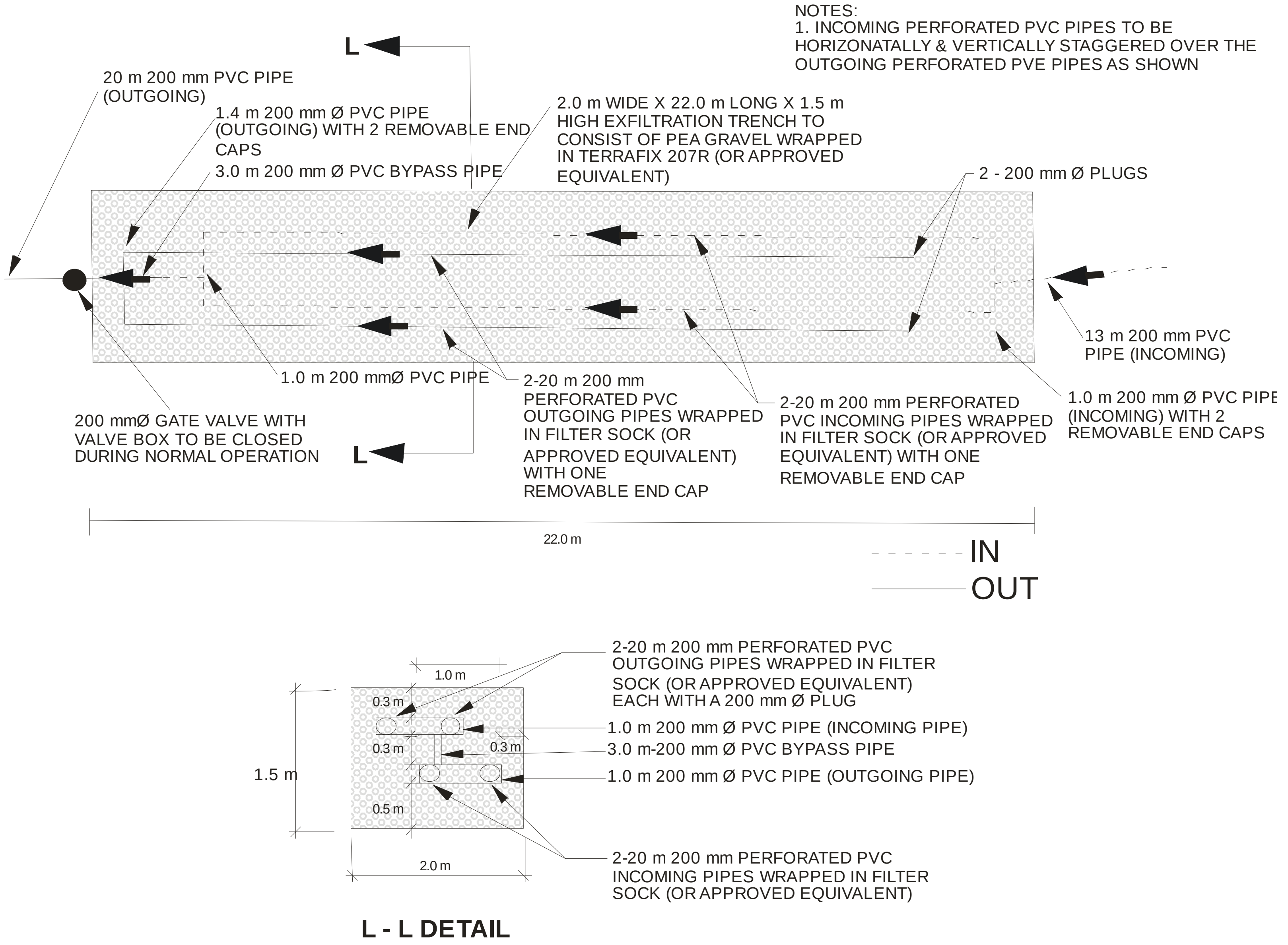


Figure A.2: Cooling Trench details

APPENDIX B: 2011 Monitoring Season

Cooling Trench System

Monitoring in 2011 was initiated in late August after the cooling trench system had been commissioned and verified to be functioning. Figure B.1 shows air and water temperatures at the inlet and outlet of the system for a one month period after initiation of monitoring. Once water started flowing through the system, temperatures dropped over several days, reaching a relatively constant equilibrium at between 15 and 17°C. During a particularly warm period from the 2nd to the 4th of September, air temperatures rose to 31°C, causing pond temperatures to rise to 27°C (Table B1). Pond water directed into the manhole reached a maximum temperature of 29°C. The maximum and average temperature of outflow from the cooling trench was 10.6 and 7.6°C cooler, respectively. This difference is greater than observed in 2012 because the trench had not been receiving warm water over the summer, and therefore had greater cooling capabilities.

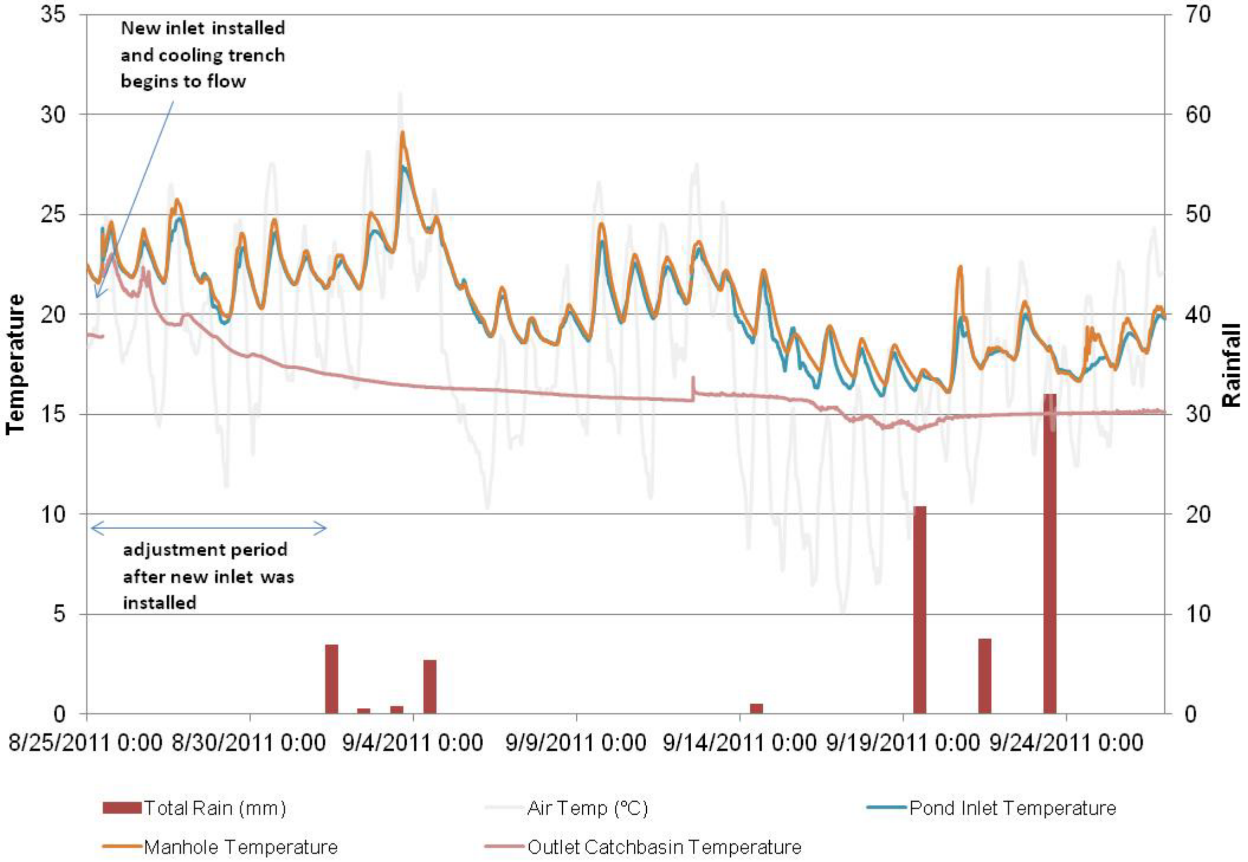


Figure B.1: Inlet and outlet temperatures for the cooling trench after modification of the inlet.

Table B.1: Temperature difference from the 2nd to the 4th of September,2011

	Air Temperature (°C)	Pond Inlet Water Temperature (°C)	Manhole Water Temperature(°C)	Cooling Trench Outlet (°C)	Temperature difference (°C) Inlet vs CT outlet
Maximum	31.0	27.4	29.1	16.8	10.6
Minimum	16.3	21.3	21.3	16.3	5.0
Average	23.1	24.1	24.4	16.5	7.6
Median	23.5	24.1	24.3	16.5	7.6

Pond Temperature Monitoring

Summary temperature statistics for the early and late summer of 2011 are presented in Table B.3. Summer data from the depth profile between these dates were not available. As shown in the Table, the maximum outlet temperature was 28.5°C. The upstream and downstream temperature measurements showed that, during the early summer period, discharge from the pond outlet resulted in a 1.5°C increase in the maximum stream temperature, and a 0.4°C increase in the average temperature. These increases were similar during the late summer, although outlet temperatures were lower during this period.

Table B.2: Pond and Stream Temperatures

	Depth Profile (°C)*				Outlet Channel (°C)	Upstream (°C)	Downstream (°C)
	1.49 m	1.23 m	0.70 m	0.27 m			
Jun 21 to Jul 18							
Maximum	29.8	29.7	27.5	25.3	28.5	25.7	27.2
Minimum	15.5	15.9	15.5	15.9	19.7	16.4	16.7
Average	23.8	23.7	22.6	21.2	23.4	20.6	21.0
Median	23.9	23.9	23.3	21.2	23.7	20.5	20.6
Aug 25 to Sept 20							
Maximum	28.3	26.6	24.2	22.8	25.2	22.7	23.9
Minimum	16.1	16.3	16.2	16.2	15.7	12.1	12.1
Average	21.1	21.0	20.2	19.8	20.7	18.0	18.4
Median	21.4	21.4	20.4	19.7	21.1	18.3	18.7

*Depth above pond bottom. Approximate depths below the permanent pool water level are, from left to right, 31 cm, 57 cm, 110 cm and 153 cm, respectively.

Figure B.2 shows temperatures in the pond during two warm periods in the early and late summer. The differences in temperature were similar to those observed in 2012. Deeper sensors showed cooler temperatures and lower variation than sensors closer to the surface.

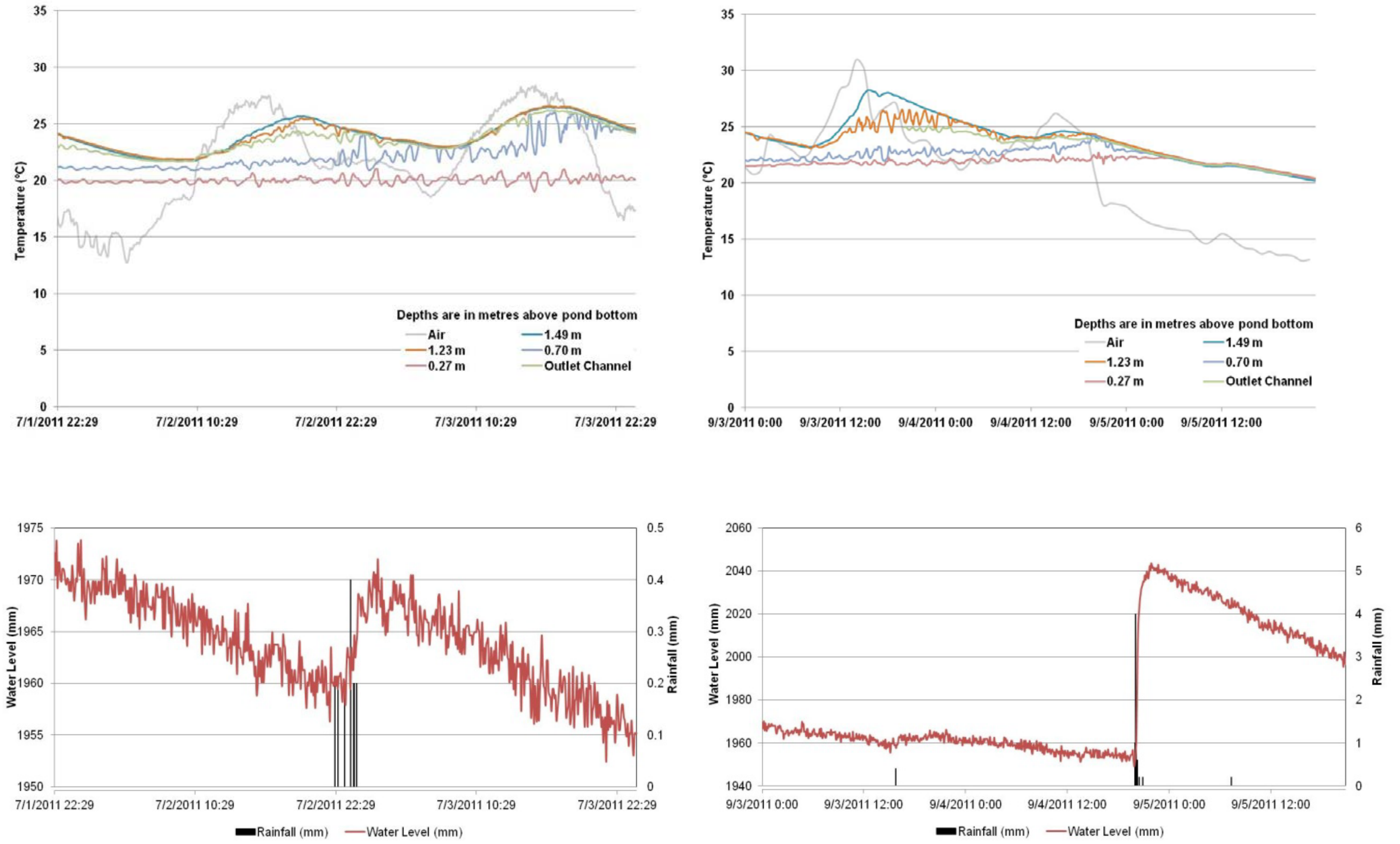


Figure B.2: Temperature depth profiles in the pond and within the outlet channel during warm periods before and after rain events.

Appendix C: Temperature Box Plots

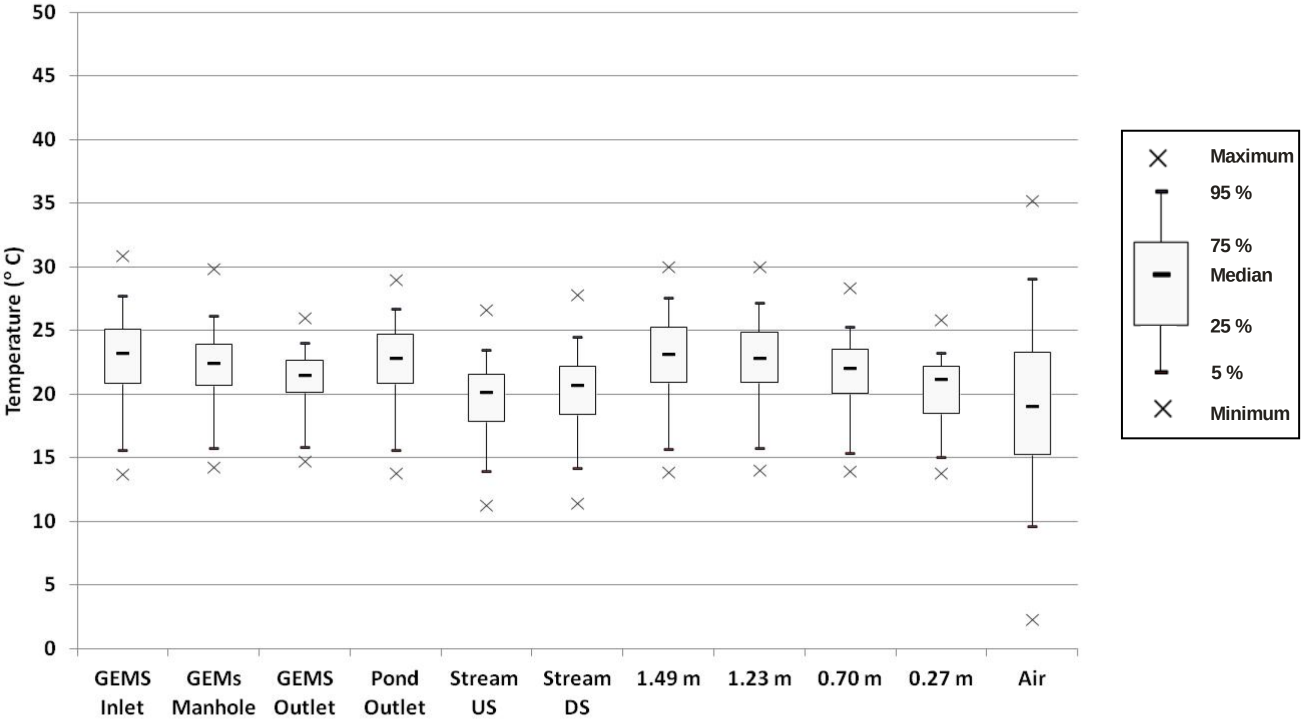


Figure C.1: Boxplots of water and air temperatures from June to September, 2012. The depth profile of temperatures in the pond were 0.27, 0.70, 1.23 and 1.49 m above the pond bottom, or approximately 0.31, 0.57, 1.10 and 1.53 m below the normal pond water level.