Sustainable Technologies
EVALUATION PROGRAM

Evaluation of shade balls for mitigating summer heating of stormwater management ponds

Final Report

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This final report summarizes key findings obtained during monitoring at the study sites, located in the City of Brampton, during the summer from 2018 to 2020. The report was prepared by Toronto and Region Conservation Authority with funding support provided by the City of Brampton. Microplastics analysis and the summary of results included herein were completed by Professor Elodie Passeport and Kelsey Smyth (MASc student and EIT) of the University of Toronto Department of Civil Engineering and Mineral Engineering.

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Documents prepared by the Sustainable Technologies Evaluation Program (STEP) are available at www.sustainabletechnologies.ca. For more information about this or other STEP publications, please contact:

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THE SUSTAINABLE TECHNOLOGIES EVALUATION PROGRAM

The water component of the Sustainable Technologies Evaluation Program (STEP) is a partnership between Toronto and Region Conservation Authority (TRCA), Credit Valley Conservation and Lake Simcoe Region Conservation Authority. STEP supports broader implementation of sustainable technologies and practices within a Canadian context by:

- 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.

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

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Context

Stormwater management ponds have become one of the most important and widespread practices for mitigating urban water quality and erosion issues in the Greater Toronto Area (GTA) since the 1980s. Although they are highly effective in improving stormwater quality and attenuating peak flows, they can also cause stormwater warming during summer months, with average temperature increases of between 4 and 11°C observed at GTA sites monitored.

These warmer outflow temperatures from GTA ponds, with maximums typically ranging from 26 to 31°C, can adversely impact certain local aquatic species that are sensitive to temperature changes, such as brook trout (Salvelinus fontinalis) and the endangered redside dace (Clinostomus elongatus). Based on this temperature sensitivity, the Ministry of Natural Resources and Forestry (MNRF) currently requests that temperatures from stormwater management ponds not exceed 24°C, particularly where facilities discharge to streams that serve as known or potential habitat for redside dace (MNRF, 2016).

A range of practices and techniques to mitigate the thermal impacts of ponds have emerged over the past few decades. This group of practices, known as thermal mitigation, covers a range of approaches that focus on either cooling water that's been warmed by the sun, preventing warming from occurring in the first place, selectively releasing only cooler water from ponds, and reducing total stormwater volumes through evaporation- and infiltration-enhancing measures like low impact development (LID). Over the past few decades, monitoring of these practices has demonstrated that while effective cooling strategies are possible, finding approaches that are easy and cost-effective to implement as retrofits to existing ponds can be a challenge.

Study description

Recognizing the limitations of existing measures, the City of Brampton decided to conduct pilot studies of cost-effective, low maintenance strategies that can be applied to retrofit existing ponds and help to meet the temperature criteria necessary to protect the habitat of species at risk in their municipality. The efficacy and feasibility of pond surface shading was identified as a promising strategy to evaluate in one of these studies.

This study pilots the partial shading of a stormwater pond in the City of Brampton using floating white shade balls and evaluates the effectiveness of this practice in preventing pond heating during summer months. Full-scale monitoring efforts focused on comparison of shade ball cooling performance to baseline conditions and to a nearby control pond, while small-scale testing was also carried out to evaluate the cooling performance of the white balls relative to black and reflectively-painted versions. Beyond monitoring of cooling performance, the study also considered the costs, maintenance requirements, and the potential for ball degradation to cause microplastics pollution.

Two stormwater management ponds located in the City of Brampton were selected for thermal monitoring as part of this pilot study: one pond where shade balls would be deployed to cover 75% of the surface (Figure 1) and one control pond. The shade balls were installed at a stormwater pond called Esker Pond, located near Moldovan Dr. and Father Tobin Rd. in the West Humber River subwatershed. The pond was selected due to its relatively small size, which made it suitable for a pilot test.

Figure 1: Esker Pond in Brampton, where shade balls were installed to provide 75% surface cover.

Separate small-scale testing of the balls was carried out using small wading pools which were placed in the photovoltaic field at the Kortright Centre for Conservation, located on Pine Valley Drive, just north of Rutherford Road in Vaughan. Testing at this site focused on understanding differences in shading performance between white, black and reflective paint-coated shade balls (Figure 2).

Figure 2: Small-scale testing to evaluate the effect of ball colour on cooling performance.

Results

Based on monitoring undertaken during the summers from 2018 to 2020, the white shade balls did not cause a significant reduction in pond warming in comparison to baseline conditions or the experimental control pond. The following are key findings from monitoring at the pilot sites:

- Comparison to baseline conditions (2018, prior to shade ball installation) revealed that the magnitude of warming from inlet to outlet was similar or even greater after the balls were in place. Before ball deployment, the median temperature increase from pond inlet to outlet was 3.3°C, and after it increased to 5.9 °C and 4.2 °C respectively in 2019 and 2020. This may be partly attributable to warmer weather, as median air temperatures were 2.8°C and 1.9°C higher in 2019 and 2020.
- There was no clear trend in the extent to which the shade balls increased the number of temperature measurements that met the 24 °C target for protection of redside dace, with 68%, 54% and 76% of measurements exceeding that threshold in 2018, 2019 and 2020 respectively.
- Comparison of shade ball to control pond outflows showed that median temperatures differed by less than 1°C during all years of monitoring, despite the fact that inflows were always much cooler at the control pond. This greater degree of warming observed in the control pond is less indicative of the shading performance of the shade balls and more likely attributable to the control pond's shallower depth and the fact that it started off with cooler inflows.
- The shade ball pond was more thermally stratified, likely due to its greater depth, with a median vertical temperature change (as measured in the shaded area) of 6.3°C, relative to only 2.1°C in the control pond. In both ponds, temperatures measured 30 cm from the bottom almost never exceeded 21°C, which backs up past research findings that subsurface draw outlets can be an effective way to achieve thermal targets, particularly in deeper ponds.
- Temperature depth profiles in the shaded and unshaded areas of the ball pond also showed that shading provided minimal cooling, as median temperatures were within 1 °C of each other at all depths. Notably, temperatures measured at the shallow sensors (near surface) were warmer under the shade balls than in the unshaded area, which could suggest that the balls are inhibiting evaporation (and the associated cooling effect) and allowing transmission of sunlight. Small scale testing later determined the balls were not opaque and were in fact transmitting light.
- In small-scale testing of white, black, and reflective-coated shade balls, the black balls were the most effective in preventing warming of water below, resulting in a median temperature 1.9 °C cooler and average daily maximum temperature 4.1 °C cooler than under the white balls. It was determined that the white balls were not opaque as originally believed at the outset of the study, while the black shade balls were opaque.
- Ball pond outlet samples contained nearly double the number of microplastics particles that were found in inlet samples, but because none of the particles found were fragments, which would be

expected from the breakdown of the balls, other sources within the pond could be contributing to the higher levels at the outlet.

- The black shade balls used in small-scale testing have double the lifespan and a16% lower capital cost than the white shade balls, making the black balls a significantly more economical choice.
- Over the course of the study, the shade balls were displaced and blown out of the containment area and into surrounding vegetated areas, likely due to emergent vegetation growing up through the shade ball area and/or freezing of the pond over the winter causing a heave effect. Preventing this displacement would likely require ball weighting (by filling with water) or taller barriers.

Recommendations

- **When selecting shade balls, opacity should be considered as a key factor determining performance.** While the shade ball's ability to fully block sunlight strongly affected its efficacy in keeping the pond cool, findings did not suggest that a full-scale installation of black shade balls would result in outflows that consistently meet the 24 °C threshold, unless the shading was combined with another thermal mitigation practice.
- **When considering installing shade balls, measures should be taken to prevent balls from being displaced and blown out of the pond.** Weighting balls by half-filling with water and/or installing a taller barrier could prevent them from being blown away. To prevent displacement, emergent vegetation should be removed regularly, or, if the facility is designed to include emergent vegetation in some areas, the balls should not be installed in that part of the pond.
- **While pond shading has the potential to prevent pond heating, it should be applied in conjunction with another thermal mitigation practice in order to provide sufficient cooling to meet thermal targets.** Research has demonstrated that shading practices like shade balls and floating islands, when applied as the only cooling practice, cannot yield pond outflows that are consistently below the 24 °C target. However if shading is applied effectively and in conjunction with other proven measures, like subsurface draw outlets, it can be an important part of a thermal mitigation design.
- **Future research on pond shading should consider the efficacy of other shading approaches and their potential for microplastics pollution.** Evaluating the performance of other shading options and approaches, like floating pond covers, alternative shade balls (e.g., fully opaque black or white balls), or more extensive surface coverage, would improve understanding of the efficacy of pond shading as a thermal mitigation practice, and determine whether the cooling effect can be significant enough to offset the reduction in evaporative cooling that may occur under any surface covers. Where plastics are being introduced by a pond shading device, microplastics analysis should be included as part of monitoring efforts in order to determine whether it's contributing to microplastics pollution in both the short and longer term.

1.0 INTRODUCTION

Stormwater management ponds have been established as an effective practice for mitigating urban water quality and erosion issues since the 1980s, and as a result, today there are over a thousand ponds currently operating in the TRCA jurisdiction. Despite their capacity to improve stormwater quality and attenuate peak flows, they have also been demonstrated to cause stormwater warming during summer months, primarily due to solar heating of stored water during inter-event periods.

1.1 The need for thermal mitigation

Figure 1.1: Redside dace

The typical maximum outflow temperatures from ponds in the Greater Toronto Area (GTA) range from 26 to 31°C, with observed inlet to outlet temperature increases of between 4 and 11°C during the summer months (TRCA, 2005; Van Seters and Graham, 2013; CVC, 2011). As this warmer water is discharged from the pond into receiving streams, it can adversely impact certain aquatic species that are sensitive to even small temperature changes, such as brook trout (Salvelinus fontinalis) and redside dace (Clinostomus elongatus), both of which inhabit local streams. Redside dace, which is found almost exclusively in the GTA, was designated as endangered in Ontario in 2007, mainly due to its sensitivity to habitat alterations that increase siltation and water temperatures. The Ministry of Natural Resources and Forestry (MNRF) currently requests that temperatures from stormwater management ponds not exceed 24°C, particularly where facilities discharge to streams that serve as known or potential habitat for redside dace (MNRF, 2016).

1.2 Current practices

There are several types of practices that have been developed and applied at ponds in Ontario to help cool water discharged from ponds during the summer season. Examples include practices that:

- Take cooler water from ponds (e.g., subsurface draw pond outlets, nighttime release outlets);
- Reduce outflow temperature (e.g., cooling trenches);
- Reduce thermal load by reducing total outflow volumes and increasing infiltration and evapotranspiration (e.g., LID); and
- Prevent solar heating of detained stormwater (e.g., pond shading, underground detention chambers).

The 2019 report entitled *Data Synthesis and Design Considerations for Stormwater Thermal Mitigation Measures* (TRCA and CVC) provides more detailed information on the real-life performance of these measures based on data collected in southern Ontario.

Deeper ponds that incorporate subsurface draw structures are one of the more commonly applied thermal mitigation measures in the GTA. While they are simple to design and construct, they can be more costly to maintain and challenging to apply on certain sites, such as retrofits and sites where the footprint available for a pond is limited. To construct a deeper pond, a larger footprint is often necessary to meet provincial criteria for side slopes of wet ponds, i.e., 5:1 above the permanent pool and 3:1 elsewhere. Further, the extent to which a deeper pond with a subsurface draw outlet, when applied as the only mitigation measures, can cool pond discharge to the desired temperature for protection of cold water fisheries is yet to be well established.

1.3 Thermal mitigation in Brampton

Recognizing the limitations of existing measures, the City of Brampton – home to over 650,000 residents, 180 stormwater management ponds, and many streams that serve as habitat for redside dace – has decided to explore the efficacy of new thermal mitigation approaches through pilot studies. The City is interested in cost-effective, low maintenance strategies that can be applied to retrofit existing ponds and help to meet the temperature criteria necessary to protect cold water habitat for species at risk. One of the thermal mitigation practises identified for evaluation on a pilot site is pond surface shading with shade balls. Since direct solar radiative heating of water is the primary cause of pond thermal enrichment, partially covering the ponds with a material that reflects solar radiation should significantly reduce the warming effect, resulting in cooler outflows.

2.0 STUDY OBJECTIVES

This study pilots the partial shading of a stormwater pond in the City of Brampton using high albedo shade balls and evaluates the effectiveness of this practice in preventing pond heating during warm summer months. The floating white shade balls, which were deployed to provide 75% coverage of the pond surface area, are used to cover its surface with a high albedo material that reflects incident solar radiation, deter bacterial contamination from birds, and allow heat transfer from the pond to the air at times when air temperatures are cooler than water temperatures. The specific objectives of this project are to:

- Evaluate the extent to which the presence of shade balls results in cooler pond discharge by comparing to temperatures measured before the balls were deployed and also to temperatures at a nearby control pond with similar characteristics;
- Assess the extent to which ball colour dictates reflectance, and accordingly the amount of heat transmitted through the ball and emitted to the water below, by conducting small-scale temperature monitoring of black, white, and reflective silver balls; and
- Assess and summarize other considerations that dictate the feasibility and desirability of shade balls as a solution, including costs, maintenance requirements, and the potential for ball degradation to contribute to microplastics pollution.

If proven effective, this cooling approach could be applied to new ponds and retrofits of existing ponds in Brampton and other municipalities, helping them to come closer to meeting the ministry's thermal criteria.

3.0 MONITORING SITES

3.1 Pond sites

Two stormwater management ponds located in the City of Brampton were selected for thermal monitoring as part of this pilot study: one pond where shade balls would be deployed to cover 75% of the surface and one control pond (Figure 3.1). The shade balls were installed at a stormwater pond called Esker Pond, located near Moldovan Dr. and Father Tobin Rd. in the West Humber River subwatershed (Figure 3.2). The pond was selected due to its relatively small size, which made it suitable for a pilot test. Once deployed into the pond the balls remain in place year round and are not removed or replaced until the end of their lifespan.

Figure 3.1: Shade balls pond (top) and control pond (bottom).

Figure 3.2: Location of Esker pond in Brampton where shade balls were installed in July 2018.

Installed within the shade ball pond was a barrier system (Figure 3.3) to hold in place the shade balls, which covered approximately 2000 m^2 - approximately 75% of the pond surface area. The barrier system, which keeps the balls in place, is a turbidity barrier consisting of geotextile fabric attached to a floating component at the water surface and an anchor component at the pond bottom. The float component extended 20 cm above the water surface to keep the balls in the enclosed area, while the anchor component consisted of chain and cinderblocks. The barrier was installed in a total of 10 sections, each having dimensions of 0.9 m by 15.2 m.

The hollow, white, high density polyethylene balls installed in the pond are roughly 10 cm in diameter. White balls were selected for their assumed higher albedo and capacity to reflect sunlight compared to black balls that were also available from the manufacturer. Typically referred to as bird balls and sold by the company Bird-X, the product's main applications are to prevent waterfowl from landing on toxic tailings and airport ponds, and to block UV light from drinking water reservoirs to prevent the formation of carcinogens like bromate (Oved, 2016). They are also used to prevent evaporation from water surfaces, which can be useful for keeping water in a reservoir but also for preventing odours leaving facilities like wastewater treatment lagoons. According to the supplier, the balls do not upset oxygen circulation or harm fish or other wildlife using the water body.

Figure 3.3: Barrier system in place before shade balls were deployed into the pond

The control pond selected for the study (Figure 3.4) is similar to the shade ball pond in size, located in the same subwatershed, and has a contributing drainage area that is similar with respect to land use. Design parameters of both ponds and characteristics of their contributing drainage areas are summarized in Table 3.1.

Figure 3.4: Location of control pond

Table 3.1: Design parameters of the shade ball and control ponds monitored

Design parameter	Shade ball pond	Control pond
Contributing drainage area (ha)	17.2	16.85
Permanent pool depth (m)	2	1.5
Permanent pool volume (m^3)	2774	2600
Extended detention depth (m)	0.9	0.61
Extended detention volume (m^3)	2577	2440
Quantity control depth (m)	0.3	0.26
Quantity control volume (m^3)	1066	1220
Outlet details	375 mm PVC plug with a 100mm circular orifice opening at the permanent water level elevation	Perforated riser pipe located on the edge of the pond where the water eventually flows through a 1.5m diameter outlet pipe

3.2 Small-scale testing site

Separate small-scale testing of the balls was carried out using small wading pools which were placed in the photovoltaic field at the Kortright Centre for Conservation, located on Pine Valley Drive, just north of Rutherford Road in Vaughan (Figure 3.5).

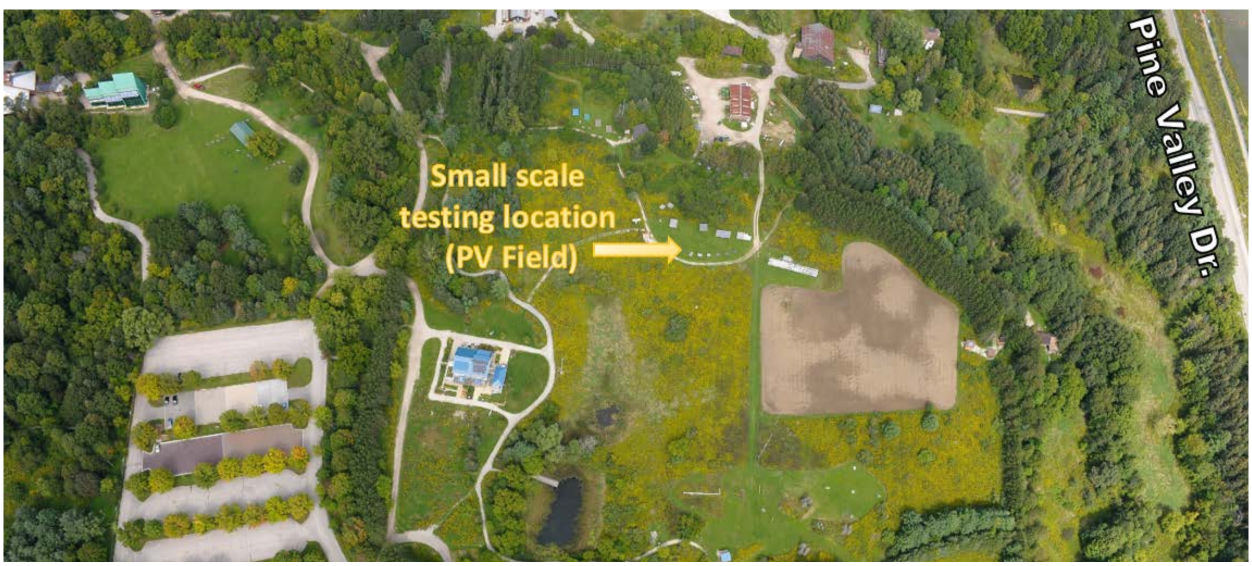

Figure 3.5: Small-scale testing location at the Kortright Centre for Conservation in Vaughan, ON.

4.0 METHODS

4.1 Pilot-scale shade ball evaluation

Monitoring of baseline temperatures and outlet water levels at the shade ball pond in Brampton was initiated in June 2018 and continued until shade balls were deployed into the pond in late August 2018. The balls were shipped and deployed into the pond (Figure 4.1) on two different dates - first on August 24, 2018, which resulted in pond surface area coverage of roughly 40%, and second on September 18, 2018, which covered the remaining 35% area to achieve the planned shading of 75%.

Figure 4.1: Installation of shade balls in August 2018.

Post-deployment monitoring at the shade ball pond continued until mid-September 2018 and resumed again over the summer months in 2019 and 2020. The control pond was monitored over the same time periods during the 2018, 2019 and 2020 monitoring seasons. Thermal data from the control pond provide a basis for comparison to data from the shade ball pond. While monitoring in 2018 was limited to pond inlets and outlets, in 2019 an additional component was added - temperature depth profiles at the deepest part of each pond. A summary of monitoring undertaken at both ponds is summarized in Table 4.2. Locations of monitoring equipment at the shade ball and control ponds are shown in Figures 4.2 and 4.3 respectively.

Table 4.1: Summary of monitoring undertaken at pilot study sites

<table>
<tr><th>Location</th><th>Monitoring period</th><th>Parameters monitored</th><th>Notes</th></tr>
<tr><td>Ball pond inlet</td><td rowspan="2">Jun - Sept 2018
Jun - Sept 2019
Jun – Sept 2020</td><td>Water temp.</td><td rowspan="2">Balls deployed in 2018 on Aug. 24 (1st shipment) and Sept. 18 (2nd shipment)</td></tr>
<tr><td>Ball pond outlet</td><td>Water temp., water level</td></tr>
<tr><td>Ball pond main cell (within shade ball area)</td><td>Jun - Sept 2019
Jun – Sept 2020</td><td>Water temp. profile (4 depths)</td><td>Placed in deepest part of pond</td></tr>
<tr><td>Ball pond main cell (just outside shade ball area)</td><td>Jun – Sept 2020</td><td>Water temp. profile (4 depths)</td><td>Placed in deepest part of pond</td></tr>
<tr><td>Control pond inlet</td><td rowspan="2">Jun - Sept 2018
Jun - Sept 2019
Jun - Sept 2020</td><td>Water temp.</td><td></td></tr>
<tr><td>Control pond outlet</td><td>Water temp., water level</td><td></td></tr>
<tr><td>Control pond main cell</td><td>Jun - Sept 2019
Jun - Sept 2020</td><td>Water temp. profile (4 depths)</td><td>Placed in deepest part of pond</td></tr>
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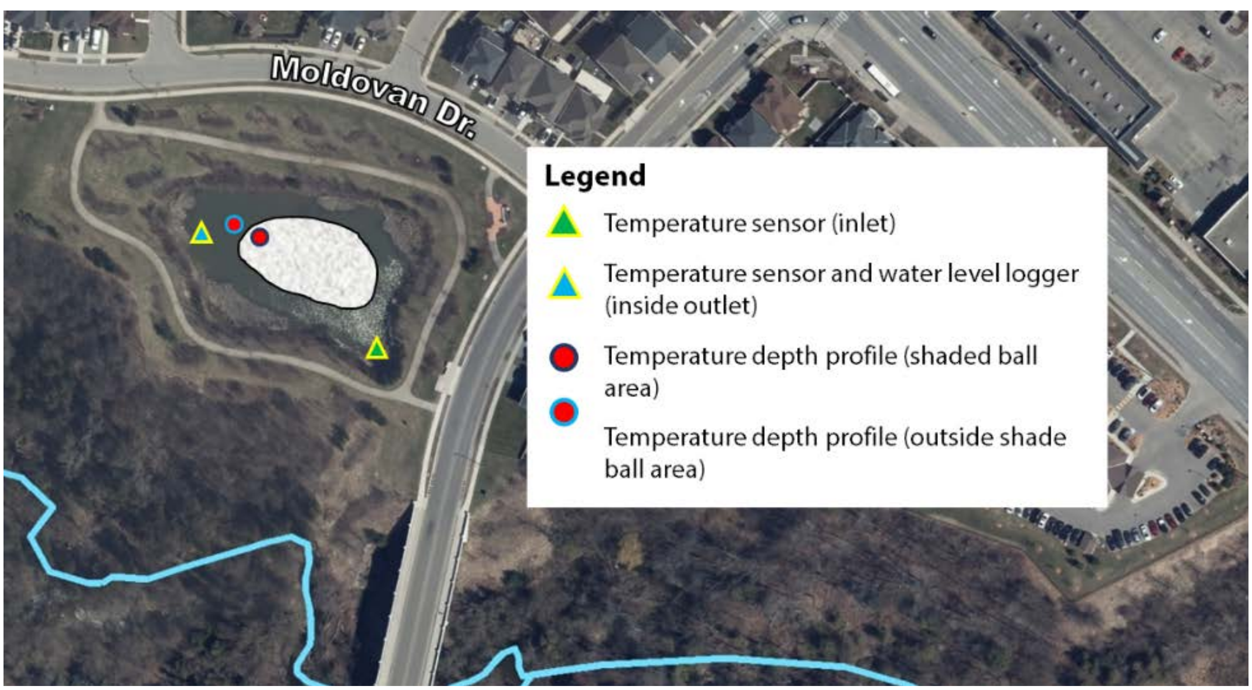


Figure 4.2: Monitoring equipment locations at the shade ball pond pilot site in Brampton, ON

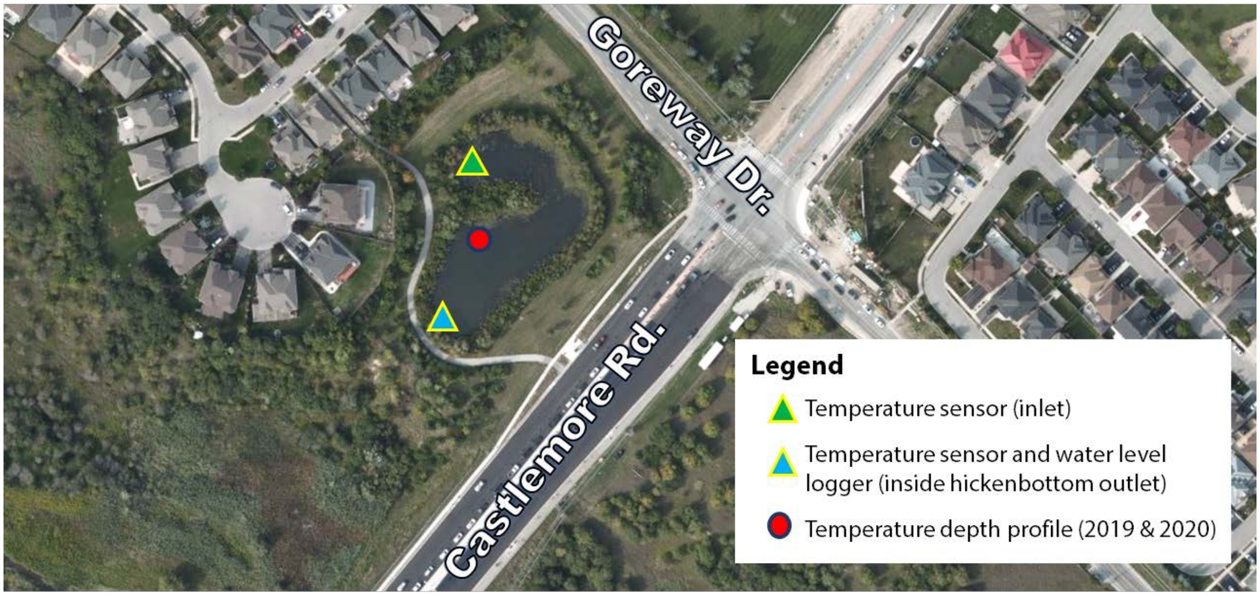


Figure 4.3: Monitoring equipment locations at the control pond pilot site in Brampton, ON

Floating temperature profile apparatuses (Figure 4.4) were installed in the shade ball and control ponds to assess the extent of thermal stratification and observe how it was affected by the shade balls. The depth profile sensors were initially placed in the ponds in 2019, with one set of sensors in the control and another in the shaded areas of the ball pond. In 2020, a second temperature profile apparatus was added in the shade ball pond, immediately outside of the shaded area. This additional data was collected to better understand whether the significant temperature stratification observed in 2019 is unique to the shaded area, which would suggest that the ball containment barrier could be impeding flow in and out of the shaded area.

Temperature data was collected at both ponds using HOBO Water Temperature Pro v2 loggers and level data was collected with HOBO Water Level Loggers.

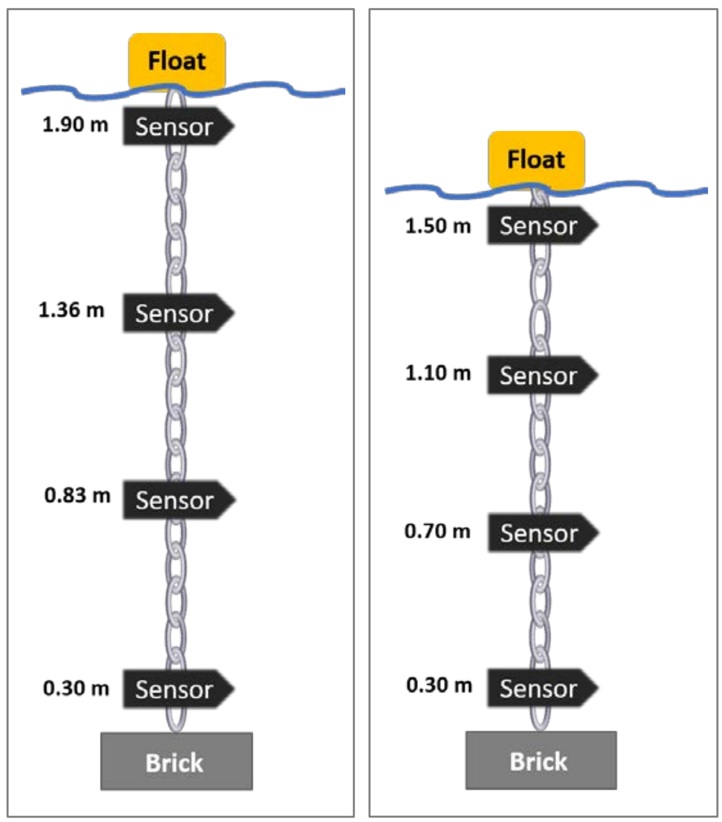


Figure 4.4: Temperature depth profile set up at both shade ball pond locations (left) and one control pond location (right)

Aside from water temperature and level data, precipitation and air temperature data were also obtained in order to facilitate interpretation of thermal data. Precipitation data used was from a TRCA Gauging Network rain gauge located at the West Humber and Highway 7. Ambient air temperature and barometric pressure data were collected at another pilot study site in Brampton near McVean Drive and Cottrelle Boulevard.

4.2 Small-scale evaluation of the effect of shade ball colour on thermal performance

A small-scale experiment was designed to simulate the way differently coloured balls respond to solar radiation in a stormwater pond. This experiment was conducted to allow for assessment of the extent to which the colour of the shade ball surface affects the amount of solar radiation reflected versus the amount transmitted through the ball and emitted to the water below. The experiment considered white, black and reflective silver shade balls. The white and black balls were purchased from the product supplier, while the reflective balls were created by painting white balls with a reflective metallic paint (labelled as "metallic finish chrome").

Four small circular wading pools, each 1.3 m in diameter, were used to simulate stormwater management ponds in four different scenarios: (i) white ball coverage, (ii) silver reflective ball coverage, (iii) black ball coverage, and (iv) no ball coverage. The pools were placed on the ground at the Kortright Centre for Conservation photovoltaic field (Figure 4.5), which was selected as the experiment location because it's a large, open area free of structures that could cast shadows over the pools and is gated to prevent public access. Before the wading pools were set up, the area was landscaped to remove any large weeds and grass and levelled out to ensure the pools would sit on a flat surface. Each pool was filled with tap water to a depth of 23 cm, and except for the control, 150 shade balls.

Figure 4.5: Wading pools at the small-scale shade ball testing site

HOBO Water temperature loggers were attached to bricks at the centre of each pool at a depth of 13 cm. Initially only the black, white and control pools were set up in the experiment. Temperature was monitored for those three pools from June 18 to July 23, 2019. Pools were periodically drained and refilled as needed, and all were refilled at the same time to ensure consistency. As a second phase to this experiment, the silver reflective ball pool was added, and the insides of all the pools were painted black to better represent the colour of the bottom of a stormwater pond. Prior to the start of monitoring for this second phase, all four pools were drained and refilled with new tap water. Simultaneous thermal monitoring of all four pools occurred from August 13 to September 16, 2019.

Precipitation and air temperature data used for interpretation of thermal data from this experiment were obtained from a TRCA Gauging Network weather station located on the Kortright property.

4.3 Small-scale testing of shade ball thermal response to simulated solar heating

In order to better understand how differently coloured shade balls reflect, transmit and emit heat to the water below, a small-scale experiment was set up in which the shade balls were artificially heated with a heat lamp (Figure 4.6). Following the heating the thermal behavior of the balls was monitored through measurement of temperature inside the balls and below the water, and by taking thermal images to observe the transmission of heat through the balls.

The test was conducted inside the Archetype Sustainable House at the Kortright Centre for Conservation in November 2019. Three empty ISCO water sampler carousels - each 50 cm in diameter - were used to hold the three differently coloured balls. The sampler carousels were filled with tap water to a depth of approximately 20 cm and then 16 balls were added to each to cover the water surface. A heat lamp was positioned above the balls and their surface temperatures were measured using a handheld TiR FLUKE Thermal Imager. In each of the three sampler carousels, a HOBO smart temperature sensor was inserted into one of the balls to measure the temperature increase inside the ball. Smart temperature sensors were also placed at the bottom of the sampler carousels.

Figure 4.6: Heating black shade balls with a heat lamp during experiment

The heat lamp was applied to each carousel of balls to heat them up for 20 minutes before turning off the lamp and monitoring the cooling of the balls for an additional 15 minutes. The temperature sensors were set to measure at 1-minute intervals. During the heating and cool down period, the thermal imager was used to capture ball surface temperatures.

4.4 Microplastics analysis of shade ball pond

Two grab samples, each 900 ml in volume, were collected from the shade ball pond inlet and outlet on August 2, 2019. They were analyzed at the University of Toronto microplastics laboratory to determine whether microplastics levels increased from the inlet to the outlet, and further, whether any increase could be attributable to the high density polyethylene (HDPE) shade balls. A brief description of the sample analysis methods is provided below.

The samples were sieved in the lab to a threshold size fraction of 106 µm using stainless steel test sieves obtained from Fisher Scientific. Samples were dosed with isopropyl alcohol at a concentration of 10% by volume. In the lab, 100% cotton lab coats and nitrile gloves were worn whenever handling the samples. Glassware and sieves were washed with dish soap and tap water followed by a triple rinse with reverse osmosis water before and in between uses to reduce contamination.

Using stainless steel sieves, the samples were then split into four size fractions of: 106 - 300 µm, 300 - 500 µm, 500 µm – 1mm, and > 1 mm. The 106 - 300 µm and 300 - 500 µm size fractions were subjected to a density separation using a 1.4 g/cm^3 $CaCl_2$ solution for a minimum of 24 hours.

Plastic particles were visually identified using an SM-1B binocular zoom stereo microscope with 80x magnification from Amscope (Irvine, USA). Particles were categorized based on morphology (fiber, fragment, film, foam, rubber, sphere or pellet) and colour within each of the above described four size fractions. Distinction between synthetic versus organic particles was based on visual characteristics and texture adapted from previous studies and the Royal Microscopy Society. All coloured particles that matched synthetic descriptions were identified as microparticles. All transparent coloured fibers were tested for texture and identified conservatively. The first 10 particles in each morphology and colour category within each size fraction were collected on double-sided tape for polymer identification.

5.0 RESULTS AND DISCUSSION

5.1 Pilot scale evaluation

In the pilot scale shade ball evaluation, the ball pond and control pond were monitored during summer months from 2018 to 2020 to establish shade ball performance. The effectiveness of the shading was largely determined based on the extent to which there was an observed reduction in temperatures at the outlet of the ball pond. In order to assess whether there was a significant temperature reduction, outlet temperatures observed before and after ball deployment (pre-August 2018 vs. after) were compared. Ball pond temperatures were also compared to temperatures observed at the control pond during the same time period in order to eliminate year to year variations in ambient temperature and precipitation as a factor.

5.1.1 Comparing shade ball pond temperatures before and after ball deployment

Temperature, rainfall and pond level data collected during three seasons of shade ball pond monitoring are presented as timeseries in Figures 5.1a, b and c. Shade ball deployment into the pond began on Aug. 24, 2018, which is indicated by the dashed red line in Figure 5.1a, but the installation of balls wasn't complete until Sept. 18, 2018.

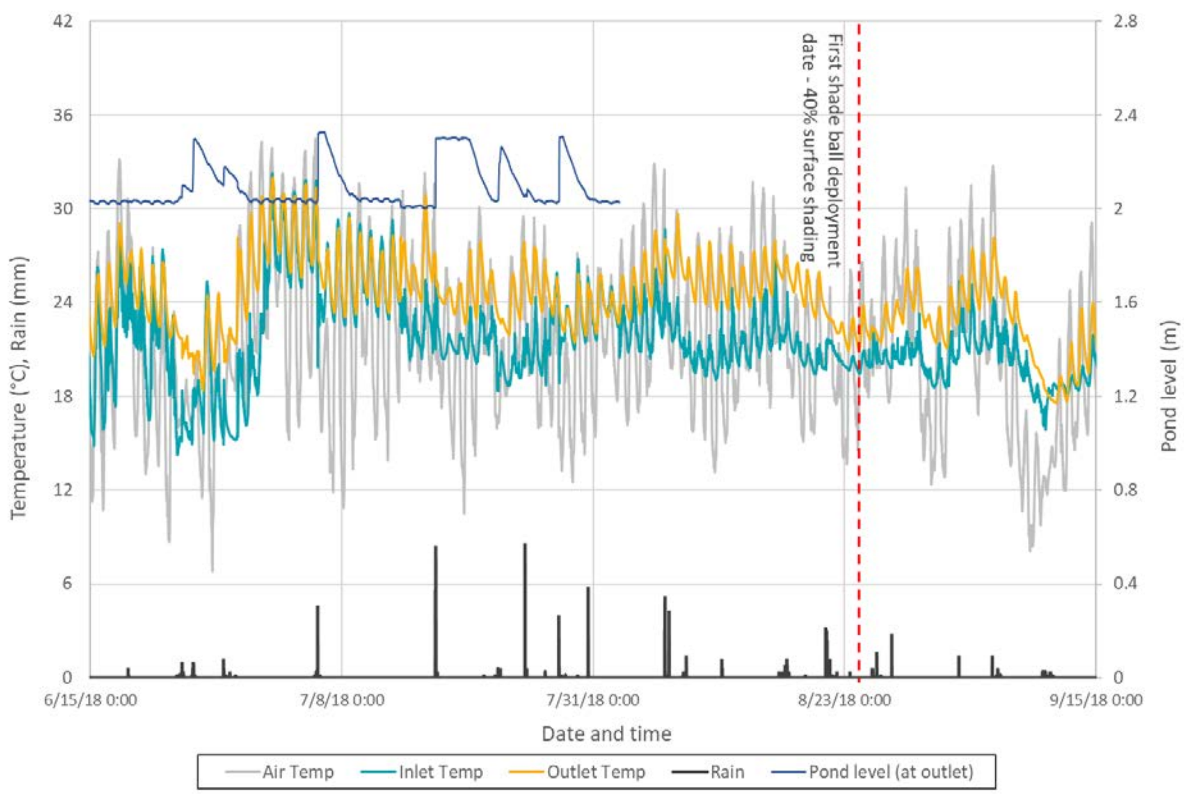


Figure 5.1a: Air, shade ball inlet and outlet temperatures, rainfall and pond levels in 2018. Shade ball deployment into the pond began on Aug. 24, 2018.

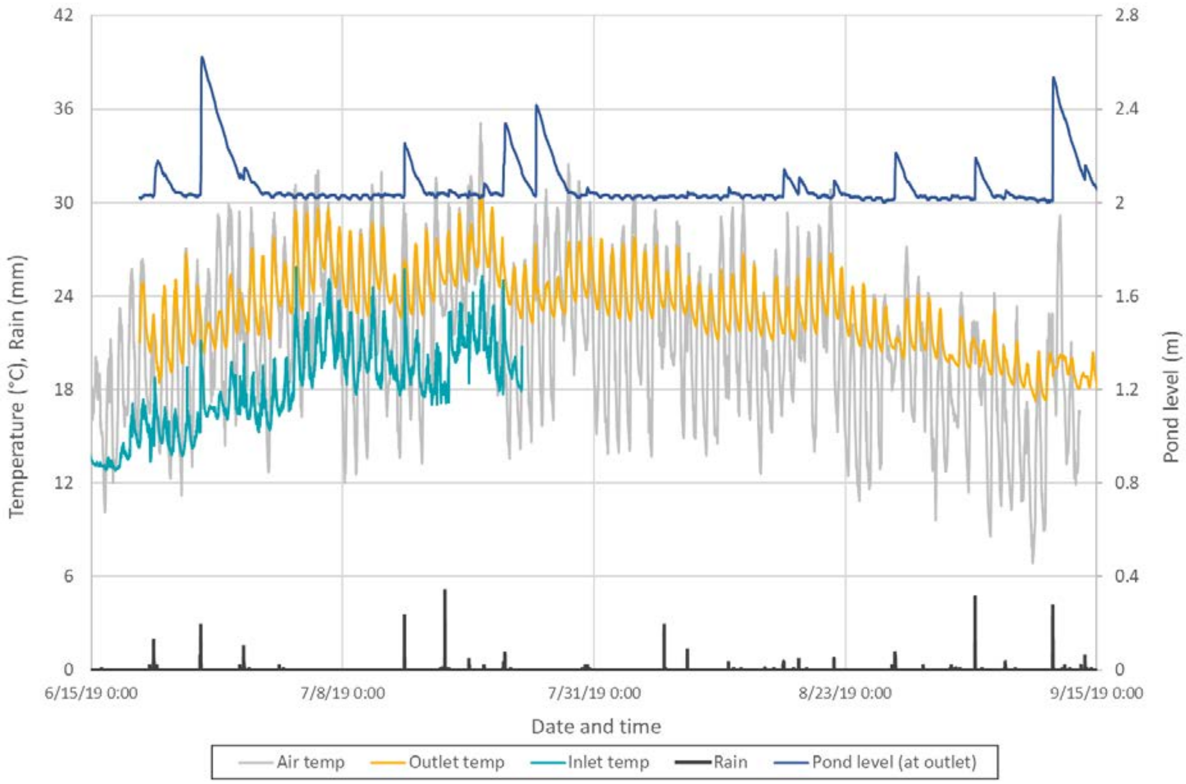


Figure 5.1b: Air, shade ball inlet and outlet temperatures, rainfall and pond levels in 2019.

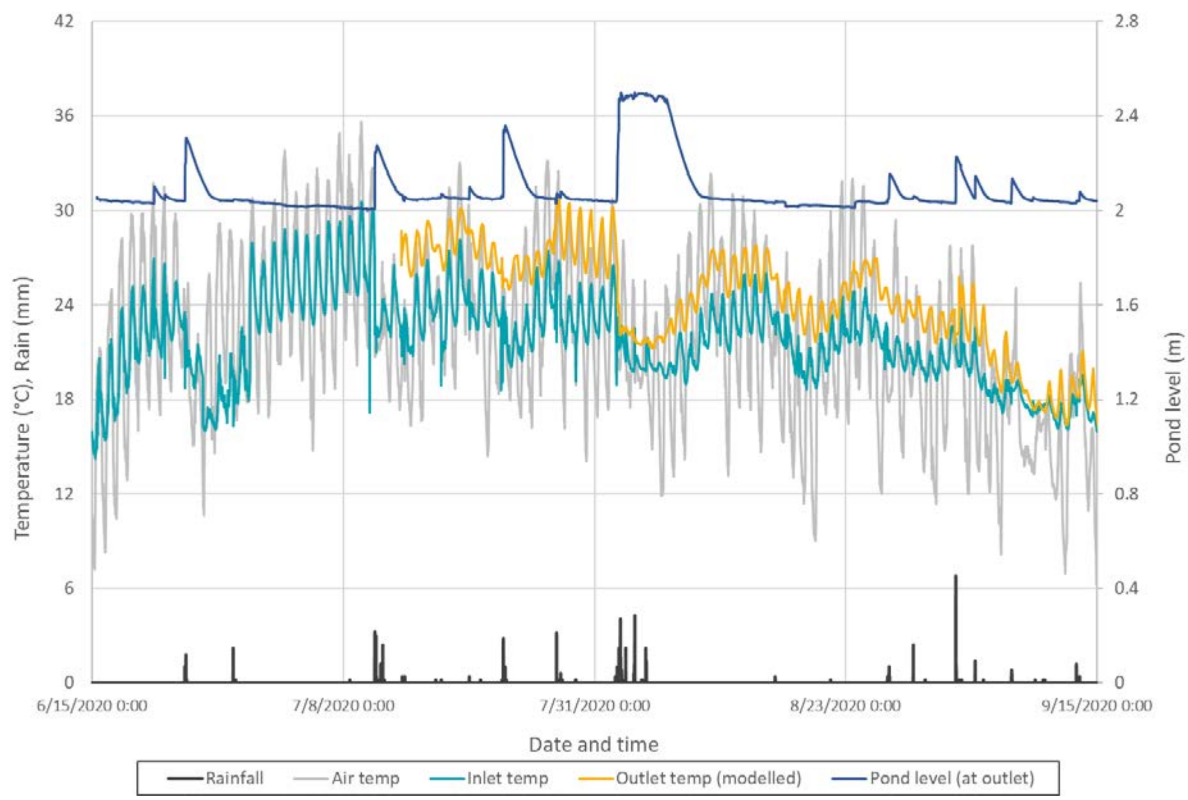


Figure 5.1c: Air, shade ball inlet and outlet temperatures, rainfall and pond levels in 2020. Outlet temperatures are modelled based on nearby temperature sensor in the shaded (ball) area.

Figure 5.1a shows that in 2018 outlet temperatures were usually a few degrees warmer than inlet temperatures, as expected during the summer season in a stormwater detention pond, however there are instances when the difference between inlet and outlet temperatures is minimal, and these instances occurred prior to deployment of any shade balls. When compared to Figures 5.1b and c, which show 2019 and 2020 data, the differences between inlet and outlet temperatures are similar, and in many instances greater, during these two years following the installation of shade balls. Overall, the data presented in the charts shows that based on the temperature differences between inlet and outlet observed before and after shade ball deployment, it does not appear that the balls caused outflows to be significantly cooler. When average temperatures were compared, the percent increase in temperature from inlet to outlet was found to be similar in 2018 and 2020, at 14.3% and 14.6% respectively. Data from 2019 data was not compared due to the lack of continuous inlet temperature data during that monitoring season.

The comparison of pre to post shade ball deployment temperatures is also shown in the temperature distribution curves in Figure 5.2, which are based on temperature data collected from July 13th – 24th during each year of monitoring (2018 to 2020). The 2018 curve represents temperatures prior to the deployment of the shade balls while 2019 and 2020 data are from post-deployment.

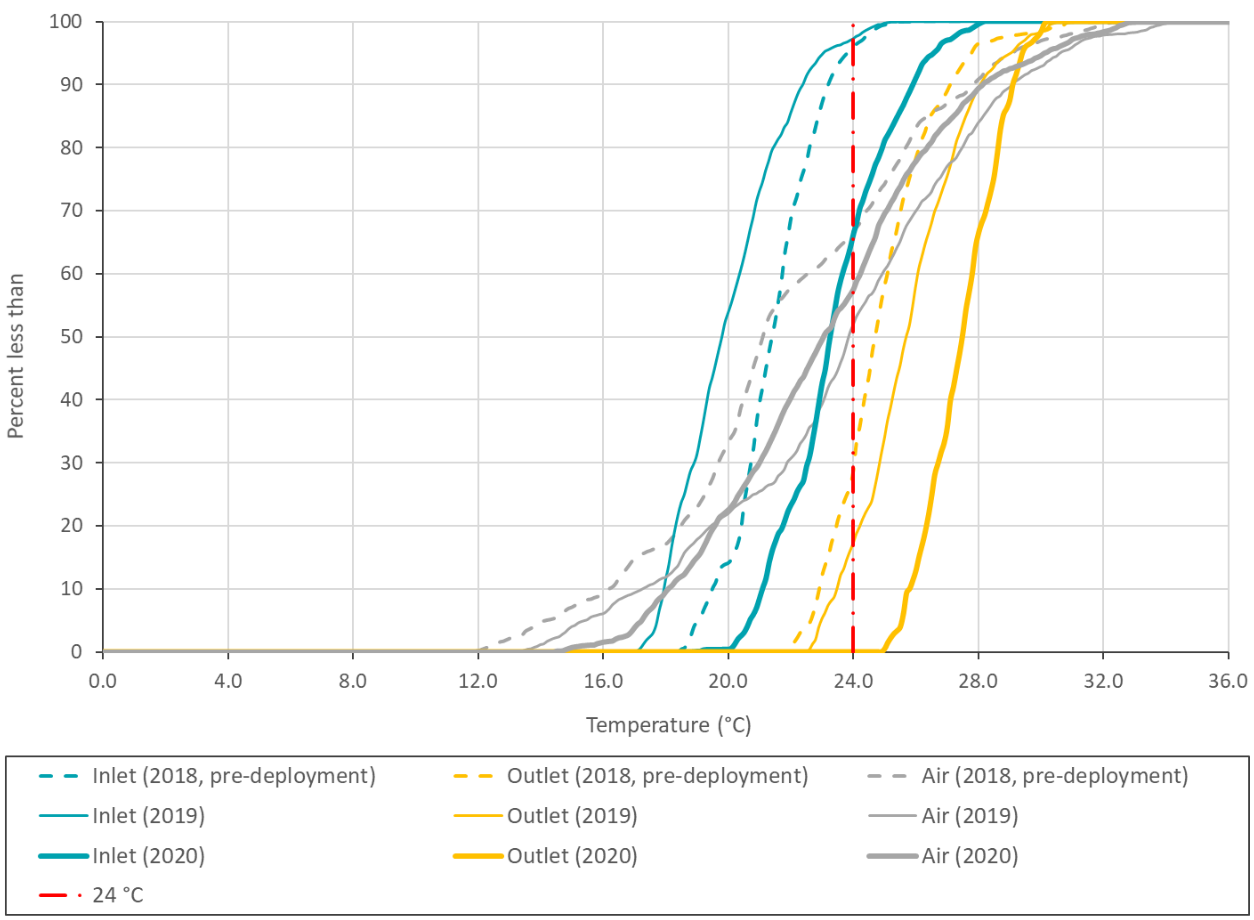


Figure 5.2: Temperature frequency curves for the shade ball pond before and after ball deployment. Each curve represents data collected from July 13 – 24 during that year.

By comparing the curves for each year side by side over this period of time, it becomes clear that the balls did not provide a significant cooling benefit. Figure 5.2 shows that prior to shade ball deployment, the 50th percentile (median) temperature increase from pond inlet to outlet was 3.3°C. In 2019, once the shade balls were deployed, the 50th percentile temperature increase from inlet to outlet was much higher at 5.9°C. In 2020 the warming from inlet to outlet was not as high but still greater than the pre-deployment (2018) warming at 4.2°C. It should be noted that ambient air temperatures during this period were coolest in 2018, and median temperatures in 2019 and 2020 were 2.8°C and 1.9°C higher, respectively. While this may account for some of the greater warming observed in the pond in 2019 and 2020, these results still indicate that the shade balls provided little to no cooling benefit. The warming observed in 2019 is particularly surprising given that the inlet temperatures were coolest that year, despite the air temperatures being highest.

With respect to meeting temperature targets for protection of redside dace, measurements during this time period (July 13 – 24) in 2019 and 2020 more frequently exceeded the 24°C threshold than pre-deployment temperature measurements. In 2019 and 2020, the proportions of measurements that exceeded the threshold were 83% and 100% respectively, while in 2018, before ball deployment, only 71% of measurements were in exceedance.

Table 5.1 provides pond outflow and air temperature statistics from July 13 to August 24 during each year of monitoring to help facilitate comparison of pre and post shade ball deployment data. Annual outlet and air temperature comparisons for the same time period are also depicted in the temperature frequency curves in Figure 5.3.

Table 5.1: Shade ball pond outflow and air temperature statistics for 2018 to 2020 monitoring seasons

Temperature parameter (°C)	2018	2019	2020
Median, air	21.6	22.4	22.7
Average, air	21.8	22.3	22.8
Maximum, air	32.8	35.1	33.2
Median, shade ball pond outflow	24.8	24.1	26.1[1]
Average, shade ball pond outflow	24.7	24.3	25.8[1]
Maximum, shade ball pond outflow	30.9	30.5	30.7[1]

Note: Statistics calculated based on data collected from July 13 to Aug. 24 of each monitoring year.
[1] Based on modelled temperature data (as described in section 5.1.1)

Within this larger data set (July 13 – August 24) outlet temperatures were cooler overall and there was a reversal of the trend noted for 2018 and 2019 in Figure 5.2. While air temperatures were coolest in 2018, outlet temperatures did not follow this trend; median outlet temperatures were 0.7 °C cooler in 2019 relative to 2018. The slightly cooler outflow temperatures observed in 2019 could be interpreted as a cooling effect attributable to the shade balls, however the same trend was not observed in 2020, during which air temperatures were similar to 2019, but median and average outflow temperatures were 2 °C and 1.5 °C higher, respectively.

With respect to meeting the 24 °C threshold, most outlet temperature measurements were in exceedance for all three years, with 68%, 54% and 76% of measurements exceeding the threshold in 2018, 2019 and 2020 respectively.

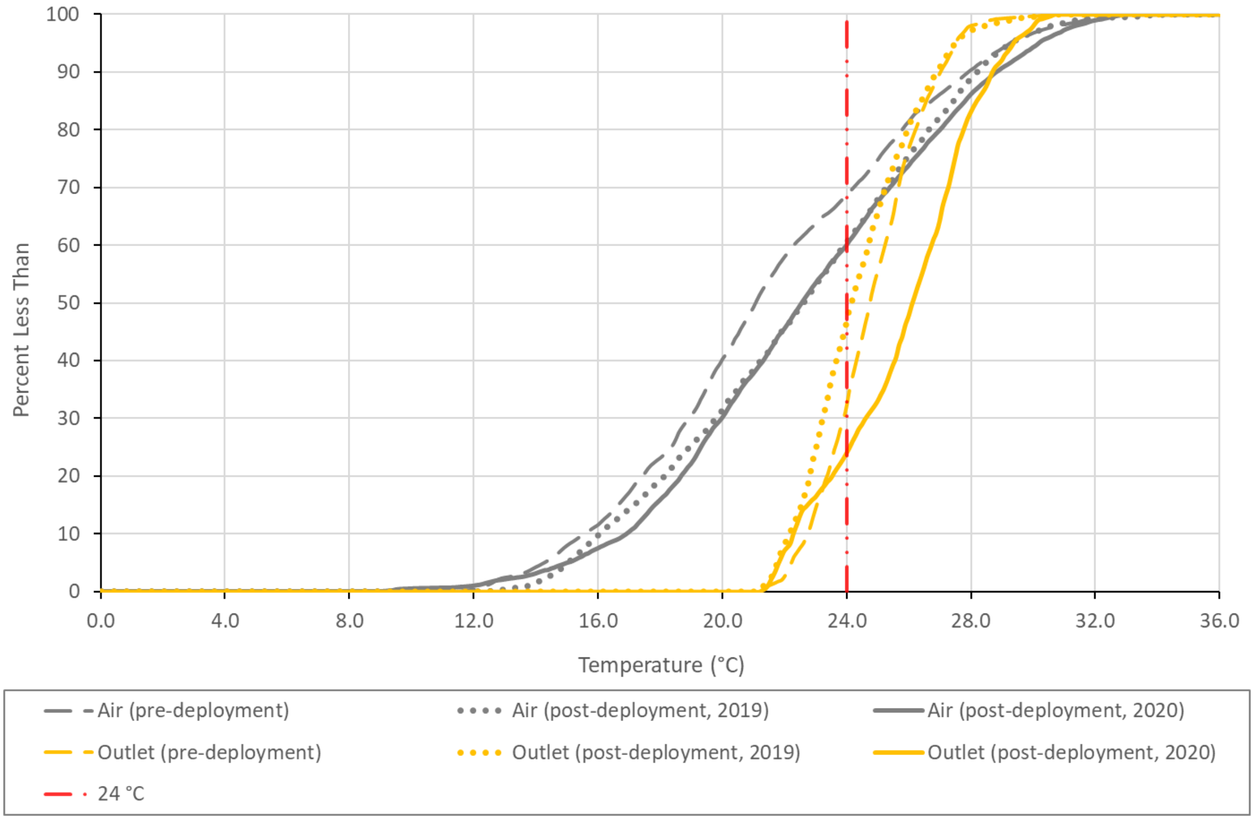


Figure 5.3: Comparison of ball pond outlet temperatures during July 13 to Aug. 24 of each year.

5.1.2 Comparing shade ball and control pond temperatures

Temperature frequency distributions observed at the inlet and outlet of the shade ball pond were also compared to those observed at the experimental control pond. Figure 5.4 compares the ball pond to the control pond during baseline monitoring (2018, before ball deployment), while Figures 5.5 and 5.6 show the 2019 and 2020 seasons, respectively.

During all years, the inflows at the control pond were much cooler than at the ball pond, while the differences in outflows at the two ponds were minimal. Relative to the ball pond, median outflows at the control pond were slightly cooler in 2018 and 2020, and slightly warmer in 2019, but in all cases the difference between the sites was less than 1°C.

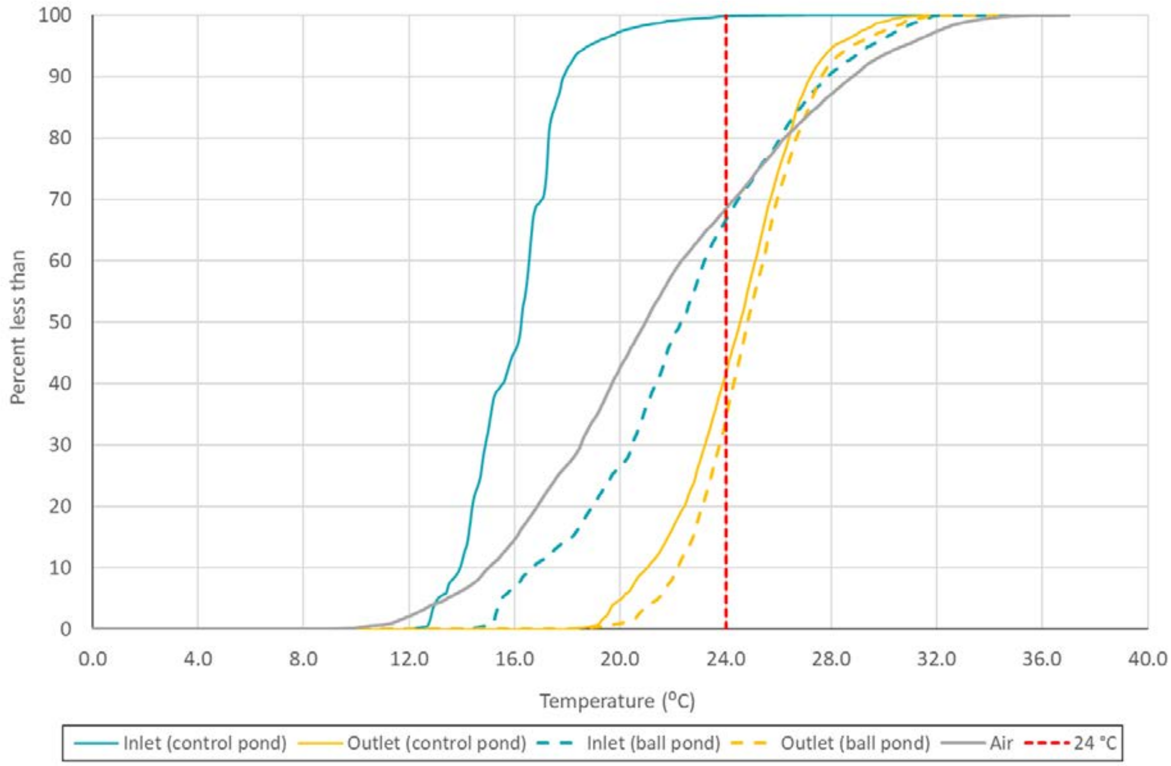


Figure 5.4: Comparison of temperature frequency curves for control and ball ponds in 2018. Based on temperature data collected between Jun. 19 and Aug. 23, 2018.

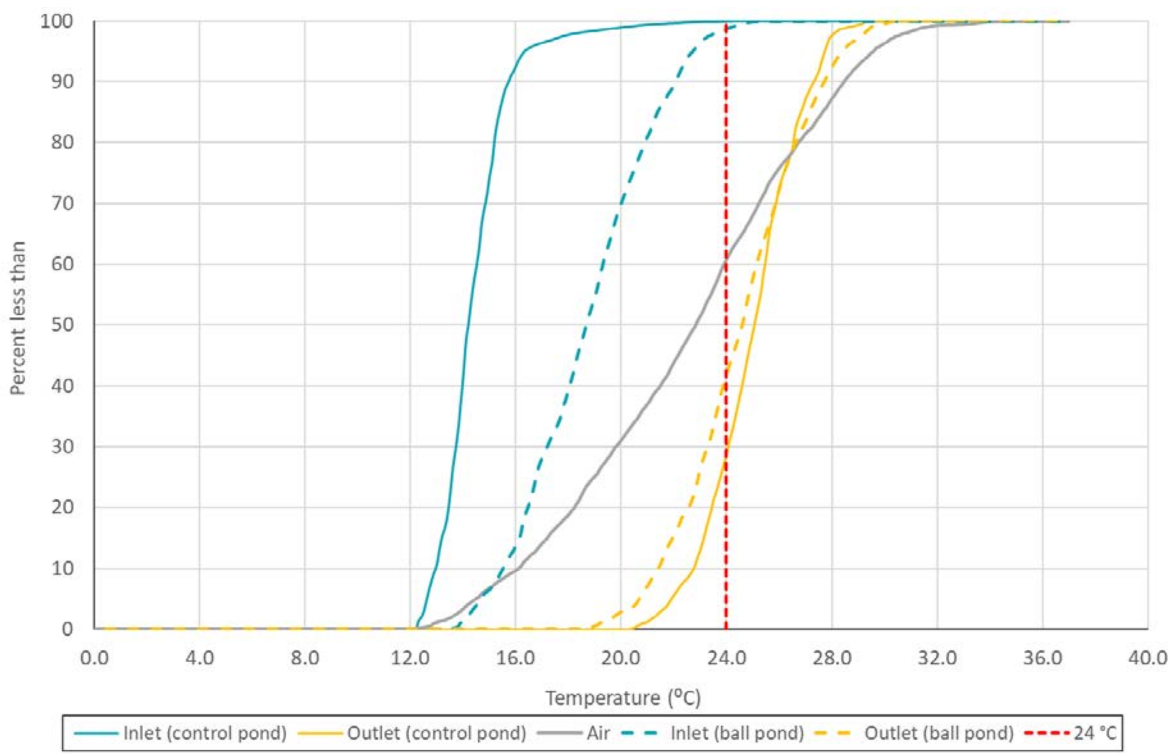


Figure 5.5: Comparison of temperature frequency curves for control and ball ponds in 2019. Based on temperature data collected between June 19 and July 24, 2019.

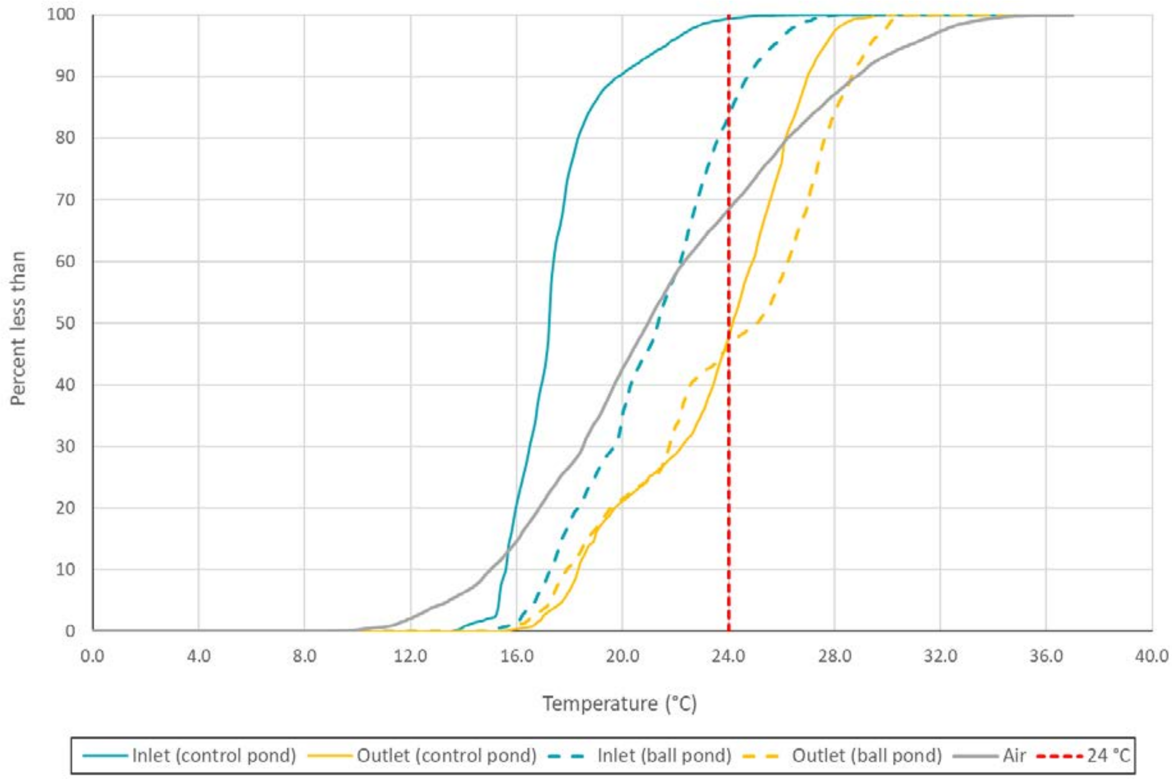


Figure 5.6: Comparison of temperature frequency curves for control and ball ponds in 2020. Based on temperature data collected July 13-Aug. 11 & September 1-15. Ball outlet temperatures are modelled.

Relative to the ball pond, the control pond caused a greater degree of warming during all years. Median increases from inlet to outlet ranged from 6.6 to 11.4 °C at the control pond and only 3.1 to 5.9 °C at the ball pond. This cannot necessarily be considered indicative of a cooling effect of shading at the ball pond relative to the control. As described in section 5.1.1, warming from inlet to outlet at the ball pond did not decrease after the shade balls were installed, but rather the ball pond caused less warming prior to their installation (2018) than it did in the two subsequent years. The higher magnitude of warming at the control pond could be mainly a consequence of its cooler inflows. While water starts off cooler coming into the control pond, outflow temperatures at the control and ball ponds end up similar because warming plateaus at a point that is mainly dictated by local air temperatures, precipitation events and pond detention times.

In 2018, temperatures met the 24 °C thermal target 41% of the time at the control pond and 34% of the time at the ball pond. In 2019, after the balls were installed, the ball pond outflows met the target more often than the control (42% met target vs. 29% for control), while in 2020 the percentage of measurements that met the target was nearly the same at both sites (~47%). Because ball pond inflows were notably warmer in 2018, it cannot be demonstrated that the cooler outflow is directly attributable to the effect of the shade balls.

Figure 5.7: Control pond (left) and control pond inlet (right).

5.1.3 Temperature depth profiles

Temperature depth profiles were installed at the ball and control ponds during the 2019 and 2020 monitoring seasons to look at the extent of thermal stratification and how it is affected by the shade balls.

Comparing control and ball pond temperature depth profiles in 2019

In 2019 two depth profiles were installed: one in the control pond and one in the shaded area of the ball pond. Temperature timeseries data collected from the profiles in 2019 are shown in Figures 5.8 and 5.9. Results revealed that there was significantly more thermal stratification under the shade balls, with much cooler temperatures recorded near the bottom of the pond relative to the control pond. Table 5.2 lists median, maximum and minimum temperatures measured at the bottom sensor at both sites in 2019 and shows that for the deepest sensor in the ball pond, median temperatures were nearly 5 °C cooler than the equivalent sensor at the control pond. This difference between ponds is likely partially attributable to the ball pond being 50 cm deeper, making it more susceptible to stratification.

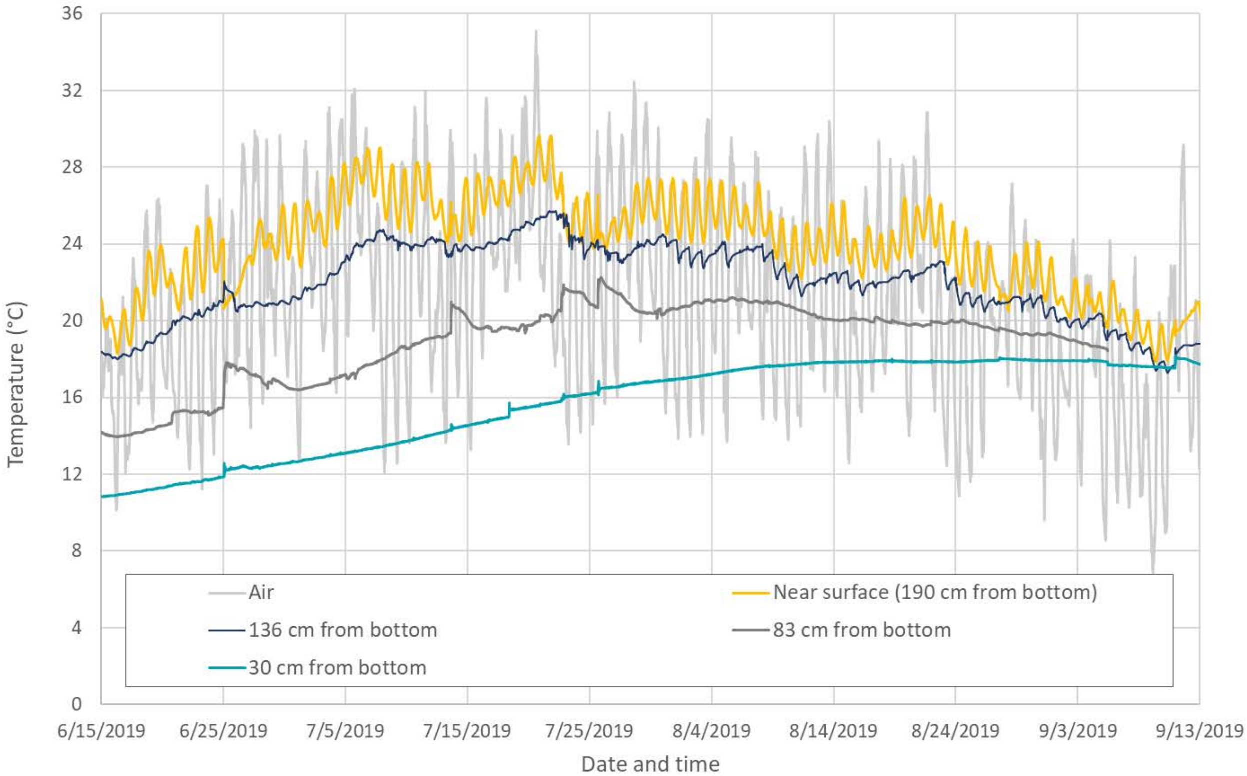


Figure 5.8: Timeseries of temperature depth profile measured in the ball pond shaded area in 2019.

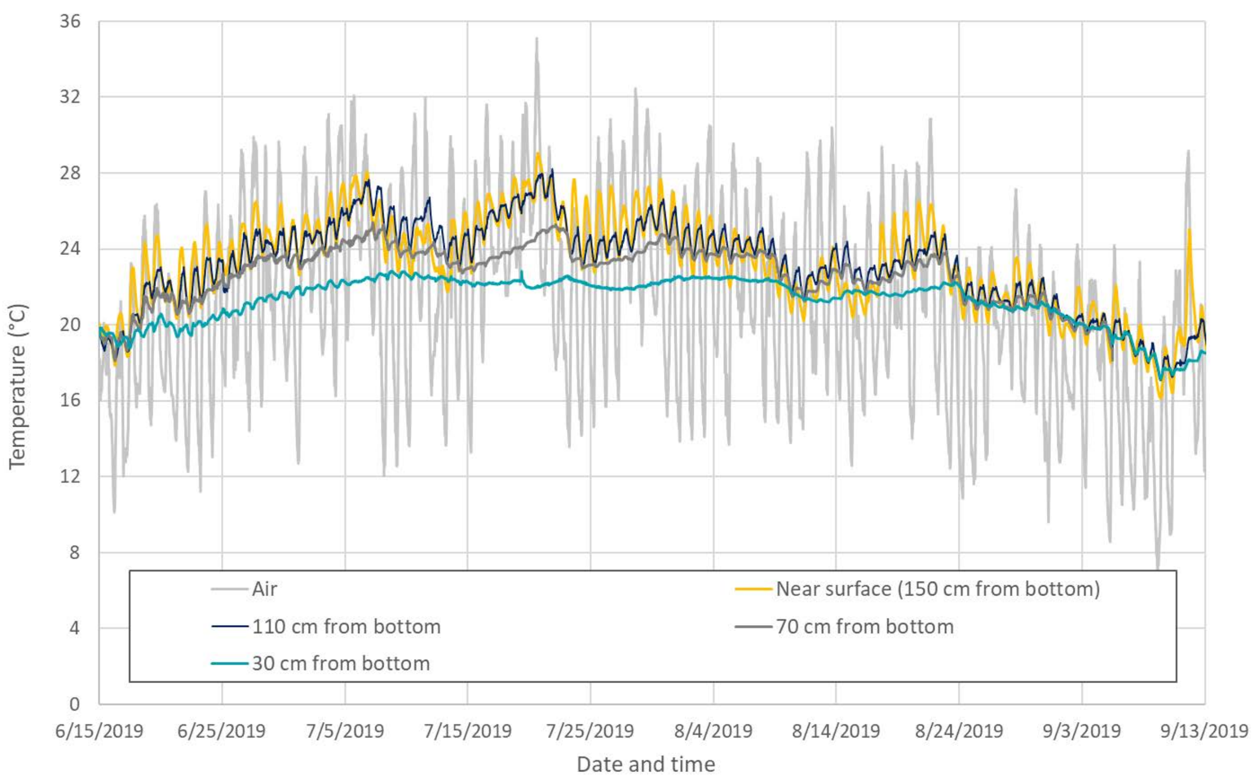


Figure 5.9: Timeseries of temperature depth profile measured within the control pond in 2019.

Table 5.2: Median, minimum, and maximum temperatures measured at the bottom sensor (30 cm from pond bottom) in the depth profiles of the ball and control ponds in 2019.

	Temperature measured at 30 cm from pond bottom	
	Ball pond (shaded)	**Control pond**
Median	16.9	21.7
Minimum	10.8	17.1
Maximum	18.2	22.8

This pronounced stratification with much lower temperatures observed at the deeper sensors did not ultimately translate into significantly cooler pond outflows relative to the control pond. As described in Section 5.1.2, the difference between median outflow temperatures at the control and ball ponds was less than 1 °C in 2019. One hypothesis considered as an explanation for why the cooler temperatures observed under the shade balls did not translate into cooler outlet temperatures was the concept that the turbidity curtain suspended vertically around the ball area could cause some diversion of incoming flows around the ball area rather than through it. In this case the ball area would remain cooler but somewhat isolated from the rest of the pond.

To better understand whether the barrier system was altering the flow path and creating a cooler zone under the balls that was not being pushed through to the outlet, the temperature profile was analysed during several small rainfall events in July 2019, the largest of which occurred on July 22 and showed a corresponding increase in water level (Figure 5.10). The chart shows that incoming flows from the 7 mm rainfall event did in fact cause water to mix in the ball containment area, affecting the two top sensors in the profile (down to 136 cm above pond bottom). Temperatures recorded at those two top sensors were overlapping, the stratification that previously existed being eliminated as water flowed through the pond during the event. The lower part of the profile was much less affected by the inflow of water, with the sensor at 86 cm showing a small warming of approximately 1°C during the event, and the lowest sensor (at 30 cm) showing no significant warming.

This observation suggests that the much cooler water found near the pond bottom beneath the shade ball containment area was not being pushed through the pond to the outlet during rainfall events. If the ball barrier system was impeding flow through to some extent, this could explain why the full cooling effect of the shade balls, which seems to be evident in the profile data, is not translating into a significantly cooler pond outflow.

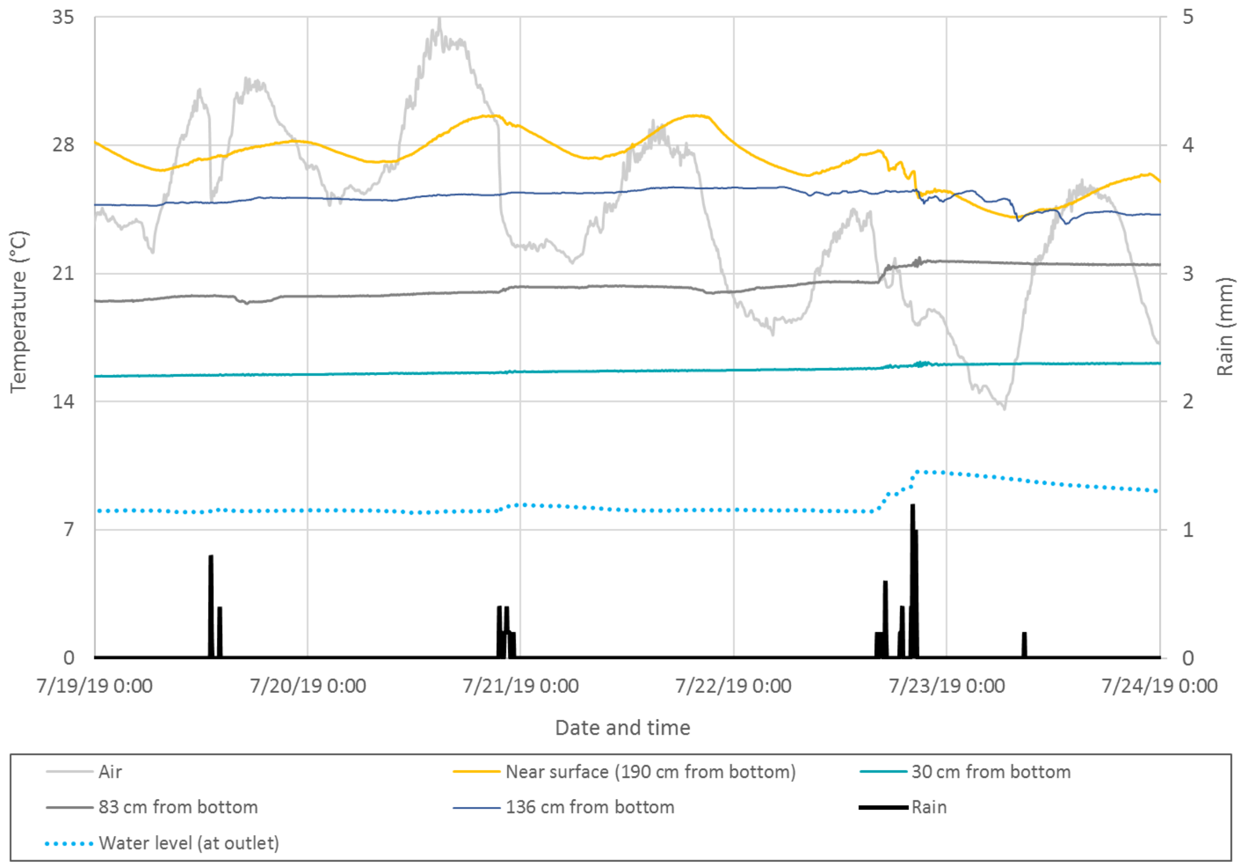


Figure 5.10: Temperature depth profile of shade ball pond during a 7 mm rain event on July 22, 2019.

Comparing control and ball pond temperature depth profiles in 2020

In 2020 there were three profiles installed and monitored: the two that were installed in 2019 and a second ball pond profile that was placed just outside the shade ball containment area (Figure 5.11). This was installed to investigate whether the temperature stratification observed in the shaded area of the ball pond would also be observed in unshaded areas. If the stratification was significantly more pronounced in the shaded area, that would lend credence to concept that the barrier (turbidity curtain) used to contain the balls was to some extent impeding water flow, despite being permeable.

Table 5.3 provides mean, median and maximum temperatures at each depth for the three profiles installed. Figures 5.12 to 5.14 show timeseries of temperature depth profiles from the control pond and the shaded and unshaded areas of the ball pond, respectively. Temperatures in the depth profile at the control pond followed similar patterns in 2020 as in 2019, with minimal stratification observed. At the control pond, the median temperature drop from the top to bottom sensor was 2.1 °C, while the equivalents at the shaded and unshaded ball pond profiles were 6.3 °C and 5.0 °C respectively.

Figure 5.11: Temperature depth profile locations at shade ball and control ponds in 2020.

Despite this difference in extent of stratification, comparing profile locations by looking at the median temperatures at each sensor depth reveals that temperatures were very similar at shallower depths and began to diverge more at the deeper sensors. At the shallowest sensor, the two unshaded profiles (control and unshaded ball pond sites) were in fact cooler than the shaded profile in the ball pond. The finding that temperatures at the control pond were similar to those at the ball pond in 2020 is in line with the results discussed in Section 5.1.2 – that outlet temperatures from the control pond were within 1 °C of those from the ball pond. The warmer temperatures at the deepest sensor in the control pond are also expected given that the ball pond is deeper and as such more susceptible to stratification and reaching cooler temperatures near the bottom.

Table 5.3: Mean, median, and maximum temperatures in control and ball pond depth profiles in 2020.

Sensor details		Mean*	Median*	Maximum*
Sensor 1 (deepest)**	Ball pond shaded	18.6	18.6	21.0
	Ball pond unshaded	19.3	19.2	21.1
	Control	21.4	22.2	25.0
Sensor 2**	Ball pond shaded	21.6	22.1	23.9
	Ball pond unshaded	21.8	22.5	24.0
	Control	22.6	23.4	25.8
Sensor 3**	Ball pond shaded	22.4	23.1	25.5
	Ball pond unshaded	22.5	23.5	25.7
	Control	22.9	23.6	27.3
Sensor 4** (shallowest)	Ball pond shaded	24.0	24.9	28.8
	Ball pond unshaded	23.3	24.2	29.0
	Control	23.6	24.3	29.6

** Note: Statistics shown here are calculated from data for matching time periods to ensure valid comparison. Data used is from July 13 – Aug. 15 and Sept. 2 – Sept. 15, 2020.*

*** Sensor locations in ball pond, starting from bottom are: 30 cm (sensor 1), 83 cm (sensor 2), 136 cm (sensor 3), 190 cm (sensor 4) Sensor locations in control pond, starting from bottom are: 30 cm (sensor 1), 70 cm (sensor 2), 110 cm (sensor 3), 150 cm (sensor 4)*

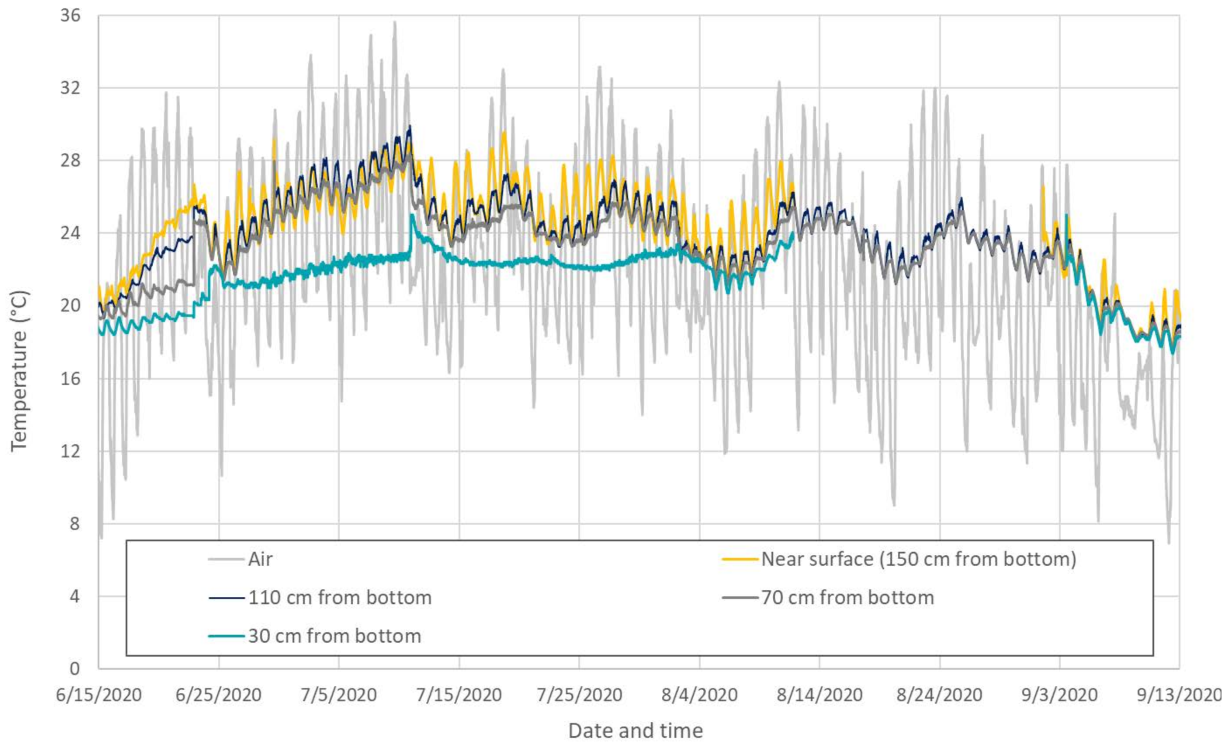


Figure 5.12: Timeseries of temperature depth profile measured within the control pond in 2020.

Note: Statistics shown here are calculated from data for matching time periods to ensure valid comparison. Data used is from July 13 – Aug. 15 and Sept. 2 – Sept. 15, 2020.

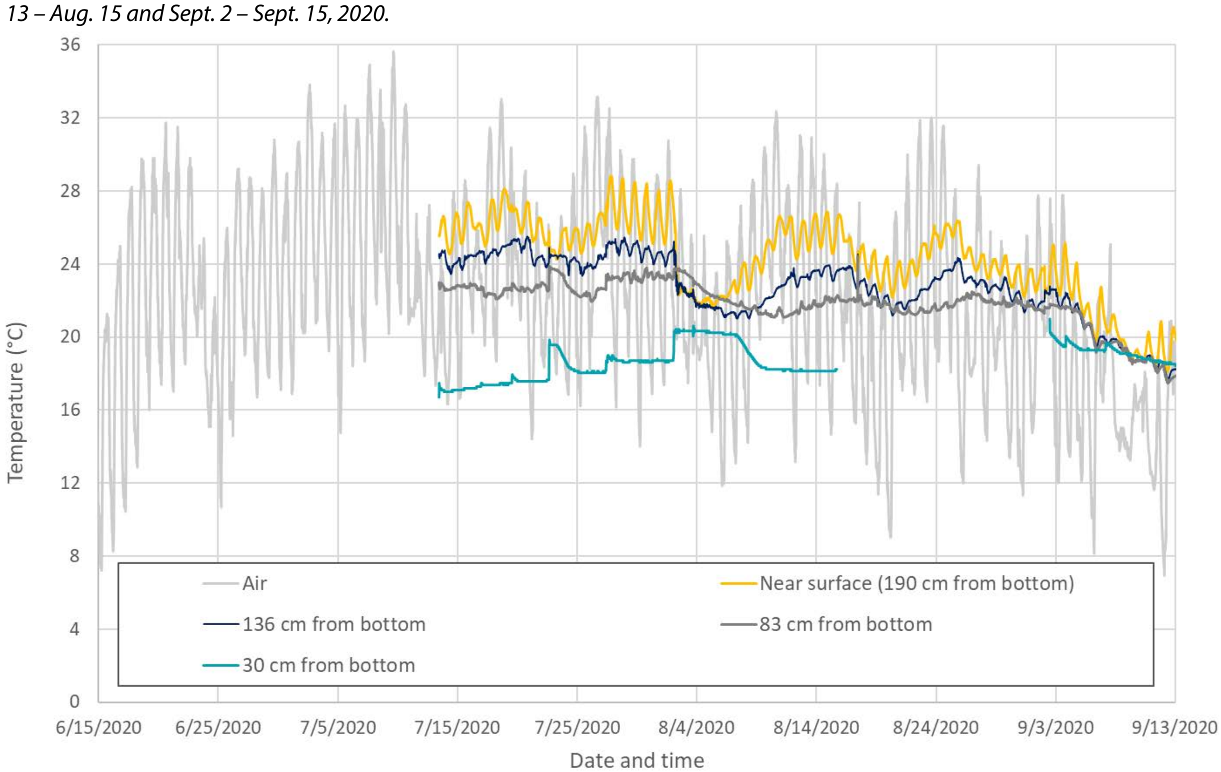


Figure 5.13: Timeseries of temperature depth profile measured in ball pond shaded area in 2020.

Note: Statistics shown here are calculated from data for matching time periods to ensure valid comparison. Data used is from July 13 – Aug. 15 and Sept. 2 – Sept. 15, 2020.

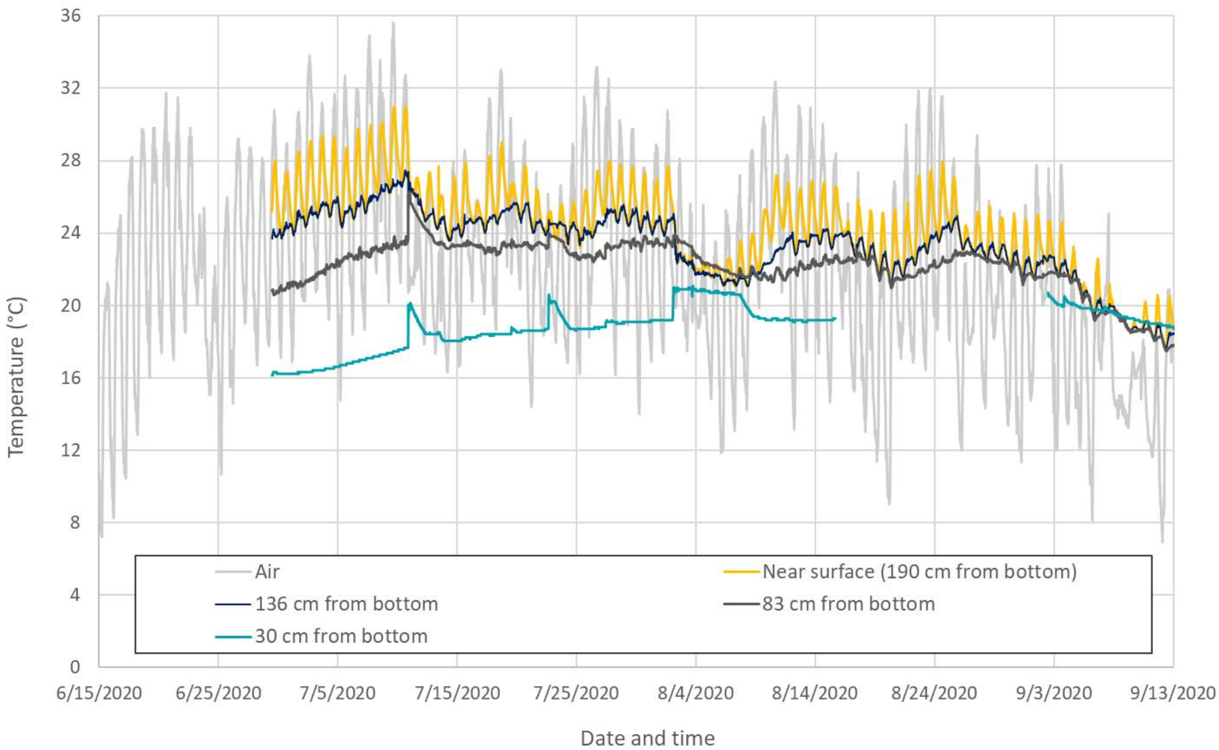


Figure 5.14: Timeseries of temperature depth profile measured in ball pond unshaded area in 2020.
Note: Statistics shown here are calculated from data for matching time periods to ensure valid comparison. Data used is from July 13 – Aug. 15 and Sept. 2 – Sept. 15, 2020.

When the shaded and unshaded ball pond profiles are compared, the results shed light on exactly how the shade balls are influencing temperatures below them. Figure 5.15 shows temperature frequency curves for the shaded and unshaded ball pond profiles. Overall, the difference between temperatures at the two profile locations was minimal, with median temperatures with 1 °C of each other at all depths. The curves reflect the same trend described above in the comparison to the control pond –the shaded profile was slightly cooler at the deepest sensors, but this was reversed at shallower depths, with the top sensor under the shade balls measuring slightly warmer than the equivalent in the unshaded ball pond profile

This is also illustrated by the data in Table 5.4, which lists median temperatures at each sensor depth and the percent decrease in temperature associated with the shading. While the median temperature at the deepest sensor (30 cm above the pond bottom) was 3.1% cooler in the shaded area, this cooling effect got smaller at shallower depths and reversed at the top sensor, at which the temperature was 2.9% warmer in the shaded area. Ultimately, the hypothesis that the ball barrier could be inhibiting flow through was not borne out by the data, as the unshaded profile was not significantly warmer than the shaded profile.

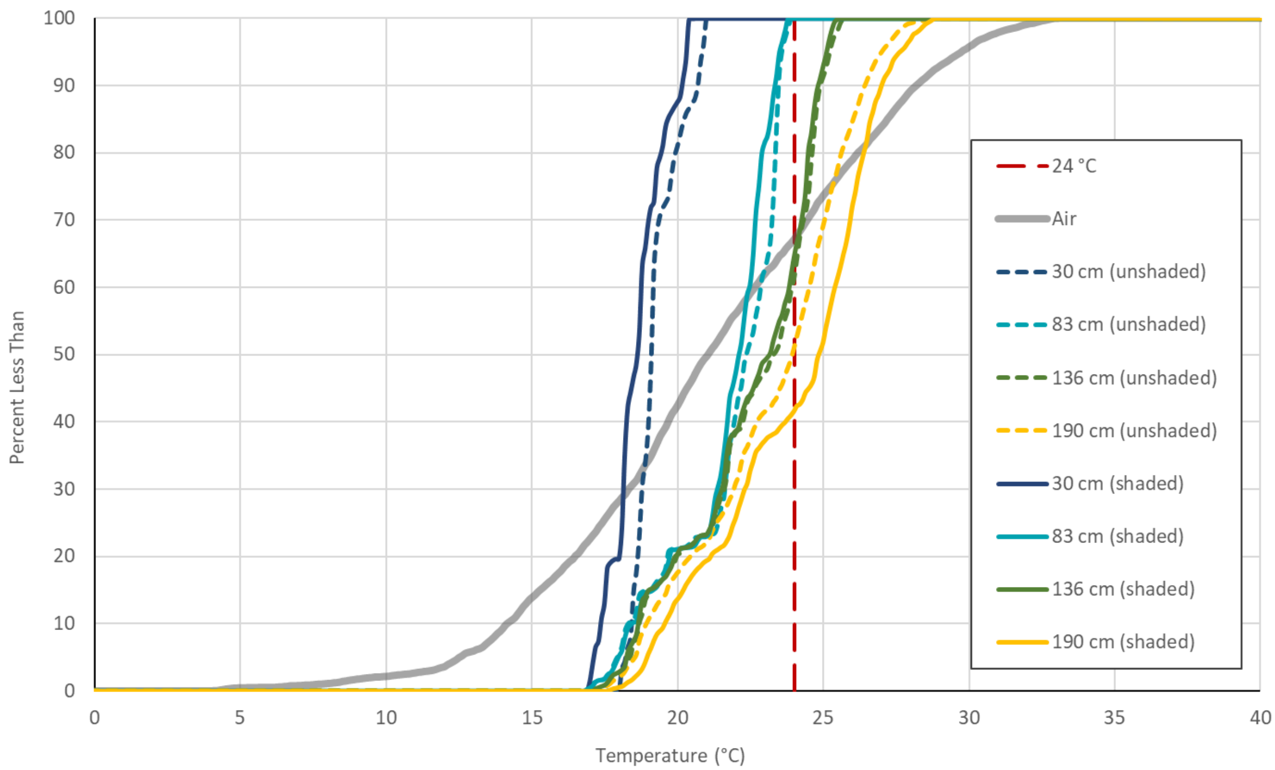
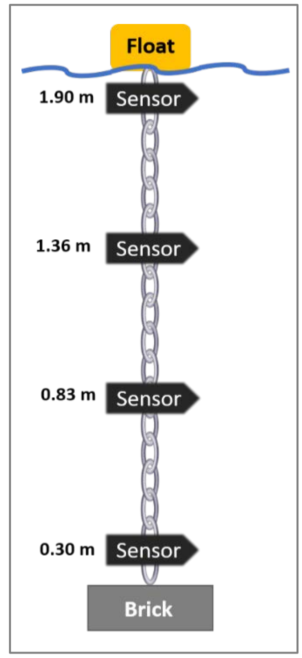


Figure 5.15: Comparison of temperature frequency curves for the covered and uncovered temperature depth profiles at the ball pond in 2020.

Note: Statistics shown here are calculated from data for matching time periods to ensure valid comparison. Data used is from July 13 – Aug. 15 and Sept. 2 – Sept. 15, 2020.

Table 5.4: Comparison of median temperatures at the shaded and unshaded ball pond temperature depth profiles in 2020.

Sensor details		Median* temp. (°C)	% Temp. decrease due to shading
190 cm from bottom	Ball pond shaded	24.9	-2.9%
	Ball pond unshaded	24.2	
136 cm from bottom	Ball pond shaded	23.1	1.7%
	Ball pond unshaded	23.5	
83 cm from bottom	Ball pond shaded	22.1	1.8%
	Ball pond unshaded	22.5	
30 cm from bottom	Ball pond shaded	18.6	3.1%
	Ball pond unshaded	19.2	



** Note: Statistics shown here are calculated from data for matching time periods to ensure valid comparison. Data used is from July 13 – Aug. 15 and Sept. 2 – Sept. 15, 2020.*

While the difference between temperatures observed at the two profiles was minimal, these findings do at least indicate that the shade balls did not cause a pronounced cooling effect and could even have caused a slight warming effect at the top of the pond profile. This finding suggests that the balls were inhibiting evaporation and the associated cooling effect at the pond surface. The concept that the shade balls reduce evaporation is consistent with the fact that they are also marketed as a solution to preventing evaporation from water reservoirs.

The opacity of the balls should also be considered when interpreting the warmer surface temperatures observed under the balls. If the balls were capable of completely blocking the transmission of sunlight through them, a sensor directly beneath them should be cooler than a sensor of the same depth at an unshaded location nearby, in the same pond. As described in Section 4.2, experiments investigating the opacity of the shade balls were carried out in 2019. These small-scale experiments were carried out to understand the extent to which the white shade balls could transmit light in comparison to black shade balls and balls with a reflective coating. The results of the experiments, which are presented in Section 5.2, indicated that the balls were not opaque as originally believed, and were in fact transmitting light. This provides some important context for understanding the findings that the shade balls provided no significant cooling benefit in comparisons to baseline temperatures (pre-installation), control pond temperatures, and temperatures at an unshaded location in the ball pond.

5.2 Small-scale test results: impact of ball colour on performance

As described in Section 4.2, a small-scale experiment was conducted using wading pools containing differently coloured shade balls to simulate the way the balls would respond to solar radiation in a stormwater pond. The timeseries in Figure 5.16 shows water temperatures measured at the bottom of the wading pools in the experimental control (no shade balls) and under the white, black and reflective balls. The chart shows that the black shade balls kept the water below them coolest relative to the other balls and the control. The average daily maximum water temperature was 4.1 °C cooler and the median water temperature was 1.9 °C cooler in the black ball pond relative to the white ball pond. The reflective balls were a close second to the black balls, but the reflective ball pool consistently had higher daily maximum temperatures (see Figure 5.17). Of the three ball colours, the white balls were the least effective at shading the water below them from solar heating. It was also observed that all the shade balls had warmer minimum nighttime temperatures relative to the control, even though the control reached the highest daily maximum temperatures. This suggests that the balls are having an insulating effect and contributing to the retention of heat in the water at night.

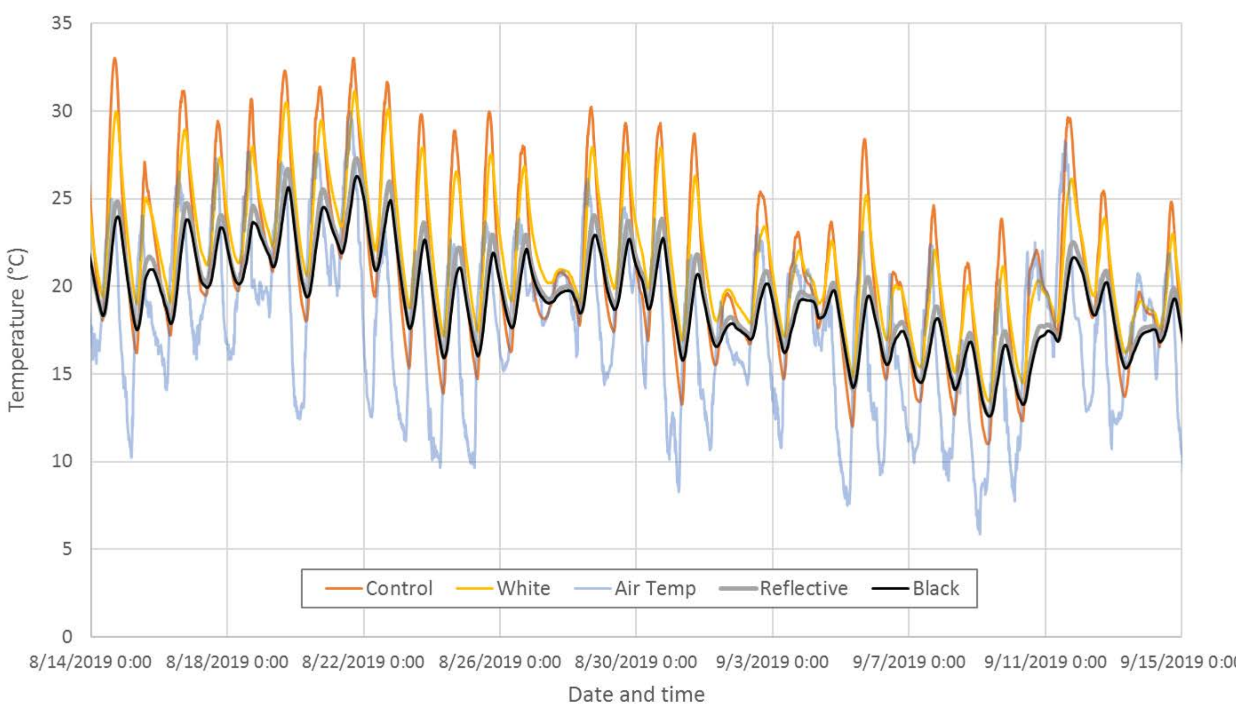


Figure 5.16: Temperatures measured at the base of wading pools with no shading (control) and shading with black, white, and reflective shade balls.

The shading performance of the black ball was unexpected based on colour alone, given that white surfaces have a higher albedo than darkly coloured surfaces. While a white surface should reflect light more than an equivalent black surface, this is not the case with the shade balls because their opacity differs. Closer inspection of the white balls revealed that they allow light to be transmitted through them, while the black balls are opaque. Figure 5.18 shows how light is transmitted through the white ball, while none passes through the black ball. This would also explain why the shading performance of the reflective ball came the closest to the black ball, as the reflective coating made the previously white ball nearly opaque.

While the white balls were originally chosen largely based on the hypothesis that they would better reflect sunlight due to their light colour, the opacity of the ball was demonstrated to be the more important factor. The impact of ball colour and the extent to which a lighter colour would better reflect light (and thereby minimize heating) can only be evaluated in an experiment where both balls are equally opaque.

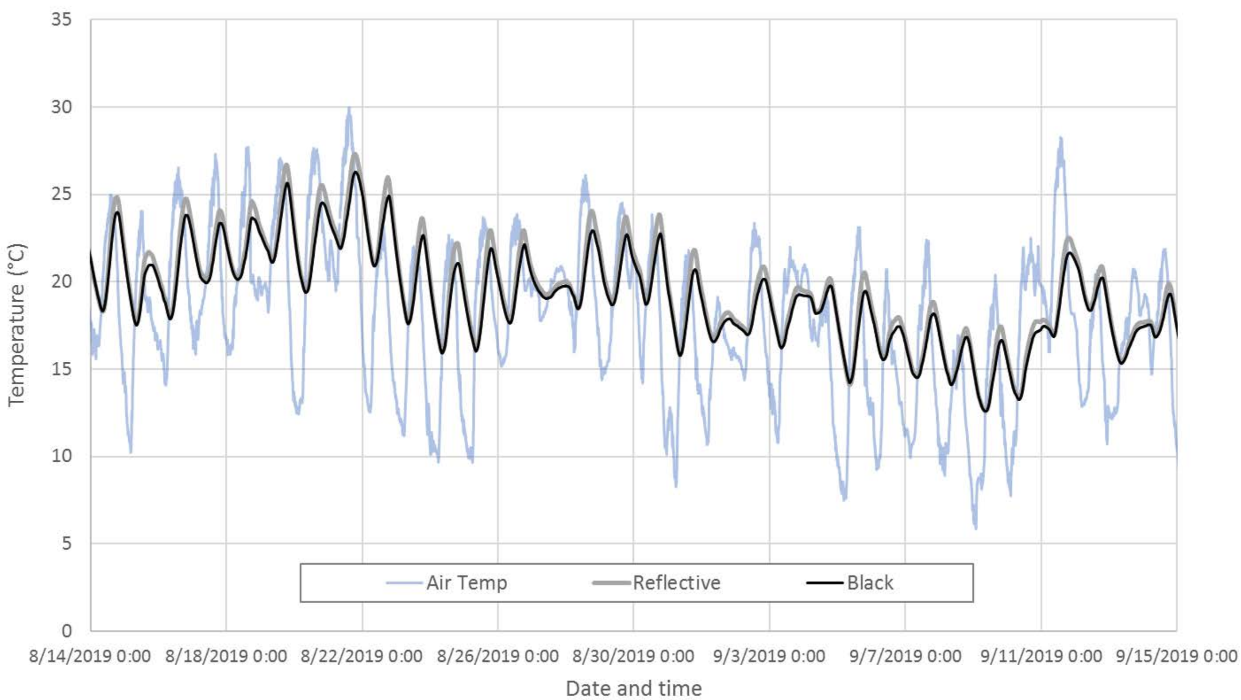


Figure 5.17: Temperatures measured at the base of wading pools shaded by black and reflective balls

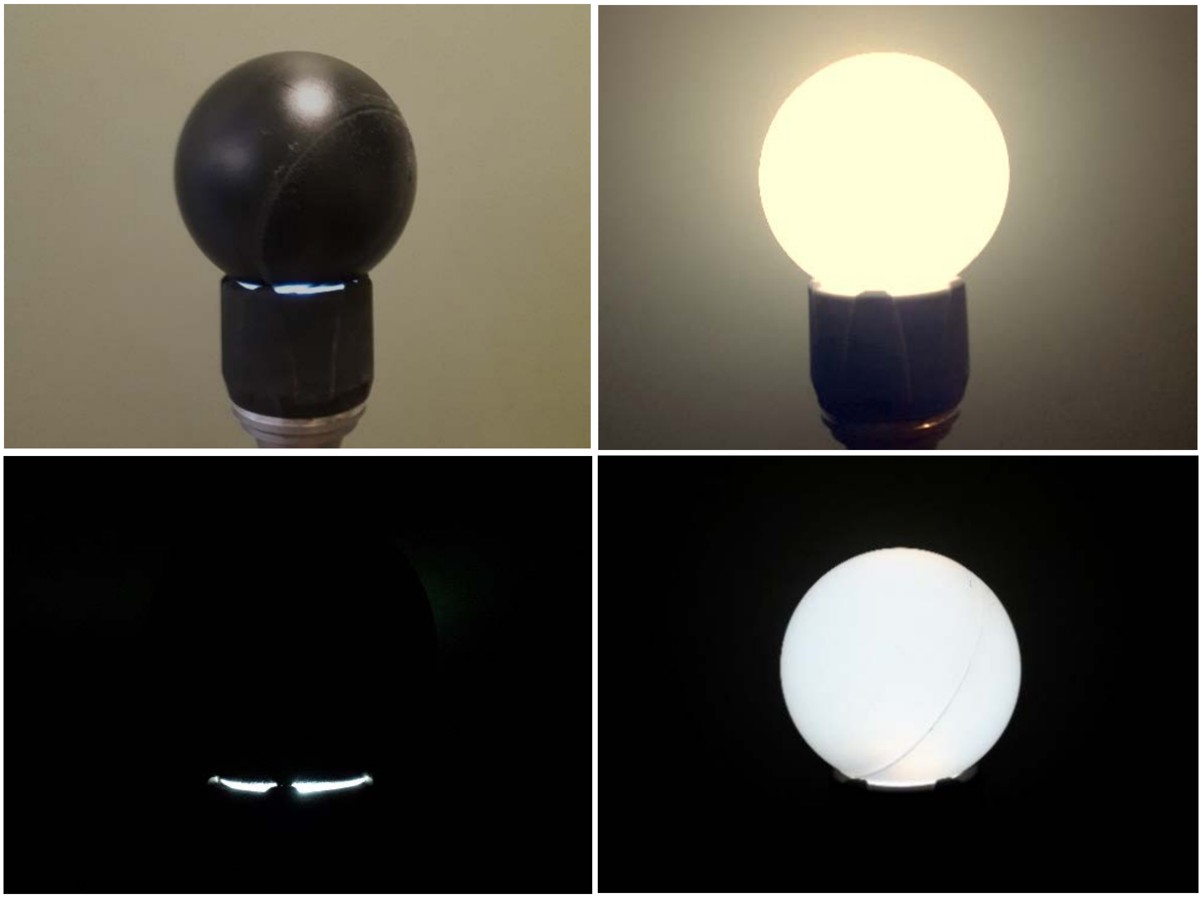


Figure 5.18: Illumination of a white shade ball (right) vs. a black shade ball (left). Pictures on the top row were taken with lights on, pictures on bottom row were taken in the dark.

5.3 Small-scale test results: transmission of heat through differently coloured balls

As described in Section 4.3, an additional small-scale experiment was set up in which the different shade balls were artificially heated with a heat lamp and their thermal response was monitored. Figures 5.19 to 5.20 show the shade ball internal temperatures and changes in internal temperatures following heating with the lamp. It was determined that the black balls had the lowest internal temperature of 19.0°C while the white balls had the highest (30.0°C) and the reflective balls were closer to the white balls at 26.5°C. While the heat lamp doesn't emit radiation in every part of the electromagnetic spectrum the way the sun would, this experiment does reveal differences in the extent to which radiation is transmitted through the white and black shade balls.

Cross sections of the balls were also compared visually using IR pictures taken after heating was complete. The white balls seemed to show more of a temperature gradient that suggest the heat from the lamp was transmitted throughout the ball (Figure 5.21). Air temperature and water temperature remained virtually unchanged as the test was short.

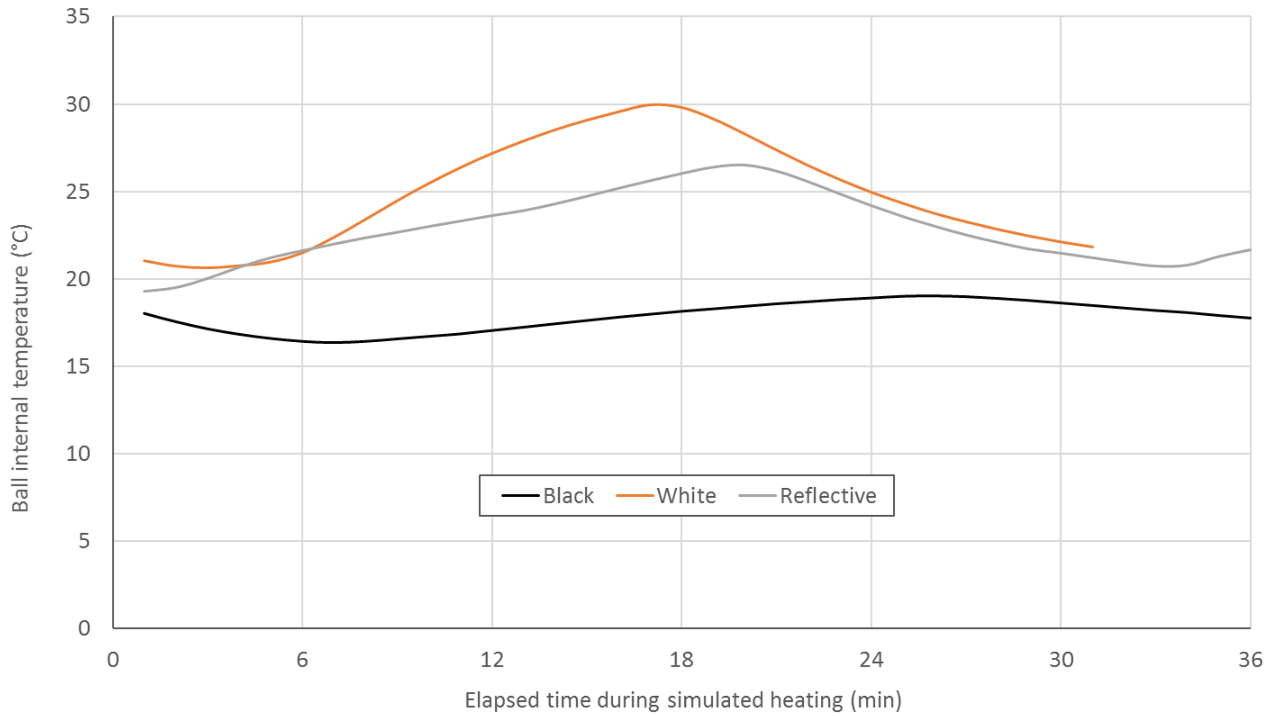


Figure 5.19: Internal temperature of black, white and reflective balls as measured during heating with a heat lamp

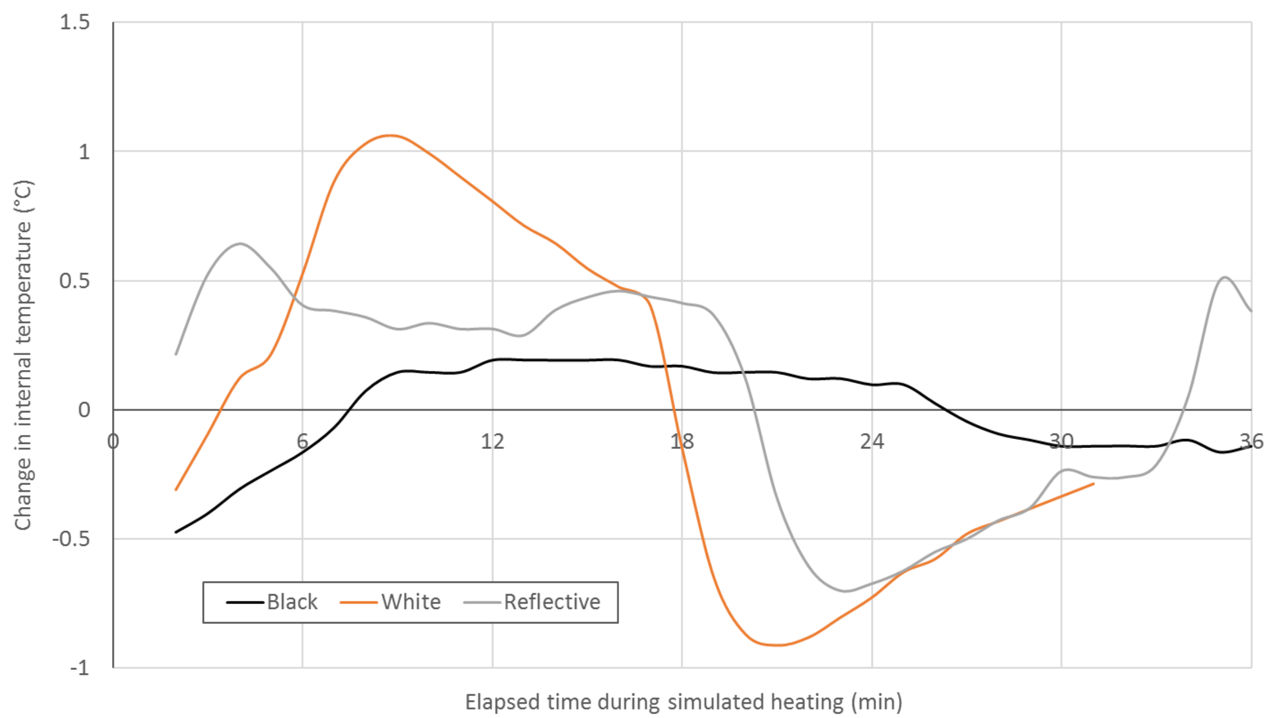


Figure 5.20: Change in internal temperature of black, white and reflective balls following heating

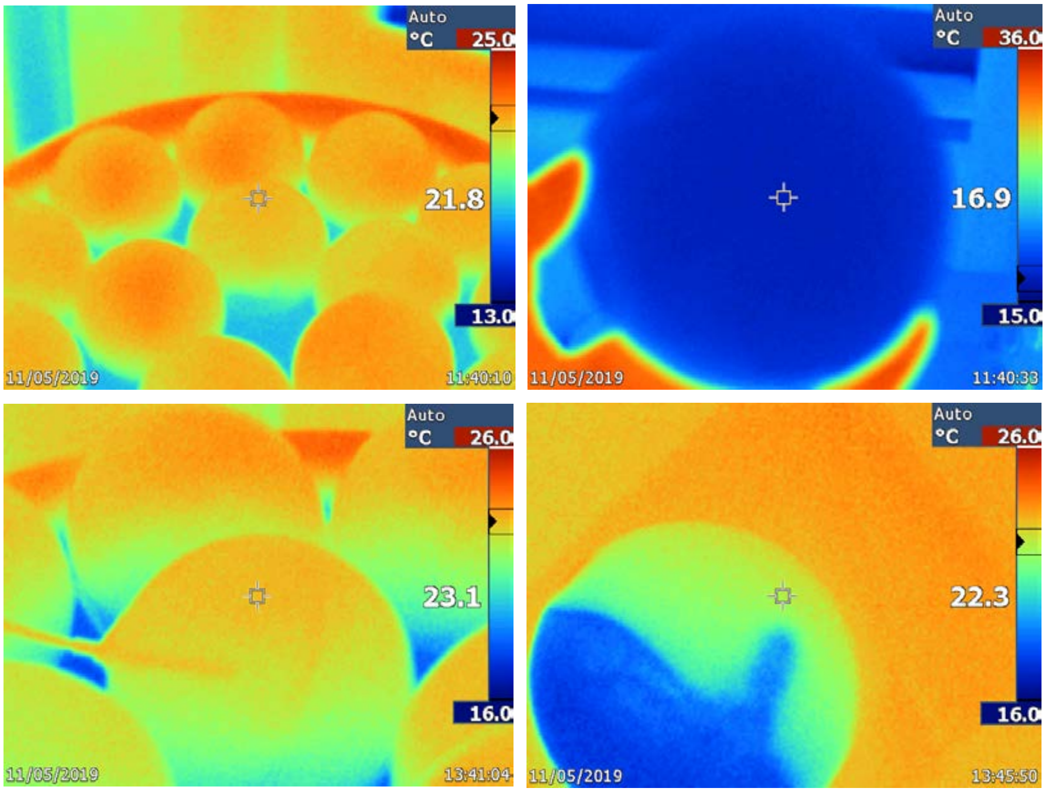


Figure 5.21: Thermal images of black (top) and white (bottom) shade balls. Images on the right show the underside of the balls which were in the water and not directly irradiated by the heat lamp.

5.4 Microplastics levels

Microplastics analysis of grab samples from the shade ball pond in 2019 was focused on determining whether microplastics levels increased from inlet to outlet, and whether any notable increase was caused by the shade balls themselves. The total number of microparticles counted in the inlet and outlet samples are provided in Table 5.5.

There were two main results:

1. The counting results show that the outlet samples contained more microparticles than the inlet samples. This was observed across all size fractions except the smallest size range.

2. When looking at the type of microparticles in each sample, it appears that both the inlet and outlet samples were dominated by fibers.

The following are potential hypotheses that could explain the microplastics results.

- While fibers could come from the inlet stormwater, they are also present in the air. These results could suggest that fibers have deposited from the atmosphere on the surface of the pond water and balls and have been carried towards the outlet. Without more information about the catchment area and potential contributions of atmospheric deposition of fibers in the inlet, it is difficult to provide definitive conclusions.

- The ageing of the balls over time should be tested to investigate if the balls could be the source of the fibers. If this was the case it would be expected that "fragments" (a category of microparticles) would be detected in outlet samples, but this was not the case and they were not reported in the microplastics analysis results.
- Some fibers might be cotton, others could come from clothing. To investigate if the microparticles found in these samples are from the same material as the balls in the pond, a ball sample fragment could be provided to be tested against some of the fibers found by spectroscopic techniques.

Table 5.5: Number and type of microparticles in inlet and outlet samples from the shade ball pond.

Size fraction	INLET			OUTLET		
	# of particles	Concentration (# particles/L)	type	# of particles	Concentration (# particles/L)	type
> 1 mm	4	4.4	4 fibers	22	24	21 fibers, 1 film
500 µm - 1 mm	4	4.4	4 fibers	13	14	13 fibers
300 µm - 500 µm	11	12	11 fibers	17	19	17 fibers
106 µm - 300 µm	13	14	12 fibers, 1 rubber	11	12	11 fibers
TOTAL	**32**	**36**		**63**	**70**	

5.5 Cost considerations

The cost of the shade ball system is provided in Table 5.6 and includes the costs associated with purchase and installation of both white and equivalent black shade balls based on 2018 pricing. As described in Section 4.1, the balls were designed to cover 75% of the pond surface area. The costs listed are per unit area of pond shading provided. Costs associated with planning, design, and installation are subject to economies to scale, and would represent a lower proportion of the total cost as the size of area to be shaded becomes larger.

Table 5.6: Capital costs for purchase and installation of shade balls and containment system. All figures are based on 2018 pricing and listed as \$ per m^2 of pond surface shading provided.

	Planning and design	Materials cost– shade balls	Materials cost - boom and anchors (turbidity barrier)	Installation	Total
White shade balls	\$0.56/m^2	\$45.29/m^2	\$11.87/m^2	\$1.95/m^2	\$59.67/m^2
Black shade balls	\$0.56/m^2	\$39.05/m^2	\$11.87/m^2	\$1.95/m^2	\$53.43/m^2

At the time of purchase, black shade balls were found to cost 16% less than the equivalent white shade balls and their quoted life span was also at least twice as long. The expected lifespan of the black balls is 10 years while that of the white balls is 3 to 5 years. The smaller lifespan of the white balls is a result of the UV stabilizers used in their manufacture. As demonstrated in the small-scale tests, the black balls were much better at preventing heating of water below and reached a lower internal temperature when irradiated. The black balls were also confirmed to be opaque while the white balls were not. Considering these findings, the black balls could be a more effective and affordable shading option than the white balls, although the extent to which they could result in significant pond cooling would need to be verified in a full-scale evaluation.

5.6 Maintenance considerations

The shade balls are marketed as a low maintenance solution requiring no routine maintenance to keep them operating as intended. They adjust to fluctuating water levels, remain in the pond all year round, and are not meant to require any cleaning. They are comparatively easy to install relative to other thermal mitigation solutions and can be added to existing ponds without requiring any dewatering or major construction.

In practice, some unanticipated maintenance needs were observed over the course of monitoring at the shade ball pond. Several shade balls were blown out of the ball containment area and into vegetated areas around the pond, from which they had to be removed (Figure 5.22). Suppliers of the balls do note that strong winds can sometimes cause shade balls to be blown away. The balls may also be more susceptible to wind displacement during the winter when the pond is frozen, as the ice causes a heave effect that results in balls sitting higher than their normal level relative to the barrier. An additional factor that could contribute to ball displacement is the growth of emergent vegetation, which was observed in the shade ball containment area (Figure 5.22). Suppliers suggest that where shade balls are at risk of wind displacement, there is the option to weight the balls by half filling them with water (Layfield, 2019). Alternatively, a taller barrier around the ball containment area or fencing around the pond could be installed to keep the balls from blowing away.

Figure 5.22: Shade ball displacement issues observed, including balls blown into surrounding areas (left) and emergent vegetation growing into the ball containment area (right).

At the end of the lifespan of the balls, they can be removed, recycled, and replaced with new balls. As they are HDPE, which is one of the easiest plastic polymers to recycle, they are widely accepted for recycling around the world. The turbidity barrier used to contain the balls is constructed from a durable XR-5 geomembrane which has a lifespan of 20 years. Given that the balls have a shorter lifespan (3 to 5 years for white balls and 10 years for black balls), the turbidity barrier could continue to be used even when the balls are replaced, up until the end of its lifespan. Costs of ball replacement would then exclude planning and design and the purchase of the turbidity barrier but would potentially include additional installation-related costs associated with ball removal, transport and disposal / recycling.

6.0 CONCLUSIONS

Based on monitoring undertaken during the summers from 2018 to 2020, the white shade balls did not cause a significant reduction in pond warming in comparison to baseline conditions or the experimental control pond. Research at the pilot ponds and additional small-scale experiments have led to the following key study conclusions:

- **Comparison to baseline conditions (2018, prior to shade ball installation) revealed that the magnitude of warming from inlet to outlet was similar or even greater after the balls were in place.** Prior to shade ball deployment, median temperature increase from pond inlet to outlet was 3.3°C, but the median warming increased to 5.9 °C and 4.2 °C respectively in 2019 and 2020. This increase may be partly attributable to increases in ambient temperatures, as they were 2.8°C and 1.9°C higher during the same time period in 2019 and 2020.
- **Installation of the shade balls did not cause a notable improvement in the extent to which outlet temperatures met the 24 °C temperature target for protection of redside dace.** The proportion of measurements that exceeded the target were 68%, 54% and 76% in 2018, 2019 and 2020 respectively.
- **Comparison to the control pond showed that while control pond inflows were always cooler, differences in outflows at the two ponds were minimal.** Relative to the ball pond, median outflows at the control pond were slightly cooler in 2018 and 2020, and slightly warmer in 2019, but in all cases the difference between the sites was less than 1°C. The higher magnitude of warming at the control pond is likely attributable to its shallower depth and the fact that it had cooler inflows. Outflow temperatures at the control and ball ponds end up similar because warming plateaus at a point based on controlling factors like air temperature, precipitation event frequency and magnitude, and pond detention times.
- **Temperature depth profile measurements showed that the shade ball pond exhibited a much higher degree of thermal stratification than the control pond.** Based on data collected in 2020, the median temperature drop from the top (shallowest) to bottom (deepest) sensor at the control pond was 2.1 °C, while the equivalent profile depths at the shaded and unshaded sections of the ball pond were 6.3 and 5.0 respectively. This difference between ponds is likely partially attributable to the ball pond being 50 cm deeper, making it more susceptible to stratification.
- **Temperatures measured at the deepest sensor in both ponds were almost never above 24 °C.** At the shade ball pond, the sensors located 30 cm below the bottom never exceeded the 24 °C threshold for protection of redside dace, as the maximum temperatures in both the shaded and unshaded profiles were around 21 °C. At the control pond the temperatures at the deepest sensor only exceeded the threshold briefly on two occasions, both in 2020.
- **Comparison of temperature depth profiles in the shaded and unshaded areas of the ball pond showed that median temperatures were within 1 °C of each other at all depths.** This

comparison also revealed that in 2020 the shaded profile was slightly warmer than the unshaded profiles in both the ball and control ponds at the shallowest sensor in the profile.

- **Warmer temperatures observed at shallow sensors under the shade balls suggest that the balls are inhibiting evaporation (and the associated cooling effect) and allowing transmission of sunlight.** Median temperatures under the shade balls showed a pattern of being coldest at greater depths and warmest close to the surface when compared to the other two unshaded profiles in the ball and control ponds. While the median temperature at the deepest sensor (30 cm above the pond bottom) was 3.1% cooler in the shaded area of the ball pond relative to the unshaded area, this cooling effect got smaller at shallower depths and reversed at the top sensor, at which the temperature was 2.9% warmer in the shaded area. The hypothesis that the balls could be reducing evaporative cooling at the surface is in line with their marketing as a solution to prevent evaporative loss from water reservoirs.
- **Small-scale testing comparing white, black, and reflective-coated shade balls showed that the black balls were most effective in preventing warming of water below.** It was determined that the white balls, originally chosen based on the premise that they would better reflect sunlight, were not opaque as originally believed at the outset of the study, while the black shade balls were opaque. Testing of the different ball colours in wading pools showed that the black balls kept the water below them coolest, resulting in a median temperature 1.9 °C cooler and average daily maximum temperature 4.1 °C cooler than under the white balls. An additional small-scale experiment that measured ball internal temperatures as they were irradiated by a heat lamp revealed that the black balls reached a maximum temperature 11°C cooler than the white balls, suggesting the white balls allow greater transmission of radiation.
- **Ball pond outlet samples contained nearly double the number of microplastics particles that were found in inlet samples, but the balls could not be identified as the source.** Because most microplastics identified were fibers, there are other sources that could have contributed, like atmospheric deposition or particles from the turbidity barrier. The types of particles expected from the breakdown of balls would be fragments, but those were not found in any samples collected.
- **The black shade balls used in small-scale testing have a longer lifespan and lower capital cost than the white shade balls.** At the time of purchase, black shade balls were found to cost 16% less than the equivalent white shade balls, and their quoted life span was also at least twice as long. The expected lifespan of the black balls is 10 years while that of the white balls is 3 to 5 years, due to differences in the stabilizers used in their manufacturing processes.
- **Balls were found to become displaced and blown out of the containment area and into surrounding vegetated areas.** This displacement of the balls could have been exacerbated by emergent vegetation growing up through the shade ball area and/or freezing of the pond over the winter causing a heave effect that made the balls more susceptible to being carried away by strong winds. Preventing this displacement would likely require ball weighting (by filling with water) or installation of taller barriers.

- **Considering study findings and past research, shading alone cannot result in outflows meeting thermal targets.** Based on the results of this study and other local research on floating islands for stormwater pond shading (CVC, 2016), shading alone has not been shown to provide enough cooling to result in pond outflows that meet the 24 °C target. As observed in the CVC (2016) study, temperatures measured at deep sensors in the shade ball and control ponds (1.7 m and 1.2 m below the permanent water level respectively) were almost always below the 24 °C target. This reinforces the finding that subsurface draw outlets are a highly effective thermal mitigation strategy that can result in meeting the redside dace target, particularly when applied in deeper ponds.

7.0 RECOMMENDATIONS

This study was undertaken to assess the efficacy and viability of white shade balls as a solution to prevent summer heating of stormwater management ponds. While the balls tested did not provide a significant cooling benefit at the pilot site, lessons learned from the study shed light on how pond shading solutions could be improved, as described in the following recommendations.

- **Shade ball selection.** When selecting shade balls the opacity of the balls must be considered. While white balls could be considered favourable due to their high albedo, they must be fully opaque to block the penetration of solar radiation into the water below. If the results of small-scale testing comparing black and white shade balls are replicable in a full-scale installation, the use of black shade balls could result in better shading performance, but it's unclear that they would result in outflows that consistently meet the 24 °C threshold.

- **Operations and maintenance considerations for shade balls.** Because shade balls were displaced and blown out of the pond area during windy periods, consideration should be given to how displacement can be mitigated. Ideas that have been put forth by distributors of shade ball products are weighting of the balls by half-filling with water and increasing the height of the barrier around the balls. Due to the observed growth of emergent vegetation into the shade ball containment area, removal of this vegetation is recommended in ponds where shade balls are installed to ensure that ball displacement is minimized. Removal of emergent vegetation, particularly invasives, should be carried out in line with established local best practices and with consideration of the season and plant life cycle. Shade balls should not be applied in areas of ponds that are designed to support emergent vegetation (e.g., pond-wetland hybrid facilities).

- **Cost considerations.** The black shade balls investigated in small-scale tests are significantly more cost-effective relative to the white shade balls from the perspective of both purchase price, which is 16% lower, and life cycle, which is at least twice as long. Given that the black shade balls also performed better during small-scale testing, likely due to their greater opacity, they are a better pond shading option than the white balls tested.

- **Addressing knowledge gaps.** To gain a better understanding of the potential of pond shading as a means of preventing warming of stormwater management ponds, the performance of other shading options and approaches, like floating pond covers, alternative shade balls (e.g., fully opaque black or white balls), or more extensive surface coverage, could be further investigated. One of the key research questions to be answered is whether the shading effect of the cover would be significant enough to offset the reduction in evaporative cooling that seemed to be occur under the shade balls. With respect to microplastics, spectroscopic analysis of the shade balls and the fibers found in the pond, and investigation of local atmospheric contributions, would allow for a more thorough understanding of the origin of the particles found in outlet samples. Further, a longer-term microplastics sampling study in the pond would shed light on the extent to which the balls would break down over time and contribute to elevated microplastics levels.

8.0 REFERENCES

Credit Valley Conservation (CVC). 2011. Thermal Impacts of Urbanization including Preventative and Mitigation Techniques. Prepared by AECOM under contract to CVC, Mississauga, Ontario. Available at: https://cvc.ca/wp-content/uploads/2011/01/cvc-thermal-impacts-urbanization.pdf.

Credit Valley Conservation (CVC). 2016. Fletcher's Creek Vegetated Floating Islands Monitoring Report. https://cvc.ca/wp-content/uploads/2016/03/Floating-Islands-Monitoring-Report.pdf

Layfield Group. 2019. Ball Covers. Online document. Available at: https://www.layfieldgroup.com/geosynthetics/floating-cover-products/ball-covers.aspx#item0. Accessed March 22, 2022.

Ministry of Natural Resources and Forestry (MNRF). 2016. Guidance for Development Activities in Redside Dace Protected Habitat. Version 1.2 Ontario Ministry of Natural Resources and Forestry, Peterborough, Ontario. iv+54 pp. Available at: https://files.ontario.ca/sar_redside_english_resize_15-03-2016_final.pdf.

Oved, Marco Chown. October 23, 2016. Shade Balls – Just Add Water. Toronto Star. Available at: https://www.pressreader.com/canada/toronto-star/20161112/282952449774508.

Toronto and Region Conservation Authority. 2005. Synthesis of Monitoring Studies Conducted Under the Stormwater Assessment Monitoring and Performance Program. TRCA, Toronto, Ontario. Available at: https://sustainabletechnologies.ca/app/uploads/2013/01/Final_SWAMP_Synthesis.pdf.

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. Available at: https://sustainabletechnologies.ca/app/uploads/2013/08/Cooling-trench-final-2013a.pdf.

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. Available at: https://sustainabletechnologies.ca/app/uploads/2019/04/Thermal-Synthesis-Final.pdf.