Sustainable Technologies
EVALUATION PROGRAM

Stormwater Management Performance Summary: Meadows in the Glen Residential Subdivision

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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 (CVC) and Lake Simcoe Region Conservation Authority (LSRCA). 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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- Credit Valley Conservation
- Town of Halton Hills
- Toronto and Region Conservation Authority
- Lake Simcoe Region Conservation Authority
- Stantec

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1.0 BACKGROUND

Wet ponds are the most common end-of-pipe stormwater management practice used in Ontario and they are a requirement for any new developments of 5 ha or greater (Ministry of Environment, Conservation and Parks [MECP], formerly Ministry of Environment [MOE], 2003). They are used to meet water quality, quantity, and erosion control criteria, however, performance declines with time as sediment accumulates in the system requiring periodic dredging and removal.

In 2015, the Ontario Ministry of Environment and Climate Change (now Ministry of the Environment, Conservation and Parks, or MECP) identified that conventional end-of pipe stormwater management practices are not sufficient on their own to fully protect watershed ecosystems (MECP, 2015). Recent studies have also shown that conventional stormwater management pipe and pond configurations alone generally do not meet thermal (Sabouri, Gharabaghi, Sattar and Thompson, 2016), water quality (Liu, et al., 2017) and water balance objectives (Ahiablame, Engel and Chaubey, 2012).

There is growing recognition of the importance of mimicking a natural hydrologic cycle and maintaining the pre-development water balance in order to mitigate the negative impacts of development on aquatic habitats, flooding, groundwater, erosion, and water quality. Low impact development (LID) practices and design principles are one way of achieving this. The LID approach to stormwater management includes practices such as using permeable pavement and bioretention facilities to promote infiltration and/or evapotranspiration as well as maintaining existing natural areas and minimizing impervious surfaces.

Stormwater Infrastructure Performance and Risk Assessment Program

CVC's Stormwater Infrastructure Performance and Risk Assessment Program (IPRA) program was initiated in 2012 and provides in-the-field evaluations of current and emerging stormwater management technologies and systems installed at a range of sites across the watershed. The IPRA program includes performance, compliance, and adaptive monitoring, through the collection of high-quality data, on LID and stormwater practices to support future implementation of LID and inform regulatory requirements for LID practices. The IPRA program partners include local municipalities, MECP, and STEP. For more information visit: **www.sustainabletechnologies.ca**

To achieve all stormwater management objectives, from flood control to maintaining the natural water balance and preserving water quality, stormwater management designs may use a treatment train approach that incorporates a combination of conventional and LID stormwater management practices. However, knowledge gaps remain for how the presence of LID practices upgradient in the catchment influence the design, performance, and maintenance needs of wet ponds. This is a consequence of the relative newness of this hybrid approach to stormwater management, meaning there is limited long-term performance and monitoring data available.

Although innovative designs can help with meeting stormwater management objectives, it is also crucial to maintain stormwater practices appropriately to ensure that design objectives continue to be met. Without maintenance, the treatment performance of stormwater management practices will decline over time

(TRCA, 2016). A study of stormwater detention ponds in Ontario revealed that many of them were not receiving adequate maintenance to enable them to continue performing as designed (LSRCA 2011). A proactive, routine, inspection and maintenance program can help identify issues before they are severe enough to impact the function of the stormwater management practice, help with prioritization and planning for allocation of resources, and provide feedback that will improve designs and guidance in future (TRCA, 2016).

Meadows in the Glen (MITG) is a 27.5 ha greenfield development of a low-density subdivision located in Halton Hills. Stormwater management for this subdivision is achieved by a combination of LID practices and two wet ponds. Credit Valley Conservation (CVC) in partnership with Intracorp and the Town of Halton Hills have conducted a long-term performance monitoring project at MITG. Over the past 5 years, CVC has conducted a robust monitoring program to investigate how lot-level, conveyance LID practices and conventional wet ponds work together as part of a stormwater management treatment train. Monitoring at one of the stormwater ponds in this subdivision, Pond A, is conducted to determine whether a full-sized wet pond is necessary for meeting the MECP requirements when there are LID practices upgradient.

1.1 Purpose

This report is intended to address preliminary questions with respect to whether the stormwater management treatment train at MITG is performing as designed. The goal of this performance study is to inform stormwater designers, consultants, and municipal professionals to support decision making for future developments, as well as asset management planning. In particular, the focus is on understanding the performance of the wet pond, and whether having LID practices upgradient have influenced its function. The presence of LID practices upgradient was not accounted for in the original design model for this pond (Stantec, 2007a).

This performance study aims to answer the following three key questions:

1. Is stormwater management Pond A performing as designed?
2. What is the influence of the upgradient LID practices on the performance of stormwater management Pond A?
3. How can the monitoring results inform asset management at MITG and of stormwater management ponds in treatment train designs?

The report will include the following sections: site description, methods, results and discussion, challenges and lessons learned, conclusions and next steps, along with appendices. These appendices include details on the monitoring setup, analysis methods, and the results of a bathymetric survey. The appendices also include the results of an interview with the subdivision developer on maintenance costs.

2.0 SITE DESCRIPTION

MITG is the first subdivision in Halton Hills designed to manage stormwater according to LID design principles working in concert with end-of-pipe stormwater management practices. MITG is a 27.5 ha low-density residential development with 35% impervious cover. It consists of 91 lots and includes single-family homes, roads, parks, open space blocks, and two wet pond facilities (Pond A and Pond B) (Stantec, 2007a). This study will focus on the catchment of one of these 2 wet ponds (Pond A). The subdivision is located on lands previously owned by Sheridan Nurseries. Construction began in 2010 and continued through to 2014. Prior to development, the site was under active agricultural land use consisting of non-native nursery stock, several plantations, a small woodlot, and some small patches of woodland and wetland.

The MITG property is at the top of a wooded slope located adjacent to the Credit River floodplain near Glen Williams as shown in Figure 1. Most of the site is underlain by silty-sand soils with two areas of sandy soils and one area of sandy-silt in the vicinity of Pond A (Terraprobe, 2007; Stantec, 2007a). A pre-development geotechnical study found that water was encountered at approximately 6 m depth or more in all boreholes. Four monitoring wells were also installed that had water levels ranging from 8.7 m-18.1 m depth as of August, 2002 (Terraprobe, 2007).

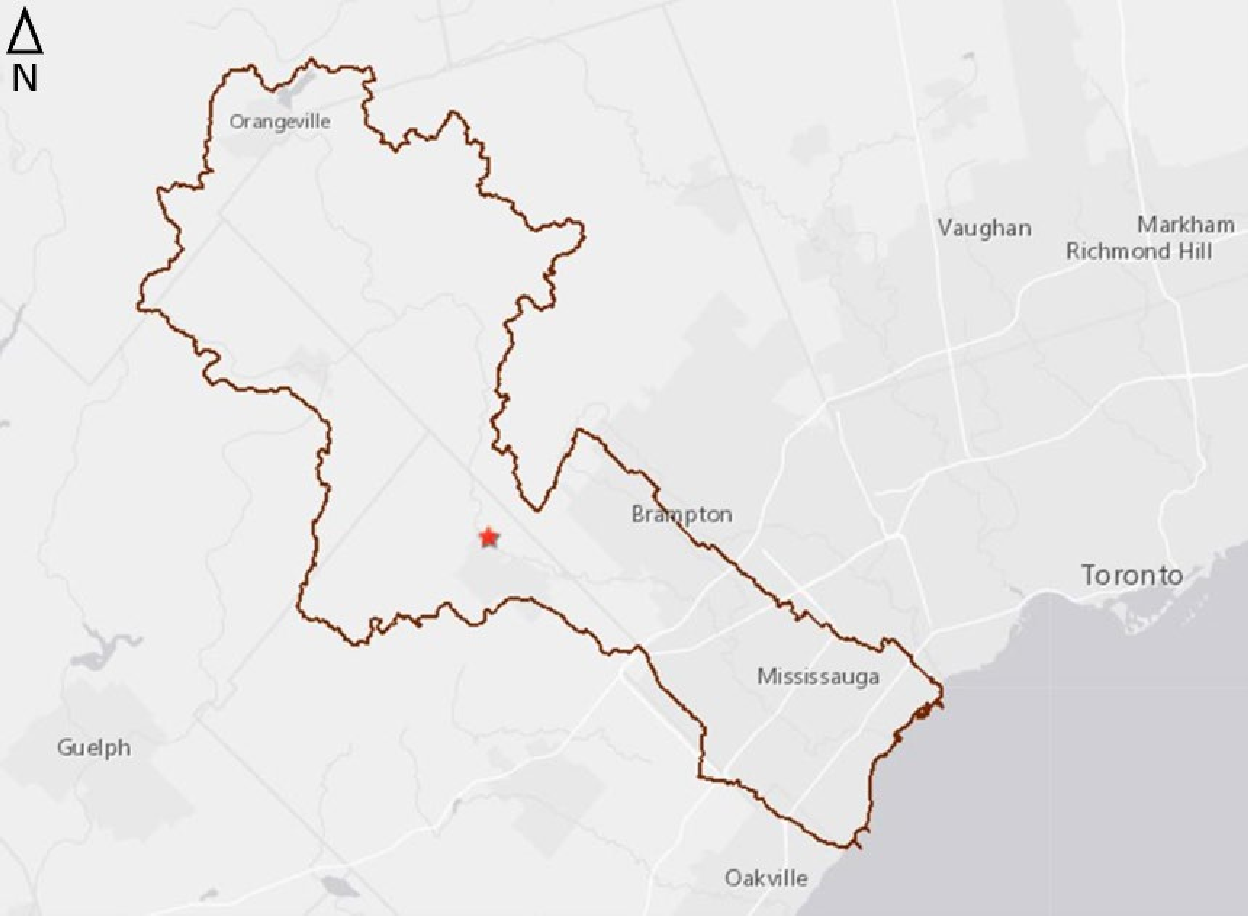


Figure 1: Location of the study site is indicated by the star within the Credit River Watershed boundary.

The primary natural surface drainage feature is Tributary F, an intermittent stream which joins the Credit River approximately 1 km downstream from the development. Tributary F has been classified as a warmwater fish community (Stantec, 2007b). An assessment of Tributary F, determined that the erosion threshold for this watercourse is 0.10 m^3/s in its uppermost reach (Parish Geomorphic, 2005), which receives discharge from Pond A. One of the stormwater management objectives is to avoid exacerbating erosion rates for Tributary F.

As illustrated by Figure 2 below, there are two main catchments in the MITG subdivision that independently drain the eastern and western areas. The as-built drainage areas were determined using a GIS analysis. Under post-development conditions the eastern catchment, which includes 9.2 ha of the MITG subdivision and 15.3 ha from the adjacent Sheridan Nursery property, drains to the northeastern stormwater management facility (Pond A). Pond A is approximately 0.77 ha and outlets to Tributary F. The western catchment area is a 12.7 ha section of the subdivision that drains to the southwestern stormwater management facility (Pond B).

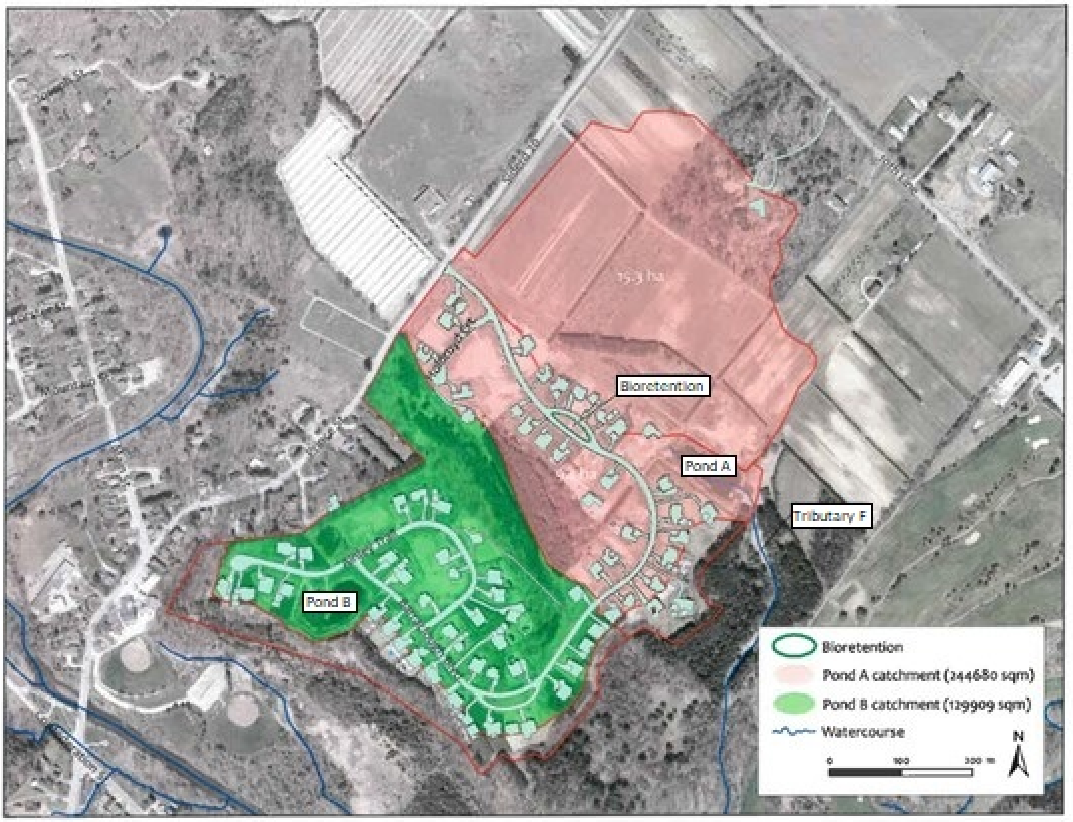


Figure 2: Two main catchments delineated in MITG, red drains to Pond A and green drains to Pond B. The Pond A catchment includes 15.3 ha of adjacent rural property.

An important objective of the stormwater management plan for MITG is to maintain or improve the amount of infiltration after development relative to pre-development conditions (Stantec, 2007a). The LID design principles in the MITG subdivision help to meet this objective by reducing impervious area and capturing rain where it falls. Impervious cover in MITG is only 35%, which is less than most subdivisions, this is primarily due to the low density of the subdivision. In addition, imperviousness was reduced by using pervious pavement for sidewalks and driveway aprons, substituting sewers with grass swales, using native plantings, and retaining existing woodlots. In addition, lot-level soakaway pits are present on most properties to infiltrate roof runoff and a bioretention cell captures some of the runoff from the road.

Figure 3 shows the general layout of the subdivision within the Pond A catchment and indicates the location of the major stormwater management facilities: the bioretention cell, Pond A, as well as the lot-level and conveyance infiltration practices that are distributed throughout the subdivision with permeable driveway aprons and soakaway pits on almost every lot to capture roof runoff and treat it at-source, and all roadways bordered by permeable sidewalks and grass swales. The grass swales are the primary conveyance feature within the subdivision, as there are no storm sewers. Therefore, any runoff that has not been infiltrated by the lot level practices or the bioretention cell would travel through the grass swales to the pond, with potential infiltration occurring along the way.

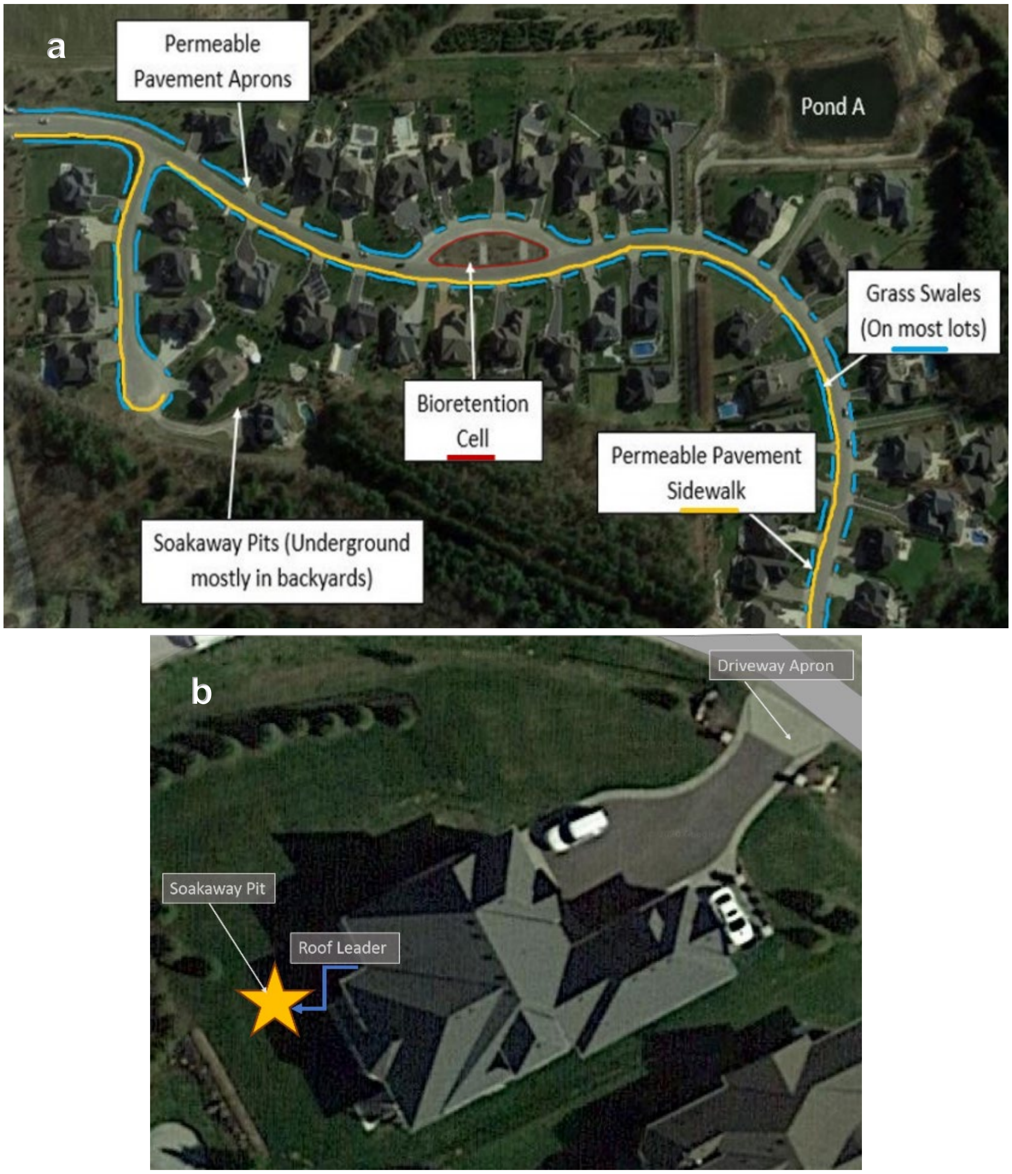


Figure 3: a) General layout of the Pond A catchment indicating the locations of the main stormwater management facilities; b) An example of the layout for lot level features which are distributed on the properties throughout the subdivision.

According to modelling results, the pre-development infiltration volume was 40,568 m^3/yr. Even though MITG was designed with less impervious cover than most subdivisions, the increase in impervious cover resulting from the development would still have reduced the infiltration volume to 23,187 m^3/yr if additional infiltration practices, specifically soakaway pits and a bioretention cell, had not been used. With these additional practices, the modelling results suggest that the pre-development infiltration amounts can be met or exceeded (Stantec, 2007a).

Lot-level soakaway pits are designed to infiltrate the first 25 mm of runoff from all roof areas. This is estimated to provide approximately 10,962 m^3 of infiltration to groundwater annually. Infiltration in grass swales and the bioretention cell (Figure 4) is estimated to infiltrate 10% of runoff not captured by lot-level infiltration practices, resulting in about 6,697 m^3 of infiltration (Stantec, 2007a). Any stormwater not treated by the LID treatment train in MITG will be treated by two wet ponds designed to provide enhanced water quality control by a combination of permanent pool storage, detention storage and a forebay to promote the settling out of sediment (Stantec, 2007a).

Figure 4: a) Bioretention cell during a rainstorm; b) Permeable pavement and grass swale during a rainstorm.

Based on the underlying soil type (sand/silty-sand), 84 of the 91 lots were deemed appropriate for lot-level infiltration practices (Terraprobe, 2007). Soakaway pits were not installed on the remaining seven lots because the underlying sandy-silt does not provide optimal infiltration conditions. All lots without soakaway pits are located in the catchment area for Pond A (Stantec, 2007a).

The bioretention cell shown in Figure 4 is located within the eastern catchment and is designed to capture and treat flows from the northeastern corner of the subdivision (Stantec, 2007a). Any outflow from the bioretention cell is discharged either by an overflow outlet at the surface or by the underdrain. All outflow is then conveyed by the swale network to Pond A.

2.1 Stormwater Design Criteria

The design criteria and objectives for the stormwater management strategy at MITG include hydrologic control, water quality control, and infiltration. Specifically, the criteria listed in the design brief (Stantec, 2007a) include:

Hydrology:

- **Peak Flow:** Maintain hydrologic functions of the site by attenuating peak flows and conveying major storm runoff safely to an appropriate outlet without increasing erosion or flooding beyond acceptable limits.
    - Erosion threshold for Tributary F 0.10 m3/s
- **Water Balance:** Post-development conditions to maintain or improve existing infiltration conditions.

Water Quality:

- **Detention Time:** The wet pond facilities are designed to provide detention volume to be drawn down in 24-48 hours.
- **Enhanced standard** - maintain storage volumes required for the long-term average removal of 80% of suspended solids (MECP, 2003). Based on the size of the Pond A catchment area, the minimum permanent pool volume required to meet this criterion is 955 m^3 (Stantec, 2007a).

3.0 STORMWATER MONITORING METHODS

In order to address the three questions outlined in the study purpose, maintenance interviews, bathymetry, site inspections, and intensive hydrology and water quality monitoring has been conducted by CVC's IPRA program from April 2015 to October 2018. Monitoring is conducted at 4 stations located around Pond A: Inlet 1, Inlet 2, Outlet and Pond A Stage (Figure 5 and Figure 6). Monitoring was also conducted at Tributary F, in groundwater wells around the subdivision, and at the outlet of Pond B, however this data will not be presented in this report.

- **Inlet 1** measures runoff from the MITG subdivision and the upgradient LID treatment train.
- **Inlet 2** measures runoff from the adjacent rural property that also drains to the pond as well as a small portion of the subdivision.
- **Outlet** measures water leaving Pond A through the outlet structure.
- **Pond A Stage** consists of measurements taken within Pond A near the outlet.
- **Rain Gauge** measures precipitation and air temperature.

Figure 5 indicates the location of monitoring stations within the subdivision. Figure 6 shows the monitoring infrastructure present at these stations.

Figure 5: Location of Pond A monitoring stations. Note: Pond A stage is in the aftbay of Pond A.

Figure 6: Monitoring infrastructure at Pond A. Note: Stage is located in aftbay of pond and is viewed from the outlet structure in photograph.

The details of the monitoring and inspections conducted at each station are summarized below in Table 1, as well as how these relate to answering the performance questions. The monitoring approach has been adapted over time in response to observations made with respect to the performance of Pond A; this has resulted in introducing new initiatives such as winter monitoring, pond stage monitoring, and continuous water quality sensors for conductivity and turbidity. For more details on the adaptations that were made see Section 5, Challenges, Limitations and Lessons Learned. The standard equipment configuration is shown in Figure 7, including an automatic sampler, flow logger, and weir. For additional details on monitoring setup please refer to Appendix D.

Table 1: Summary of monitoring type, purpose and details for monitoring stations located at Pond A.

Monitoring Type	Questions	Monitoring Purpose	Stations Monitored	Equipment Used	Details
Precipitation and Air Temperature	1 & 2	Determine precipitation amounts.	Rain Gauge	Hydrological Services TB3 rain gauge and Sutron data logger	Remotely monitored weekly and calibrated in the spring/fall.
Continuous Flow	1 & 2	Determine peak flow and runoff volumes entering and leaving the pond.	Inlet 1, Inlet 2, Outlet	ISCO 2150 area-velocity loggers and compound weirs	Downloaded and calibrated with manual measurement on approximately monthly basis.
Event-Based Water Quality Sampling	1 & 2	Determine water quality and contaminant loads entering and leaving Pond A.	Inlet 1, Inlet 2, Outlet	ISCO 6712 autosamplers powered by solar panels	Maintained during regular visits, sampling conducted after storm events.
Continuous Pond A Water Level	1, 2 & 3	Characterize seasonal pond level fluctuations and drawdown times with respect to permanent pool.	Pond A Stage	ISCO 2150 area-velocity loggers and fixed stage	Downloaded and calibrated with stage reading on approximately monthly basis, initiated 2017. Level sensor and stage installed in aftbay of pond near the outlet.
Continuous Conductivity and Temperature	1 & 2	Determine water quality when event-based analysis is not possible.	Inlet 1, Inlet 2, Outlet	HOBO specific conductivity loggers	Compensated using conductivity samples submitted to lab, initiated 2018.
Continuous Turbidity	1 & 2	Determine water quality when event-based analysis is not possible.	Inlet 1, Inlet 2, Outlet	NEP turbidity sensors and Sutron data loggers	TSS samples collected to develop a proxy relationship, initiated 2018.
Winter Flow	1 & 2	Obtain flow data when there is risk of freezing damage to ISCO 2150 loggers.	Inlet 1, Inlet 2, Outlet	HOBO water level loggers and compound weirs	Monitoring plan did not initially include winter monitoring, initiated winter of 2016-2017.
Maintenance Inspections	3	Track condition of LID features and identify maintenance issues.	Throughout subdivision	Camera and checklist	Completed every few months for bioretention cell, permeable pavers and grass swales. Only completed once at Pond A.
Bathymetric Survey	3	Determine baseline sediment build up in Pond A.	Pond A	Performed by consultant	Completed September 2017. See Appendix B.
Maintenance Interview	3	Find out costs of maintenance for developer prior to assumption.	N/A	N/A	Completed in September 2017 with developer of MITG subdivision. See Appendix C.

Figure 7: Typical monitoring equipment installed at Pond A monitoring stations

3.1 Data Analysis

Data from 2015-2018 have been analyzed for this report using standard metrics that relate to pond performance. These include peak flow reduction, drawdown time, detention time, as well as more detailed analyses for selected precipitation events and summary statistics on pond stage and water quality data. The analysis of Pond A's performance is complemented with an analysis of the volume and total suspended solids (TSS) load reduction provided by the upgradient LID practices. Further details on these analyses can be found in Appendix A.

4.0 RESULTS AND DISCUSSION

During the 2015-2018 monitoring period at MITG, 223 precipitation events greater than 2 mm have been monitored. Figure 8 shows the distribution of precipitation depth among these monitored events.

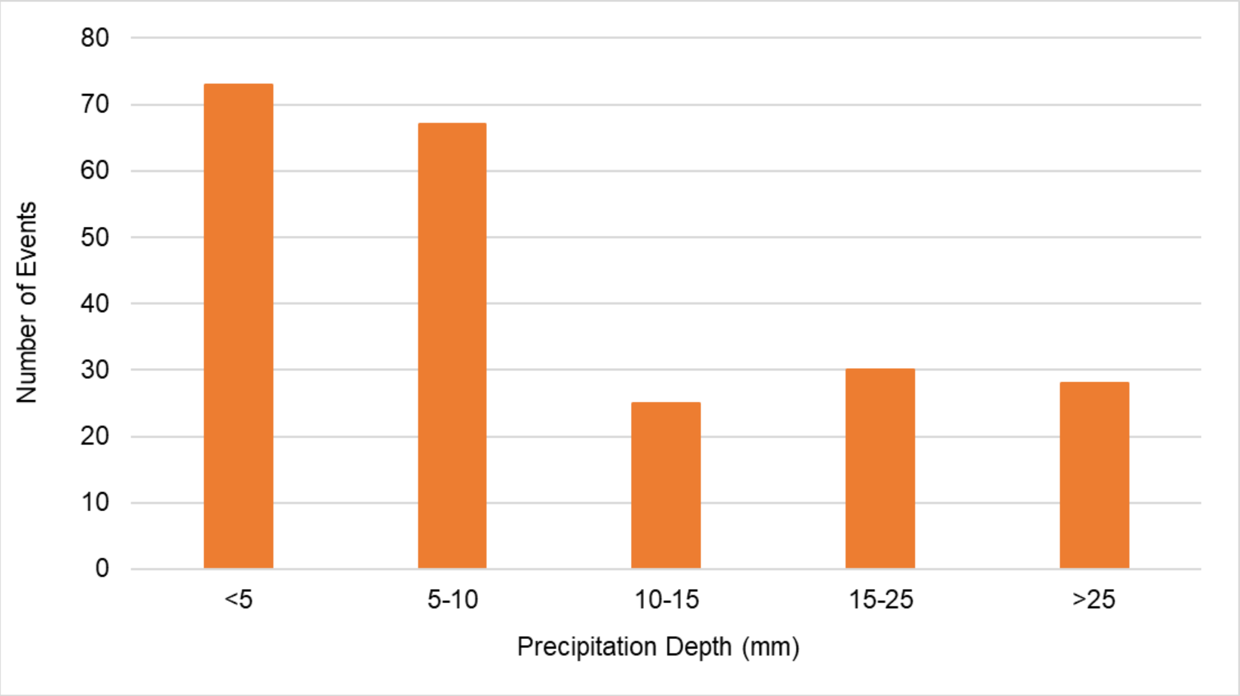


Figure 8: Precipitation depth distribution for events during the monitoring period (2015-2018).

However, monitoring did not start at all stations at the same time due to a combination of logistical issues at Inlet 2, and adjustments to the monitoring plan that led to the installation of the Pond A Stage. Table 2 summarizes the monitoring period at each station and the number of water quality samples that were collected during that time. Further details on these logistical challenges can be found in Section 5, Challenges, Limitations and Lessons Learned.

Table 2: Summary of monitoring period and samples collected for Pond A.

Station	Monitoring Period	Water Quality Samples
Inlet 1	April 2015-December 2018	26
Inlet 2	March 2016-December 2018	8
Outlet	April 2015-December 2018	11
Pond A Stage	September 2017-December 2018	N/A

4.1 QUESTION 1: Is stormwater management Pond A performing as designed?

To address this question, Pond A performance data is compared to design parameters for storage, drawdown time, detention time, peak flow, and water quality. The monitoring data for Pond A is further contextualized with comparison to published performance data from other wet ponds that do not have LID practices upgradient.

4.1.1 Pond Storage

Achieving the required pond storage volume is the main consideration when sizing a stormwater management wet pond. This can be broken down into two key components: the active storage and the permanent pool volume. Active storage reflects the volume available to provide extended detention for runoff during storm events. This runoff is captured within the pond basin to be released at a controlled rate through an orifice or weir. The permanent pool volume refers to the volume of water that is retained within the pond between storm events; this volume is crucial for providing water quality control in accordance with the design criteria (MECP, 2003). The permanent pool provides water quality treatment both through dilution during an event, and settling of suspended solids between events (MECP, 2003). To meet the requirements for Enhanced treatment as described in the design criteria, Pond A must maintain a permanent pool volume of 955 m^3 (Stantec, 2007a) with an additional active storage volume of approximately 370 m^3 (MECP, 2003). According to the design report, Pond A provides a permanent pool volume of 2,893 m^3; this is significantly greater than the MECP minimum requirement for achieving Enhanced water quality treatment (Stantec, 2007a). Pond A was sized to achieve dimensions that meet peak flow control requirements for the 2 through 100-year storm, resulting in a larger permanent pool than needed for meeting water quality requirements.

A stage marker and continuous level logger were installed in Pond A in September 2017 to verify observations of very low pond levels for significant portions of the year. According to the design document, the elevation of the lower outlet orifice invert is at 256 masl, however an as-built survey determined that it was at 256.053 masl. Therefore, we are treating 256.053 masl as the expected permanent pool level against which the measured pond stage is compared. Throughout the monitoring period (September 2017- October 2018) the Pond A stage was at or above the expected permanent pool level only 21% of the time.

Figure 9 plots precipitation and the pond stage compared to the expected permanent pool level. It is evident that there is a strong seasonal pattern to the fluctuations of pond stage relative to the permanent pool. Pond levels are consistently well below the permanent pool level during the summer and fall. At this time of year there is enough extra storage that even high intensity precipitation events do not generate enough level change to result in flow leaving the pond. Continuous flow measurements at the pond outlet reinforce these observations as outflow from the pond is rarely observed from late June through December. Flow typically starts again in late December or mid-January. This means there is extra active storage available for events that occur between June and December, however it also means that the permanent pool volume is likely to be less than is specified in the design for these months. Since the design permanent pool volume is significantly more than required from a water quality perspective, the pond would still meet the minimum volume for the Enhanced standard at these times despite the lower than expected water levels.

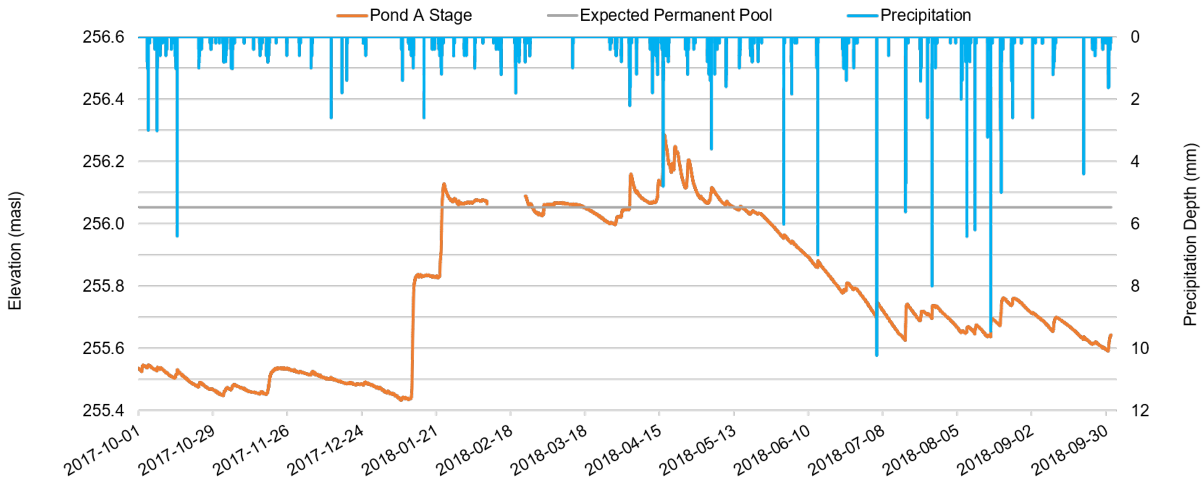


Figure 9: Pond A Stage and precipitation over the monitoring period September 2017-October 2018 compared to expected permanent pool level.

Although it is possible that this is a result of seepage or leaking from the pond (not measured in outlet measurements), the strong seasonal pattern suggests that it may be driven by increased rates of evaporation in the summer and the influence of the upgradient LID practices. The LID features were not accounted for in the design model calculations for the post-development water balance and this may explain the discrepancy between the design model estimates and the monitored pond behavior. It is probable that some combination of these factors explains the lower than expected water levels in the pond for much of the year.

It is also possible that some of the seasonal pattern reflects the influence of the rural property that is adjacent to the MITG subdivision. This is supported because the Sheridan Nursery property that feeds into Inlet 2 generates runoff primarily in the months from January-June, whereas only very high intensity events produce runoff from Inlet 2 during the summer. By contrast, Inlet 1, which drains the subdivision, generates runoff for most precipitation events that occur, even in the summer. According to the design report, since the drainage area for Inlet 2 represents the pre-development condition, treatment is not required and this water is just routed through the pond. Therefore, the Inlet 2 drainage area would not have factored into the permanent pool volume calculations (Stantec, 2007a).

Table *3* summarizes the Pond A Stage data for September 2017 through October 2018. It indicates the percent of time the pond level is at or above the expected permanent pool level each month as well as how the actual pond level for each month compares to the expected permanent pool level. The average pond level is lowest in November and December and reaches its maximum in April. During the early spring the pond may continue to flow for months at a time. This is in stark contrast to late fall when the pond may be more than half a metre below the permanent pool level for prolonged periods of time. From June to December the pond level was measured below the permanent pool 100% of the time. This may result in maintenance issues related to stagnant water such as excess algae, odour issues, mosquitoes, and low oxygen levels in the pond.

Table 3: Summary of monthly average pond stage relative to the permanent pool elevation (256.053 masl as surveyed September 2017) over the monitoring period September 2017-October 2018.

Month	Measurements Equivalent or Above Permanent Pool (%)	Average Pond Level (masl)	Average Pond Level Relative to Permanent Pool (cm)
Jan	28	255.76	-29
Feb	39	256.06	1
Mar	49	256.04	-1
Apr	91	256.13	7
May	42	256.04	-1
Jun	0	255.85	-20
Jul	0	255.71	-35
Aug	0	255.69	-36
Sep	0	255.66	-39
Oct	0	255.51	-54
Nov	0	255.49	-56
Dec	0	255.50	-56

Bathymetric Survey

A bathymetric survey involves conducting depth measurements for a water body to develop a detailed picture of the underwater topography. In the context of stormwater management ponds, bathymetric surveys provide crucial information for planning maintenance. Bathymetric surveys are used to track sediment accumulation over time and allow a direct calculation of the permanent pool volume, which can be compared to design requirements. To support lifecycle planning, sediment accumulation rates can then be used to predict the amount of time before a full cleanout will be required (STEP, 2016). Furthermore, a bathymetric survey can provide estimates of the volume of sediment needing to be cleaned out which can assist with budgeting and planning for cleanout. The *STEP Inspection and Maintenance Guide* recommends conducting sediment depth measurements, either by bathymetric survey or a simple transect, approximately every 3-5 years (STEP, 2016).

To determine whether Pond A was meeting its design specifications, a bathymetric survey was conducted in September 2017, included as Appendix B. Pond storage characteristics from the design report and the bathymetric survey are summarized in Table 4 below. The design permanent pool volume of 2,893 m^3 (Stantec, 2007a) would have been calculated based on the expected permanent pool elevation specified in the report, however, as seen in Figure 9 above, the pond was well below its expected permanent pool elevation at the time that the bathymetric survey was completed. The pond water level was 255.50 masl, which is 0.553 m below the permanent pool elevation. This results in a smaller measured permanent pool volume compared to the design. The calculations provided by Calder Engineering were based on the water level at the time of the survey. At a water level of 255.50 masl, the provided permanent pool volume was 2,100 m^3. While this is less than the value indicated in the design document it is still more than double the minimum required by the *MECP Stormwater Management Planning and Design Manual* (MECP, 2003). Furthermore, it is likely that this discrepancy results from the low water level at the time of the survey, rather than a significant accumulation of sediment.

Table 4: Pond A storage volume characteristic summary

Pond Characteristic	Design Report	Bathymetric Survey Results
Required permanent pool volume	955 m^3	N/A
Required active storage	370 m^3	N/A
Provided permanent pool volume	2,893 m^3	*2,100 m^3
Lower Orifice Invert (expected permanent pool elevation)	256 masl	256.053 masl
Pond elevation used in permanent pool volume calculation	256	255.50

*The lower permanent pool volume from the survey were a result of low water levels in the pond in the fall

The consultants who completed the bathymetric survey noted that there was some sediment accumulation, but this was primarily in the forebay, while the main cell was believed to have been over-excavated during construction. Figure 10 shows the bathymetric survey results, including as-built elevation of the lower orifice in the pond, which would correspond to the expected permanent pool level. The pond was cleaned out in October 2017, shortly after the survey was completed, therefore the permanent pool volume at the end of monitoring (in 2020) is likely equal to or slightly greater than the value reported above of 2,100 m^3.

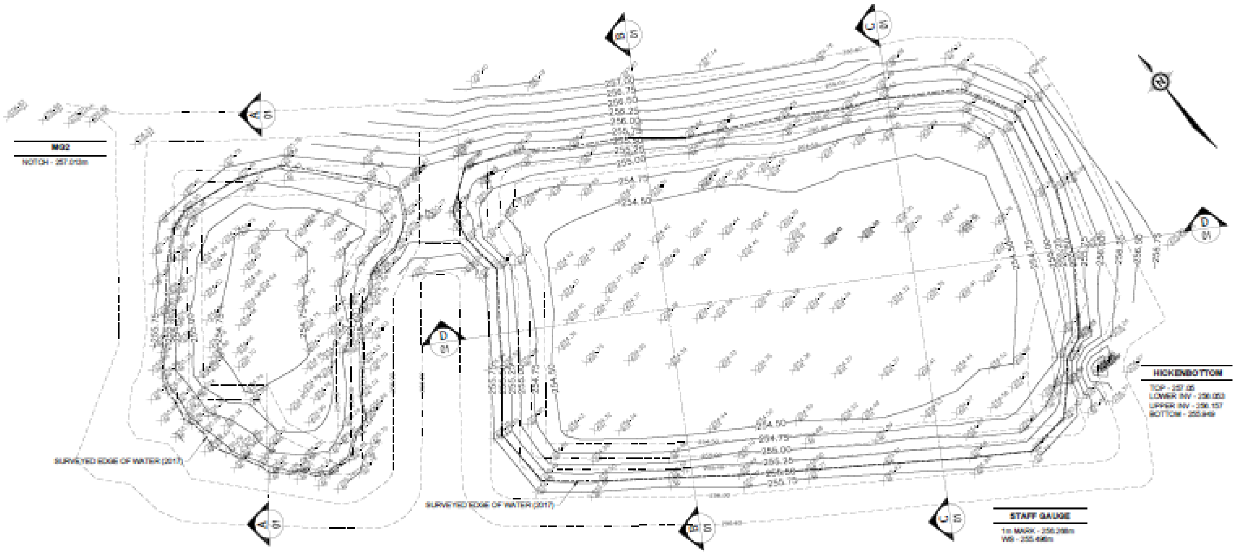


Figure 10: Bathymetric survey results (refer to Appendix B).

4.1.2 Drawdown Time

Drawdown time is defined as the period between the maximum water level and the minimum level (dry-weather or antecedent level) in the pond. The wet pond facilities are designed to provide extended detention volume to be drawn down in 24-48 hours (Stantec, 2007a). Table 5 and Table 6 below summarize the drawdown times calculated during the monitoring period; these were evaluated for events meeting all three criteria below:

1) initial precipitation > 2 mm,
2) pond stage increased by > 3 mm over the course of the event, and
3) the drawdown completed before the start of the next precipitation event.

Table 5: Summary of drawdown times for Pond A for events meeting all three criteria results.

Calculated Statistic	Drawdown Time (hours)
Overall Average	40.0
Median	27.0
Min	0.3
Max	197.0
Count of Events	37
January-June Average	37.6
January-June Median	27.5
July-December Average	41.9
July-December Median	23.3

Table 6: Summary of drawdown times for Pond A for events meeting all three criteria binned by precipitation depth.

Precipitation Depth (mm)	Event Count	Median Drawdown Time (hours)
<5	12	14.5
5-10	18	27.6
10-15	4	66.3
15-20	0	N/A
20+	3	88.8

To streamline the analysis, only precipitation events consisting of a single defined event were included in the analysis. This refers to precipitation events where the pond returned to its pre-event level before another precipitation event occurred. In this context, an individual precipitation event is defined as precipitation occurring without any gaps that lasts for 6 hours or longer. Events were excluded if multiple precipitation events occurred with more than 6 hours of dry weather between them before the pond had returned to its pre-event level as this would prolong drawdown time and make it difficult to compare between event sizes. Since the pond only has discharge at certain times of the year, the full year analysis includes events when there is no discharge from the pond. For these events the drawdown times would be controlled by factors such as seepage or evaporation rather than the outlet orifice.

There is a wide range in drawdown times, reflecting a wide range in sizes of monitored events. The average drawdown time is higher than the median suggesting that perhaps a small number of very long drawdown times may have caused a higher average. Similar to the overall median, the seasonal medians are both lower than the seasonal averages, supporting the argument that in both cases the average is influenced by a small number of outliers.

As expected, drawdown time appears to have a positive relationship with the depth of the precipitation event:

- The overall average drawdown time of 40 hours fits within the range specified by the design of 24-48 hours, as does the median of 27 hours.
- Forty-one percent of precipitation events resulted in drawdown times of less than 24 hours; however, these were primarily for events with less than 5 mm.
- Twenty-three per cent of precipitation events had drawdown times longer than the design drawdown time of 48 hours. These were mostly for events with greater than 10 mm of precipitation.
    - For the three events that were less than 10 mm but still had drawdown times that exceeded 48 hours, all had more than 5 mm of precipitation fall within three days before the event.
    - This suggests the soils within the catchment area may still have been saturated or partially saturated at the start of the event, contributing to greater flow into the pond.
    - The maximum drawdown time of 197 hours occurred for an event that was only 4.8 mm (6 mm total by the time drawdown was achieved). This event occurred in March and was potentially influenced by snow melt, which would explain the prolonged drawdown.

The median drawdown times for July-December are slightly lower than the median drawdown times for January-June. However, the difference between the average and the median in each season is greater than the difference between seasons. This was not expected because during the January-June period the outlet orifice would have been the primary control on the drawdown time, whereas for the July-December period there is no outflow, and the drawdown time would reflect either evaporation or seepage. Furthermore, the flow characteristics at both inlets change between these two time periods.

The Stormwater Assessment Monitoring and Performance Program (SWAMP) monitored 5 wet ponds to evaluate performance and relate it to design characteristics. In general, wet ponds with greater storage, longer drawdown times and better length-to-width ratios exhibited a better performance in terms of water quality (SWAMP, 2005). The ponds monitored were compared to the provincial guideline for drawdown times which suggest that drawdown time should be no less than 24 hours for the 25 mm 4-hour storm (MECP, 2003). The SWAMP study found that drawdown times for the ponds monitored ranged from 16-144 hours for precipitation events in the 20-30 mm range (SWAMP, 2005). From the MITG monitoring data there are only 3 out of 10 precipitation events in this range that meet the criteria for analysis described above; these are events where the pond stage returns to its pre-event level before additional precipitation falls. For these events, drawdown times range from 58-172 hours, which is similar to the drawdown times reported in the SWAMP study and exceed the design criteria. There are potential flood management implications from stormwater management ponds exceeding the MECP drawdown guidelines in the case where multiple large storm events occur in close succession, as there would be less active storage available to provide flood control. On the other hand, stormwater management ponds that do not meet the minimum 24 hour drawdown time may not be providing adequate water quality control.

For other precipitation events in the 20-30 mm range that occurred during the monitoring period, the prolonged drawdown meant that the pre-event pond level was not reached prior to additional precipitation falling. This resulted in total precipitation amounts of 41-343 mm before the drawdown period was concluded. If these events are included in the analysis the average drawdown time would be increased to

1040 hours. Figure 11 provides an example of one of these events, where the drawdown time was 40 days. This could have implications for the amount of active storage available if multiple precipitation, melt or rain-on-snow events occurred in close succession, and this might impact the amount of treatment provided for the later storms.

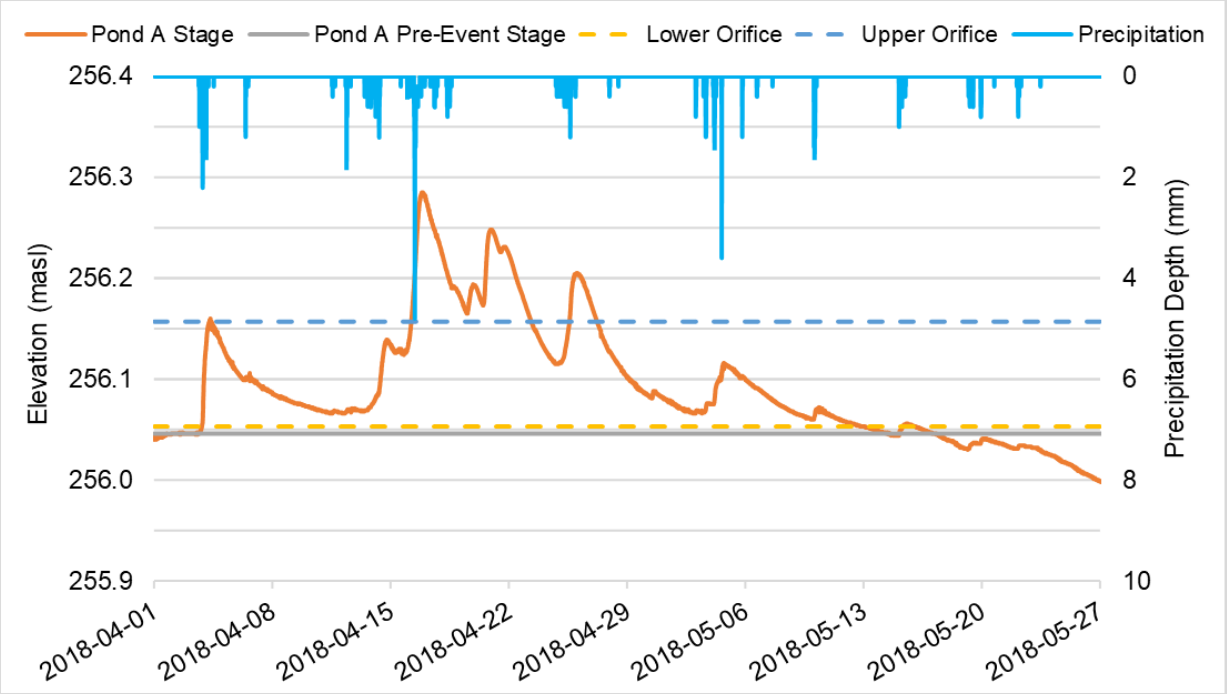


Figure 11: An example of one of the very long drawdown times (40 days) that result from the slow recession combined with additional precipitation events.

4.1.3 Detention Time

Detention time directly relates to the water quality performance of a stormwater management pond. According to conventional settling theory, the longer the detention time the greater the TSS removal rate will be, however there is an inverse relationship between detention time and the rate at which storage availability within the pond recovers after an event (Papa et al., 1999). This would increase the likelihood that untreated stormwater runoff would be released during a subsequent storm event, therefore these conflicting factors would need to be considered to optimize the long-term water quality performance of the pond (Papa et al., 1999). Furthermore, longer detention times can result in warmer effluent water temperatures during summer months (Papa et al., 1999).

There was a wide range in the measured detention times observed at Pond A, from only a couple of hours up to 75 hours:

- The median was 13.7 hours and the average was 17.8 hours.
- Detention time could only be calculated for the period when both inlets were monitored and during the seasons when outflow was measured at the pond (January to June). Given the prolonged nature of Pond A flow events during these months, these estimates are based on a relatively limited number of results (15 events).
- The average and median detention times are both significantly less than the expected range of 24-48 hours.

  - This might be a consequence of prolonged flow into the pond at the inlets (one because of the upgradient LID features and the other because it drains from a rural property). The inlet draining the rural property (Inlet 2) in particular has a very long drawn-out falling-limb on its event hydrograph as shown in Figure 12 below.
  - This would delay the inlet centroid and limit the difference between the inlet and outlet centroids. Therefore, since there is prolonged flow at both the inlets and the outlet it is difficult to isolate the effect of the pond itself.
  - Furthermore, the measured inflow would exclude the precipitation falling directly on the pond, or snow melt that drains from the immediate area; if this flow were included in the inlet flow it might result in the inlet centroid occurring slightly earlier. Thus, excluding it may also result in a shorter calculated detention time.

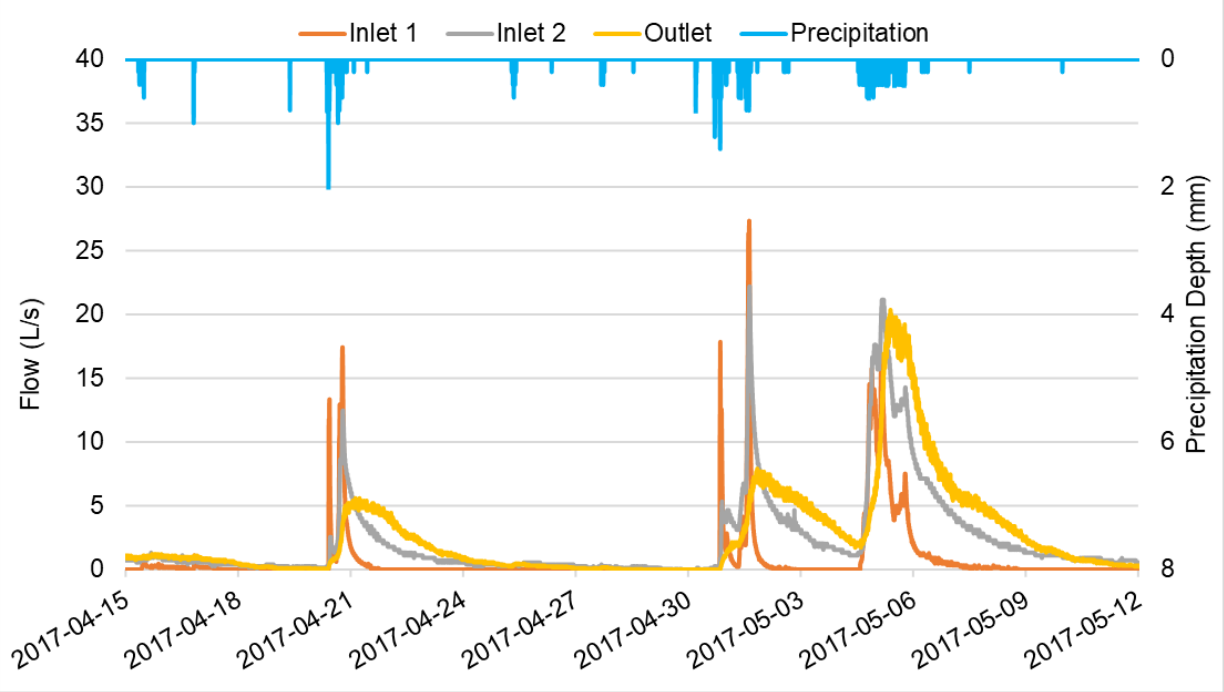


Figure 12: Inlet and Outlet hydrographs illustrating the prolonged falling-limbs observed at Inlet 2 during the spring of 2017.

Table 7 below shows that the detention time also varies significantly by month. This may be a consequence of the limited number of events per month that were possible to analyze, and a larger sample set may be needed in order to obtain a reliable breakdown of detention times by month. However, the SWAMP study found a similar variability of detention times with results that ranged from 1 to 31 hours with an average value of 9 hours (SWAMP, 2005). Pond A is therefore still performing relatively well in terms of detention times compared to the other wet ponds studied in the SWAMP study.

Table 7: Average detention times by month at MITG compared to design.

Month	Event Count	Average Detention Time (hours)
Jan	3	21.0
Feb	3	33.8
Mar	1	13.7
Apr	3	12.6
May	3	6.0
Jun	2	16.6
Overall Median	15	13.7
Overall Average	15	17.8
Design	*N/A*	*32.5*

4.1.4 Peak Flow Reduction

The design objective for peak flow was to maintain hydrologic functions of the site by attenuating peak flows and conveying major storm runoff safely to an appropriate outlet without increasing erosion or flooding beyond acceptable limits (Stantec, 2007a). To assess the success of the stormwater management practices in meeting this objective the peak flow reductions were calculated using monitoring data. In addition, peak flow monitoring data for larger precipitation events is analyzed separately and compared to modelled values.

Due to the continuous flows observed at the outlet of Pond A during the wet season (January to June) the peak flow data was analyzed and compared to the following criteria in order to isolate the influence of the size of precipitation events (Appendix A). Figure 13 and Figure 14 are based on events that meet all 4 criteria below, while Table 8 includes all events that meet criteria 3 and 4. Events that only meet these last two criteria would represent a “worst-case scenario” where the pond level is already elevated at the start of the event as a result of multiple precipitation events occurring in close succession. Events that meet all 4 criteria represent those events that should not be overly influenced by previous storm events.

Criteria 1: Prior to the start of the event, was the flow decreasing or constant?

Criteria 2: Was there flow preceding the start of the event; if so, was it 20% or less of the peak flow attained during that event?

Criteria 3: Was the total precipitation 2 mm or more?

Criteria 4: Is there flow measured in at least one of the inlets?

As illustrated by Figure 13 and Figure 14 there appears to be a strong seasonal influence on the peak flow reductions observed at Pond A at MITG.

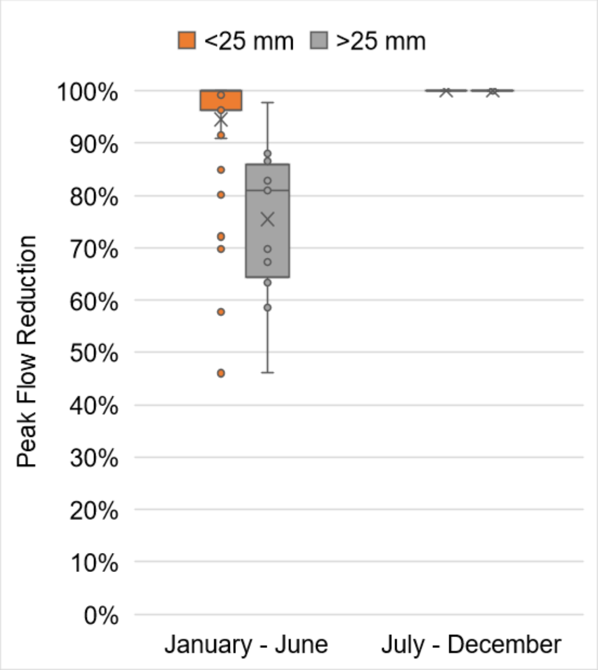


Figure 13: Seasonal comparison of peak flow reduction at Pond A (note these are events meeting all 4 criteria).

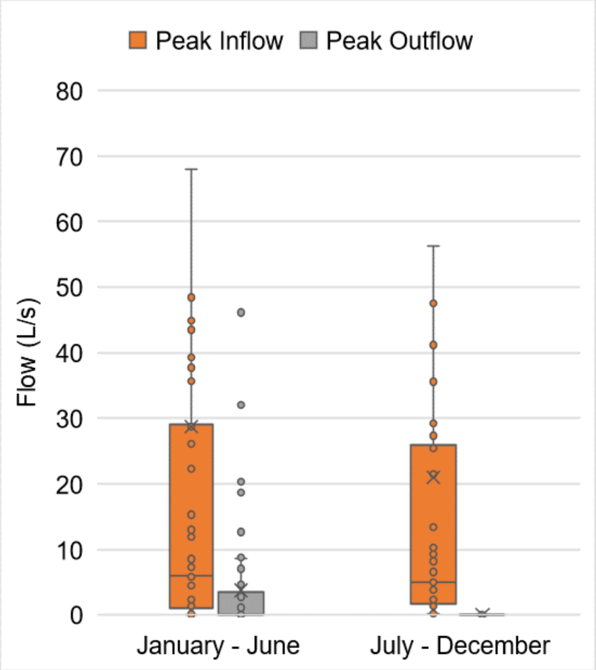


Figure 14: Note some outliers for inflow have been excluded. Illustrates that the difference in peak flow reduction cannot entirely be explained by differences in inflow (based on events that meet all 4 criteria).

From July-December there is typically no outflow at all from Pond A, meaning that all events have 100% peak flow reduction. From 2015-2018 there has only been one event with outflow, which was observed in August 2015, otherwise no outflow has occurred during these months. Unfortunately, this event is excluded from the analysis, as it occurred prior to the start of monitoring at Inlet 2 so there is no measured peak inflow to compare it to.

Some of the seasonal difference is explained by the difference in inflow, as illustrated in Figure 15, since the peak inflows are lower during the period from July to December. However, the difference is much less dramatic than is observed for the outflows from the pond. Additionally, some of the difference in peak flows could be explained by a difference in the distribution of precipitation depth between these seasons. Figure 15 shows the difference in the distribution of precipitation depth between these seasons and it should be noted that there are no events greater than 30 mm that occurred during the summer months in this dataset. Despite this, the median precipitation depth is greater during the July-December period of the dataset, so it is unlikely that this fully explains the seasonality.

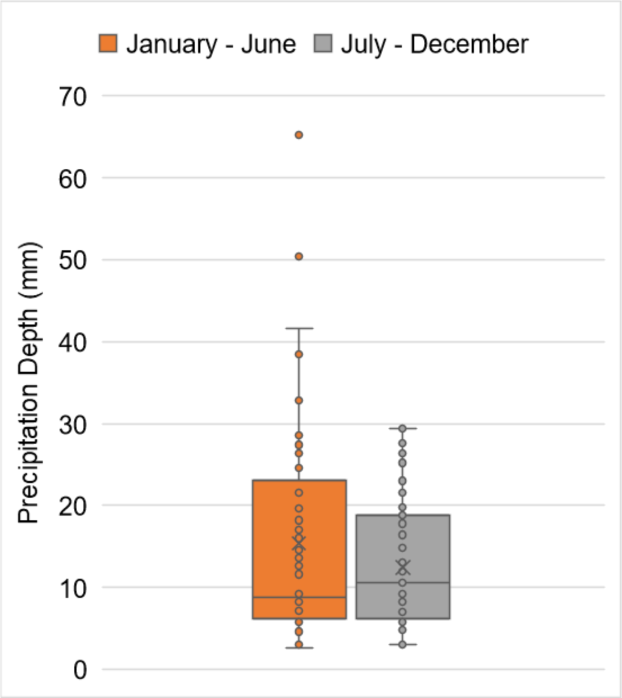


Figure 15: Illustrates that while some of the difference in peak flow reduction may be explained by the difference in the precipitation events, this likely does not explain the whole difference (based on events that meet all 4 criteria).

It is also possible that the volume reductions provided by the upgradient LID features have impacted the water balance of the pond sufficiently that the pond level remains well below the permanent pool during the warmer months when evapotranspiration is high. This results in a larger available storage volume within the pond, and the reduced volume of inflow from storm events is not sufficient to fill the pond to the level of the outlet orifice.

During the spring and winter this effect is less pronounced. Snow melt, reduced evapotranspiration, and frozen ground likely reduce the amount of volume reduction provided by the LID features, and continuous outflows are observed leaving the subdivision in Inlet 1 to the pond. Furthermore, the rural property that also drains into the pond typically has continuous flow during this period as well. The rural property produces limited runoff during the summer and fall months and typically only flows as a result of high-intensity thunderstorms. The seasonality of the runoff from the rural property is reflected in the seasonality of runoff leaving the pond.

Table 8 below summarizes all results from January to June that meet criteria 3 and 4 for the monitoring period beginning in 2016 when Inlet 2 was installed. Figure 16 shows the distributions of these events but has excluded some outliers. These events would include precipitation events occurring in close succession where the pond is still responding to the preceding event. Overall, during this period median peak flow reduction is 75% for events greater than 25 mm. For precipitation events in the 5-25 mm range the median is 96%, while the average is a bit lower due to an outlier result. The negative peak flow reduction for the minimum value in the 5-25 mm range is the consequence of the prolonged drawdown observed at the pond outlet. In this instance the pond had not finished drawdown before a new storm event occurred. Therefore, for this event the peak flow was representative of multiple events in succession. Furthermore, this was a smaller precipitation event (<10 mm) meaning that the cumulative flow observed at the outlet was significantly more than the flow measured at the inlets for that event.

Table 8: Peak flow reduction data for events occurring between January-June based on events that meet Criteria 3 and 4.

Summary Statistics	Events 5-25 mm	Events 25-70 mm
Average	79%	73%
Min	-94%	46%
Quartile 1	72%	62%
Median	96%	75%
Quartile 3	100%	83%
Max	100%	98%
Count	49	14

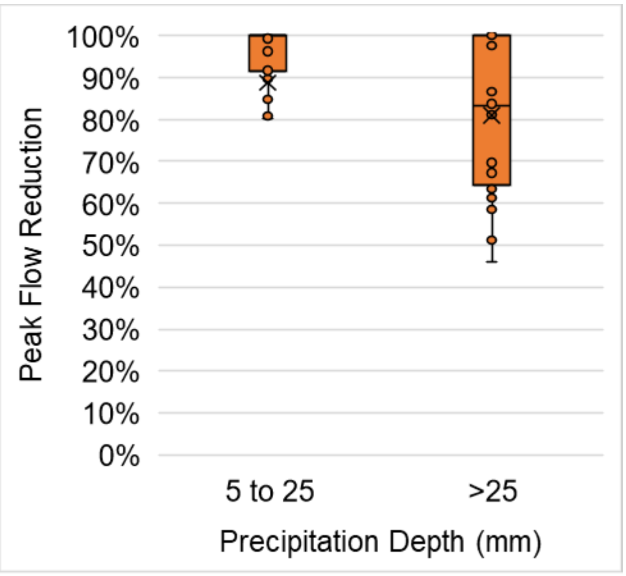


Figure 16: Boxplot shows peak flow reductions by precipitation depth, with outliers excluded.

Comparison of Monitoring Data to Design Model

Stormwater management Pond A was designed for controlling peak flows to prevent exacerbating downstream erosion rates and flooding. In order to fully evaluate the performance of the pond it is necessary to consider its performance under more extreme precipitation events. The design model was developed by the design consultants using SWMHYMO which is an event-based model. Hydrologic modelling was done to simulate catchment response to various design storm events and IDF parameters from the preliminary design were used to generate peak runoff rates for the site under existing conditions to determine post-development peak-flow targets. The original modelling was done using a 6-hour Chicago rainfall distribution and completed for the 2-100-year return storms. The results of this model are summarized in Table 9. This model was done in part to evaluate how the pond would perform relative to the following criteria (Stantec, 2007a):

- Quality peak flow release rate 0.002 m^3/s
- Erosion threshold for Tributary F 0.10 m^3/s

Table 9: Design model predicted peak flows for Pond A catchment (Stantec, 2007a).

Return Period	Precipitation Duration (hours)	Precipitation Depth (mm)	Pre-Development Flow Rate (m^3/s)	Flow Rate with Pond (m^3/s)
2-Year	6	39.62	0.55	0.04
5-Year	6	54.11	1.02	0.12
10-Year	6	64.61	1.38	0.27
25-Year	6	77.63	1.86	0.5
50-Year	6	87.58	2.26	0.76
100-year	6	97.07	2.65	1.06

CVC does not have a new calibrated model to compare the design model to, however the model's results have been compared to select monitored events, based on average precipitation intensity. Precipitation data from the monitoring period was compared to the calculated average intensity of events with a return period of 2-years or greater of equivalent duration. This was calculated using the same IDF parameters used in the original model. Based on this process, monitored events that had average precipitation intensities equal to or greater than the equivalent duration 2-year storm have been selected; these events are summarized below in Table 10.

Table 10: Monitored peak flow data for precipitation events exceeding 2-year return period according to average intensity.

Date	Return Period Range (year)	Precipitation Duration (hours)	Precipitation Depth (mm)	Peak Precipitation Intensity (mm/hr)	Measured Peak Flow (m^3/s)
2018-07-05	>2<5	0.3	20.2	120	0.000
2016-08-25	>2<5	0.8	26.4	115.2	0.000
2015-08-10	>5<10	7.3	59.0	62.4	0.006
2017-06-22	>5<10	12.6	65.2	129.6	0.013

As shown in Table 10 the measured peak flow for these events was significantly less than what was modelled for a 2-year return period event. Two of the events had average precipitation intensities greater than the equivalent duration 5-year storms, however these events also had peak flows that were less than what was modelled for the 2-year storm. There are a few potential explanations for this including:

- The duration of the monitored events is different from that of the design storms. Even for events that were of similar duration or longer than the design storms, the resulting peak flow was still less.
- The ponds were modelled without considering the upgradient LID features; the volume reduction provided by these facilities may explain the lower peak flows.
- The events that met these criteria occurred during the summer, when extra storage is available within the pond, and when pond levels tend to be significantly below the permanent pool.

Although the model suggests that the erosion threshold of 0.10 m3/s would be exceeded during the 5-year storm, the monitored peak flow of 0.013 m3/s was almost one order of magnitude less than this. This data suggests that for significant precipitation events that occur during the summer months the pond performance is exceeding the design.

However, when the actual peak flows measured for these events are compared to the rest of the dataset, several events were identified that have greater measured peak flows, despite being for lower return period storms. In contrast to the events with greater than 2-year return period, all of these events took place in the months from February-June, as shown in Table 11 below. During this time of year, the pond level usually stabilizes closer to the permanent pool level, and there is less available storage within the pond. Furthermore, at this time of year the second inlet to the pond, which drains from the adjacent rural property, is flowing continuously.

Table 11: Monitored peak flow data for events with peak flows exceeding 0.013 m^3/s

Date	Return Period (year)	Precipitation Duration (hours)	Precipitation Depth (mm)	Measured Peak Flow (m^3/s)
2015-06-16	<2	4.4	34.0	0.014
2016-03-31	<2	19.8	32.8	0.019
2017-04-06	<2	16.9	29.8	0.019
2017-05-04	<2	30.3	50.4	0.020
2018-02-14	<2	2.8	7.2	0.032
2018-02-19	<2	26.0	26.8	0.046

Although these events have a lower average precipitation intensity compared to the 2-year storm they may represent rain-on-snow events or be influenced by already saturated or frozen ground. In other instances, they represent multiple melt and precipitation events occurring in close succession. This sort of event occurred in February 2018 when the greatest peak flow for the entire monitoring period was reached. This peak flow value was 0.046 m^3/s, which is close to the peak flow modelled for the 2-year storm event (0.04 m^3/s). According to Environment Canada's historical data for Pearson Airport, there was 19 cm of snow on the ground on February 11, 2018. February 14, 2018 was the first day after this with maximum daytime temperatures above 0^oC. A moderate amount of rain fell (7.8 mm) on this day which combined with snowmelt to produce significant outflow. This moderate precipitation was followed by a larger rain event (26.8 mm) on February 19th that resulted in the greatest peak flow of the whole monitoring period. Both precipitation events were smaller and less intense than those that have occurred at other times of year and generated smaller peak flows, indicating the importance of winter conditions for generating high peak flows. Figure 17 shows the hydrographs for the two pond inlets and the pond outlet for the rain-on-snow storm events in February of 2018.

By contrast, Figure 18 shows the hydrographs for a much higher intensity event that occurs later in the season. Based on average precipitation intensity, this event would have a greater than 5-year return period. In this case the Inlet 1 response is much greater, but the peak flow measured at Inlet 2 and the Outlet is only about one-fourth of that observed in February. Since peak flow at Inlet 1 was much higher for the June event, this is largely a consequence of different peak flow reduction performance of the pond observed at these different times of year. For the June 2017 event the peak flow reduction achieved by Pond A was 98% compared to 65% peak flow reduction for the event in February 2018.

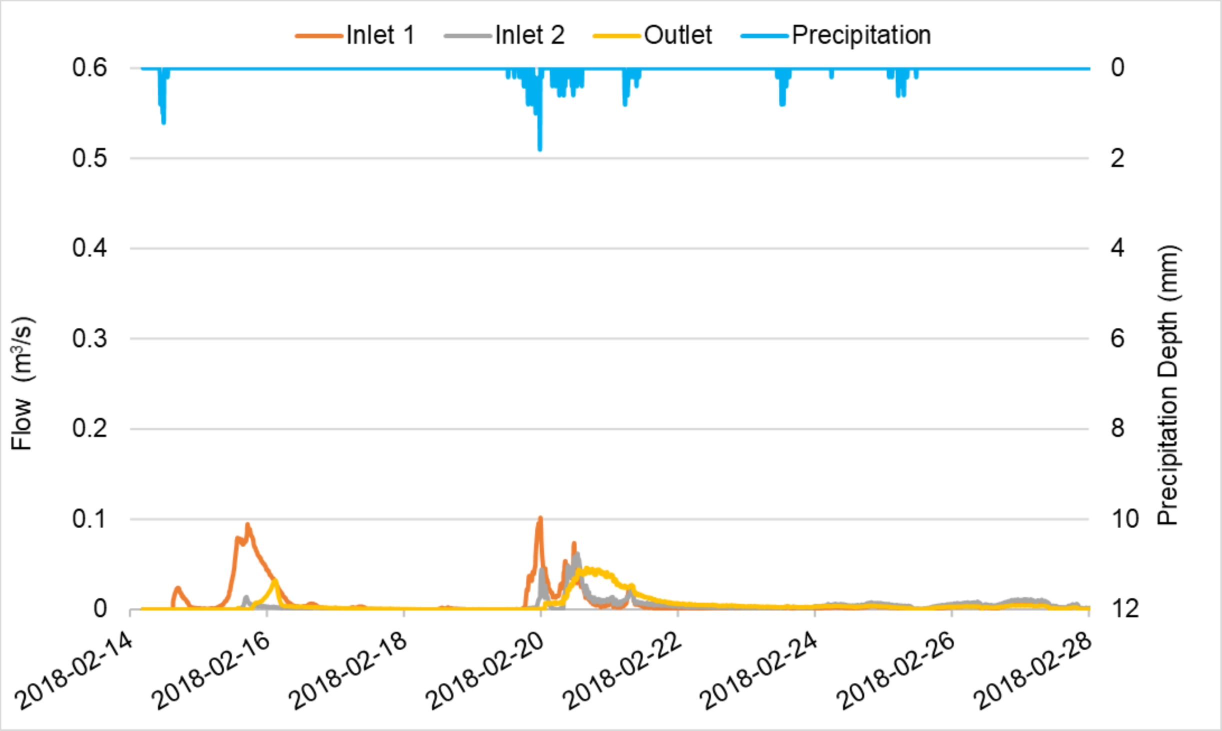


Figure 17: Inlet and outlet hydrographs for event in February 2018, with maximum peak flow measured at outlet of pond.

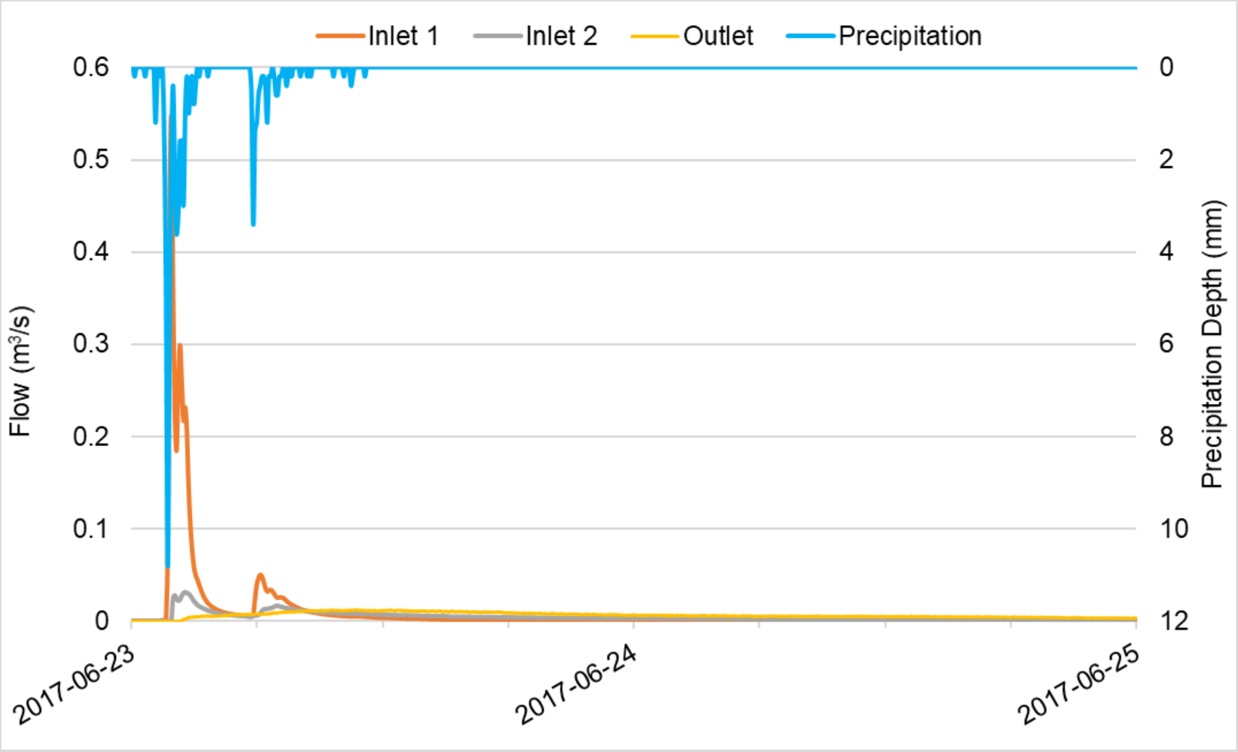


Figure 18: Inlet and outlet hydrographs for event in June 2017 with precipitation event exceeding 5-year return period.

The strong seasonal influence on the performance of the pond suggests that the conventional design approach of using event-based models may not be the best representation of the conditions that generate the largest flow at this site for the following reasons:

- An event-based model that assumes the water level is at the permanent pool prior to the event would not fully consider the pre-event storage actually available in the pond.
- Influence of the flow regime for the rural property adjacent to the MITG subdivision. The flow from this rural property is meant to be passed through the pond and makes up a significant amount of the flow going into the pond in the winter and spring, then in the summer it dries up and only flows for the largest events.
- Upgradient LID features are reducing the runoff volumes going into the pond, which further influences the water balance and the amount of storage available in the pond. Differences in the seasonal performance of the LID features could also be reflected in seasonal differences in the performance of the pond.

4.1.5 Water Quality

Water quality data collection for Pond A Outlet has been restricted by several challenges including the limited time of year that Pond A Outlet flows, combined with the prolonged duration of flow events that do occur. A further challenge is that much of the flow at Pond A takes place during the winter months when staff are not able to trigger the autosamplers based on water level data (these loggers are removed to protect them from damage due to ice formation). This has made it very difficult to collect representative flow-weighted event samples for determining event mean concentrations (EMCs). The limited samples that were collected may have only captured a portion of a flow event that went on for weeks or sometimes months, therefore the data presented below in Figure 19 should be considered preliminary. Continuous turbidity monitoring was initiated in 2018 at the outlet of Pond A, which will provide further insight to the water quality of flow leaving Pond A. Figure 19 shows the concentrations for TSS samples collected during the spring of 2017. Despite being collected during different flow rates and storm events, these samples have a very consistent concentration with minimal variability. They are all well below the instream guideline for TSS. This suggests Pond A is performing well in terms of TSS removal.

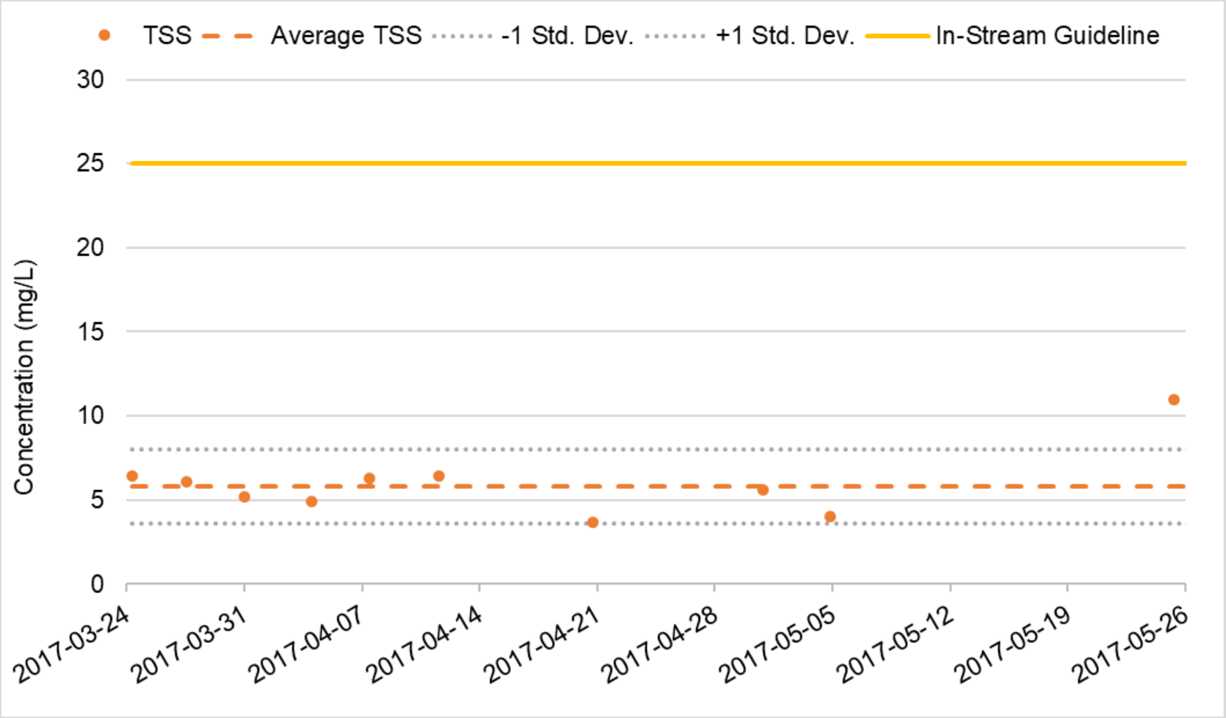


Figure 19: Pond A effluent TSS concentrations for spring 2017 compared to in-steam guideline.

Conclusions- Is stormwater management Pond A performing as designed?

Pond A is not performing as expected in terms of permanent pool level as the pond level is well below the intended normal water level starting in June and continuing through to mid-January. This results in extra storage being available during these months and a strong seasonal pattern in terms of the ponds performance. Despite the low pond levels that were observed during the summer and autumn, based on the bathymetric survey the pond is still meeting the MECP requirements for permanent pool volume. This result is supported by the preliminary water quality data at the Pond A outlet which shows that the pond is performing relatively well compared to other ponds and wetlands.

Although Pond A is not performing exactly as expected, it is still meeting its key design criteria. The pond is designed to maintain hydrologic functions of the site by attenuating peak flows and conveying major storm runoff safely to an appropriate outlet without unduly increasing erosion or flooding. Since peak flow never exceeded the erosion threshold of 0.10 m^3/s during the monitoring period, it is unlikely that erosion has been increased beyond acceptable limits. Based on the design model it was expected that the erosion threshold would be exceeded during the 5-year storm, however this was not observed in the monitoring data. Overall, peak flow reductions met or exceeded design expectations; this was especially true during the summer and autumn months where 100% reduction was achieved for most precipitation events with only one exception.

Unpredictable high-intensity precipitation that occurs during summer thunderstorms poses a challenging flooding risk that may be exacerbated by climate change. The extra storage available in Pond A during the summer means that the pond performs well for flood control even for these more extreme events. However, climate change projections also suggest that winters will become wetter in this part of southern Ontario (Auld et al., 2016). This will likely result in increased overall outflow from Pond A and enhance the existing seasonal pattern of flow occurring predominantly in the winter and spring. Based on current data it is likely that the highest peak flows should be expected during the winter and spring.

Pond A was also designed to provide extended detention volume to be drawn down in 24-48 hours. The data shows that this drawdown time was met for precipitation events >5 mm and <10 mm. For precipitation events exceeding 10 mm drawdown time typically exceeded 48 hours. However, since the pond was rarely sitting at the permanent pool level prior to precipitation events and many precipitation events did not produce any flow at all, it is not surprising that there is a discrepancy in terms of the time it takes to return to pre-event water levels. Although no tracer tests were performed to determine residence times, based on preliminary water quality data for TSS, Pond A is also performing well in terms of water quality treatment.

4.2 QUESTION 2: What is the influence of the upgradient LID practices on the performance of stormwater management Pond A?

Water quantity and quality monitoring data from Inlet 1, which represents runoff entering Pond A from the subdivision, was analyzed as a method of quantifying the influence of the LID practices. Therefore, these results do not reflect the performance of any individual LID, but the impact of the whole treatment train prior to entering the pond, including both lot level and conveyance features. Furthermore, the water quality samples collected represent the quality of all the surface runoff from the treatment train, therefore it is not possible to distinguish between water that has been treated through infiltration and water that might be overflow from individual features. Published water quality data from a similar subdivision that does not have LID features was used to estimate influent water quality and for comparison.

The upgradient lot-level and conveyance LID features provide water infiltration, storage, and quality control before runoff enters the pond. Therefore, the performance of the pond reflects that of the treatment train working together as a whole. The volume reduction achieved by these LID practices was not factored into the original design calculations and this may have had implications for the Pond A water balance resulting in low water levels during the summer and fall.

4.2.1 Seasonal Volume Reductions

Table 12 shows the total estimated runoff from the subdivision, discharge to Pond A, and seasonal volume reduction during the summer and autumn months. Runoff volume is estimated using the Simple Method (Appendix A). The highest runoff and discharge volumes occurred during the month of June, resulting in the lowest volume reduction of 66%. Greater discharge volumes are entering the pond from the subdivision during the summer months than in autumn.

Table 12: Pond A – Inlet 1 seasonal volume reductions.

Month	Count	Estimated Runoff (m^3)	Measured Discharge from LID Treatment Train (m^3)	Volume Reduction (%)
June	28	12500	4244	66
July	16	5031	995	80
August	26	9960	2813	72
Summer	**70**	**27491**	**8051**	**71**
September	20	6570	950	86
October	17	5947	1104	81
November	14	4252	837	80
Autumn	**51**	**16770**	**2891**	**83**

Note: Winter and spring volume reduction data is not presented due to monitoring data collection challenges caused by freezing temperatures and continuous flow. This prevents event-based analysis because the duration and amount of flow cannot be reasonably defined.

The volume reductions of 70-80% calculated for the months of July through November suggest that the upgradient LID features are significantly redistributing water storage through evapotranspiration and infiltration throughout the subdivision. This impact on the water balance by the LID features may help to explain the low water levels and absence of outflow observed in Pond A.

4.2.2 LID Treatment Train Water Quality

The water quality performance of the LID features in the subdivision was analyzed to determine whether there are likely to be water quality implications for the performance of Pond A. Due to the inherent difficulties of monitoring numerous lot-level and conveyance features throughout the subdivision, LID influent water quality samples were not collected. Instead, to provide estimated influent concentrations, values were used from a stormwater wetland system study conducted by SWAMP in Aurora, Ontario, located about 48 km northeast of MITG (SWAMP, 2003). The inlet data from this study was used as an approximation of water quality for a comparable subdivision with no LID features present. These samples were determined to be representative because of the similar contributing drainage area consisting of medium density residential and agricultural land use located in a metropolitan area subject to the same climate. For this study, stormwater quality samples were collected at the inlet between 1996 and 1998 using similar methods. The average of the 18 Aurora event mean concentration (EMC) samples collected between May and November was used to estimate the influent LID treatment train values. Between June and November of 2015 to 2018, the results of 30 EMC samples collected from Pond A - Inlet 1 represent the effluent LID treatment train values. The average of these values for each parameter was applied to the remaining 91 unsampled events. For this period the total discharge for the monitored events is 10,942 m^3 while the discharge for all events sampled is 3,362 m^3. Therefore, the cumulative percent of total discharge sampled for water quality is 31%. The events for which samples were collected ranged in precipitation depth from 3.2mm to 29.6mm for this period, however the full range of events included in this analysis range from <2mm (only if they generated flow due to antecedent conditions) to 66.6mm. Therefore the load calculation might be less accurate for the largest and smallest event sizes.

Influent and Effluent Concentrations

Parameters of concern identified in Credit Valley Conservation's *Water Quality Strategy* (CVC, 2009) and the estimated LID influent and calculated effluent values for this project are summarized in Table 13 along with the Provincial Water Quality Objectives (PWQO) for context. Although these objectives are in-stream guidelines and were not specifically developed for stormwater discharges, Environment Canada, MECP, and the United States Environmental Protection Agency (U.S. EPA) have long recognized that urban stormwater is a major contributor to pollutant loading to creeks, rivers, and Great Lakes. Table 13 also includes preliminary Pond A effluent data to demonstrate the overall water quality performance of the treatment train as a whole.

Table 13: Parameters of concern concentrations and guidelines for Aurora Inlet, LID effluent entering Pond A, and Effluent from Pond A.

Parameter of Concern	Unit	PWQO	CCME	Estimated LID Influent Average EMC (Aurora Inlet)	Calculated LID Effluent Average EMC (Pond A – Inlet 1)	Calculated Pond Effluent Average Concentration (Pond A – Outlet)
Total Suspended Solids (TSS)	mg/L	N/A	For clear flows, maximum increase of 25 mg/L from background levels for any short-term exposure (e.g., 24-h period). Maximum average increase of 5 mg/L from background levels for longer term exposures (e.g., inputs lasting between 24 h and 30 d).	135.1	34.2	5.69
Total Phosphorus (TP)	mg/L	0.02 (Interim value to eliminate nuisance concentrations of algae in lakes)	<0.004 to >0.1 depending on existing conditions	0.15	0.36	0.03
Nitrate + Nitrite (NO_2+ NO_3)	mg/L	N/A	3 (Nitrate)	N/A	1.03	1.49
Copper (Cu)	µg/L	1 – 5 depending on hardness (Interim)	2 – 4 depending on hardness	10.6	11.6	3.06
Zinc (Zn)	µg/L	20 (Interim)	30	33.6	116	12.63

Note: Preliminary water quality results for Pond A outlet based on a sample count of 13, representing 9 distinct precipitation events.

Sources: Water Management Policies, Guidelines, Provincial Water Quality Objectives (PWQO) of the Ministry of the Environment (July 1994, Reprinted February 1999); Canadian Environmental Quality Guidelines. Canadian Council of Ministers of the Environment (CCME). (2015).

With the exception of nitrate, average LID effluent EMC results for parameters of concern were above guidelines where one exists. Total phosphorus, copper and zinc effluent results were higher than the estimated LID influent values. This increase in some nutrients and metals may be a result of fertilization for lawn maintenance or historic agricultural practices within the catchment area. Furthermore, although the Aurora subdivision shares similarities with MITG, the subdivisions are of different ages which might be a contributing factor for these differences. Wherever possible it is preferable to measure the actual site-specific influent, however this is often very challenging for LID features. This highlights the importance of monitoring stormwater runoff to develop comprehensive datasets that adequately characterize water quality for different land uses to support performance evaluation of stormwater quality treatment.

Although the influent concentrations exceeded guidelines, the Pond A effluent water quality was within guidelines except for total phosphorous and copper. According to the SWAMP Synthesis report the majority of TSS concentrations during storm events in ponds and wetlands ranged between 10-60 mg/L (SWAMP, 2005). The average TSS effluent for Pond A was less than 6 mg/L. For the ponds and wetlands studied in the SWAMP report, the average effluent concentrations for phosphorous, zinc, and copper were found to exceed receiving water objectives. The average concentrations for TSS, total phosphorous and copper at MITG Pond A were lower than those reported for any of the ponds and wetlands in the SWAMP report. The average concentration of zinc at MITG was lower than all but one of the SWAMP ponds; Heritage Estates reported a slightly lower concentration of zinc at 10 ug/L. The water samples collected at the outlet of Pond A fit within a narrow range of concentrations for all parameters. However, it should be noted that all these samples were collected within a narrow time window from late March to late May as a consequence of the flow pattern at MITG and the challenges of collecting water quality data at this station. These results suggest that the treatment train including LID features and Pond A are performing better in terms of water quality when compared to data from other ponds and wetlands where no LID features are present upgradient.

Importance of Load Reduction on Water Quality

Water quality control of LID features is best measured as load reduction, which accounts for all volume and pollutant reduction mechanisms. It is also the most relevant for understanding the impact of the upgradient LIDs on Pond A. Pollutant load is calculated by multiplying the event volume of stormwater by the EMC of the parameter of interest and results in a value representing the total mass of that parameter. Load reduction in LID practices is influenced by several mechanisms: volume reduction (e.g., infiltration and evapotranspiration), filtration, settling, and adsorption. While infiltration decreases pollutant loadings to surface water, it is possible that it may provide a pathway for water-soluble pollutants (e.g., chlorides) to reach groundwater. Filtration, settling, and adsorption removes pollutants from surface water by retaining them in the filter media. Even if the concentration of a parameter is not reduced there is still less runoff overall due to volume reductions, potentially leading to a lower overall mass of that parameter in the receiving water body.

Pollutant Load Calculation

Due to the nature of the LID features at this site, it is impossible to directly measure the influent volumes and concentration as the water enters the features. The influent volumes were calculated using the Simple Method (Appendix A) and the estimated influent EMCs from the Aurora project were used.

For events where a water quality sample was collected from Pond A – Inlet 1, the EMC from that sample was used for the effluent value. For events where effluent discharge was recorded but no water quality sample was collected, loads were computed with the median EMCs from the collected samples at each site. For events with measured precipitation and estimated inflow but no effluent volume was recorded, the estimated pollutant load reduction was 100%.

Total Suspended Solids Load Reduction

TSS represents the concentration of particles in the water that may transport adsorbed pollutants, including metals and total phosphorus, and is the primary parameter used for pond performance evaluation in the MECP *Stormwater Management Planning and Design Manual* (MECP, 2003). Increasing TSS load is a concern for downstream receiving water bodies because of the possible pollutants associated with these particles as well as the direct effects of increased sediment load such as elevated turbidity.

The estimated influent load, LID effluent load, and resulting load reductions for TSS are shown in Figure 20. Overall, the LID treatment train effluent met the MECP Enhanced level of 80% TSS removal, prior to entering Pond A, across all event sizes. Despite fewer occurrences of larger events, cumulative TSS loads increased with increasing event sizes. TSS removal efficiency decreased marginally with increasing event sizes and correlates with the decreasing runoff volume reduction. As previously discussed, due to the volume reduction provided by upgradient LID features, there is less flow to transport sediment into the pond, and therefore some of the sediment is captured within the bioretention cell, permeable pavement, and grass swales. With no outflow from Pond A during the summer and autumn months, this indicates that the remaining suspended solids and potential contaminants are retained by the pond at least until flow begins during the winter and spring months.

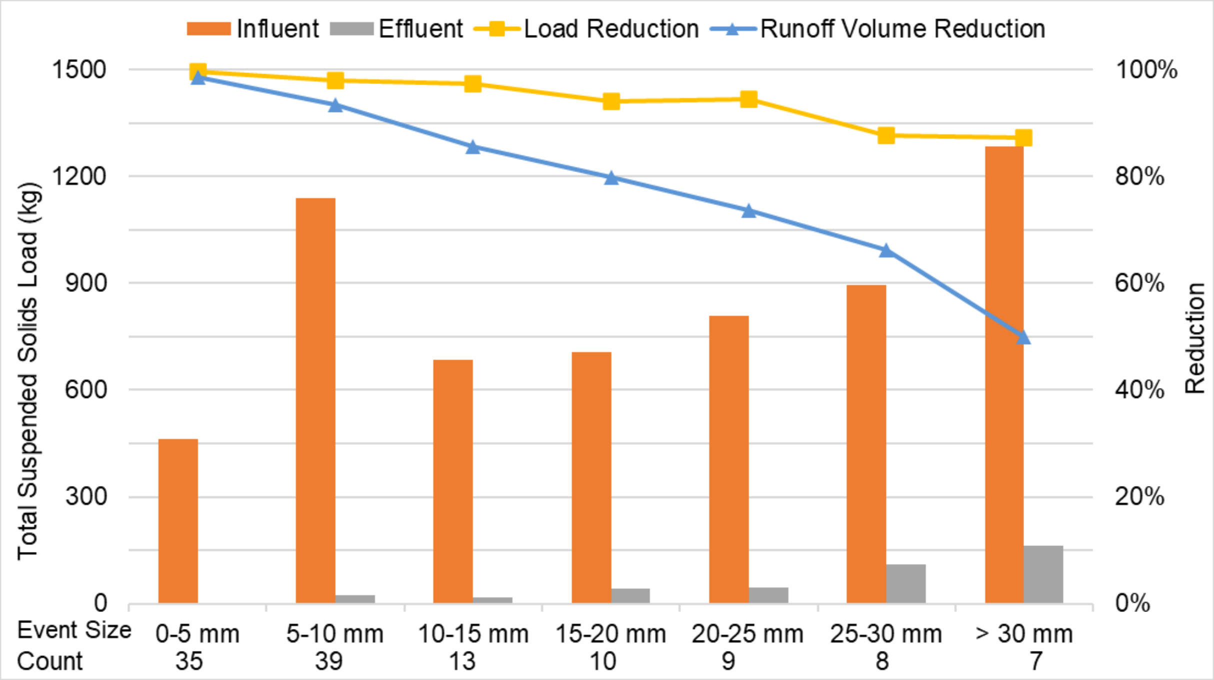


Figure 20: Total suspended solids load and runoff volume reduction at Pond A – Inlet 1.

Cumulative Load Reductions

The cumulative influent and effluent loads and reductions for the LID treatment train between 2015 and 2018 are shown in Table 14. This represents the total load for the monitoring period for months June-November. Except for zinc, all loads for parameters of concern were reduced by at least half throughout the LID treatment train. Each of these shared a similar trend to TSS with respect to increased loading with lower runoff volume reduction during larger events. Nitrate and nitrite reduction could not be calculated due to the absence of estimated influent data.

Table 14: Cumulative parameter of concern loads and removal efficiency for LID treatment train. Influent load is estimated based on Simple Method runoff estimates and the Aurora inlet average EMCs. The effluent load is calculated based on monitoring data from the Pond A – Inlet 1 station.

Parameter of Concern	Estimated Influent Load (kg)	Calculated Effluent Load (kg)	Load Reduction (%)
Total Suspended Solids (TSS)	5979.7	404.6	93
Total Phosphorus (TP)	15.5	4.2	73
Nitrate + Nitrite (NO_2+ NO_3)	N/A	12.2	N/A
Copper (Cu)	0.5	0.1	72
Zinc (Zn)	1.5	1.3	12

According to these calculations, more than 5000 kg of sediment were prevented from entering Pond A over the course of the monitoring period for the months of June-November, as a result of the LID treatment train. Reduced loads for other contaminants indicate that this runoff is less contaminated than might be observed at a comparable subdivision. This could reduce the potential for release of contaminants trapped in the pond sediment when the pond is flowing.

Conclusions-What is the influence of the upgradient LID practices on the performance of stormwater management Pond A?

The upgradient LID practices reduce the volume of runoff that enters Pond A by approximately 70-80% for the months of July-November, and this may be a contributing factor to the low water levels observed in Pond A during these same months. The LID features were not included in the original calculations for the pond design and this may be the reason for the apparent discrepancy in the water balance of Pond A. However, it is also possible that other factors contribute to the low pond level, such as seepage or any deviations from design that might have occurred during construction. A secondary consequence of the volume reduction by the LID features is that they also provide water quality benefits and reduce the sediment load reaching the pond. This is expected to slow the rate at which sediment accumulates in the pond. Overall, the upgradient LID features seem to have a significant impact on the pond resulting in low water levels and additional storage during the summer and fall. This suggests that the LID features could have been taken into consideration when sizing the pond, while still meeting design objectives, although a detailed modelling analysis would be needed to confirm this.

4.3 QUESTION 3: How can the monitoring results inform asset management at MITG and of stormwater management ponds in treatment train designs?

To track the condition and maintenance needs of the stormwater management features in the MITG subdivision, inspections were carried out every few months. Most of the maintenance inspections conducted were focused on the LID features, however one inspection was done which focused on the pond. One of the issues that was identified during the inspection of the LID features is the accumulation of garbage in the grass swales after windy days. This problem seems to be exacerbated by using open recycling bins which the residents put outside in advance of garbage collection. Another observation with the grass swales was that sediment accumulated in some of the culverts; this seemed to relate mostly to areas where considerable landscaping was going on, such as replacement of sod. An example of this where significant accumulation of sediment was observed is shown in Figure 21. There were also some swales that remained wet in the bottom even between storm events and during the summer; an example is shown in Figure 22.

Figure 21: Culvert and grass swale with accumulated sediment in it.

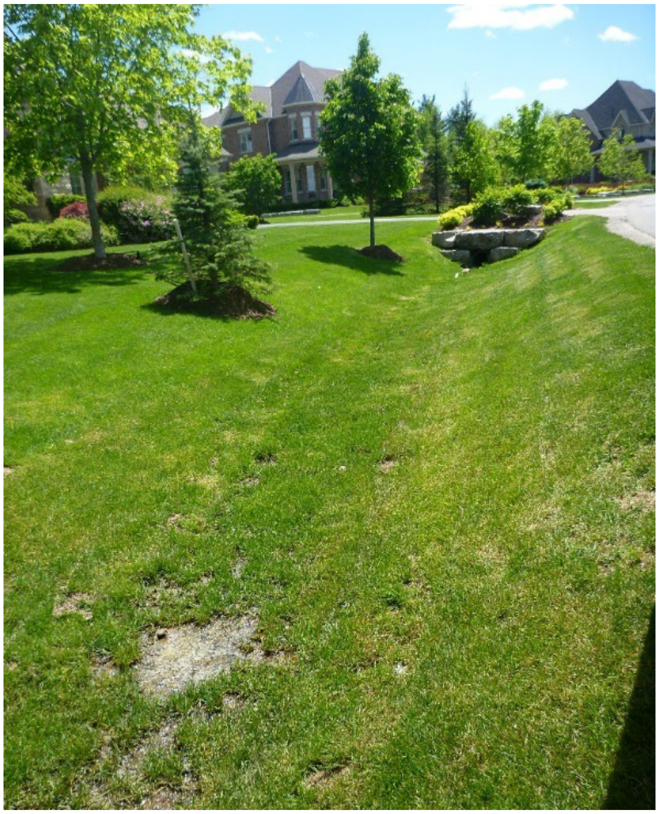


Figure 22: Swale adjacent to Pond A that has wet patches most of the year.

These swales that were consistently wet at the bottom were in the minority and seemed to be located mostly in the lower lying areas near the inlet to Pond A; this may correspond to areas with sandy-silt soils that were mentioned in the design report (Stantec, 2007a). These swales were found to be more prone to erosion problems and had more sediment build-up in the culverts. It is unclear what the cause of this difference is, though it may be a combination of the topography and potentially less permeable soils leading to some localized perching of the water table. This is exacerbated during the winter and spring months where continuous flow is measured at Inlet 1 and has been observed in some of these nearby swales as well.

Despite these issues, the grass swales appear to be fairly well maintained and many residents have incorporated maintenance of the swales as part of their landscaping including lawn mowing and litter removal (Figure 23). Although the swales are being well maintained, there is potential that landscapers are using pesticides or fertilizers that could easily enter the runoff and potentially contribute to downgradient water quality issues.

Figure 23: Example of a grass swale that appears to be regularly maintained by resident.

Another issue that was observed in the vicinity of Pond A is that the permeable sidewalk in this area (almost directly across the road from the Inlet 1 swale) showed evidence of clogging and appeared to be slower to drain during storm events compared to the permeable pavement in other parts of the subdivision. Water ponded over the pavement in this area during storm events (Figure 24). This may be a consequence of topography as stormwater would concentrate in this area from the rest of the catchment, resulting in increased loading to this stretch of pavement. It may be preferable to focus more frequent maintenance effort on this stretch of permeable pavement.

Figure 24: Permeable pavement across the road from Inlet 1, shown during a precipitation event.

The vegetation in the bioretention cell appears to be healthy and providing good coverage (Figure 25), however some residents have informally commented to staff that they have concerns about sightlines and potential safety hazards with respect to some of the larger shrubs. This highlights the importance of regular vegetation maintenance such as trimming and removal of dead vegetation.

Figure 25: Bioretention cell vegetation growth.

A maintenance interview was conducted by CVC with the developer on September 29, 2017 to quantify the maintenance costs of the LID features at MITG. Since the development had not yet been assumed the maintenance costs were quite high as several issues were identified throughout the assumption process which required remediation. These costs might also be inflated by the impact on the features of higher sediment loads during the construction and establishment periods, or potential failure of sediment and erosion control measures. Landscaping activities by residents may also have contributed, for example it was indicated that repairs were needed when heavy equipment was parked within one of the features causing the drain to collapse. The high costs for remediating some of the features emphasizes the benefit to the municipality of having site specific and detailed assumption protocols that ensure these issues are identified and resolved prior to assumption. Furthermore, some of the costs associated with remediation might be avoided through construction inspections that focus on ensuring proper sediment and erosion control measures, and appropriate storage of materials and equipment. It is also likely that the routine maintenance costs would be less once the subdivision has fully stabilized. Summarized in Table 15 below are several repair and rehabilitation costs incurred during the assumption process.

Table 15: Repair and rehabilitation costs incurred during the establishment period based on developer interview. (Rusu, 2017) These costs include those required to repair deficiencies as part of assumption and establishment, and are therefore may not be indicative of cost for ongoing future maintenance. See Appendix C for more details.

Feature	Repair and Rehabilitation Activities	Cost
Underdrain	Repair of collapsed underdrain	$7,000
Pond A	Clean out forebay	$75,000
Bioretention Cell	Repair filter media/ replanting	$40,000
Grass Swales	Trash removal, clear sediment and debris, snow removal, flush underdrains	$15,000/ year
Permeable Pavement	Replace chip-stone and displaced pavers, vacuum & sweep pavers, pressure wash	$50,000/ year

During the cleanout of the Pond A forebay in 2017 it was observed that invasive plant species were present in Pond A (Rusu, 2017). There were no additional significant maintenance issues identified during the pond inspection conducted by CVC staff in October of 2019, however the consistently low water levels in the pond throughout much of the year may have some maintenance implications in the future. As shown in Figure 26 and Figure 27 the pond level can be very low and stagnant; during the summer this may promote the growth of excess algae.

Figure 26: Low water level in Pond A on October 4, 2019.

Figure 27: Algae growth in Pond A on August 2, 2018.

Potential maintenance issues for stormwater ponds with low water levels are discussed in the U.S. EPA Stormwater Wet Pond and Wetland Management Guidebook (EPA, 2009); they include potential for water quality and aquatic habitat degradation, mosquitoes, and aesthetic concerns such as excess algae.

The LID features in the catchment upgradient are achieving significant volume and TSS load reductions as discussed in Questions 1 and 2 above. The reduced loading of sediment to the pond could prolong the pond cleanout frequency. However, this captured sediment load would accumulate within the LID practices and regular maintenance would be needed to ensure that they continue to perform as designed. To extend the life of LID practices and allow for simpler maintenance pre-treatment devices could be used in future designs to capture sediment and prevent it from building up within the LID practices themselves.

The stormwater management design document suggests a cleanout period of 41 years (Stantec, 2007a), however given the lack of data for the impact of upgradient LID features on pond maintenance requirements it would be recommended that the cleanout frequency be determined based on actual measurements of sediment accumulation. The STEP Inspection and Maintenance Guide recommends conducting sediment depth measurements, either by bathymetric survey or a simple transect, approximately every 3-5 years (STEP, 2016). In addition to permanent pool storage volume requirements, the MECP Stormwater Management Planning and Design Manual (MECP, 2003) provides water depth specifications for wet ponds. These guidelines indicate that the forebay should have a minimum depth of 1 m and be sized to ensure non-erosive velocities leaving the forebay (MECP, 2003). To minimize re-suspension while avoiding creating anoxic conditions, the permanent pool should have a mean depth between 1 - 2 m, with a maximum depth no greater than 3 m (MECP, 2003). Due to the specific dimensions of Pond A, water depth in the forebay could decrease significantly below the 1 m depth guideline while the permanent pool volume remained adequate to meet the Enhanced standard. Therefore, it is recommended that the MECP depth guidelines be used as the threshold for determining when cleanout should be done at Pond A. The water depth can be tracked using a consistent transect of measurements in the forebay, where sediment is expected to accumulate the quickest.

Since these guidelines are intended for water quality purposes it is most important that they be met at times when the pond is discharging. Therefore, the depth measurement transects should be made at times when the pond level is at or close to the outlet orifice invert. Due to the seasonal variability of the water level in Pond A, this would likely require taking these measurements during the spring when the pond level tends to stabilize within a couple centimetres of the outlet orifice invert. Alternatively, the average elevation of the bottom of the forebay could be measured and that value could be compared to the elevation of the outlet orifice invert (256.053 masl) to ensure a minimum 1 m depth. Using this approach, the forebay should be cleaned out when the average elevation of the bottom of the forebay exceeds 255.053 masl. At this time the full pond should be surveyed to determine the extent of cleanout required.

The volume reductions achieved by the upgradient LID features may also explain the low water level in the pond by altering the water balance. If the water balance analysis is not accurate this can result in low water levels due to evaporation (EPA, 2009). The infiltration practices were not included in the initial water balance calculations to determine pond sizing requirements and this may explain the discrepancy. Although it is possible that seepage or leaking might explain the low water levels, no obvious evidence of this was observed during the pond inspection. However, it is possible, as it has been observed that soils in this area appear to be prone to developing natural soil pipes, caused by erosion of preferential flow-paths. It is more likely that the low pond levels during the summer and fall are a result of a combination of factors including seepage, the flow regime of the neighboring rural property, the influence of the LID features on the water balance, and increased evaporation rates during the warmer months, as the pond does return to its permanent pond level during the winter.

Conclusions- How can the monitoring results inform asset management at MITG and of stormwater management ponds in treatment train designs?

Overall, this inspection and monitoring data indicate that many maintenance issues at MITG are localized, and maintenance efforts could be directed most efficiently by conducting regular inspections of targeted areas. In terms of maintenance for Pond A, the upgradient LID practices significantly reduce the TSS loads entering the pond potentially prolonging the amount of time before cleanout is required. However, in order for the LIDs to continue providing this level of TSS load reduction it will be crucial to consistently perform routine maintenance on them. In future designs it may be beneficial to include pre-treatment that captures sediment, especially for those LID features located in areas where higher loading is expected, such as at a topographic low point where flow paths converge. Issues related to the stagnant pond conditions could exacerbate over time. It is recommended that any resident complaints of strong odour and algal growth are tracked to help understand if conditions in the pond are worsening. Observations, suggestions, and concerns for each stormwater management practice at MITG are summarized in Table 16 below. For recommendations on routine maintenance activities for LID practices consult the STEP manual "*Low Impact Development Stormwater Management Practice Inspection and Maintenance Guide*" (TRCA, 2016).

Table 16: Summary of asset management observations, suggestions and concerns.

Feature	Observations	Suggestions/ Concerns
Grass Swales	Trash accumulation after waste collection days	Promote use of recycling and garbage bins that have lids
	Sediment accumulates in culverts	Include culvert cleaning in routine maintenance
	Some swales are consistently wet at bottom, may erode more readily	Consider topography and natural hydrology for future designs
		More frequent maintenance may be needed for these areas
	Appear to be well maintained by residents	Potential water quality consequence if pesticides/fertilizers being used
Permeable Pavement	Clogging of permeable pavers in topographic low near the pond, this would be where flow paths converge possibly resulting in higher loads	For future designs consider including pre-treatment in areas prone to higher sediment loads
		More frequent maintenance may be required in this area
Bioretention Cell	Overgrown vegetation could impede sightlines and be a safety problem	Include pruning and trimming as part of routine maintenance
Pond A	Invasive plant species present	Remove invasive plant species and continue to monitor in future

	Low water levels might be encouraging algae growth and mosquitoes	Consider impact of LIDs on water balance in future designs
	Volume reduction from LIDs reduces the sediment load to pond	Complete depth transect measurements of pond every 3-5 years to determine cleanout frequency
		Ensure that upgradient LIDs are well maintained so that treatment level is maintained and frequency of pond cleanout may be prolonged
General	Costly remediation during establishment period	Benefit to municipality of having clear assumption protocols
		Construction inspections to ensure that design and sediment and erosion control is implemented properly

5.0 CHALLENGES, LIMITATIONS AND LESSONS LEARNED

There have been considerable challenges related to monitoring at MITG. Some of these relate to the strong seasonality observed in pond performance. The original plan was to only conduct monitoring at MITG from March/April through to December, as the expensive monitoring equipment is vulnerable to freezing and all monitoring infrastructure is located in open channels. However, when it was observed that most of the flow from the pond occurs in the winter and spring this monitoring plan had to be adjusted. To address this, during the winter, the ISCO level loggers are replaced with hardier, but lower resolution Hoboware loggers. These unfortunately cannot be used to trigger the autosamplers, and therefore once temperatures begin to warm up the equipment needs to be switched back to allow for water quality event sampling.

The original monitoring plan was to focus exclusively on event-flows, however during the winter and spring, flow is nearly continuous at all monitoring stations. The outflow from Pond A also does not appear to return to a consistent flow rate that could be separated out as baseflow, but instead has a very flattened and drawn-out hydrograph, causing multiple events to merge. The approaches used for event-based analysis for the metrics presented in this report are outlined in Appendix A. The EMCs and event-based volume reduction analysis provided for Inlet 1 has been limited to the months where continuous flow is not observed at the inlet.

Other challenges relate to the monitoring infrastructure and the native soils being prone to the formation of natural soil pipes. The formation of soil pipes that bypassed the weir at Inlet 2 necessitated major repairs using a bentonite clay liner to allow monitoring in this location. Soil pipe formation has also been observed downstream of Pond A, in the vicinity of Tributary F. Regular repairs are also required at the Pond A weirs, where staff have observed significant leaking; this is likely a consequence of the weir completely drying out during the prolonged period without flow. Although this could lead to some underestimation of flow at the outlet, it does not fully explain the lack of measured outflow for large portions of the year. The absence of flow is verified by in-field observations as well as the pond stage data and the leaks are not sufficient to prevent the weirs from filling once significant flow is occurring.

Monitoring Challenges:

- Seasonal pattern of flow necessitated winter monitoring which was not part of original monitoring plan.

  - More difficult to collect water quality samples during the winter due to concerns about equipment operation and damage.
- Needed to modify event-based sampling approach to account for continuous flows observed in winter and spring.
- Soil type is prone to formation of natural soil pipes and significant repairs to one of the weirs was needed in order to prevent bypass causing delays to monitoring program.
- Weir leakage resulting in need for frequent repairs.

Limitations:

- Due to challenges with water quality sample collection, we have fewer water quality samples for the outflow of the pond and some of the samples collected do not strictly meet the criteria for EMCs.
- Since the monitoring plan was developed to adapt to challenges as they were encountered the dataset is spread over different timeframes depending on the data type.
- Intensive monitoring of the individual components of the LID treatment train was beyond the scope of this project.
- Secondary external inlet to Pond A complicates the interpretation of results with respect to the influence of upgradient LID practices on the performance of the pond.
- Lack of monitoring data for LID influent for water quality and runoff volumes necessitates estimates to be used from other locations adding some uncertainty to the interpretation of the results.

Lessons Learned:

- Be prepared to adapt monitoring plans to local conditions and apply different approaches to monitoring and analysis, for example, focusing on event-based analysis may not be appropriate for all study sites.
- Incorporate pond stage measurements into future monitoring plans for stormwater ponds.
- Whenever possible monitor influent quantity and quality directly to allow for greater accuracy in volume and load reductions.

6.0 CONCLUSIONS AND NEXT STEPS

This report summarizes data collected at Meadows in the Glen (MITG) from 2015-2018. The analysis provides insights on the performance of the stormwater management treatment train and information to determine if the design criteria are being met.

These are the 3 main questions that this performance monitoring study seeks to address:

1. Is stormwater management Pond A performing as designed?
2. What is the influence of the upgradient LID practices on the performance of stormwater management Pond A?
3. How can the monitoring results inform asset management at MITG and of stormwater management ponds in treatment train designs?

Summarized below are the major conclusions from the data analysis:

1. Pond A is not performing as designed, but in some ways the expected performance is exceeded:

- The pond does not return to its permanent pool level for much of the year but is significantly below that level from approximately June through to mid-January.
- A bathymetric survey completed in October 2017 found Pond A had a permanent pool volume of 2,100 m^3 despite the low water levels at this time. This significantly exceeds the minimum permanent pool volume requirement for providing Enhanced water quality treatment.
- For most events, drawdown times meet the 24-48 hours guideline. Twenty-three per cent have drawdown times that exceed 48 hours, which may have a positive influence on water quality but might be detrimental in terms of the amount of available active storage for subsequent events.
- Although the calculated average detention time is less than the design criteria, Pond A still performs well in terms of detention times compared to the other wet ponds reported on in the SWAMP study.
- Peak flow reductions generally exceed model estimates; however, time of year and pre-event storage availability seem to be more important controls than precipitation depth or average intensity.
- The absence of flow leaving the pond for much of the year means that there is no contaminant load to downstream ecosystems during this time. Certain contaminants would be expected to be released once flow starts again in winter, however the absence of summer flow would mean that the risk of thermal loading downstream is negligible.
- Preliminary pond effluent water quality data suggests that TSS concentrations in the water leaving Pond A are below the in-stream PWQO guideline of 25 mg/L.

2. The upgradient LID features have implications for the pond performance:

- It is suspected that volume reductions provided by upgradient LID features influence water balance and contribute to low pond water levels during the summer and autumn seasons.
- Contaminant load reductions by the LID features improve water quality in the pond.
- TSS load reductions in particular will likely reduce the rate that sediment accumulates in the pond, but regular inspection and maintenance of the upstream LIDs may be required in order to maintain this.
- Overall, the upgradient LID features have been found to impact on the pond function by:
    - Lowering water levels
    - Providing additional storage available during the summer and fall
- This suggests that the LID features could have been taken into consideration when sizing the pond, while still meeting design objectives.

3. The results can inform asset management at MITG:

- Key maintenance issues for the LID features include the build-up of trash in the swales, sediment accumulation in culverts, and localized ponding and erosion issues for the permeable pavement and grass swales.
- Maintenance issues related to low pond level may be expected at Pond A; these may include water quality issues, mosquitoes, and aesthetic issues such as excess algae.
- CVC suggests that due to lack of data on sediment accumulation in ponds with LID features upgradient that pond cleanout be determined based on future sediment depth measurements:

  - The STEP Inspection and Maintenance Guide recommends conducting sediment depth measurements, either by bathymetric survey or a simple transect, approximately every 3-5 years (STEP, 2016).
  - A transect of depth measurements taken in the forebay could be used to ensure that a minimum average water depth of 1m is provided as per MECP guidelines (MECP, 2003).
    - Due to the seasonal variability in pond water level at Pond A, water depth measurements should be completed in the spring at a time when the water level in the pond is at or close to the outlet orifice invert.
    - Alternatively, the average bottom elevation in the forebay could be compared to the threshold value of 255.053 masl, with cleanout taking place as soon as this value is exceeded.
    - Once the threshold is met in the forebay a survey of the full pond should be completed to determine the extent of cleanout required.

While Pond A appears to be generally meeting its design objectives, it is not performing exactly as expected. This is particularly apparent with respect to the pond water level, which is well below the expected permanent pool level for much of the year. As a result, most precipitation events during the summer do not cause any flow to leave the pond at all. This results in enhanced resiliency with respect to any extreme precipitation events that occur during the warmer months. This could prove beneficial in the context of climate change, as these kinds of precipitation events are expected to increase. On the other hand, the resulting stagnant conditions within the pond may promote algae growth or other maintenance issues.

It is likely that the low pond water levels are at least in part a result of the water balance impact of the LID features in the upgradient catchment, as these were not accounted for when sizing the pond. Based on the results at MITG it would be reasonable to include any infiltration practices in the catchment of a proposed wet pond in the water balance calculations used for sizing that pond. However, the flow characteristics at Pond A likely reflect the influence of both the upgradient LID features and the rural property adjacent to MITG that enters Pond A through Inlet 2. Unfortunately, this reduces the degree to which the results from Pond A can be generalized to other wet ponds with LID features upgradient as it is difficult to differentiate the influence of the upgradient LID features from the influence of the neighboring rural property. It is also possible that other factors contribute to the low pond levels, such as seepage or discrepancies from the design. Most likely the flow regime observed at Pond A results from a combination of these factors, and this should be kept in mind when interpreting these results.

Furthermore, the monitoring data for MITG illustrates some of the drawbacks of using discrete event-based models for designing wet ponds. Monitoring data indicates that season and antecedent water levels have a strong relationship with the magnitude of peak flows and flow durations observed at the Outlet of Pond A. It would be difficult to explore the intricacies of this relationship using a discrete event-based model, and therefore such a model would likely not accurately demonstrate the kind of conditions that would generate the highest peak flows leaving the pond.

Next Steps

- Due to challenges with the timing of flows and with collecting composite samples at the outlet of Pond A, the question of characterizing the water quality leaving the pond has not been addressed. One of the next steps is to analyze the continuous water chemistry data that has been collected over the past couple of years to address this question.

- Opportunities to develop a calibrated model of the site will be investigated to compare this with design storms and assess the performance of the site for larger return period events.
- Report on the data collected for the full monitoring period ending in 2020 including:
    - Groundwater, Soil Chemistry, Pond B outlet flow, and additional water quality parameters in order to get a full picture of how these factors contribute to overall performance and water balance of the site.

LIST OF ACRONYMS AND ABBREVIATIONS

µg/L	Micrograms per litre
CCME	Canadian Council of Ministers of the Environment
cm	Centimetre
Cu	Copper
CVC	Credit Valley Conservation
EMCs	Event mean concentrations
ha	hectare
hrs	Hours
IDF	Intensity Duration Frequency
kg	Kilogram
km	kilometer
L	Litre
L/s	Litres per second
LID	Low Impact Development
LSRCA	Lake Simcoe Region Conservation Authority
m	Metre
m^3	Cubic metre
m^3/s	Cubic metre per second
m^3/yr	Cubic metre per year
masl	Metres above sea level
Max	Maximum
MECP	Ministry of the Environment, Conservation and Parks
mg/L	Milligram per litre
Min	Minimum
MITG	Meadows in the Glen
mm	Millimetre
MOE	Ministry of Environment
NO_2 and NO_3	Nitrite and nitrate
PWQO	Provincial Water Quality Objectives
Std. Dev.	Standard Deviation
STEP	Sustainable Technologies Evaluation Program
SWAMP	Stormwater Assessment Monitoring and Performance Program
SWMHYMO	Stormwater Management Hydrologic Model
TP	Total Phosporus
TRCA	Toronto and Region Conservation Authority
TSS	Total Suspended Solids
U.S. EPA	United States Environmental Protection Agency
Zn	Zinc

GLOSSARY OF TERMS

Term	**Definition**
Adaptive monitoring	Monitoring designed to evaluate how stormwater management practices can be adjusted to improve performance. For example, practices could be adjusted to improve water quality, meet hydrologic goals, last longer, require less maintenance, or meet new challenges of climate change [1]
Assumption	Refers to the time at which the municipality takes over responsibility for maintenance of a subdivision from the developer
Auto sampler	An autosampler is used to collect composite samples from a flow event to test the water quality. It has the ability to collect several samples with variable program lengths, which can be adjusted based on the rainfall period[1]
Bathymetric Survey	A bathymetric survey involves conducting depth measurements for a water body to develop a detailed picture of the underwater topography [2]
Bioretention	A shallow excavated surface depression containing prepared filter media, mulch, and planted with selected vegetation [3]
Boreholes	A borehole is a narrow shaft bored in the ground, either vertically or horizontally [4]
Catchment area	The land draining to a single reference point; similar to a subwatershed, but on a smaller scale [3]
Compliance monitoring	Monitoring designed to evaluate whether a management measure or facility is functioning as intended and meeting minimum acceptable requirements [1]
Conveyance	Movement of water from one location to another, for example, movement of runoff from lot-level features downstream to an end-of-pipe facitiy[3]
Drawdown	The period of time it takes for a wet pond to return from the maximum water level reached during an event to its antecedent water level [5]
Dredging	Clean out or excavation of material from a water body [4]
Driveway aprons	Portion of a regulary established driveway lying between a property line and any curb, the purpose of which is to provide vehicular access from the street across the curb, parkway and sidewalk to the property fronting thereon or abutting thereto [6]
Effluent	The outflow or discharge of stormwater exiting the stormwater management feature[4]
End-of-pipe	A structural best management practice that is located at the end of a flow conveyance route. End-of-Pipe Controls include but are not limited to wet ponds, constructed wetlands and other similar systems [3]
Evapotranspiration	The combined loss of water to the atmosphere from land and water surfaces by evaporation and from plants by transpiration [3]
Flow logger	A flow logger is used to monitor continuous stormwater flow. The logger will measure level depth and velocity. Most loggers will also calculate the flow rate if the dimensions of the pipe, weir, or flow area are entered into the logger[1]

Hydrologic cycle	The circulation of water from the atmosphere to the earth and back, through precipitation, runoff, infiltration, groundwater flow and evapotranspiration [3]
Influent	The incoming or inflow stormwater into the stormwater management feature[4]
Performance monitoring	Monitoring designed to evaluate how a stormwater management facility or practice performs when compared to a range of performance indicators or targets. Performance monitoring also allows comparison with other facilities, technologies, and/or development contexts [1]
Water balance	The accounting of inflow and outflow of water in a system according to the components of the hydrologic cycle [3]
Lot-level	The treatment of urban runoff as close to the source area as possible through application of small scale stormwater management practices on individual properties that are linked to downstream conveyance and end-of-pipe practices [3]
Low impact development (LID)	A stormwater management strategy that seeks to mitigate the impacts of increased urban runoff and stormwater pollution by managing it as close to its source as possible. It comprises a set of site design approaches and small scale stormwater management practices that promote the use of natural systems for infiltration and evapotranspiration, and rainwater harvesting [3]
Oulet orifice	Orifices are holes which restrict the flow of water. They may be used at the downstream end of the stormwater management feature to provide flow control as water leaves the feature [7]
Peak flow	Peak flow is the maximum flow rate recorded during an event
Rain gauge	A monitoring device that collects and measures the amount of rainfall at a facility [8]
Soakaway pits	An excavated area lined with geotextile filter cloth and filled with clean granular stone or other void forming material, that receives runoff and allows it to infiltrate into the native soil; can also be referred to as infiltration galleries, French drains or dry wells[3]
Stage	Water level above some arbitrary point or datum [9]
Treatment train	Multiple stormwater management practices designed to work together to manage stormwater. A combination of lot level, conveyance, and end-of-pipe stormwater management practices [3]
Turbidity	Turbidity refers to the cloudiness, opacity, or thickness of water with suspended matter. This measurement is a key to test water quality [4]
Wet ponds	A wet pond is an artificial pond that temporarily stores stormwater runoff and releases it at a controlled rate. It holds a permanent pool of water between storm events [10]

Sources for Definitions:

[1] Zimmer, C., & Dougherty, J. (2015). Lessons Learned: CVC Stormwater Management and Low Impact Development Monitoring and Performance Assessment Guide. Retrieved from URL: Monitoring_Guide_Final.pdf (cvc.ca)

[2] Sustainable Technologies Evaluation Program (STEP). (2016). Inspection and Maintenance Guide for Stormwater Management Ponds and Constructed Wetlands. Retrieved from URL: https://sustainabletechnologies.ca/app/uploads/2018/04/SWMFG2016_Guide_April-2018.pdf

[3] Sustainable Technologies Evaluation Program (STEP). (2020). Terminology. Retrieved from URL: Terminology - LID SWM Planning and Design Guide (sustainabletechnologies.ca)

[4] Microsoft Definition. Retrieved, September 10, 2021.

[5] Sustainable Technologies Evaluation Program (STEP). (2013). Discussion Document – Fundamental Concepts for Pond Systems. Retrieved from URL: Microsoft Word - Pond Fundamentals.doc (sustainabletechnologies.ca)

[6] Law Insider. (2021). Driveway Apron Definition. Retrieved from URL: driveway apron Definition | Law Insider

[7] Sustainable Technologies Evaluation Program (STEP). (2019). Flow through an orifice. Retrieved from URL: Flow through an orifice - LID SWM Planning and Design Guide (sustainabletechnologies.ca)

[8] Law Insider. (2021). Rain gauge. Retrieved from URL: Rain gauge Definition | Law Insider

[9] United States Geological Survey (USGS). (n.d.). Water Q&A: What does the term “river stage” mean? Retrieved from URL: Water Q&A: What does the term "river stage" mean? (usgs.gov)

[10] Ministry of the Environment, Conservation and Parks (MECP). (2021). Understanding Stormwater Management: An Introduction to Stormwater Management Planning and Design. Retrieved from URL: Understanding Stormwater Management: An Introduction to Stormwater Management Planning and Design | Ontario.ca

REFERENCES

Ahiablame, L. M., Engel, B. A., & Chaubey, I. (2012). Effectiveness of low impact development practices: literature review and suggestions for future research. Water, Air, & Soil Pollution, 223(7), 4253-4273.

Auld, H., Switzman, H., Comer, N., Eng, S., Hazen, S., and Milner, G. (2016) Climate Trends and Future Projections in the Region of Peel. Ontario Climate Consortium: Toronto, ON

City of Vaughan. (2014). City-Wide Stormwater management Master Plan, Municipal Class EA

Credit Valley Conservation (CVC). (2009). Water Quality Strategy. Retrieved from URL: https://cvc.ca/wp-content/uploads/2011/07/Final-PII-WQSModelingReport.pdf

Lake Simcoe Region Conservation Authority (LSRCA). (2011). Stormwater Pond Maintenance and Anoxic Conditions Investigation.

Lake Simcoe Region Conservation Authority (LSRCA). (2020) Pond Maintenance Training Course

Liu, Y., Engel, B. A., Flanagan, D. C., Gitau, M. W., McMillan, S. K., & Chaubey, I. (2017). A review on effectiveness of best management practices in improving hydrology and water quality: Needs and opportunities. Science of the Total Environment, 601, 580-593.

Ontario Ministry of Environment Conservation and Parks (MECP). (2003). Stormwater Management Planning and Design Manual. Queen’s Printer for Ontario.

Ontario Ministry of Environment Conservation and Parks (MECP). (2015). Interpretation Bulletin: Ontario Ministry of Environment and Climate Change Expectations Re: Stormwater management, February 2015. Retrieved from: https://wiki.sustainabletechnologies.ca/images/9/99/MOECC_on_LID_2015.pdf.

Papa, F., Adams, B., & Guo, Y. (1999). Detention time selection for stormwater quality control ponds. Canadian Journal of Civil Engineering. 26: (72-82).

Parish Geomorphic. (2005). Sheridan Nursery Erosion Assessment.

Rusu. (2017). Personal communication: Interview with Intracorp developer.

Sabouri, Gharabaghi, Sattar & Thompson. (2016). Event-based stormwater management pond runoff temperature model. Journal of Hydrology. 540: (306-316).

Stantec (Kitchener). (2007a). The Meadows in the Glen Subdivision, Final Stormwater management and Low Impact Development Strategy Report, Glen Williams, for Intracorp Project (The Meadows in the Glen) Ltd.

Stantec (Kitchener). (2007b). The Meadows in the Glen, Environmental Implementation Report, Glen Williams, for Intracorp Project (The Meadows in the Glen) Ltd.

Sustainable Technologies Evaluation Program (STEP). (2016). Inspection and Maintenance Guide for Stormwater Management Ponds and Constructed Wetlands. Retrieved from URL: https://sustainabletechnologies.ca/app/uploads/2018/04/SWMFG2016_Guide_April-2018.pdf

Stormwater Assessment Monitoring and Performance (SWAMP) Program. (2003). Performance Assessment of an Open and Covered Stormwater Wetland System, Aurora, Ontario. TRCA, Toronto.

Stormwater Assessment Monitoring and Performance (SWAMP) Program. (2005). Synthesis of Monitoring Studies Conducted Under the Stormwater Assessment Monitoring and Performance Program.

Terraprobe. (2007). Geotechnical Investigation Proposed Residential Subdivision, The Meadows in the Glen Part of Lots 20 &21 Concession 10 Town of Halton Hills Regional Municipality of Halton.

Toronto and Region Conservation Authority (TRCA). 2016. Low Impact Development Stormwater Management Practice Inspection and Maintenance Guide. Prepared by the Sustainable Technologies Evaluation Program. Vaughan, Ontario. https://sustainabletechnologies.ca/app/uploads/2016/08/LID-IM-Guide-2016-1.pdf

United States Environmental Protection Agency (U.S. EPA). (2009). Stormwater Wet Pond and Wetland Management Guidebook. Retrieved from URL: https://www3.epa.gov/npdes/pubs/pondmgmtguide.pdf

Appendix A:

Analysis Methods

POND PERFORMANCE METRICS

All analyses were completed in Microsoft Excel spreadsheets. These spreadsheets included compiled time series of precipitation, pond stage, and flow data for all the monitoring stations. The calculations were completed using equations that would provide summary information for a given “storm event”. The equations were designed to automatically summarize a portion of data based on certain rules used to define a storm event. Depending on the requirements of the individual metric, the rules for what portion of data needed to be summarized could vary. The different metrics used, and the rules applied to defining events are all described below.

1.0 POND STAGE SUMMARY

Metric: In this case there is not a specific metric reported on, rather some basic stats are used to describe how the pond level changes over time. These focus on how the pond’s level compares to the design permanent pool. The design permanent pool is assumed to be equivalent to the as built elevation of the lower outlet orifice.

Timeframe: 2017-2018 (doesn’t start until Pond A stage is installed, as analysis requires pond level).

Event Definition: This analysis is not done on an ‘event basis’ instead the data is summarized by month, season or annually

Rationale: It doesn’t make sense to summarize the stage data according to events as the idea is to get the overall picture of where the pond level sits most of the time, not just when the pond is flowing (if it’s a flow event we already know the pond level is above the permanent pool).

1.1 Peak Flow Reduction

Metric: Peak Flow Reduction is an important metric for understanding pond performance, as it reflects a pond’s ability to reduce flood risk as well as mitigate downstream erosion effects. This section includes data comparing the maximum flow generated for different sized Precipitation events. It also calculates peak flow reductions where outlet flows are reported as a percentage of the combined inlet flows for that event. This estimate of peak flow reduction is conservative in the sense that there is likely additional inflow that enters the pond directly and is not accounted for at either Inlet, and is therefore missing from the calculations. This would result in our estimates of peak flow reductions potentially being slightly low, however this effect is expected to be minimal.

Timeframe: The full dataset is for 2015-2018 for peak outflow summarized by precipitation event size. However, we do not have flow values for Inlet 2 until 2016 so peak-flow reductions are calculated only for 2016-2018.

Event Definition

“Precipitation-only events” event starts when precipitation begins and continues until there is no precipitation for a minimum of 6 hours. The equations will pick out the maximum flow value that occurs after the start of the current precipitation event and prior to the start of the next precipitation event. To identify which events are appropriate for further analysis these events are then assessed with respect to 4 criteria:

- **Criteria 1**: Prior to the start of the event, was the flow increasing, decreasing or constant?
- **Criteria 2**: Was there flow preceding the start of the event, if so, was it 20% or less of the peak flow attained during that event?
- **Criteria 3:** Was the total precipitation 2mm or more?
- **Criteria 4:** Is there flow measured at least one of the inlets?

Rationale: These criteria are used to identify which events can be used for analysis as well as to distinguish which events are likely to be significantly influenced by previous precipitation events.

- Criteria 1 and 2 are focused on determining if there is a significant influence from the preceding event
    - If the flow rate is still increasing when the new precipitation event occurs it suggests that the pond is still under the influence of the preceding event.
    - Furthermore, if the flow is neutral or negative, but the pre-event flow is more than 20% of the event peak flow that suggests that the peak flow is impacted by the previous event.
    - These events are still important to analyze as they represent a kind of worst-case scenario, however it is important to separate them out to see a clearer relationship between precipitation and peak flow reduction.

1.2 Drawdown Time

Metric: Drawdown Time is defined as the period between the between the maximum water level and the minimum level (dry-weather or antecedent level) in the pond. A theoretical drawdown curve for a pond may be taken as the stage-discharge relationship of a specific effluent control structure. The theoretical value would be approached in practice only if there was no influent flow at the time that the pond was draining. Because there is typically some inflow the value of the actual drawdown time is expected to exceed that of the theoretical curve (SWAMP, n.d.).

Timeframe: Fall 2017-2018 (doesn't start until Pond A stage was installed as this data is required for analysis).

Event Definition:

There are two complimentary event definitions that have been used for this analysis; Precipitation-only events and Drawdown Period:

Precipitation-Only events:

- Event starts when there is precipitation and continues until there is no precipitation for a minimum of 6 hours.
- Once events have been summarized in this fashion, they are compared to 3 criteria to determine which events are subject to which analyses:
    - **Criteria 1**: Initial precipitation > 2mm
    - **Criteria 2**: stage increase by >3mm
    - **Criteria 3**: is the drawdown completed before the start of the next precipitation event?
- These have been labelled "Simple Events" because the pond stage was able to return to the pre-event level before the start of the next precipitation event.
- If an additional precipitation event occurs within this timeframe it will obviously extend the drawdown time and make it more complicated to interpret the results with respect to precipitation depth.
- These more complex events have been analyzed and summarized separately. They are included in a more limited analysis that only includes events in the 20-30 mm range. All events in this range were summarized and the results discussed with recognition that the drawdown times are extended because additional precipitation events may occur prior to the pond returning to its pre-event level.

Drawdown Period:

- This is measured from the start of the precipitation event until the antecedent pond level is reached.
    - Note this is not the drawdown time which is measured from the time of peak pond elevation to when the pond returns to its pre-event levels, this is just describing time periods over which the data is summarized in the spreadsheet.
- Multiple precipitation events may occur during this drawdown period

  - Some of the data is summarized over the precipitation-only event (precipitation depth, precipitation intensity).
  - The precipitation start time also corresponds to the pond elevation that is used as the pre-event or antecedent pond level.
  - The equations then pick out the maximum pond level that is reached in the timeframe defined as starting at the start of current precipitation event time and continuing until the start of the next precipitation event.
  - **The drawdown time** is the amount of time between the peak pond level and when it returns to its pre-event level. This is to address the issue that the pond peak may not be reached within the precipitation event defined by the 6-hour rule, however we still want to isolate the influence of individual rain events to the degree that this is possible.

Rationale: Precipitation-only events are used to summarize the data because drawdown times are being estimated both for the times when there is outflow, but also when there is no flow at all, this way the event summaries can be applied in a consistent way. Furthermore, since the antecedent water level might be lower or higher than the permanent pool level, flow is not a reliable start and stop indicator for the beginning and endpoint. The drawdown period isn't used to summarize the data because these can be spread over long periods of time and multiple precipitation events. It would then be impossible to reasonably bin the drawdown times according to precipitation characteristics.

1.3 Detention Time:

Metric: Average hydraulic detention time calculated from difference between timing of inlet and outlet flow centroids. The hydraulic detention time is a measure of the ability of the facility to smooth and extend the runoff hydrograph to reduce its impact on the receiving stream.

Timeframe: 2016-2018 (doesn't start until Inlet 2 is installed, as analysis requires combined inlet flow).

Event Definition:

Pond A Event: Event starts when there is precipitation, or if either of the Inlets or outlet begin to flow, whichever comes first. The event continues until there is no precipitation or flow at any stations for a minimum of 6 hours.

Rationale: Events are defined this way as detention time relates to what is going on within the pond, this means that the inlets and outlet must all be considered in relation to each other.

1.4 Comparison of Monitoring data to Design Model

In order to compare monitoring data to the design model selected events were identified based on average precipitation intensity. Precipitation events were identified that had greater average intensity than a 2-year return period event of equivalent duration. The equivalent duration 2-year return period event was calculated based on the IDF parameters that were used in the original design model. The average intensities of monitored events were then compared to those calculated for 5, 10, 25, 50 and 100-year storms of equivalent duration. Through this approach events were identified as being "greater than 2 year", "greater than 2 year but less than 5 year", and so on with respect to return periods. The selected monitored storm events were then compared to the design model results corresponding to the return period event results that came closest to the monitored data's approximated return period. To err on the side of being more conservative, the monitored results were compared to the design event at the low end of the range into which it fell. For example, monitored events that were identified as having a "greater than 2 year but less than 5 year" return period would be compared to the modelled results for the 2-year return period event.

WATER QUALITY AND VOLUME REDUCTION

1.0 EVENT MEAN CONCENTRATIONS

During stormwater events, flow weighted water quality samples were taken at Pond A - Inlet 1 and analyzed. The resultant flow weighted concentrations are referred to as Event Mean Concentrations (EMCs). An EMC is collected for each parameter and sampled event. EMCs provide a more accurate picture of water quality compared to a single grab sample. Multiplying the EMC by the total stormwater volume provides the total load in mass of the parameter of interest and can be used to calculate load reductions.

While EMCs can provide some information on water quality, information on stormwater volume reduction is needed for the full picture of the ability of LID features to provide pollutant load reductions. A feature that has effluent with a low concentration of contaminants, but a large volume of water may be contributing a larger mass of that contaminant compared to a feature that has effluent with a slightly higher concentration but much lower volume.

2.0 VOLUME REDUCTION USING SIMPLE METHOD

Runoff volumes entering the LID systems were not measured directly. Instead they were estimated using the Simple Method (Schueler, 1987) which transforms rainfall depth into flow and volume based on area and impervious cover (NH DEP, 2008). Outflow from the LID treatment train was monitored continuously at Inlet 1 to the pond and reported at 10 -minute intervals.

While the Simple method is intended to be applied to estimate annual runoff volume, in this case it is applied to a smaller time step. There are notable caveats to application of the Simple Method that are well documented such as:

- The Simple Method uses a runoff coefficient to calculate runoff which is entirely based on the impervious cover in the subwatershed. The linear equation used to represent this relationship is a generalized equation and would be expected to have high uncertainty especially in cases where on the ground flow measurements are unavailable for validation.
- The Simple Method is most appropriate for assessing and comparing the relative stormflow pollutant load changes of different land uses and stormwater management scenarios. Because all land surfaces are defined and the land use does not change in the catchments from year to year, this is not an issue.
- The Simple Method provides estimates of storm pollutant export that are likely representative of the "true" but unknown value for a site, catchment, or subwatershed. However, it is important not to over emphasize the precision of the results obtained. We have used data from the region to “tailor” the pollutant concentrations used in this analysis but recognize that this is not the same as measuring influent concentrations. For this reason, we have termed the influent EMCs as “estimates.”

REFERENCES

New Hampshire Department of Environmental Services. (NH DES). 2008. New Hampshire Stormwater Manual. http://des.nh.gov/organization/divisions/water/stormwater/manual.htm.

Schueler, T. 1987. Controlling Urban Runoff: A Practical Manual for Planning and Designing Urban BMPs. Metropolitan Washington Council of Governments. Washington, DC.

SWAMP. n.d. Discussion Document: Fundamental Concepts for Pond Systems. https://sustainabletechnologies.ca/app/uploads/2013/01/Fundamental-Concepts-of-Pond-Systems.pdf

APPENDIX B

Bathymetric Survey

Presented below are results from the bathymetric survey conducted September 2017. Pond Storage estimates are based on survey results by Calder Engineering. See Tables 1 and 2 below for volume summary (to nearest 10 cu.m.).

Table B1: Pond A storage volume summary

Pond A	**Survey**
Stage (m)	**Storage (cu.m)**
254.50	120
254.75	460
255.00	920
255.25	1480
255.50	2100

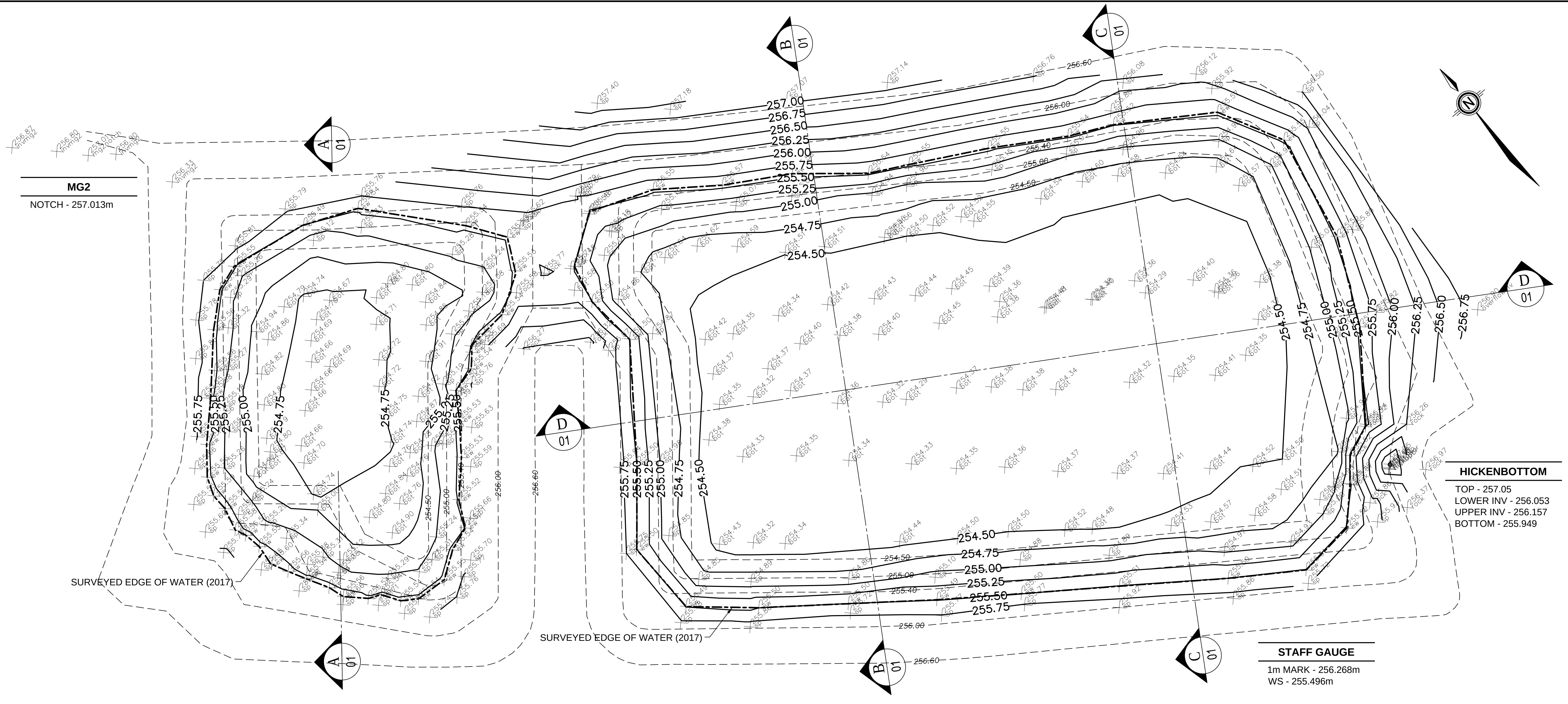
Table B2: Pond B storage volume summary

Pond B	**Survey**
Stage (m)	**Storage (cu.m.)**
243.00	260
243.25	650
243.50	1120
243.75	1650
244.00	2230

Notes from Surveyor:

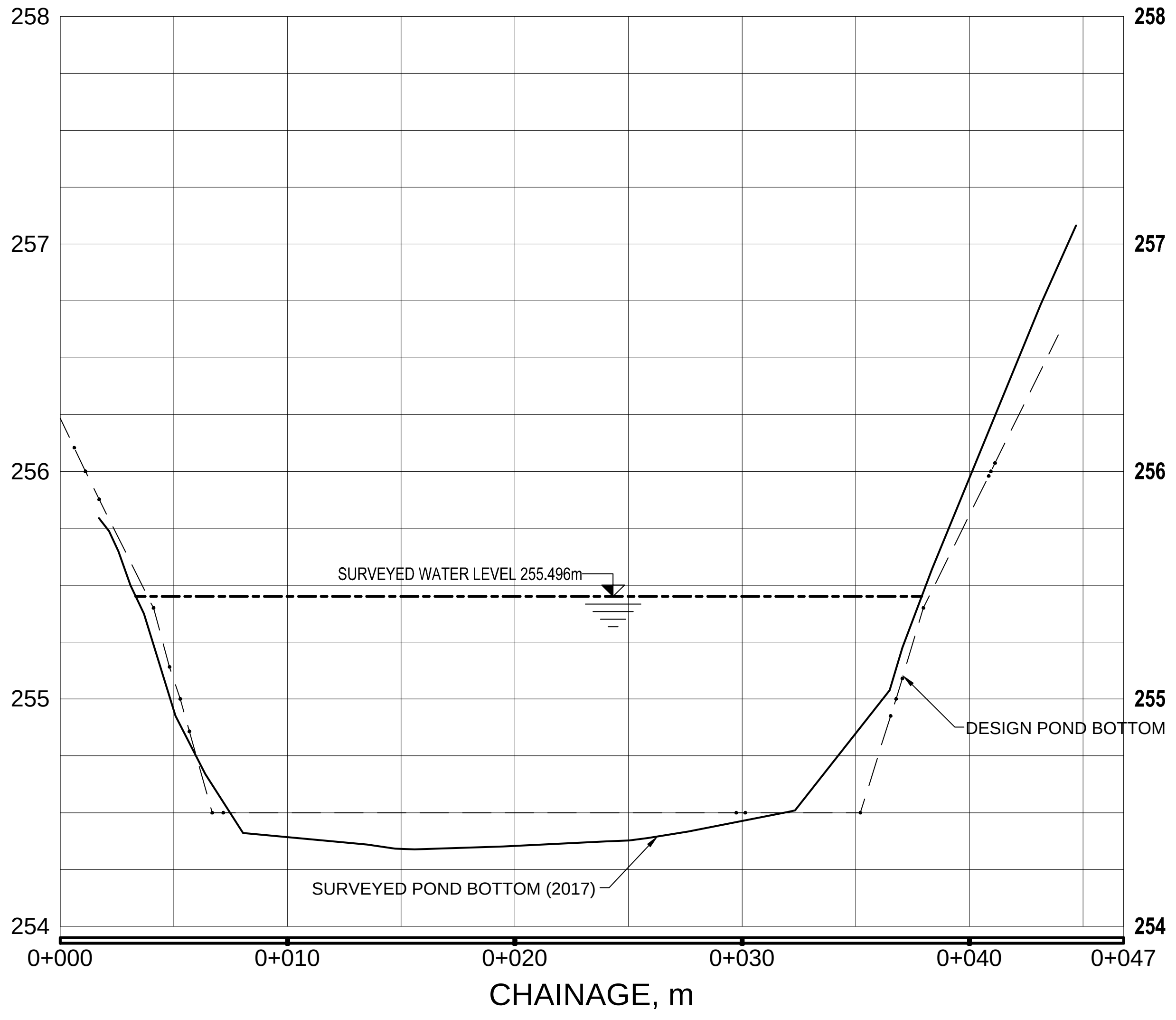
- Pond A: Accumulation primarily in the forebay. The main pond appears to have been over-excavated during construction.
- Pond B: Pond bottom generally at or below the design pond bottom.

See the following page for the detailed survey.

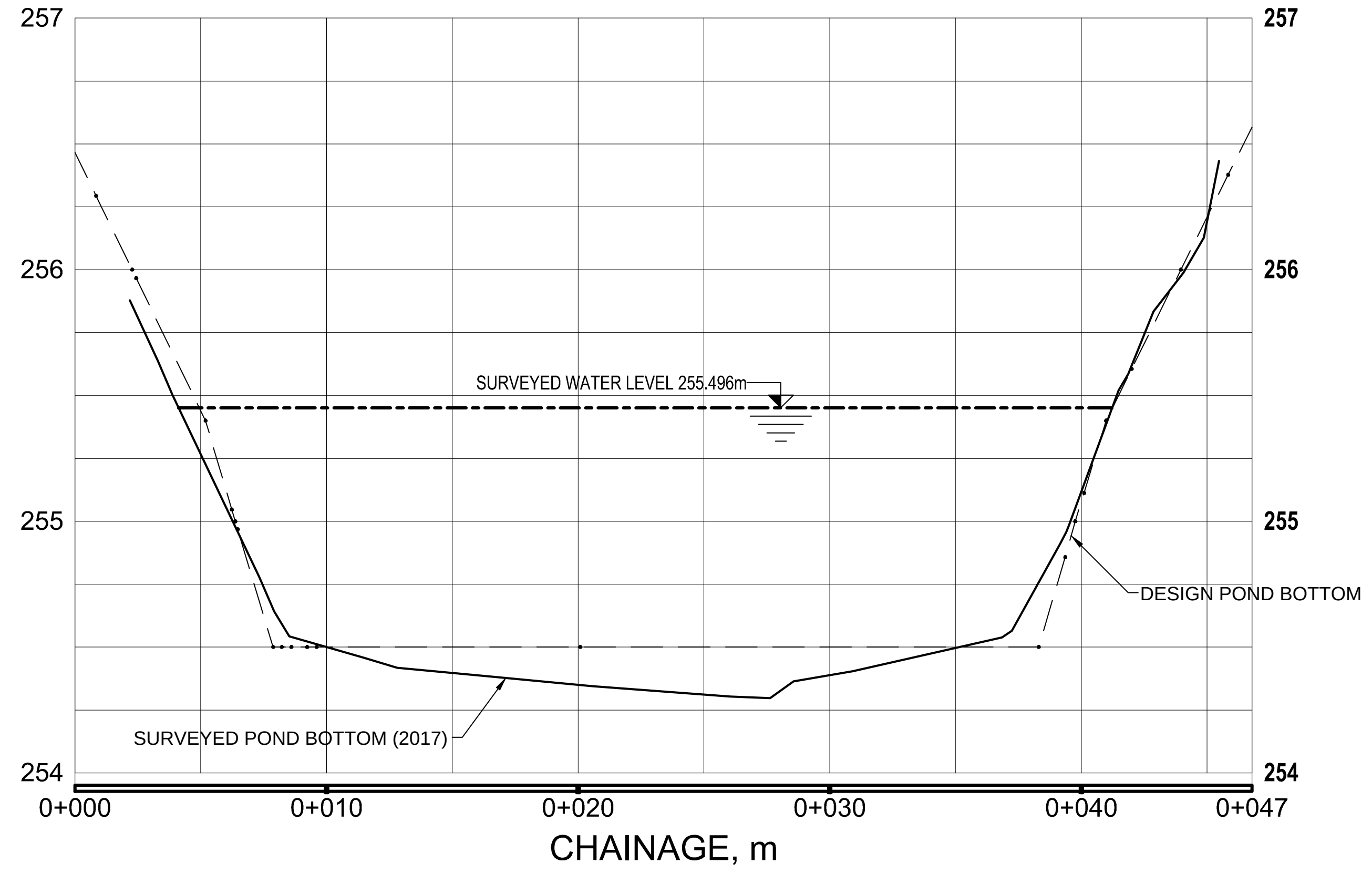


MG1
NOTCH - 257.702m

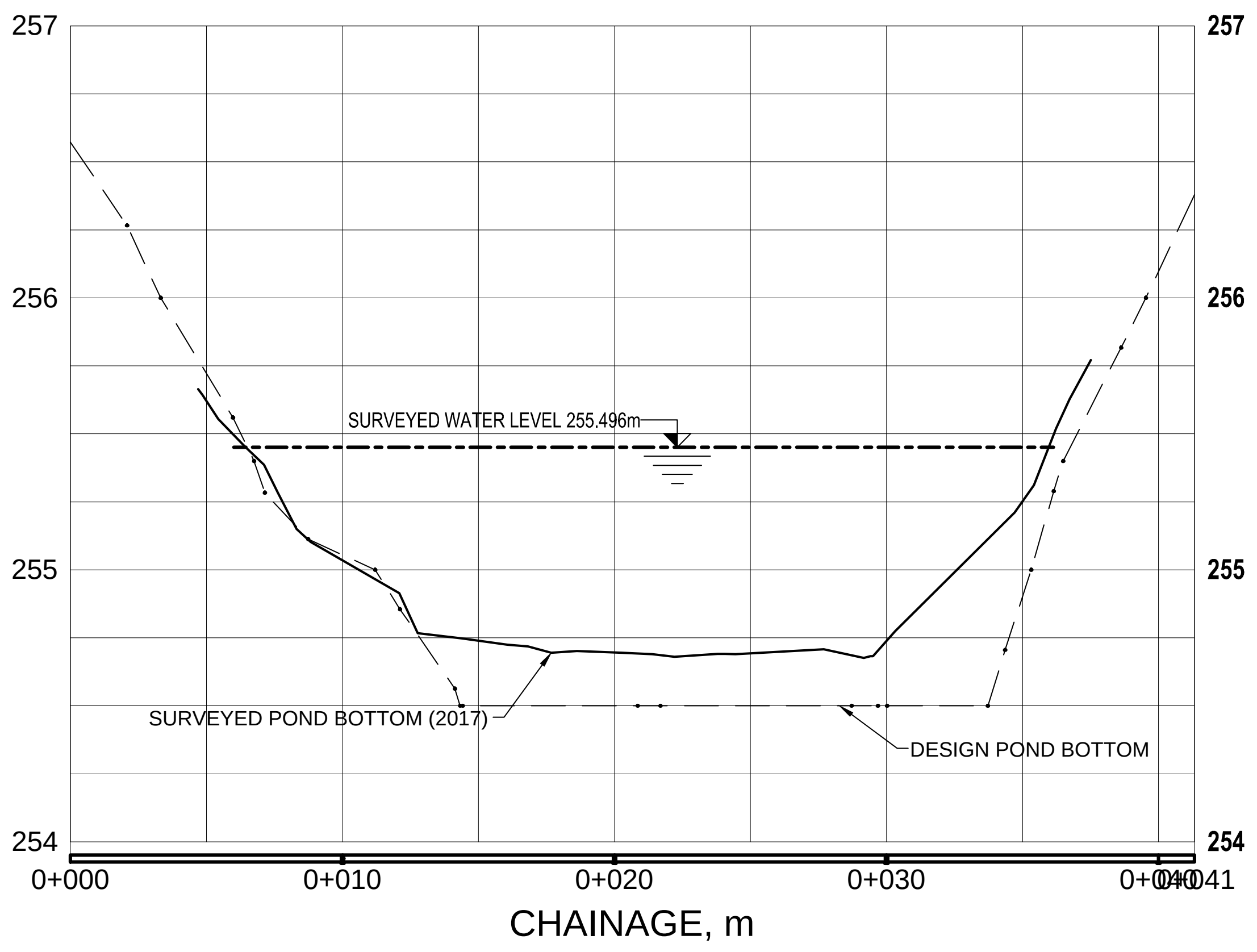
SECTION B-B SCALE H-1:250 V-1:25



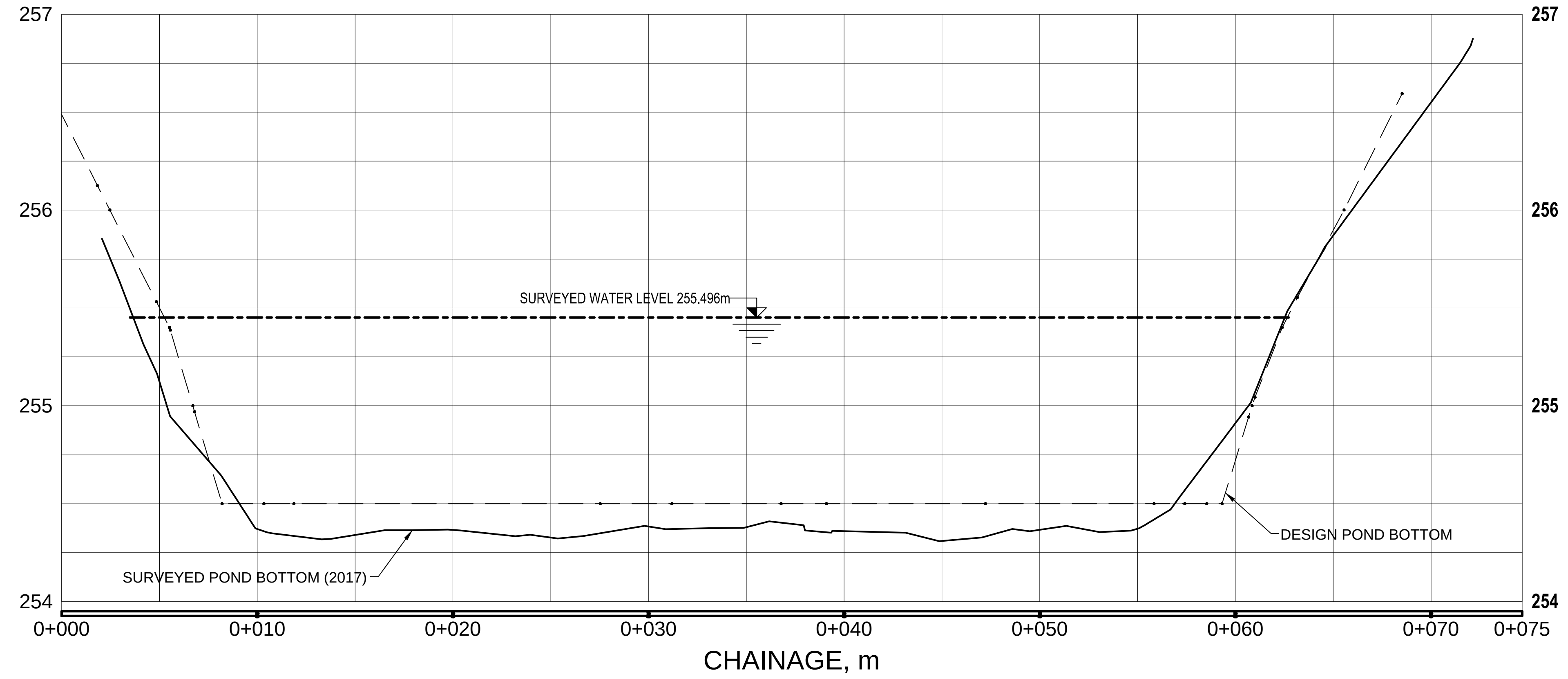
SECTION C-C SCALE H-1:250 V-1:25



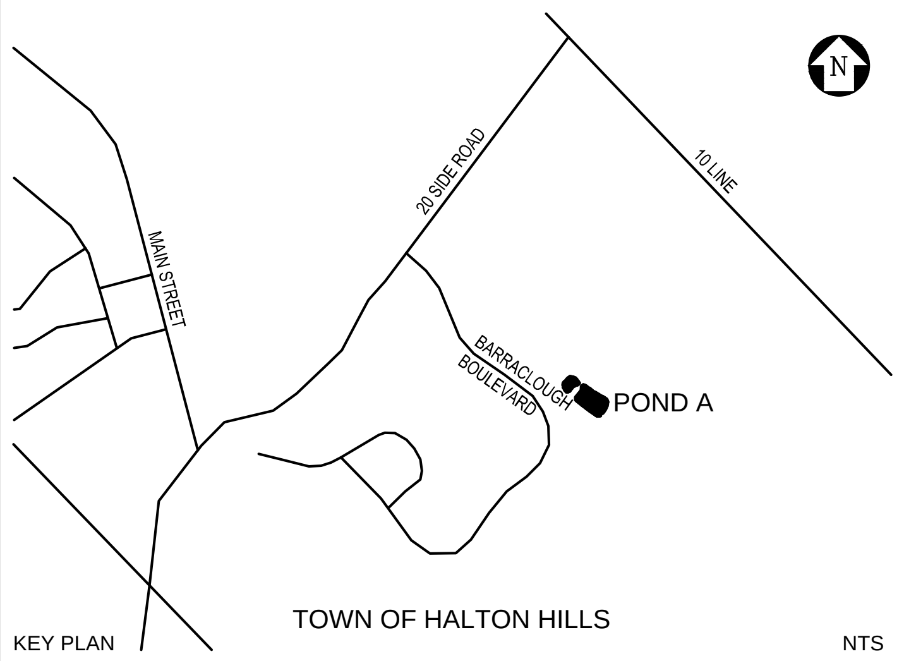
SECTION A-A SCALE H-1:250 V-1:25



SECTION D-D SCALE H-1:250 V-1:25



KEY PLAN



NOTES

1. ALL SURVEY ELEVATIONS ARE IN METERS AND REFERENCED TO GEODETIC DATUM. ALL DIMENSIONS ARE IN METRIC UNITS.
2. SURVEY INFORMATION FROM SURVEYS CONDUCTED BY CALDER ENGINEERING LTD. IN 2017.
3. DESIGN INFORMATION TAKEN FROM DRAWING C-211 (CONTRACT 24T-03001/H) PLAN & PROFILE SWM FACILITY A, REVISION 5 PREPARED BY STANTEC CONSULTING LIMITED AND DATED APRIL 8, 2010.

LEGEND

+326.34	SPOT ELEVATION (2017 SURVEY)
— 326.50 —	CONTOUR - 0.25m INTERVALS (2017 SURVEY)
—‒—‒—‒	EDGE OF WATER (2017 SURVEY)
– – –256.60– – –	DESIGN CONTOUR
—‒—‒—‒	WATER SURFACE (2017 SURVEY)
———	POND SURVEYED BOTTOM (2017 SURVEY)
– – – –	POND DESIGN BOTTOM

PROPOSED VS SURVEY:
FOREBAY:
CUT: 168 cu.m / FILL: 5 cu.m
MAIN POND:
CUT: 75 cu.m / FILL: 182 cu.m

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DESIGNED BY

APPROVED BY

N°	Date	Revisions	Dwn.	Dsg'd.	Chk'd.
②	23/FEB/2018	ADDITION OF POND DESIGN INFORMATION			
①	26/OCT/2017	SEPTEMBER 2017 POND SURVEY	KNC	-	WAD

Client:
CREDIT VALLEY CONSERVATION

Project Name:
MEADOWS POND A

Title Name:
BATHYMETRIC SURVEY

Drawing N°: **17-223-A-01**
Sheet N°: 1 OF 1
Scale: 1:250
Rev. N°: ②

Appendix C:

Developer Survey

Presented below in Table C1 are the asset management survey results from the survey conducted with Intracorp and CVC.

Table C1: Asset management survey results

Survey Questions	Meadows in the Glen Answers
CONTACT	
Survey date	29-Sep-17
	Via the phone
Survey participant	Stefan Rusu Controller and Manager of Finance of Intracorp (Developer)
Surveyor	Nathan McFadden
STATUS (at time of survey)	
Status of project (construction, warranty, assumed)	Not Assumed – still under Intracorp's control (permeable pavement has nearly been accepted – just some minor outstanding issues)
Installation Date (Age of practice)	2014 (3 yrs)
Do you intend to apply for Stormwater Charge credit? (Y/N/not applicable)	N/A – not in Mississauga
Practices present on-site: (Bioretention, Rain Garden, Permeable Paving, Proprietary Device, Rainwater Harvesting)	Bioretention (bioswale and grass swales) Permeable pavement (driveway aprons and walkways) Infiltration galleries (soakaway pits) Two stormwater ponds (Pond A and Pond B)
ACTIVITY	
What is the nature of the maintenance activities? (establishment, routine, repair/upgrade)	Establishment (post-construction, under warranty)
Who is responsible for operation and maintenance? (staff/landscaper/volunteers)	Currently most of the LID features are the responsibility of Intracorp. Intracorp has a crew of 2 people that complete most of the maintenance required. Anything else required is done through outside contractors.
LID practice maintenance tasks: Bioswales/Rain Gardens: visual inspection, trash removal, clear debris from inlets, snow removal at inlets, remove mulch and rake surface, flush underdrain, weeding, watering, top up mulch, mow grass filter strip, cut back perennials, remove plant debris, prune out dead wood/suckers, edge garden bed, other Permeable Paving: inspection, spot vacuum debris, full vacuum, blow debris, sweep debris, weed pavers, snow removal, other Proprietary Device: visual inspection, trash removal, removal of sediment, other	The bioswale and grass swales have/are: inspected, trash removal, clear inlets and outlets of sediment and debris, snow removal at inlets and outlets, remove sediment from surface, flush out underdrain, weed, tidy up or top up mulch and pruning Permeable pavement are : inspected, spot vacuumed debris from pavers, full vacuumed debris from pavers, blow debris from pavers, sweep debris from pavers, weed pavers, and are power washed on an as needed basis
Contributing drainage area maintenance tasks (inspection, sweeping/vacuuming, mowing, leaf blowing/raking, trash removal, snow removal, de-icing, other)	Bioswales and grass swales are: inspected, mowed, and have trash removed Permeable pavement in the contributing drainage area is inspected, swept/vacuumed of sediment and trash removal
Repair/rehabilitation tasks:	Bioswales and grass swales have been repaired or replacement of broken structures (repaired an

Bioswales/Rain Gardens: addition/repair/replace underdrain, repair/replace broken structure, soil amendment, replace soil media, core aeration/deep tilling, repair eroded areas, replace plants, thin plants, add/repair/replace erosion control, regrade, repair/remove sod, repair/replace other items, other Permeable Paving: top up chipstone, replace chipstone, replace uneven or broken pavers, repair/remove sod, replace broken structures, repair/replace other elements, other Proprietary Devices: repair/replace broken structure, repair/replace other items, other	underdrain section), soil amendments, repair eroded areas (2 days ago), replaced trees and shrubs, added repaired or replaced erosion control by adding more rip rap and replacing a filter in Cell 3 of the bioswale, re-grading and contouring. Permeable pavement has had the top up chipstone in paver joints added, replaced chipstone in the paver joints, replaced uneven or broken pavers
Relative ease of maintenance (difficult, moderately difficult, not difficult)	Bioswales and bioretention identified as a 3 but noted that it is getting better Permeable pavement also identified as a 3 and noted that the trades don't like coming in multiple times to complete the same work (pavers keep getting plugged)
COSTS	
Do you track LID maintenance activities and spending separately? (Y/N)	Y – possibly not intentionally but several large LID related repair/maintenance costs were incurred in the previous year
What is the annual expenditure on LID maintenance? ($)	Approximate values of the costs over the past year: $15,000 per year $7,000 on the broken underdrain (lot 54) in the swale (resident had heavy equipment travel over it breaking it) Spent $40,000 as a one-time cost to ensure that the bioretention feature has the proper infiltration rate Permeable pavement costed approximately $50,000 per year during the maintenance period SWM Pond – although not a LID feature the cleanout of Pond A Forebay approximately $75,000 as sediment has accumulated (20 cm above the norm) requiring a cleaning by the Town of Halton Hills -Currently doing a study regarding invasive species in the pond (DNA analysis) cost unknown
What is the frequency of LID maintenance? (weekly, monthly, quarterly, semi-annually, annually, as needed, never, other)	Typically weekly to monthly but really done on an as needed basis.
How much time is spent on maintenance? (hours)	2 people from Intracorp usually 3 days a week. Trades/contractors for specialized work are extra and unaccounted for.
ISSUES	

Any performance issues? Bioswales/Rain Gardens: trampling/compaction, vandalism, trash, weeds, invasive species, pests, grass creep, erosion, sediment, ponding, mulch degradation/migration, other Permeable Paving: vandalism, trash, weeds, grass creep, erosion, sediment, ponding, snow storage, other Proprietary Devices: degradation/breakage, vandalism, trash, excess sediment, clogging, other	Issues for permeable pavement are vandalism, trash, grass creeping in, sediment collecting in the feature Issues for the bioretention are vandalism from kids, trash accumulating, weeds, mulch migration or degradation
Any contributing drainage area issues? (leaves, litter, sediment, salt, snow storage)	Leaves blowing in aren’t such a big issue right now but most of the trees are young so this may change -Biggest issue is litter blowing in from adjacent properties (blue bins with recycling area source of this) covered bins may help
Any issues with ability to maintain practice? (physical access, access to water, difficulty finding qualified crew, lack of maintenance information, limited or no dedicated budget, other)	
Any equipment issues? (specialized equipment needed, unavailable, hard to find)	No – sometimes difficult to find contractors with the right experience (i.e. pond cleanout) also find it difficult to get contractors to respond to them during the summer monts
Any vegetation issues? (dieback, broken limbs, slow growth rate, fast growth rate, unable to compete, other)	
Any appearance issues? (bare patches, unattractive, messy-looking, other)	-Homeowners don’t like all of the features. Homeowners like the appearance of the permeable pavement (that it matches the roadway) -Homeowners do not like the look of the bioswale (some residents have asked the Town of Halton Hills to remove it) -Don’t always like the grass swales
RECOMMENDATIONS	
Any recommendations re: LID maintenance for this practice or others?	
Notes	

APPENDIX D

Additional Monitoring Details

1.0 WATER QUALITY SAMPLING

Water quality samples were collected using ISCO autosamplers. The samplers were triggered based on changes in water level behind the weir (which is also where the sampler intake was located). Samples were composite samples that were flow-weighted based on the flow measured for the event. Water quality samples were retrieved from autosamplers as soon as possible, and left for no more than 48 hours after the end of the event. Due to the prolonged flows observed at the pond outlet, in some cases very long program lengths were required, e.g., 72 hours. Since this would mean the first bottles collected would be left sitting for a prolonged amount of time, when these long programs were used staff would go to site in the middle of the sample program and retrieve sampler bottles that had already been collected and bring them back to the office so they could be kept refrigerated until the program was complete and the composite sample could be collected.

1.1 Equipment Set-up

Autosamplers and ISCO loggers were kept in locked equipment boxes for security and protection from the elements. The ISCO level sensors were installed in the standpipes (Figure D1 and Figure D2) and the pipe was connected to the open swale so levels would be equivalent. The sampler intakes were installed in the same pipe where it opens in the middle of channel. All level and water quality sensors were located behind weirs, with the continuous turbidity sensor located the furthest upstream, to minimize disturbance to it from the sampler intake and accessing the other sensors. Conductivity loggers were installed in a perforated pipe with caps at either end that had holes to allow for flow through. These were attached to bricks to weigh them down and keep them secure during high flow events.

When Hobo loggers were used for winter monitoring, they were installed in the pipes as close as possible to where the ISCO level loggers were installed, this hopefully makes the levels as comparable as possible. Also, the underground part of the pipe provides some insulation against freezing. The Hobo loggers were installed 3 cm below the weir notch elevation so water levels would reach it before flow started but not right at the bottom to minimize risk of freezing during low water times.

Figure D1: Installation of sampler intake in swale, the pipe that can be seen in the bank of the swale leads back to the equipment box.

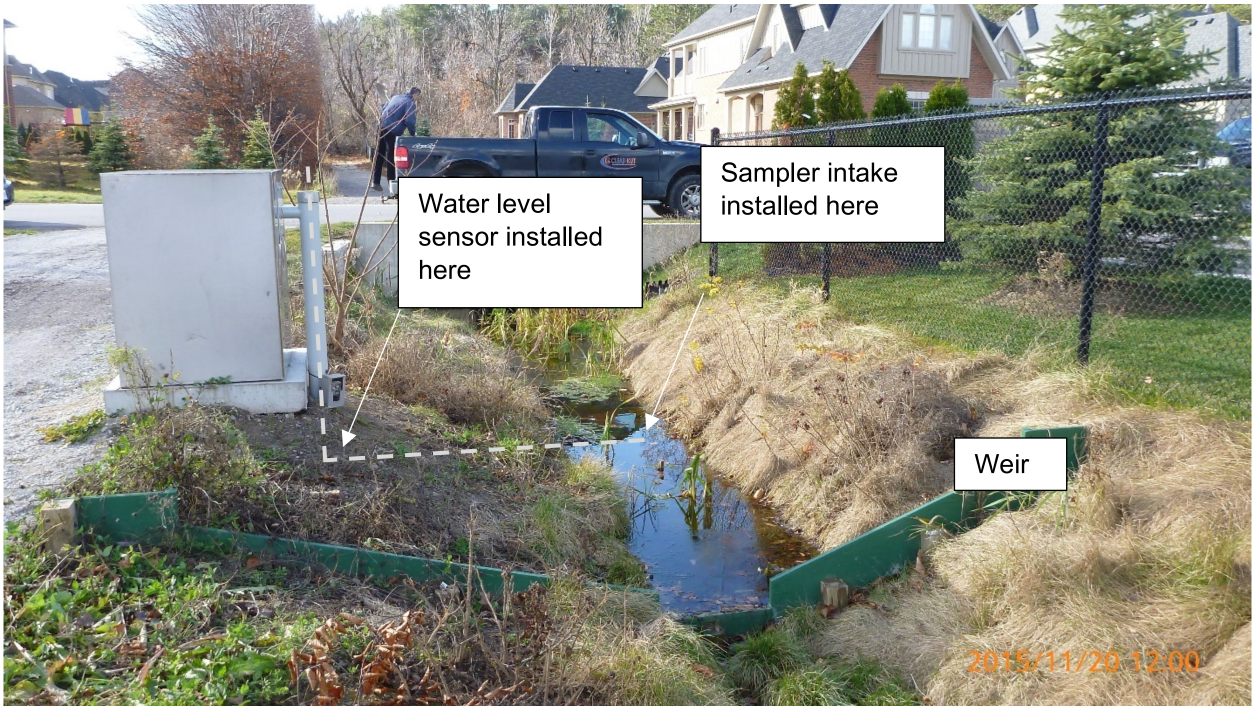

Figure D2: Layout of inlet monitoring station, indicating locations of the weir, and where the water level sensor and sampler intake are installed. Note: that there is an open pipe leading from the swale to the location of the level sensor.

Figure D3: Illustrates port through which the tubing and sensor cables are directed out of the sampler box.

Figure D4: Outlet monitoring station layout.

Conductivity logger installed in short piece of perforated pipe with perforated end caps to allow water to flow through, located in middle of channel

Pipe is secured to a brick to weigh it down and keep it in place

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Figure D5: Shows how conductivity logger is installed in inlet swale.

Figure D6: Shows how pond level measurements were taken. a) Shows ISCO level logger installed in the outlet structure, the cable to the sensor can be seen going into a grey plastic pipe that leads out to the pond. b) Shows the location of the staff gauge, which was used to calibrate the level sensor. The small piece of rebar in the water beside the stage indicates the location that the level sensor was installed within the pond.

Figure D7: Illustrates staff gauge cleaning that was required after 2 years due to algae build up that made the stage unreadable.

Figure D8: Shows how turbidity sensors were installed in the inlet swales. Sensors were installed upstream of other instrumentation (sampler intake/ conductivity sensor) to minimize disturbance. Rebar was used to secure a metal plate, and the sensors attached to the plate using u-bolts to keep the sensors secure during high flow, but to also allow for easy removal for cleaning and maintenance

Figure D9: Turbidity sensors were left in place during the winter to capture melt events. However, the wiper was removed to prevent the motor burning out when it got stuck in ice.

2.0 INSPECTION CHECKLIST

LID Inspection Checklist

Site: MITG
Inspector: ____________________
Date: ________________________

Site Characteristics:

MITG	
Drainage Area	Meadows in the Glen Subdivision
LID Features	Permeable pavement, Bioretention cell and grass swales

BIORETENTION CELL:

Contributing Drainage Area:		**Category:**	**Notes:**
% of Trash/Debris Present	0% --- 5% --- 10% --- 15% --- 20% +		
% of Sediment Accumulation	0% --- 5% --- 10% --- 15% --- 20% +		

Inlets (External):

% of Trash/Debris Present	0% --- 5% --- 10% --- 15% --- 20% +		
% of Sediment Accumulation	0% --- 5% --- 10% --- 15% --- 20% +		
% of Erosion	0% --- 5% --- 10% --- 15% --- 20% +		
Structural damage?	Yes or No		

Inlets (Internal):

% of Trash/Debris Present	0% --- 5% --- 10% --- 15% --- 20% +		
% of Sediment Accumulation	0% --- 5% --- 10% --- 15% --- 20% +		
% of Erosion	0% --- 5% --- 10% --- 15% --- 20% +		
Structural damage?	Yes or No		

Facility:

% of Trash/Debris Present	0% --- 5% --- 10% --- 15% --- 20% +
% of Sediment Accumulation	0% --- 5% --- 10% --- 15% --- 20% +
% of Bare Exposed Soil	0% --- 5% --- 10% --- 15% --- 20% +
% of Erosion	0% --- 5% --- 10% --- 15% --- 20% +
Evidence of Ponding?	Yes or No
Approximate depth of Ponding?	______________________

Vegetation (changes seasonally):

% Vegetation Cover:	0% --- 25% --- 50% --- 75% --- 100%
% Dead Vegetation:	0% --- 5% --- 10% --- 15% --- 20% +
% of Invasives/Weeds	0% --- 5% --- 10% --- 15% --- 20% +

Outlets:

% of Trash/Debris Present	0% --- 5% --- 10% --- 15% --- 20% +
% of Erosion	0% --- 5% --- 10% --- 15% --- 20% +
% of Sediment Accumulation	0% --- 5% --- 10% --- 15% --- 20% +
Structural damage?	Yes or No
Is outlet clear and able to accept overflow?	Yes or No

PERMEABLE PAVEMENT & GRASS SWALES:

A)Permanent Stations (Driveways, Sidewalks & Swales):

1)Barraclough #16

Driveway:	
% vegetation in gaps	0% --- 5% --- 10% --- 15% --- 20% +
Area of broken/cracked/heaving pavers or curbs	0% --- 5% --- 10% --- 15% --- 20% +
% of Sediment Accumulation	0% --- 5% --- 10% --- 15% --- 20% +
Structural damage?	Yes or No
Evidence of Clogging	Yes or No
Sidewalk:	
% vegetation in gaps	0% --- 5% --- 10% --- 15% --- 20% +
Area of broken/cracked/heaving pavers or curbs	0% --- 5% --- 10% --- 15% --- 20% +
% of Sediment Accumulation	0% --- 5% --- 10% --- 15% --- 20% +
Structural damage?	Yes or No
Evidence of Clogging	Yes or No
Swale (Sidewalk Side):	
% of Trash/Debris Present	0% --- 5% --- 10% --- 15% --- 20% +
% of Erosion	0% --- 5% --- 10% --- 15% --- 20% +
% of Sediment Accumulation in swale or culvert	0% --- 5% --- 10% --- 15% --- 20% +
% Dead/damaged sod	0% --- 5% --- 10% --- 15% --- 20% +
Ponded water present?	Yes or No
Structural damage?	Yes or No
Is culvert clear and able to accept flow?	Yes or No
Swale (No-Sidewalk Side):	
% of Trash/Debris Present	0% --- 5% --- 10% --- 15% --- 20% +
% of Erosion	0% --- 5% --- 10% --- 15% --- 20% +

% of Sediment Accumulation in swale or culvert	0% --- 5% --- 10% --- 15% --- 20% +
%Dead/damaged sod	0% --- 5% --- 10% --- 15% --- 20% +
Ponded water present?	Yes or No
Structural damage?	Yes or No
Is culvert clear and able to accept flow?	Yes or No

2) Barraclough #25

Driveway:

% vegetation in gaps	0% --- 5% --- 10% --- 15% --- 20% +
Area of broken/cracked/heaving pavers or curbs	0% --- 5% --- 10% --- 15% --- 20% +
% of Sediment Accumulation	0% --- 5% --- 10% --- 15% --- 20% +
Structural damage?	Yes or No
Evidence of Clogging	Yes or No

Sidewalk:

% vegetation in gaps	0% --- 5% --- 10% --- 15% --- 20% +
Area of broken/cracked/heaving pavers or curbs	0% --- 5% --- 10% --- 15% --- 20% +
% of Sediment Accumulation	0% --- 5% --- 10% --- 15% --- 20% +
Structural damage?	Yes or No
Evidence of Clogging	Yes or No

Swale (Sidewalk Side):

% of Trash/Debris Present	0% --- 5% --- 10% --- 15% --- 20% +
% of Erosion	0% --- 5% --- 10% --- 15% --- 20% +
% of Sediment Accumulation in swale or culvert	0% --- 5% --- 10% --- 15% --- 20% +
% Dead/damaged sod	0% --- 5% --- 10% --- 15% --- 20% +

Ponded water present?	Yes or No
Structural damage?	Yes or No
Is culvert clear and able to accept flow?	Yes or No

Swale (No-Sidewalk Side):

% of Trash/Debris Present	0% --- 5% --- 10% --- 15% --- 20% +
% of Erosion	0% --- 5% --- 10% --- 15% --- 20% +
% of Sediment Accumulation in swale or culvert	0% --- 5% --- 10% --- 15% --- 20% +
%Dead/damaged sod	0% --- 5% --- 10% --- 15% --- 20% +
Ponded water present?	Yes or No
Structural damage?	Yes or No
Is culvert clear and able to accept flow?	Yes or No

3) Barraclough #84

Driveway:

% vegetation in gaps	0% --- 5% --- 10% --- 15% --- 20% +
Area of broken/cracked/heaving pavers or curbs	0% --- 5% --- 10% --- 15% --- 20% +
% of Sediment Accumulation	0% --- 5% --- 10% --- 15% --- 20% +
Structural damage?	Yes or No
Evidence of Clogging	Yes or No

Sidewalk:

% vegetation in gaps	0% --- 5% --- 10% --- 15% --- 20% +
Area of broken/cracked/heaving pavers or curbs	0% --- 5% --- 10% --- 15% --- 20% +
% of Sediment Accumulation	0% --- 5% --- 10% --- 15% --- 20% +
Structural damage?	Yes or No

Evidence of Clogging	Yes or No
Swale (Sidewalk Side):	
% of Trash/Debris Present	0% --- 5% --- 10% --- 15% --- 20% +
% of Erosion	0% --- 5% --- 10% --- 15% --- 20% +
% of Sediment Accumulation in swale or culvert	0% --- 5% --- 10% --- 15% --- 20% +
% Dead/damaged sod	0% --- 5% --- 10% --- 15% --- 20% +
Ponded water present?	Yes or No
Structural damage?	Yes or No
Is culvert clear and able to accept flow?	Yes or No
Swale (No-Sidewalk Side):	
% of Trash/Debris Present	0% --- 5% --- 10% --- 15% --- 20% +
% of Erosion	0% --- 5% --- 10% --- 15% --- 20% +
% of Sediment Accumulation in swale or culvert	0% --- 5% --- 10% --- 15% --- 20% +
%Dead/damaged sod	0% --- 5% --- 10% --- 15% --- 20% +
Ponded water present?	Yes or No
Structural damage?	Yes or No
Is culvert clear and able to accept flow?	Yes or No

B) Rotating Stations: (Driveways, Sidewalks and Swales)

Temporary Address 1: ______________________

Driveway:

% vegetation in gaps	0% --- 5% --- 10% --- 15% --- 20% +

Area of broken/cracked/heaving pavers or curbs	0% --- 5% --- 10% --- 15% --- 20% +
% of Sediment Accumulation	0% --- 5% --- 10% --- 15% --- 20% +
Structural damage?	Yes or No
Evidence of Clogging	Yes or No
Sidewalk:	
% vegetation in gaps	0% --- 5% --- 10% --- 15% --- 20% +
Area of broken/cracked/heaving pavers or curbs	0% --- 5% --- 10% --- 15% --- 20% +
% of Sediment Accumulation	0% --- 5% --- 10% --- 15% --- 20% +
Structural damage?	Yes or No
Evidence of Clogging	Yes or No
Swale (Sidewalk Side):	
% of Trash/Debris Present	0% --- 5% --- 10% --- 15% --- 20% +
% of Erosion	0% --- 5% --- 10% --- 15% --- 20% +
% of Sediment Accumulation in swale or culvert	0% --- 5% --- 10% --- 15% --- 20% +
% Dead/damaged sod	0% --- 5% --- 10% --- 15% --- 20% +
Ponded water present?	Yes or No
Structural damage?	Yes or No
Is culvert clear and able to accept flow?	Yes or No
Swale (No-Sidewalk Side):	
% of Trash/Debris Present	0% --- 5% --- 10% --- 15% --- 20% +
% of Erosion	0% --- 5% --- 10% --- 15% --- 20% +
% of Sediment Accumulation in swale or culvert	0% --- 5% --- 10% --- 15% --- 20% +

%Dead/damaged sod	0% --- 5% --- 10% --- 15% --- 20% +
Ponded water present?	Yes or No
Structural damage?	Yes or No
Is culvert clear and able to accept flow?	Yes or No

Temporary Address 2: ____________

Driveway:

% vegetation in gaps	0% --- 5% --- 10% --- 15% --- 20% +
Area of broken/cracked/heaving pavers or curbs	0% --- 5% --- 10% --- 15% --- 20% +
% of Sediment Accumulation	0% --- 5% --- 10% --- 15% --- 20% +
Structural damage?	Yes or No
Evidence of Clogging	Yes or No

Sidewalk:

% vegetation in gaps	0% --- 5% --- 10% --- 15% --- 20% +
Area of broken/cracked/heaving pavers or curbs	0% --- 5% --- 10% --- 15% --- 20% +
% of Sediment Accumulation	0% --- 5% --- 10% --- 15% --- 20% +
Structural damage?	Yes or No
Evidence of Clogging	Yes or No

Swale (Sidewalk Side):

% of Trash/Debris Present	0% --- 5% --- 10% --- 15% --- 20% +
% of Erosion	0% --- 5% --- 10% --- 15% --- 20% +
% of Sediment Accumulation in swale or culvert	0% --- 5% --- 10% --- 15% --- 20% +
% Dead/damaged sod	0% --- 5% --- 10% --- 15% --- 20% +
Ponded water present?	Yes or No

Structural damage?	Yes or No
Is culvert clear and able to accept flow?	Yes or No

Swale (No-Sidewalk Side):

% of Trash/Debris Present	0% --- 5% --- 10% --- 15% --- 20% +
% of Erosion	0% --- 5% --- 10% --- 15% --- 20% +
% of Sediment Accumulation in swale or culvert	0% --- 5% --- 10% --- 15% --- 20% +
%Dead/damaged sod	0% --- 5% --- 10% --- 15% --- 20% +
Ponded water present?	Yes or No
Structural damage?	Yes or No
Is culvert clear and able to accept flow?	Yes or No

Temporary Address 3: ____________

Driveway:

% vegetation in gaps	0% --- 5% --- 10% --- 15% --- 20% +
Area of broken/cracked/heaving pavers or curbs	0% --- 5% --- 10% --- 15% --- 20% +
% of Sediment Accumulation	0% --- 5% --- 10% --- 15% --- 20% +
Structural damage?	Yes or No
Evidence of Clogging	Yes or No

Sidewalk:

% vegetation in gaps	0% --- 5% --- 10% --- 15% --- 20% +
Area of broken/cracked/heaving pavers or curbs	0% --- 5% --- 10% --- 15% --- 20% +
% of Sediment Accumulation	0% --- 5% --- 10% --- 15% --- 20% +
Structural damage?	Yes or No

Evidence of Clogging	Yes or No
Swale (Sidewalk Side): % of Trash/Debris Present	0% --- 5% --- 10% --- 15% --- 20% +
% of Erosion	0% --- 5% --- 10% --- 15% --- 20% +
% of Sediment Accumulation in swale or culvert	0% --- 5% --- 10% --- 15% --- 20% +
% Dead/damaged sod	0% --- 5% --- 10% --- 15% --- 20% +
Ponded water present?	Yes or No
Structural damage?	Yes or No
Is culvert clear and able to accept flow?	Yes or No
Swale (No-Sidewalk Side): % of Trash/Debris Present	0% --- 5% --- 10% --- 15% --- 20% +
% of Erosion	0% --- 5% --- 10% --- 15% --- 20% +
% of Sediment Accumulation in swale or culvert	0% --- 5% --- 10% --- 15% --- 20% +
%Dead/damaged sod	0% --- 5% --- 10% --- 15% --- 20% +
Ponded water present?	Yes or No
Structural damage?	Yes or No
Is culvert clear and able to accept flow?	Yes or No

C) General Observations (Driveways, Sidewalks and Swales):

Non-LID Feature:

Sign on Site? Yes or No

Damage to Sign? Yes or No

Site Comments: