Credit Valley Conservation

PERFORMANCE ASSESSMENT TEMPLATE FOR EVALUATING INNOVATIVE STORMWATER MANAGEMENT PRACTICES AT IMAX HEAD OFFICE, MISSISSAUGA

CVC
CREDIT VALLEY CONSERVATION

NOTICE

This research is being undertaken collaboratively between the Credit Valley Conservation Authority (CVC) (Project Manager: Phil James, P. Eng, Project Coordinator: Amna Tariq, B. Eng, Monitoring Lead: Saleh Sebti, P. Eng) and the University of Guelph, School of Engineering (Project Leads: Jennifer Drake, PhD candidate and Andrea Bradford, PhD, P.Eng). Christine Zimmer (Department Manager, P. Eng, MSc.) provided project management support. Andrew O' Rourke provided field support. Other CVC staffing support acknowledges Kyle Vander Linden, Robb Lukes, Luke Reed, Chris Despins, and Amanjot Singh.

Additional review support was provided by the Project Partners:

- Imbrium (Regional Manager: Reagan Davidson, Product Manager: Joel Garbon), Unilock (Sales Manager: Dave Laurie, Consultant: Harald Langsdorff),
- Aquafor Beech (Water Resources Engineer: Chris Denich, MSc., EIT, Water Resources Engineer: William Cowlin, B. Eng, EIT),
- IMAX Corporations (Facility and Administration Manager: Nancy Cole),
- Maxxam (Account Manager: Kassandra Roussy) and
- Ontario Centers for Excellence (Business Development Manager: Leanne Gelsthorpe).

Citation: Drake, J., Bradford, A., James, P., Zimmer, C., Sebti, S., Tariq, A. 2012. Development of an Experimental Design Template for Performance Evaluation of Innovative Stormwater Management Practices. Credit Valley Conservation Authority.

1.0 INTRODUCTION

Commercial and industrial land uses are often analogous with expansive impermeable surfaces comprised of rooftops, parking lots, laneways and roads. During rain events these surfaces generate large amounts of runoff which must be collected and managed by costly stormwater infrastructure. Pollutants which accumulate on these surfaces are washed away by runoff and enter downstream ponds, creeks and streams. Poor stormwater management can put the environment, infrastructure and human safety at risk. In Ontario, flooding, a potential outcome of poor stormwater management is "considered to be the most significant natural hazard in terms of death, damage and civil disruption" (MNR, 2011). Other possible negative outcomes include stream erosion, habitat degradation, loss of aquatic diversity, loss of groundwater recharge, increased thermal impacts and reduced water quality. Traditional stormwater management, which has prioritized rapid collection and conveyance of stormwater along with centralized management, can no longer meet the needs of urban communities.

Low Impact Development (LID) is an emerging philosophy, encompassing planning methods and stormwater management technologies, designed to minimize the negative environmental impacts most commonly associated with urban stormwater (CVC and TRCA, 2010). Pre-development or natural conditions and flow paths are emulated with the use of LID systems which treat locally and manage, at source, as much stormwater as possible. LID technologies include green roofs, bioretention, permeable pavements, soakaways, perforated pipe systems, enhanced grass swales, dry swales and rainwater harvesting (CVC and TRCA, 2010). Although the performance of LID systems is supported by a large body of research many LID products have not received widespread use within Ontario. In particular, LIDs have yet to be extensively applied in commercial and industrial land use applications. With emerging technologies, demonstration projects are required to increase awareness, understanding and acceptance.

The parking lot retrofit at the IMAX Headquarters in Mississauga presents the opportunity to demonstrate and study the performance of several LID systems in a commercial/industrial application. The purpose of this report is to present the experimental design and monitoring plan which will be executed by the Credit Valley Conservation Authority (CVC) in partnership with the University of Guelph. The report includes background information for the project as well as a brief review of LID performance monitoring literature. Research objectives, research phasing, data collection and planned analysis methods will be outlined and explained further in this report.

2.0 BACKGROUND / CONTEXT

In 2007 the Credit River Water Management Strategy Update found a direct link between public-well being and the ecosystem health of the Credit River watershed. Existing environmental conditions within the watershed show signs of degradation. The report concluded that current planning and design practices are not adequate if long-term watershed goals are to be met. Urban growth within the watershed can occur only if improvements are made to current planning and design practices by implementing Low Impact Development (LID) including source, conveyance and end of pipe measures for new and existing urban areas. Furthermore, climate change is expected to exacerbate the impact of urbanization by increasing the risk of flooding, reducing groundwater recharge and base flows, increasing erosion, and decreasing water quality.

To date, despite the MOE (1991 and 2003) Stormwater Management Guidelines and watershed studies such as the CRWMSU, which recommend the adoption of LID for new development and retrofitting existing urban areas, LID has not been widely adopted in Ontario. This is mainly due to perceived barriers such as:

- Lack of performance data for LIDs applied in various land use sectors and soil types (i.e. a bioretention system may perform differently in a residential setting, where runoff from rooftops and smaller drainage areas would typically be treated, versus a public lands setting (e.g. school) where runoff from parking lots and larger drainage areas may need to be managed)

- Lack of sustainable municipal funding mechanisms for retrofitting existing urban areas and long-term maintenance of SWM practices

- Municipal design standards which do not accommodate LID and a lack of funding, training and resources to update municipal standards

- Lack of integration between disciplines from early in the planning process results in missed opportunities for LID

- Lack of awareness of LID by plan review staff, development community, consulting engineers, planners, contractors, maintenance staff, and landscape professionals

- Perceived uncertainties and risk associated with source controls on private property (e.g. will controls be maintained? what regulations and policies are needed to ensure that private landowners maintain them? will additional staff be needed to enforce maintenance? how will MOE’s Certificate of Approval be enforced?)

- Despite information from the USA and Australia, municipalities and designers are reluctant to implement LID as there is a general lack of knowledge regarding the performance of LIDs in Ontario's climate and areas with low permeability soils.

Currently, integrated water management in Ontario, which includes LID techniques and broader water conservation efforts, faces numerous challenges associated with implementation including:

- Public consultation/community outreach;
- Project site selection;
- By-law and policy considerations;
- Incentive creation;
- Testing and Information requirements;
- Design;
- Approvals;
- Specifications and tender preparation;
- Physical construction;
- Construction supervision and administration requirements;
- Construction phasing;
- Capital cost and Operation & Maintenance requirements/estimates;
- Monitoring requirements; and
- Performance assessment issues.

Based on discussion with various Ontario municipalities, the numerous challenges listed above are restricting broader implementation, with only a handful of physical pilot sites to represent a decade of effort by CVC and others. With the lack of guidance and functional example projects to build capacity and reduce uncertainties, there continues to be underperformance with respect to LID implementation and under-realization of the broader goals and targets of watershed planning.

To address these implementation barriers in Ontario, CVC has partnered with over 40 private and public sector organizations to implement more than 10 LID demonstration sites. The IMAX Research project will showcase and evaluate the as-built performance of several LID systems. The project involves partnerships between CVC, the University of Guelph and industry. New LID designs that enhance benefits to stormwater and adapt LID practices to a broader range of urban conditions will be tested, providing valuable information for LID manufacturers and designers operating within Ontario.

The LIDs that will be evaluated and monitored in this study include:

- **Bioretention cells:** a stormwater management technique that uses the chemical, biological, and physical properties of plants and soils to treat stormwater runoff. They are designed to mimic natural conditions promoting infiltration, retention and the slow release of stormwater runoff.

- **SorbtiveMedia**: an oxide-coated, high surface area reactive engineered media that sorbs and retains large phosphorus loads.
- **Jellyfish Filter**: a pretreatment and membrane filtration technology in a compact stand-alone treatment system that is capable of removing a high proportion and wide variety of stormwater pollutants.
- **Eco-Optiloc:** an alternative paving system, which allows stormwater to drain through the surface and into a stone reservoir where it can be temporarily detained and infiltrated into the underlying native soil.

3.0 LITERATURE REVIEW OF LID PERFORMANCE MONITORING

The following sections provide a brief summary and overview of key in-situ monitoring studies of LID technologies. The purpose of this literature review is to summarize the current and past experimental approaches of field-based monitoring and evaluation programs. The literature review is structured under the following topics: research approaches and objectives, data collection methods, analysis techniques and in-practice challenges.

3.1 RESEARCH APPROACHES AND OBJECTIVES

Monitoring projects of full-sized, in-use LID systems allow researchers to observe and evaluate the performance and behaviour of LIDs. In addition to research objectives, full-sized LID projects create benefits for the communities in which they are constructed. These projects provide opportunities to develop and expand the technical knowledge and execution experience of the local industries involved in the planning, design, construction and implementation of the LID system. The infrastructure created as a part of the research project can be used for demonstration and educational purposes by the local community both, during, and beyond active data collection and monitoring. And lastly, full-sized functional LID systems provide management and treatment of stormwater from the contributing catchment areas. Examples of multi-purpose education, demonstration and research facilities include LID systems built at the Kortright Centre for Conservation (Vaughan, Ontario), the University of New Hampshire Stormwater Centre (Durham, New Hampshire), and the EPA Edison Environmental Centre (Edison, New Jersey).

The most common research objective of a monitoring program is evaluation and verification of the environmental benefits of an as-built LID system. The benefits of an LID system are categorized in terms of effects on stormwater quantity and quality. The impact of a permeable pavement or bioretention system is assessed in relation to runoff from traditional asphalt-to-catchbasin lots. To date, the majority of research has been conducted at a lot-level scale but there have been a few studies (e.g. James and Dymond, 2012; Chapman and Horner, 2011) which have addressed cumulative effects of LIDs at a catchment scale. Hydrologic effects of LIDs are discussed in terms of stormwater flow paths (i.e. infiltration to soils, drainage via underdrains, evapotranspiration and overflow) and flow characteristics (i.e. volume, rate, duration and frequency). Water quality effects of LIDs are evaluated in terms of pollutant concentration and mass loading. Pollutants which are frequently monitored include suspended solids, metals, nutrients, polyaromatic hydrocarbons (PAH), bacteria and pathogens, as well as, general chemistry parameters such as pH, alkalinity, conductivity and temperature. Research has focused on newly built LIDs and true long-term behaviour (i.e. > 2 years) has rarely been evaluated.

Several monitoring studies have evaluated the performance of different LID designs. Side-by-side testing of LIDs subjected to the same inputs and conditions allows for direct comparisons between different designs and technologies. For example, testing of different bioretention media, performed in mesocosms, has demonstrated that nutrient removal can be improved through the use of soil amendments (Randall, 2011; Kim et al., 2003). Side-by-side testing of different permeable pavements has highlighted the trade-offs and advantages of different aggregate materials and paving surfaces (Drake et al., 2012; Collins et al., 2008; Brattebo and Booth, 2003; Booth and Leavitt, 1999). Side-by-side monitoring of bioretention cells and permeable pavements has demonstrated the unique attributes of each technology (TRCA, 2008; Roseen et al., 2009) as well as the advantages of in-series design which create a treatment train (Rushton, 2001). The integration of proprietary products such as oil-and-grit separators for pre-treatment has not been extensively monitored.

In recent years, maintenance and operational practices have received increased attention in the literature. Maintenance techniques on permeable pavements have been tested in Canada by Drake and Bradford (2012), Henderson and Tighe (2011) and van Duin (2008) but consensus regarding best practices has yet to be achieved. Questions regarding the required frequency of maintenance, most effective type (i.e. pressure washing vs. vacuuming) and overall impact of maintenance remain unanswered. Maintenance practices for bioretention systems have received less attention even though it is critical for ensuring long-term benefits and functionality. For example, Brown and Hunt (2012) reported that restorative maintenance on monitored bioretention cells decreased the volume of overflow/bypass stormwater by over two-thirds. Additionally, construction practices have been almost entirely overlooked in the literature. Excavation techniques and compaction induced by construction activities has a permanent influence on long-term behaviour of an infiltration system. Brown and Hunt (2010) recommended the ‘rake’ method over the ‘scoop’ method for extraction during bioretention construction because underlying soils maintain a high hydraulic conductivity. Optimizing of construction practices will maximize the benefits of new LID systems and increase their effective lifespan.

Much of the current field-based LID literature has aimed to demonstrate the capacity of LID technologies to meet quantity and quality objectives within the context of local or regional climatic and geologic conditions. The performance of infiltration systems (e.g. permeable pavements and bioretention) is regulated by inputs, such as pollutant loadings and precipitation characteristics, as well as boundary conditions, such as soil permeability. LID systems have been shown to improve stormwater quality during winter conditions. Metal removal rates of bioretention mesocosms studied by Denich (2008) were unaffected by 15-year equivalent loading of synthetic winter runoff containing road salt. Full-sized bioretention systems and porous asphalt studied by Roseen et al. (2009) had over 94% removal efficiency for TSS and total Zn during winter. Similar removal efficiencies have also been observed in permeable pavements located in Ontario (Drake et al., 2012). However, despite these promising results, long-term winter performance of LIDs remains untested and their potential effect on winter stormwater flows has not been extensively examined.

The use of LIDs in areas with low permeability soils is a topic of interest. Hydraulic conductivity is a challenging parameter to accurately estimate and heterogeneous features such as fractures and localized deposits of coarse material can substantially increase infiltration (Tyner et al., 2009). In some instances (e.g. Fassman and Blackbourn, 2010; Dreelin et al. 2006) this has led to higher than anticipated volume reductions from LID systems. The placement and sizing of underdrains in LIDs draining to low permeability soils regulates the contact time of stormwater with LID media and the time allowed for infiltration and evaporation. Increasing detention time has been shown to decrease the volume of outflow produced by underdrained permeable pavements (Drake et al., 2012). Brown and Hunt (2011b) observed that longer hydraulic retention of stormwater within bioretention media decreased nutrient concentrations in stormwater outflow. These results have suggested that optimizing drainage design can maximize the quantity and quality benefits of LID systems.

3.2 DATA COLLECTION METHODS

In order to evaluate the performance of LID systems researchers monitor climatic (precipitation, temperature etc.) and hydrologic (inflow/run-on, water level/moisture, and outflow) parameters, and collect water samples for water quality analysis. In most studies, the monitoring period ranges from a few months (e.g. Brattebo and Booth, 2003) to three years (e.g. Davis, 2008). In this section only the most commonly used methods are discussed, for a complete review of data collection methods refer to the

Urban Stormwater BMP Performance Monitoring Manual (Geosyntec Consultants and Wright Water Engineers Inc., 2009).

3.2.1 **CLIMATIC**

Input parameters are measured using rain gages or tipping buckets located near, or preferably at, the monitored LID. Additional climatic parameters such as air temperature, wind speed, relative humidity are also frequently recorded. Evapotranspiration is rarely included in monitoring programs due to the expense and complexity associated with measurement. There is no systematic approach for measuring parameters related to snow (accumulation, removal, melt) in cold climates. Snow removal activities affect the volume of snow storage and road salting affects the release of melt water.

3.2.2 **WATER QUANTITY**

Typically, hydrologic parameters are monitored continuously. When an LID system has isolated points of inflow, such as a bioretention system with curb cuts, inputs to the system can be directly monitored and sampled. However, many LIDs, such as permeable pavements, have distributed inputs. Using a reference or control system, such as asphalt-to-catchbasin catchment, changes in outflow characteristics and water quality can be evaluated even in the absence of direct input measurements. It is advantageous to monitor groundwater levels in studies where there is a risk of seasonally high groundwater levels influencing the LID performance (Chopra et al., 2010; Line and Hunt, 2009; Collins et al., 2008).

Underdrains or collection pipes serve as access points and outflow from these pipes is measured using stage-based or volume-based methods. Stage-based methods employ weirs or flumes equipped with water level loggers to monitor outflow. For the volume-based approach tipping buckets directly measure the volume of outflow. Each method has its own advantages and limitations. Volume-based measurements are recommended for low flows but require additional physical depth at the outlet for equipment. Weirs and flumes can be installed easily at outlets as shown in Figure 1, but may have large errors during low or unsteady flows (Geosyntec Consultants and Wright Water Engineers, 2009). V-notch weirs are a good choice to minimize errors associated with low flow measurements. Changes in storage within an LID system are monitored using wells and water level loggers. To evaluate surface permeability infiltration measurements can be collected following the ASTM 3385 test for soil media and the ASTM C1701 test for permeable pavements.

Figure 1: Flow monitoring set-up

3.2.3 WATER QUALITY

Monitoring studies address broad-based, as well as specific, research questions related to water quality. Some projects have evaluated a complete range of pollutants including solids, metals, nutrients, PAHs, bacteria, pathogens etc. (e.g. Drake et al., 2012) whereas other have focused exclusively on a single pollutant category such as nutrients (e.g. Collins et al., 2010). Some of the most regularly reported water quality parameters include: total suspended sediments, copper, cadmium, zinc, lead, nitrogen species, phosphorus species, pH and temperature. Water quality samples have been almost exclusively collected as composite flow-weighted samples through the use of automatic samplers as shown in Figure 2 below. For fast draining LID systems outflow from collection pipes may occur only on rare occasions and the use of grab samples may be required to compile water quality data (Brown and Hunt, 2011). Temperature is one water quality parameter which is continuously measured during monitoring studies by placing temperature loggers at inlet and outlet locations (Jones and Hunt, 2009).

Figure 2: Water quality sampling

3.3 ANALYSIS TECHNIQUES

Analysis of in-use LID systems is challenging and analytical approaches vary depending on the objectives of researchers. In this section only key analysis tools are presented. For further information on analysis techniques refer to the *Urban Stormwater BMP Performance Monitoring Manual* (Geosyntec Consultants and Wright Water Engineers, 2009) and Burton and Pitt (2001) *Stormwater Effects Handbook: A Toolbox for Watershed Managers, Scientists, and Engineers*.

The hydrologic effects of an LID system are assessed in terms of changes to outflow volume, peak flow rate, timing and frequency. Individual events are defined based on outflow from studied LIDs and thus may contain multiple discrete precipitation events. The three most widely used methods to evaluate volume reduction for individual storm events include:

- Presence/Absence of discharge
- Relative volume reduction ([In – Out]/In)
- Discharge volume per area

For LIDs with distributed inflow, volume reductions may be calculated in reference to a control lot. Negative volume reductions (i.e. increases in volume) have been reported in some studies of permeable pavements (Drake et al., 2012; Abbott and Comino-Mateos, 2003) for isolated events. These have been attributed to delayed release of stormwater from past precipitation events. An alternative yet similar approach is to discuss volume reductions in terms of the ratio of outflow to inflow (e.g. Davis, 2008). In addition to event-based metrics, volume reductions may be computed for other relevant durations such as weekly, monthly, or yearly. Relative peak flow reductions can be similarly calculated. Changes to the timing of outflow can be evaluated using the ratio of the outflow hydrograph centroid to the inflow (or reference catchment) hydrograph centroid. Discussions of hydrologic performance should be prefaced with analysis of precipitation data and critical evaluation of the climatic conditions experienced during data collection, as exceptional or irregular conditions will influence the hydrologic results.

The impact of an LID system on stormwater quality is evaluated in terms of concentration and pollutant mass. Event mean concentration (EMC) is one of the most widely used parameters for water quality analysis. When combined with outflow data, event-based pollutant loads can be computed. Pollutant removal efficiencies (RE) are computed using the ratio of EMC outflow to EMC inflow (or reference lot). Removal efficiencies are dependent on inflow water quality and thus low removal efficiencies do not necessarily imply poor performance. Residual pollutant concentrations as well as pollutant exceedance frequencies for relevant water quality guidelines, such as the

Provincial Water Quality Objectives, provide insight and context for observed water quality performance.

The variability associated with stormwater data is high and consequently statistical analysis is often not possible until numerous events have been monitored. Descriptive statistics including mean, median, standard deviation and variation, skewness, kurtosis and coefficient of variation provide relevant information. Using these statistics researchers can evaluate the sample size required for representative data sets as well as the distribution of the data. Stormwater quality data tends to follow a lognormal distribution (EPA, 1983) however, because of the Central Limit Theorem, computed data such as reductions and efficiencies are likely to be normally-distributed, especially if the data set is large. When pollutant concentrations are below maximum detection limits analysis methods must account for censored data. Simple substitution is not recommended if the number of non-detects exceeds 10% of the total data set (Geosyntec Consultants and Wright Water Engineers, 2009). Regression on Order Statistics (ROS) may be used for censored data up to a 50% level of censoring (Geosyntec Consultants and Wright Water Engineers, 2009).

Hypothesis tests are generally performed for a 95% confidence level ($\alpha = 0.05$). Researchers frequently use paired t-tests to evaluate statistically significant differences in dependent, normally-distributed data (e.g. Luell et al., 2011). Paired-tests are well suited for side-by-side studies where studied LIDs are subjected to the same climatic and geologic conditions. Comparison tests which assume independent data, such as ANOVA, can be used to evaluate performance differences between separate LID installations and explore seasonal behaviour (e.g. Hunt et al., 2006). Graphics including box-and-whisker plots (e.g. Hatt et al., 2010), and probability-plots (e.g. Davis, 2008) are used as tools for identifying differences in performance.

Time series analysis is not widely used but is relevant to monitoring studies. If substantial changes in surface permeability occur during data collection, hydrologic data may not follow a standard distribution and non-parametric analysis may be required. For example, Collins et al. (2008) used non-parametric analysis for surface runoff data which could not be transformed. In cold climates, the performance of LID systems may be seasonally-dependent and time-series analysis may reveal annual cyclic trends.

3.4 IN-PRACTICE CHALLENGES

One of the most challenging components of field-based research is ensuring that new LID systems function according to design specifications. Best management practices during construction are still evolving and often unforeseen outcomes result from construction. For instance, investigations of 43 bioretention cells in North Carolina revealed that 22% of the cells exhibited signs of prolonged saturation (i.e. ponding water), 53% of cells required maintenance, 75% of cells contained media which did not meet design specifications and 53% were deemed to be moderately to severely undersized (Wardynski and Hunt, 2012).

The recent experiences of researchers at the University of New Hampshire (Line et al., 2012; Brown and Hunt, 2011a; Brown and Hunt, 2012) exemplify the challenges of monitoring LID systems and the effects poor construction can have on results. Three LID systems at a commercial/industrial site monitored by Line et al. (2012) did not function as per design. Bioretention cells were found to be clogged by granite fines associated with the gravel material used for base layers in the adjacent parking lot that had washed into the bioretention cell during construction. The geotextile fabrics used to protect bioretention media had openings which were larger than these fines (Brown and Hunt, 2011a). The bioretention system had been designed to infiltrate rainfall events up to 2.5 cm in depth but as a result of the construction error, overflow was generated by rainfall events as small 0.9 cm. Constructed wetlands, at the same site were built without a 3.8 cm drawdown orifice which was specified in design drawing and, consequently, behaved hydraulically as a wet detention basin (Line et al., 2012). Finally, the seasonally high groundwater table was underestimated and, as a result, groundwater entered underdrains throughout the monitoring period.

Construction of collection and control systems must also be closely monitored for research purposes. After construction of the Kortright permeable pavement parking lot, runoff from control pavement was found to be infiltrating into native soils as a result of an unsealed connection between a catchbasin and a conveyance pipe (Drake et al., 2012). Losses were so substantial that monitored outflow from permeable pavement plots was larger than runoff flows from the asphalt. Researchers were successful in retrofitting the catchbasin to seal the connection with the collection pipe. Without this retrofit the hydrologic performance of the permeable pavements would have been misrepresented by the erroneous runoff data.

Analyzing data and interpreting results for field-based LID research is challenging. Although guidance documents for statistical analyses are available, most studies do not provide any explanation of their analysis methodology. Statistical results are often reported without any discussion of the sample size or data variability. For example, Bean et al. (2007) evaluated the differences in pollutant concentrations from permeable pavement outflow and asphalt runoff and reported the surprising result that TSS concentrations were not significantly altered. However, the results were based on only 6 to 14 water quality samples. Without a discussion of the variability of the water quality data, it is unclear if insignificant results, such as the TSS finding, are truly relevant or simply a result of the limited sample size.

In field studies, researchers cannot control many of the conditions. Performance data is influenced by these conditions and its analysis should be supported by descriptions of field conditions. To provide context, researchers often report the range of rainfall events monitored during a study either in terms of rainfall intensity or return period. In some cases, extreme events, such as tropical storms occur during the monitoring period. These events are analyzed separately (Bean et al., 2007; Collins et al., 2008) or omitted (Bean et al., 2007) as LID systems may not have been designed to manage large events. At the other extreme, drought conditions can limit the amount of data collected during monitoring and the impact of dry conditions on results should be discussed (Dreelin et al., 2006). Regardless of the conditions experienced during monitoring, valuable performance data can be produced but should be presented and interpreted in the context of field conditions.

4.0 OBJECTIVES

The research project will directly address several knowledge gaps which are impeding a wider use of LID technologies within Ontario. The IMAX parking lot provides the unique opportunity to construct and monitor multiple LID systems for a commercial/industrial application as well as demonstrate the use of LID for retrofit projects. The objectives of this research are to:

1. Apply and demonstrate LID systems within an urban community in the GTA.
2. Evaluate the behaviour of LID technologies as individual and collective systems relative to a traditional asphalt-to-catchbasin system;
3. Assess designs of permeable pavement systems to meet multiple environmental and non-environmental objectives;
4. Evaluate the potential of in-series LID systems (Jellyfish to Bioretention and Bioretention to SorbtiveMedia) to maximize water quality improvements;
5. Investigate long-term performance of LID systems and the implications to receiving surface and groundwater systems;
6. Monitor and assess the operational and maintenance needs of LID systems and the subsequent effects on performance;
7. Refine and customize guidelines for LIDs (design, construction and O&M) to suit various Ontario conditions (e.g. high groundwater sensitivity, commercial/industrial land use, low permeability soils, cold weather climate, etc.).

These overarching objectives will be used to answer specific and practical questions about the performance and operation of LID systems within the CVC watershed and Southern Ontario. Questions which may be explored include but are not limited to:

Hydrologic Questions

- What are the volume, timing and rate of outflows from the LID systems and asphalt? How do they compare?
- What conditions (i.e. rain events) produce no outflow? In other words, what magnitude storm is fully retained?
- What conditions (i.e. rain events) cause overflow/bypass?
- What are the event-based peak flow reductions, volume reductions and lag coefficients?
- What are the overall hydrologic performance statistics for the monitored events (e.g. annual volume reduction, average peak flow reduction, etc.)

Water Quality Questions

- What are the differences in water quality between LID system outflow and asphalt runoff in terms of TSS, nutrients, heavy metals and temperature?
- What are the event-based removal efficiencies and pollutant loadings?
- What is the longer-term water quality performance (e.g. annual TSS removal)?

Design Questions

- Could the LID features used at the site reduce the size of pond required downstream if applied in a new development?
- What are the differences in performance between aggregate “O” and 20 mm clear stone as a base layer for permeable pavement?
- Do secondary systems (i.e. Jellyfish and SorbtiveMedia) used with bioretention improve stormwater quality?
- Can increasing drawdown time (e.g. by adding a moveable 90^{o} elbow at the outlet of permeable pavement systems) increase the environmental benefits of LID systems?

Operation and Maintenance Questions

- Can maintenance activities be linked to overall performance?
- What performance thresholds may be appropriate triggers for maintenance activities?
- Does regular O&M (such as removal of trash, surface sweeping (twice a year); inlet structure clean out (monthly); pruning, weeding, mulching, watering, fertilizing):
    - Enhance plant survival?
    - Reduce maintenance costs?
    - Increased life expectancy of parking lot?

- What is the required frequency of other O&M activities? (e.g. media replacement, sediment removal)
- What are the life cycle costs for these LID practices (i.e. permeable pavement, bioretention cells, JellyFish Unit and the SorbtiveMedia Unit)

Long-term Questions

- How do LID systems perform over the long-term?
- Are environmental benefits sustained over the long-term?
- What are the seasonal effects on hydrologic behaviour and stormwater quality?
- What performance measures may be appropriate to determine potential rebates on development charges, credits on municipal stormwater rates and/or reductions in flood insurance premiums?

The seven overarching objectives for this study were selected to meet the interests of the Conservation Authority as well as the interests of industrial and academic partners. Other agencies that were consulted in the development of these objectives include municipalities, Ministry of the Environment (MOE), Building Industry and Land Development Association (BILD), CTC Source Protection Region as well as developers. It is CVC's goal to foster awareness and understanding of innovative stormwater management practices and the IMAX parking lot is intended as a demonstration site of LIDs for industrial/commercial applications (*Objective 1*). Local performance data is needed so that the impacts of LID on stormwater flows and quality within the Credit River watershed can be better understood. Performance of full-sized LID systems has not been widely studied and some of the LID designs in this project have never been tested in field installations (*Objective 2*). Monitoring studies have tended to be limited to individual installations of a single LID technology but integrated designs, like IMAX, frequently use several LID systems on a single lot. Evaluating the performance of LIDs as a collective system as well as individual systems relative to a traditional asphalt-to-catchbasin system will help inform designers and watershed managers of the environmental benefits of these technologies when used together (*Objective 2*).

Currently, the use of LID systems within Southern Ontario is restricted by real and perceived obstacles. One barrier which limits the use permeable pavements is the cost of aggregate bases required for structural pavement design. If alternative aggregate products are shown to provide sufficient storage and treatment of stormwater, permeable pavements may be designed at lower costs for a broader range of uses within urban environments (*Objective 3*). Two aggregate bases will be monitored at IMAX, 20mm clear stone and aggregate 'O'. Clear stone is typically recommended for permeable pavement systems because the granular material does not include fines and has large void spaces which provide storage for infiltrating stormwater. However, because of the lack of fines larger aggregate depth may be required to properly support traffic loadings. Aggregate 'O', which is a readily available product in Southern Ontario, will be tested in this study as an alternative base material which may offer better balance between structural and environmental design objectives.

Another barrier limiting the use of LIDs is the unknown risk to groundwater systems. Fully lined and underdrained permeable pavements are not anticipated to pose a significant risk if all infiltrating stormwater is routed to a conventional storm sewer system. Since the IMAX property is not in an area of groundwater sensitivity it is a good location to test and monitor a lined permeable pavement system. The collected performance data can be used to assess the option of using lined infiltration systems in groundwater sensitive areas as found in CVC's upper watershed and across Southern Ontario (*Objective 3*).

The proposed monitoring program of in-series LIDs (i.e. Jellyfish to bioretention and bioretention to SorbtiveMedia) is the first of its kind in Canada. Performance data from these systems will be used to evaluate if this treatment-train approach improves stormwater quality (*Objective 4*). Performance data will also allow managers to analyze costs and benefits of in-series LID systems and determine if bioretention systems are enhanced by secondary treatment measures.

As discussed previously in the literature review, there is a lack of true long-term studies (i.e. > 2 yrs) for LID installations. It is the intent of this experimental design to implement the monitoring program for up to ten years (*Objective 5*). This will create a continuous performance data set and allow for the analysis of performance patterns over several years. If fully implemented, the monitoring program at IMAX will produce one of the most comprehensive LID performance datasets within North America. Cold climate performance is another research area which has yet to be fully examined and is a critical topic for the adoption of LIDs throughout Canada and within the Credit River watershed. Long-term monitoring will identify seasonally-dependent LID performance behaviour in terms of both stormwater quantity and quality (*Objective 5*).

Questions and concerns regarding operation and maintenance (O&M) continue to impede the use of LID systems. As new technologies emerge, development, testing and refinement of O&M practices is needed. Performance data collected through the monitoring program will help inform IMAX staff and will be used to plan and adapt maintenance activities accordingly (*Objective 6*). Road salting is a standard winter practice and chloride is a pollutant of concern within the Credit River watershed and Southern Ontario. Researchers will investigate if permeable pavements require less winter maintenance than asphalt surfaces by monitoring winter salting (*Objective 6*).

The role of drainage design and operation on LID performance has not yet been thoroughly examined. The design of the IMAX parking lot presents the opportunity for researchers to test alternative drainage design and operational settings by controlling drawdown time at underdrain outlets. Testing of alternative drainage settings will explore how environmental benefits may be optimized by regulating outflow (*Objective 3, Objective 4 and Objective 6*).

The experiences and data generated by the monitoring program will be used by CVC to produce guidance documents for the design, construction and operation and maintenance of LID systems within the Credit River watershed and Southern Ontario (*Objective 7*). These documents will provide technical resources for developers, designers, engineers and property owners and support the necessary shift to LID technologies and sustainable stormwater management.

5.0 EXPERIMENTAL DESIGN

The following experimental design is intended to provide a detailed action plan which will allow the project partners to achieve the stated research objectives. The design of the monitoring program as well as the plans for data collection and analysis will be explained and justified in the following sections. The experimental design is presented through five topics.

1. *Site Information*
   As with any project, geologic and hydrologic factors at the lot level form constraints which the design and placement of the LIDs must accommodate. In this section, the IMAX property is described and relevant environmental issues for the Sheridan Creek watershed are explained.

2. *LID Design*
   Based on these constraints, combined with the employee parking needs of IMAX, a new parking facility has been designed which applies several LID systems. To address research goals additional infrastructure features have been added to facilitate the testing and monitoring of the LIDs. These features are required specifically to allow for future installation of monitoring equipment and access to outflow from the LID system. In this section, the design of monitoring infrastructure and LID systems is presented and justified.

3. *Phasing of Research*
   In this section, a phasing plan for research activities is outlined. Many of the research objectives are inter-connected and sequencing activities for immediate, short and long term goals will ensure that invested resources produce meaningful

results and minimize redundant data collection practices which are costly and labour-intensive.

4. *Data Collection*
   In order to evaluate the performance of the LID systems, quantity and quality parameters will be monitored. The selection of these parameters and data collection methods are explained and justified in this section. To evaluate the O&M needs of LID systems, CVC will work with IMAX staff to document and monitor maintenance activities at the site.

5. *Data Management, Analysis and Reporting*
   Monitoring projects generate large amounts of data which can be challenging to organize and manage. This section provides an action plan for processing field data and interpreting performance.

The experimental design presented herein has been developed after reviewing current literature. There are many uncertainties in field-based research and as a result the experimental design, monitoring program and planned analysis methods should be regularly reviewed and adapted as necessary.

5.1 SITE INFORMATION

The IMAX property is located within the headwaters of the Sheridan Creek watershed (See Figure 3 below). The Sheridan Creek Watershed is a long, narrow, urbanized watershed located on the west side of the City of Mississauga. The watershed drains an area of approximately 1,035 hectares (ha) that outlets to Rattray Marsh on Lake Ontario, a Provincially Significant Wetland and Provincial Area of Natural and Scientific Interest. Industrial/Commercial land use dominates the upper Sheridan Creek watershed within Mississauga and makes up 32% of the total watershed area. The native soils are comprised of clay till with an estimated hydraulic conductivity ranging between 1.96 - 4.84 mm/hr and are underlain by bedrock (Aquafor Beech Limited, 2012; Aquafor Beech Limited, 2011). Groundwater has been encountered at the site at depths between 2.7 and 3.5 m (Aquafor Beech Limited, 2011).

Figure 3: Location of study area inside the Sheridan Creek Watershed

The CVC *Impact Monitoring Program* summarized current conditions in the Credit River watershed and identified several key water quality issues.

1. Chloride: Road salting practices have led to contamination of both the creek and groundwater. Chloride levels within Sheridan Creek remain above the CCME objective during snow-free and dry weather conditions.
2. Nutrients: High nutrient levels are contributing to excessive algal growth within the creek. Total phosphorus concentrations exceed PWQO during wet weather particularly during the first flush. Nitrate concentrations meet the CCME objectives and are not currently a concern.
3. Metals: Levels of metals (indicated by zinc concentrations), which exceed the PWQO, occur in Sheridan Creek. The highest levels are associated with first flush from industrial land-uses.
4. Total Suspended Sediments: PWQO are exceeded during wet weather conditions, with TSS concentrations increasing downstream.
5. E-coli: Concentrations exceed the PWQO during wet and dry weather. The highest levels are associated with residential land uses.

5.2 LID DESIGN

The IMAX retrofit applies the philosophy of LID design by developing a stormwater management system which is customized to suit local hydrology and geology through the use of multiple technologies. The layout of the retrofit parking lot, shown below in Figure 4, outlines the locations of the various SWM technologies. The parking lot has been divided into seven subcatchments, defining the drainage area entering each SWM system. There are a total of eight monitoring stations where stormwater flows will be monitored and water samples collected. The soil conditions are unsuitable for complete stormwater infiltration and accordingly, the bioretention cells and permeable pavements are designed as underdrained systems (i.e. infiltrated stormwater will be collected through buried perforated pipes). The underdrains serve a dual purpose by providing access points to measure and sample infiltrated stormwater while simultaneously conveying excess stormwater to the receiving municipal stormwater system. Additional, figures of the LID design are included in Appendix A.

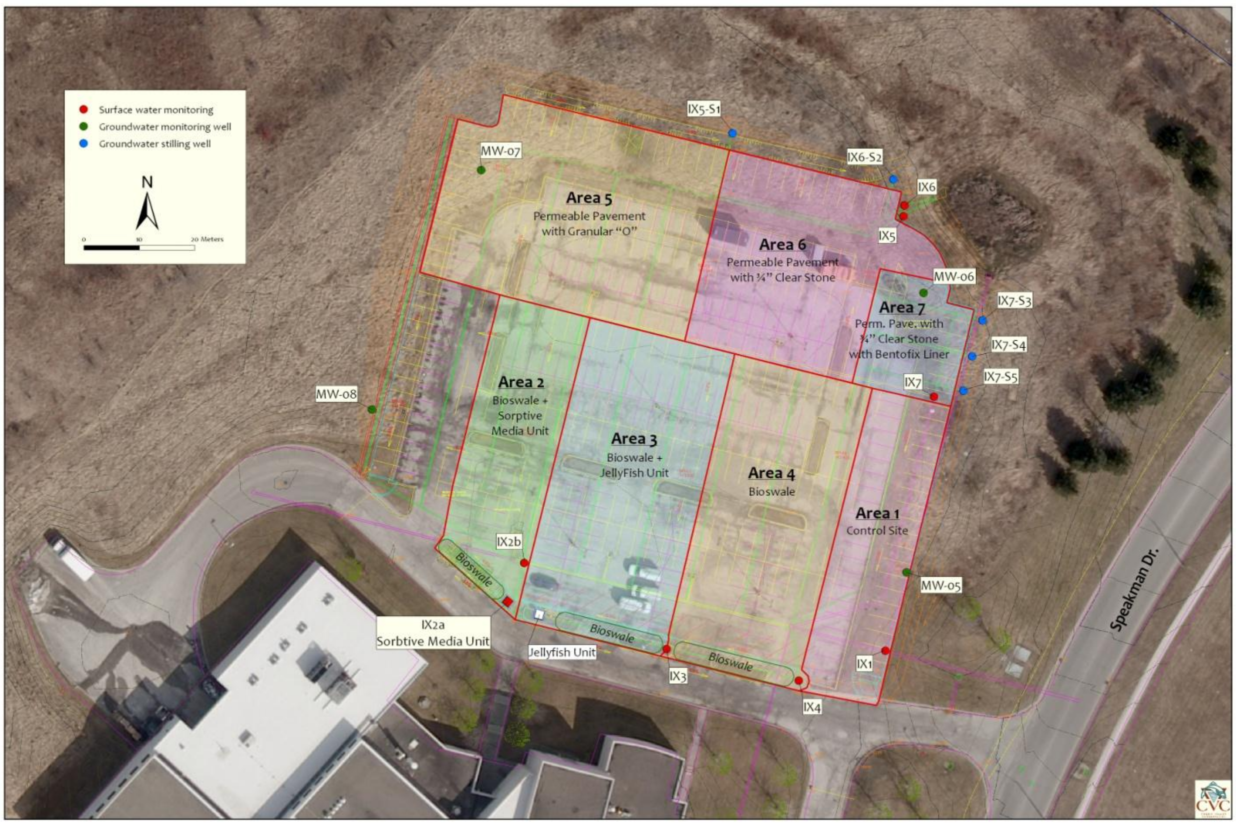


Figure 4: Retrofitted IMAX Parking lot, LID systems and Monitoring Stations

5.2.1 CONTROL AREA

Subcatchment 1 (paved area = 1714 m^2), shown in Figure 4, drains stormwater from asphalt entrance laneways. Stormwater will be managed through a traditional catchbasin collection system; this serves as a 'control' treatment for the site. The runoff will be conveyed to a manhole, Monitoring Station 1 (IX-1) and released to the municipal storm sewer network. In field-scale research, it is a common practice to monitor runoff from a traditional asphalt catchment that is located near or beside the LID installation (e.g. Drake et al., 2012, TRCA 2008, Collins et al. 2008). This practice allows for comparisons of LID and traditional drainage systems in terms of behaviour and performance while minimizing uncertainties. Side-by-side testing ensures that the systems are exposed to the same climatic and geologic conditions while receiving similar pollutant inputs. Ultimately, monitoring a 'control' treatment allows the environmental benefits of LID systems (i.e. *Objectives 1 and 2 presented in Section 4*) to be measured and reported with greater certainty.

5.2.2 PERMEABLE PAVEMENT

The placement of the permeable pavement was restricted by the orientation and depth of bedrock which has an uneven elevation across the IMAX property (Aquafor Beech Limited, 2011). Consequently, the use of permeable pavements was limited to the far end of the parking lot where there is greater depth to bedrock. The permeable pavement has a total area of 3133 m^2. As previously discussed, the permeable pavements will be underdrained because the native soils, which are comprised of silty clay till, have a limited capacity to infiltrate stormwater. A permeable 270R geotextile fabric will be used at the base of the permeable pavement system to prevent the migration of native material into the aggregate base. A schematic of a typical permeable pavement system and its components is shown in Figure 5.

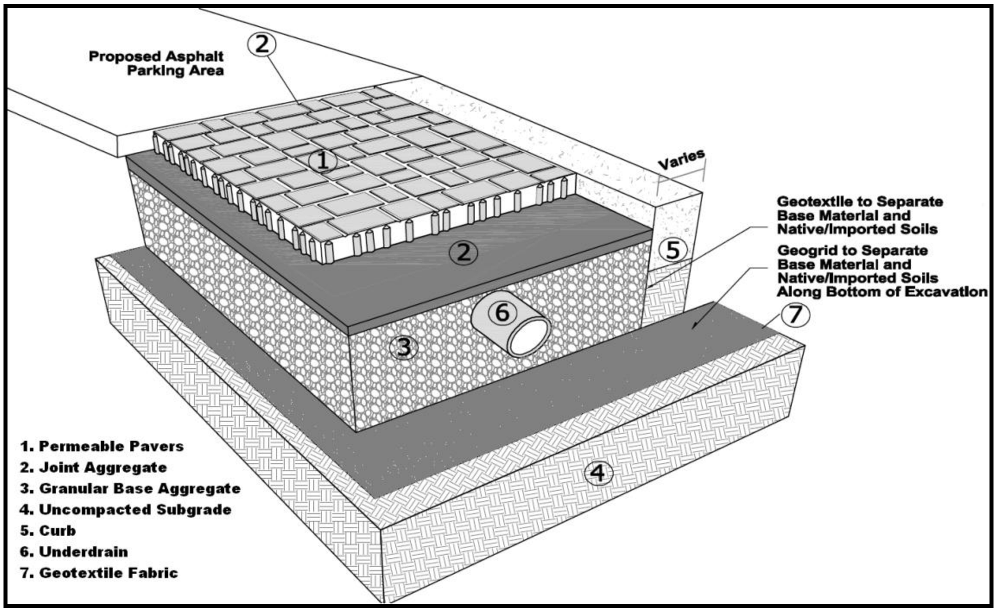


Figure 5: Schematic of a typical permeable pavement system (Aquafor Beech, 2012)

The parking lot grading has been designed to ensure that the permeable pavement will not receive any run-on from adjacent pavement surfaces. This is to ensure that the volume of stormwater inputs can be estimated with certainty. For research purposes (i.e. *Objective 3 presented in Section 4*), sections of the permeable pavement are designed with different aggregate and geotextile products. Stormwater from each section will be collected separately so that performance comparisons between the different systems will be possible. Adjacent sides of these systems will be separated by a Bentofix liner to ensure hydraulic separation.

Shown in Figure 4, the permeable pavement in Subcatchment 5 (permeable pavement area = 1640 m^2) will be constructed with a granular "O" base and the permeable pavements in Subcatchments 6 and 7 (permeable pavement area = 1163 m^2 and 330 m^2, respectively) will be constructed with a 20 mm clear stone base. Infiltrating stormwater from these catchments will be routed to manholes IX-5, IX-6 and IX-7, respectively. Stormwater from IX-5 and IX-6 discharges to a man-made wetland which is adjacent to the IMAX property, while IX-7 outlets to a sewer which connects to the municipal storm sewer system. In the event of overland flow, stormwater bypassing the permeable pavement will drain through a single curb cut to the downstream man-made wetland. Water levels within the wetland are managed by a control structure which connects to the municipal storm sewer system. Backwater effects are not expected unless an extreme rainfall event occurs.

Outlets from IX-5 and IX-6 will be fitted with moveable 90° elbows (shown in Figure 6) which will allow researchers to simulate elevated underdrains in the future (i.e.

Objectives 3 and 6 presented in Section 4). Elbows will initially be set so that stormwater drains freely from the permeable pavement system. Each subcatchment will have an observational well which is connected to the underdrain so that water levels within the pavement system may be monitored.

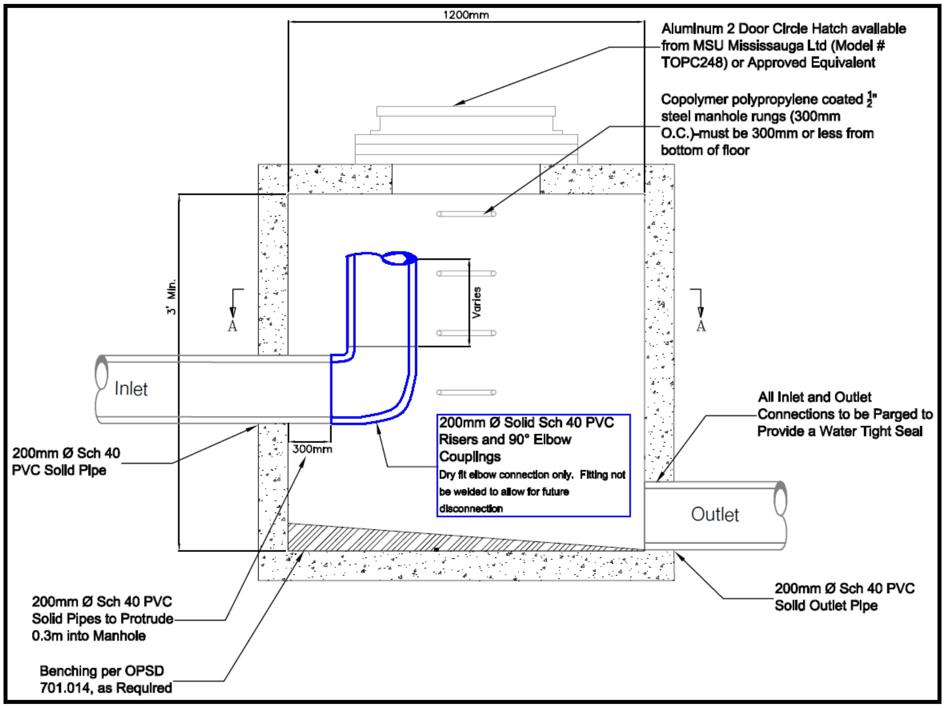


Figure 6: Moveable 90° elbows (Aquafor Beech, 2012)

Subcatchment 7 will be fully lined with an impermeable Bentofix liner. The lined permeable pavement will be evaluated for use in groundwater-sensitive areas where stormwater infiltration is not allowed (i.e. *Objective 3 and 5 as presented in Section 4*). The subcatchment will have sampling ports beneath the liner that connect to an observation well and can be used to check for leakage (Figure 7).

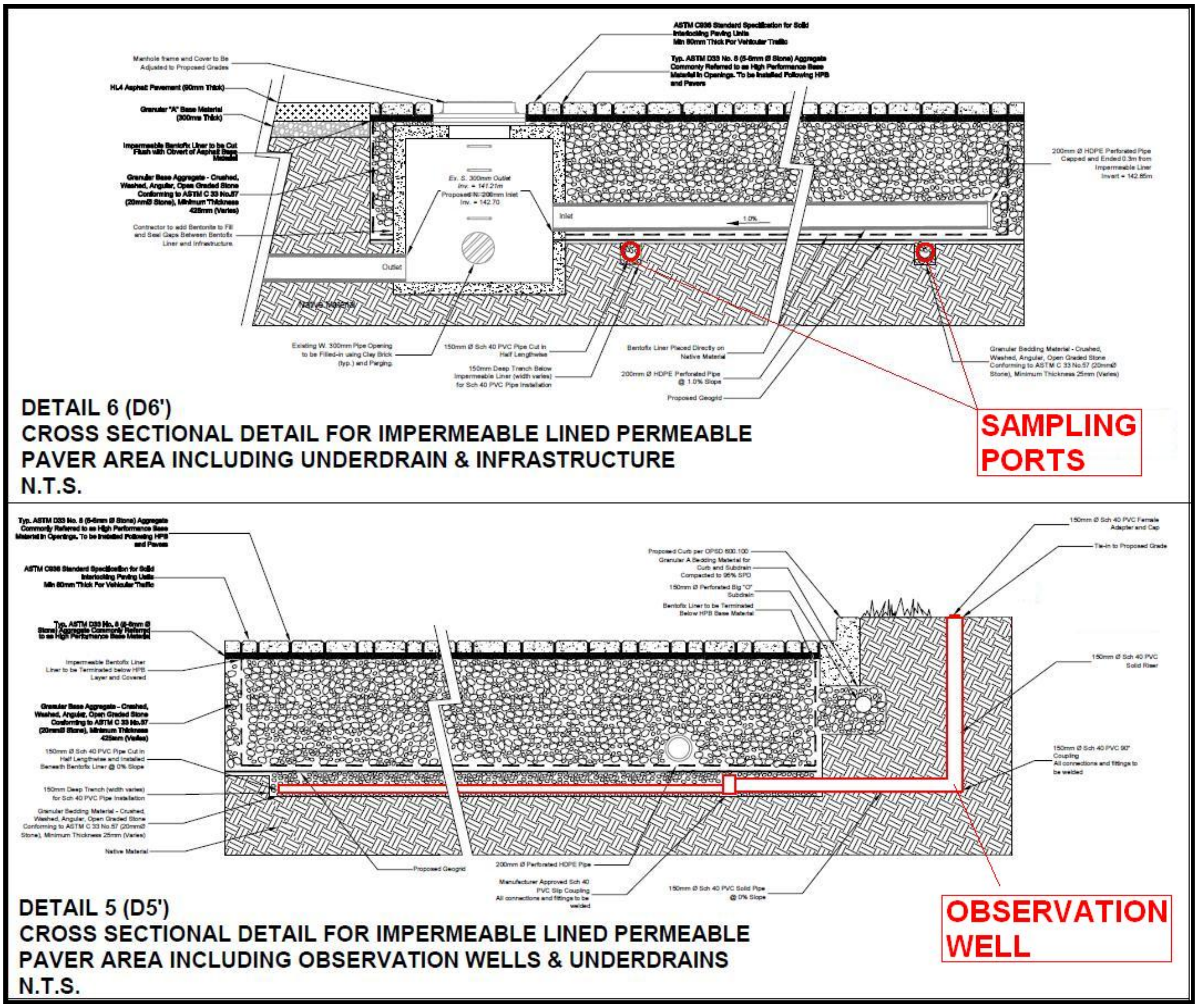


Figure 7: Sampling ports and observational wells for Subcatchment 7 (Aquafor Beech, 2012)

5.2.3 BIORETENTION

Stormwater which is not managed by the permeable pavements will be collected and infiltrated through three bioretention systems, referred to as bioswales in the design drawings. The proprietary products, Jellyfish and SorbtiveMedia, will be used in conjunction with a bioretention system as primary and tertiary treatments on individual bioretention cells. This will allow for the improvements to stormwater quality provided by these products to be evaluated separately (i.e. *Objective 4 as presented in Section 4*). During extreme events, stormwater could bypass the bioretention systems and flow overland to Speakman Drive.

Stormwater from Subcatchment 2 (drainage area = 1125 m^2) is infiltrated through Bioswale Cell 1, collected in an underdrain and routed to a SorbtiveMedia unit (Figure

8). There are two monitoring stations in this subcatchment to accommodate research equipment: IX-2a, the SorbtiveMedia vault and IX-2b, the downstream manhole. Within the SorbtiveMedia vault there are several flow bypasses that can occur depending on the rain event as shown in Figure 9. The SorbtiveMedia unit can provide a treatment flow rate of 10 gpm per design calculations and once this flow rate is exceeded, there is potential for mixed water quality being measured downstream at IX-2b. There are three scenarios that can take place which need to be considered when interpreting the water quality results.

1. No bypass occurring: runoff received complete bioswale and SorbtiveMedia treatment.
2. Bypass within SorbtiveMedia unit (over baffle wall): runoff received complete bioswale treatment and partial SorbtiveMedia treatment.
3. Bypass via bioswale overflow riser pipe: indicates that system is surcharged and runoff downstream is a mixture of flow with no treatment and flow with partial treatment.

If feasible, CVC will install additional level loggers to differentiate between these bypasses and the level of treatment being measured downstream. A level logger within the SorbtiveMedia unit will indicate when the baffle wall is overtopped and level loggers in the bioswale will measure surface ponding depth as well as level within the overflow riser pipe.

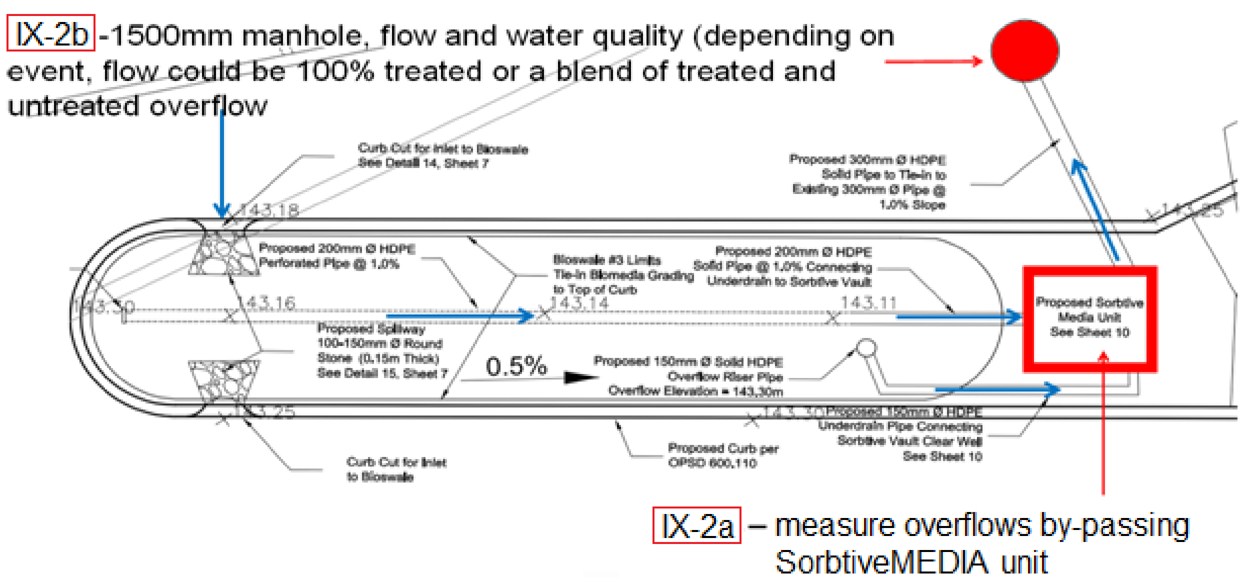


Figure 8: Bioswale Cell 1 layout (Aquafor Beech, 2012)

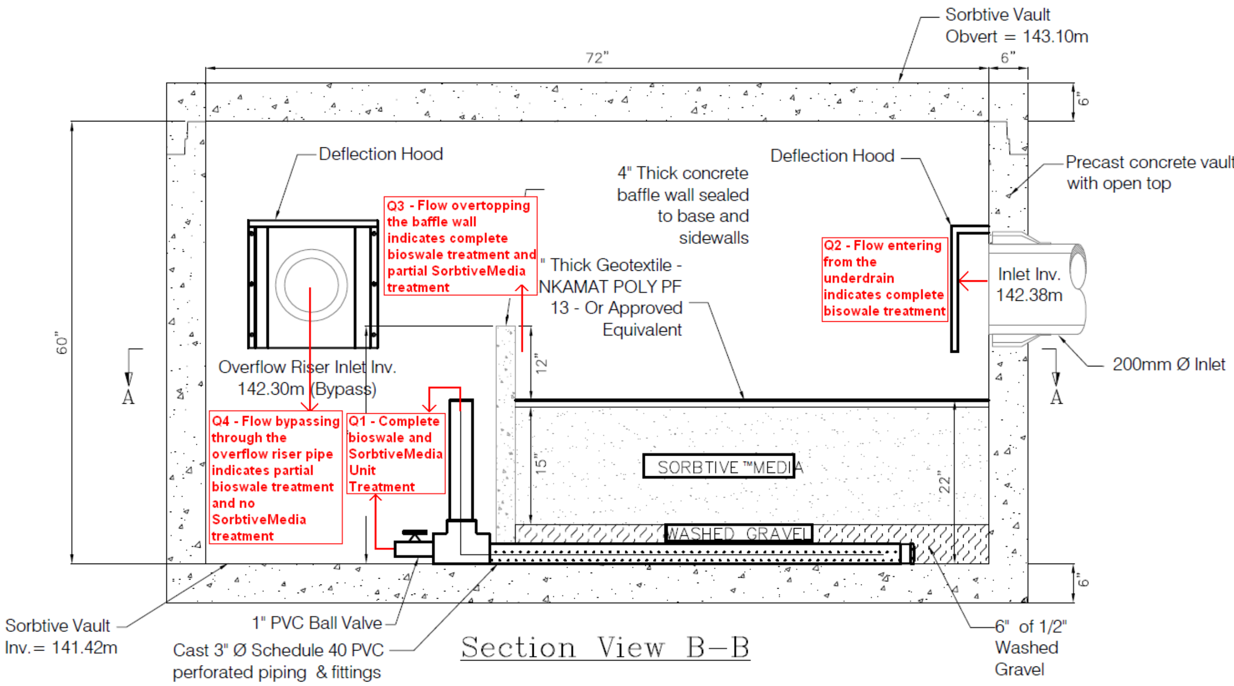


Figure 9: SorbtiveMedia Bypass (Aquafor Beech, 2012)

Stormwater from Subcatchment 3 (drainage area = 1350 m^2) is pre-treated by a Jellyfish unit before infiltrating through Bioswale Cell 2 (Figure 10). Stormwater collected in the bioretention underdrain is routed to a manhole, IX-3, and outlets to the municipal storm sewer system. Again, it is important to note when bypass occurs so the water quality measured downstream at IX-3 can be interpreted appropriately (as shown in Figure 11). The Jellyfish filter has a total treatment flow rate of 12.62 L/s and once this flow rate is exceeded, the system is surcharged.

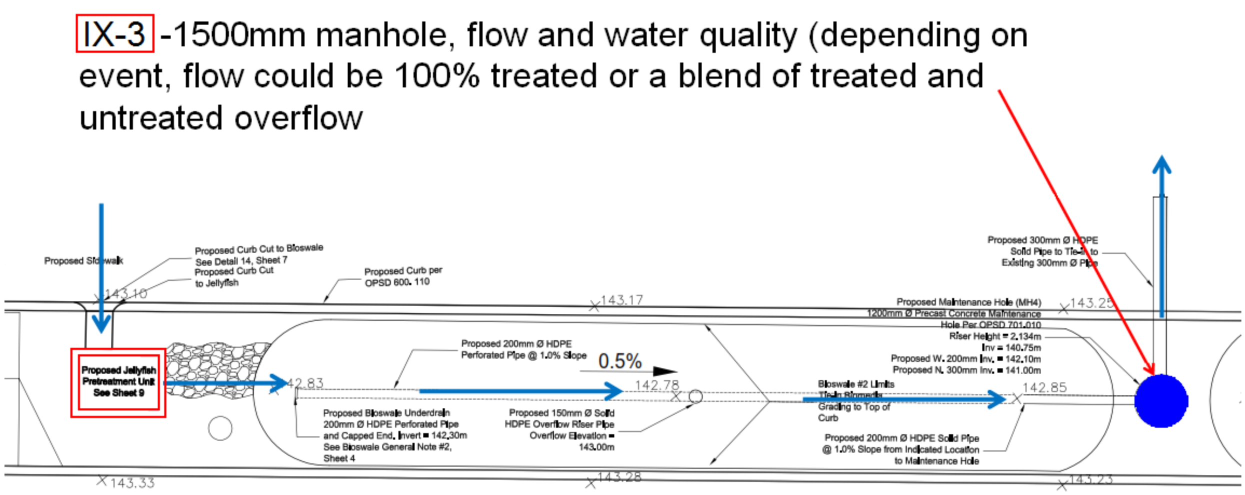


Figure 10: Bioswale Cell 2 layout (Aquafor Beech, 2012)

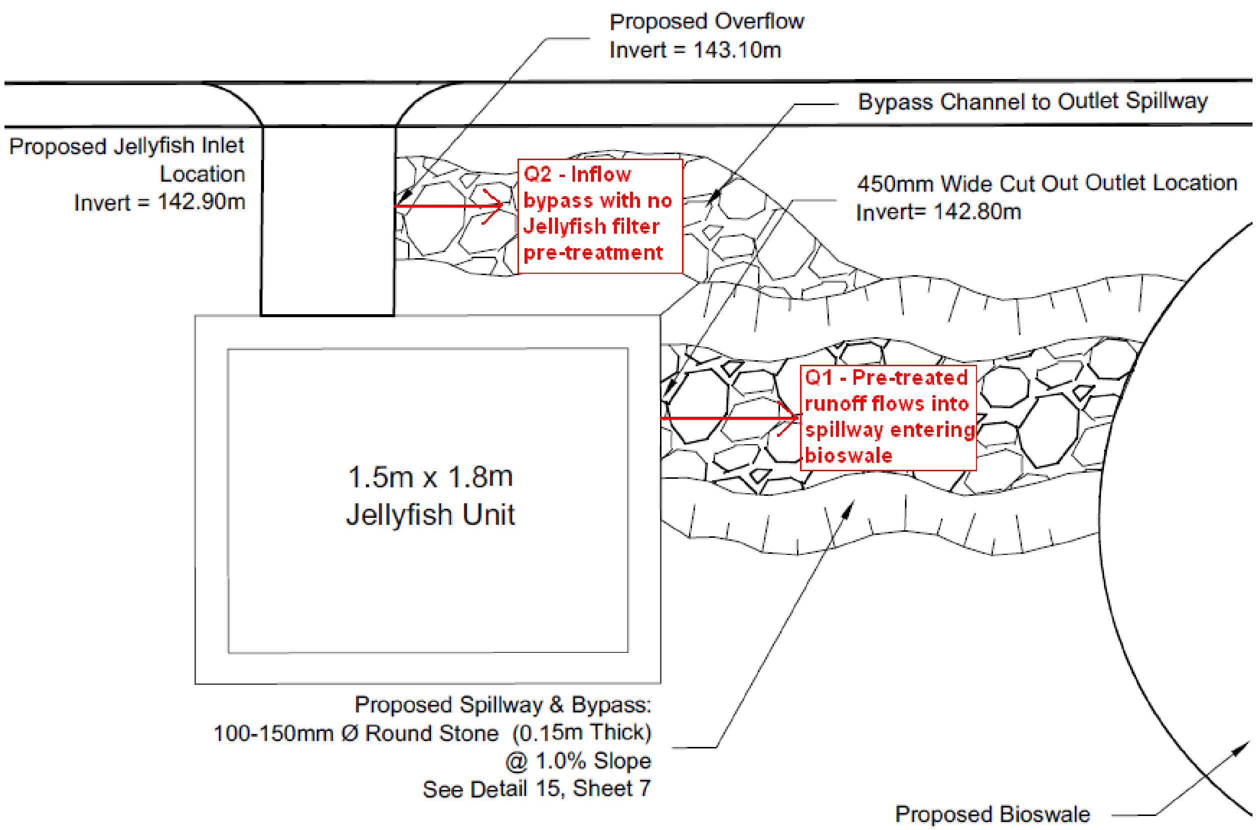


Figure 11: Jellyfish Filter Bypass

Stormwater from Subcatchment 4 (drainage area = 1566 m^2) is infiltrated through Bioswale Cell 3 (Figure 12). Stormwater collected in the bioretention underdrain is routed to a manhole, IX-4, and outlets to the municipal storm sewer system. In this case when maximum surface ponding depth is reached, the overflow bypasses through the riser pipe towards to the existing storm sewer. If feasible, CVC will install a level logger so occurrences of bypasses can be identified.

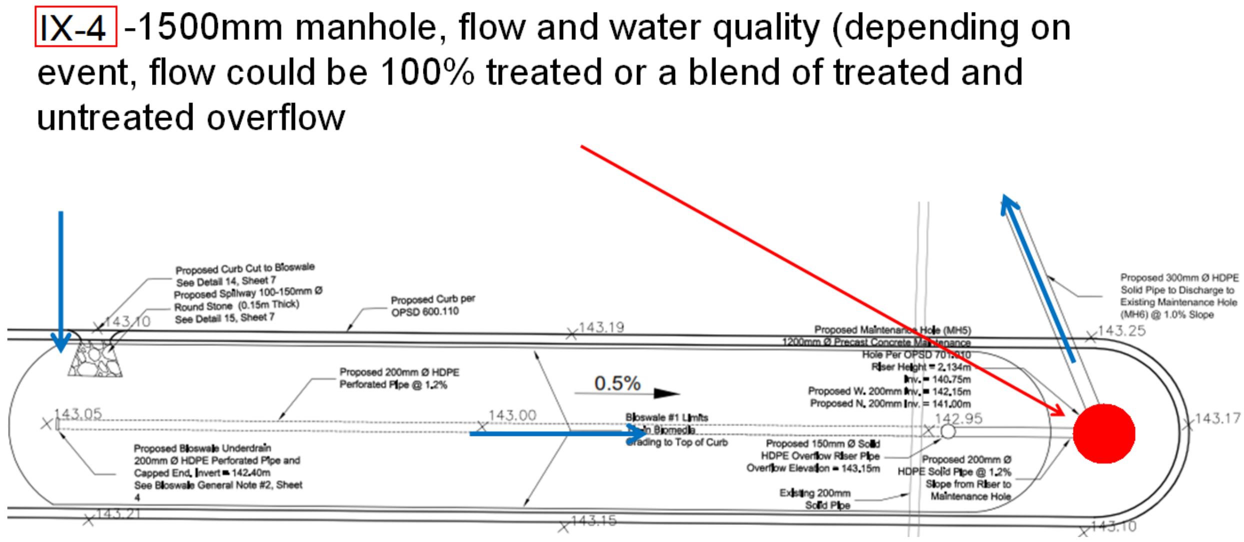


Figure 12: Bioswale Cell 3 layout (Aquafor Beech, 2012)

5.3 PHASING OF RESEARCH ACTIVITIES

Monitoring activities must be phased to address the numerous and interconnected objectives presented in Section 4 of this report. Research goals will be examined in context of immediate (Year 1, Phase 1), short term (Years 1 - 5, Phase 2) and long term (Years 1 – 10, Phase 3) time frames. Table 1 outlines immediate activities for 2012/2013. In subsequent sections data collection practices are presented for immediate and short term research objectives. Field-based observational studies should be adaptively managed and hence long term monitoring practices are most effective when designed after an initial period of observation and testing.

Two of the objectives (i.e. *Objectives 1 and 7*) presented in Section 4 are policy and community focused. These goals will be achieved through the implementation of the IMAX retrofit, the monitoring program and the application of the study findings by CVC. Signs will be installed at IMAX to provide the community with information about LID systems and stormwater management. Data collected by CVC will be used to refine guidelines for LID projects within the Credit River watershed.

All of the other objectives (i.e. *Objectives 2 through 6*) deal with questions and topics of LID performance. Evaluating the performance of a system is challenging because it continuously changes with time. Consequently, study findings and results will need to be regularly revisited and reinterpreted as monitoring data becomes available and the parking lot ages. Inherently, research questions associated with Objectives 5 and 6 cannot be answered in the immediate or short term and thus will eventually be addressed in Phase 3 of the study. During Phase 1, data collection activities will be designed to begin to address Objectives 2, 3 and 4 and results will be reported only for individual LIDs. Conclusions produced from Phase 1 will be limited and will not include comparative performance metrics because data will have been compiled from only a few months of monitoring. For Phases 2 and 3 of the study, LID data will be processed as individual and collective systems.

Table 1: Research activities for 2012 to 2014

Date	Activity
Fall 2012	• Construction of IMAX parking lot • Development of experimental design and monitoring program
Winter 2012	• Installation of monitoring equipment • Initiation of data collection program
Spring 2013	• Bioretention plantings • Installation of monitoring equipment
Spring /Summer 2013	• Testing of monitoring equipment • Troubleshooting and refinement of monitoring protocols • Initiation of data collection program
Summer/Fall 2013	• Data collection
Fall 2013	• Process summer and fall data • Assess monitoring program and implement changes as required • Plan winter data collection and monitoring of winter maintenance • Report summer/fall 2013 data
Winter 2013/2014	• Data collection
Spring 2014	• Process winter data • Review 2013 data • Assess monitoring program and implement changes as required

5.4 DATA COLLECTION

The immediate goal of the monitoring program is to demonstrate and evaluate the performance of the LID systems in terms of quantity control, water quality treatment, erosion control, thermal mitigation etc. To do this, precipitation inputs, outflows and pollutant concentrations must be measured. Information regarding the LID performance over time will be needed by IMAX operators so that maintenance needs can be anticipated and conducted in a timely manner. Data collection activities will include surface permeability measurements, elevation surveys, sediment levels and monitoring of winter maintenance. In the following section methods to collect this data are presented.

5.4.1 **QUANTITY DATA**

A heated rain gauge has been selected to collect precipitation data. Rain gauges are the most commonly used system for measuring precipitation and a heated device will allow for winter measurements. Outflow from all underdrains and runoff from the asphalt control will be measured using stage-based flow measurements (i.e. weir and water levels). V-notch weirs and instrumentation will be installed and calibrated by consultants and will be designed to accurately measure flows as small as 0.1 L/s. A stage based approach was the only option for flow measurements at IMAX because:

- As a fully operational parking lot all monitoring equipment had to be installed below grade in manholes and monitoring structures such as a vault were not allowed on the property.
- Manholes did not provide sufficient space for alternative devices such as tipping buckets.
- There is no access to electrical power at the site and as a result ultrasonic sensors were ruled out.

Observational wells will be used in this study to monitor water levels within the aggregate base and bioretention media. Wells are recommended by industrial organizations such as the Interlocking Concrete Pavement Institutes as a long-term and simple method for monitoring exfiltration rates. The incidence of overflow of permeable pavements will be observed by the presence of runoff draining by way of the curb-cut. If appropriate, permeable pavement runoff can be measured with a weir and water level logger at the curb-cut. The incidence of overflow of bioretention systems will be observed by the presence of well water levels above the bioretention media elevation. Surcharging of the Jellyfish unit will also be monitored with a water level logger. Flow monitoring will be continuous and thus, once equipment is installed and calibrated, all outflow events will be observed. Hydrologic data intervals were chosen to provide the finest resolution possible to better capture the runoff response from small areas. Precipitation data will be logged at a 5 minute interval. Water level data will be logged at a 1 minute interval at the control site (with the option to download the data at a preferred interval such as 5 minutes) and will be logged and downloaded at 10 minute intervals at other monitoring stations).

5.4.2 STORMWATER QUALITY DATA

Following other studies (e.g. Drake et al., 2012; Brown et al., 2012a; Chapman and Horner, 2010; TRCA, 2008) stormwater quality will be monitored with flow-proportioned composite samples collected by automatic samplers. Initially, a minimum of 10 precipitation events will be sampled per year. The temperature will be logged at 5 minute intervals at the control site (IX-1) and at 10 minute intervals at all other monitoring locations. Temperature will not be monitored at IX-2b, the downstream end of the treatment train at this location, because the upstream side of the weir where the sensor would be placed is not accessible. After each year of data collection the sampling plan will be evaluated and sampling will be adapted as appropriate. For the first year of monitoring, water quality sampling will be performed for events with rain depths (or snowmelt) greater than 5 mm.

The Autosampler settings will be different for the control and LID sites. The Autosampler consists of twenty four bottles where each bottle has the capacity to hold 950 mL of sample water. For the Control site, IX-1, the Autosampler will conduct samplings in a two-part program, Part A – Grab Sampling and Part B – Composite Sampling. Once the sampler is triggered, Part A will fill the first six bottles as the grab sample and Part B will fill the remaining 18 bottles (950 mL) at 20 minute intervals for the flow-weighted composite sample. For the LID sites, the Autosamplers will sample 500 mL (half a bottle) every hour. The length of the program is 12 hours for the control and 48 hours for the LID sites. At a minimum, water quality sampling will be performed at IX-1, IX-3 and IX-6 which will allow stormwater quality from asphalt runoff, permeable pavement outflow and bioretention outflow to be compared. If feasible; sampling at other monitoring stations will also be performed. Winter runoff and outflow is anticipated to have a different overall quality as a result of road salting and may be extremely variable due to irregular snow melt and road salt inputs. Water quality analysis of winter stormwater samples may be limited to only pollutants which are known to be seasonally dependent. For all other seasons, stormwater samples will be tested for:

- General Quality
    - Total Suspended Solids (TSS)
    - Total Dissolved Solids (TDS)
    - Hardness
    - Chloride
    - pH
- Nutrients:
    - Phosphorus (particulate, dissolved and orthophosphate)
    - Nitrogen
- Metals

- Oil & Grease

Appendix C provides further water quality sampling and analysis details including lowest method detection limits, analytical methods, required bottles and preservatives, and the sample hold times.

Water quality parameters were intentionally chosen to include parameters which have been studied in the existing published literature (refer to summary documents provided by the *International Stormwater BMP Database*). This will allow the quality of the IMAX stormwater and the performance of the LIDs to be interpreted and discussed in context with other LID projects. Water quality parameters were also selected to ensure pollutants of interest/concern as identified in the CVC *Impact Monitoring Program 2007-2011 Report* were included in the monitoring program. The metals monitored in this study will depend on available funds. Preferably samples will be analyzed for a complete suite of metals but testing may be limited to key metals if needed. Priority will be given to pollutants of concern for the Sheridan Creek watershed, pollutants with provincial water quality objectives (PWQO) and pollutants which have been monitored in published research. Priority metals include: arsenic, cadmium, chromium, copper, iron, nickel and zinc.

Nutrient removal within an LID system is complex, involving mechanisms such as filtration and biologically-mediated transformations. Samples will be analyzed for different species of nitrogen and phosphorus so that removal processes may be better understood. The nutrient species have been selected based on species reported in the *International Stormwater BMP Database* and include: orthophosphate, total phosphate, total Kjehldahl nitrogen (TKN), ammonia as nitrogen, nitrate as nitrogen, nitrite + nitrate as nitrogen. To limit lab expenses nitrate and total nitrogen may be calculated by CVC staff using results from other nitrogen species. The SorbtiveMedia system applied in Subcatchment 2 is specifically intended to improve the removal of dissolved phosphorus. In order to evaluate this feature stormwater samples from the bioswale catchments will need to be analyzed for dissolved and particulate phosphorus concentrations.

Microbiology can be evaluated using *Escherichia-coli* (E-coli) as a water quality indicator. E-coli is an accepted indicator of microbiological safety for drinking water in Ontario and has been regularly evaluated in published LID studies. Hydrocarbons will be evaluated using an indicator parameter such as extractable solvent (or similar) instead of testing for specific polyaromatic hydrocarbons. This approach was selected in order to minimize the costs associated with lab analysis of water samples.

The site will be visited at a minimum of every two weeks to check battery power, inspect equipment, and make sure everything is operational. Data will be downloaded either remotely or in person from each piece of equipment biweekly as a minimum using ISCO Flowlink 5 or Hoboware software (or equivalent). Field and lab data management will follow the CVC's *Data Storage, Organization, and QA/QC Protocol*.

5.4.3 **MAINTENANCE DATA AND WINTER SALT MONITORING**

Monitoring activities will track changes in permeability of the permeable pavement surfaces and bioretention media following the ASTM C1701 and ASTM 3385 tests, respectively. This will allow CVC to understand the long-term behaviour of the permeable pavements and bioretention. At least 3 permeability measurements from each LID system are recommended. Measurements should be collected at least once each season so that seasonal patterns can be tracked. Permeability measurements will be conducted during dry conditions preceded by 24 hours without precipitation. At least one measurement should be positioned over areas which are anticipated to be susceptible to clogging (inlets for bioswales, and areas of high traffic for permeable pavements). In order to characterize and identify spatial variation, detailed assessment of pavement and media permeability (i.e. > 3 measurements) should be conducted once a year. If possible permeability measurements should be repeated at the same location during each quarterly assessment.

Post construction survey of the as-built structure will provide reference elevations of the pavement and bioretention media. If settlement is experienced, which is highly unlikely, it will be possible to track and measure elevation changes. Additionally, sediment levels within the Jellyfish manhole and visual inspections of SorbtiveMedia cartridges will be recorded every 3 months. These observations will be used to schedule clean-outs of the Jellyfish, replacement or flushing of SorbtiveMedia cartridges, vacuum sweeping and joint material replacement of the permeable pavements and bioretention media replacement.

Road salting and snow removal activities will be monitored during this study starting in December 2013. Working with site operators, the volume of road salt applied on the asphalt and permeable pavements will be recorded. Road salt introduces many pollutants, beyond sodium and chloride, to winter stormwater. Samples of road salt will be analyzed to assess the type and degree of pollutants introduced to the parking lot by road salting. If feasible, Hydrolab HS-5 may be used to continuously measure parameters such as water temperature, conductivity, chloride and pH at 15 minute intervals.

5.5 DATA MANAGEMENT, ANALYSIS AND REPORTING

5.5.1 DATA MANAGEMENT

Quantity and quality data will be organized into hydrologic events so that event-based analysis can be performed. Table 2 explains the conditions which will define the beginning and end of a hydrologic event. LIDs attenuate flows and as a result events may contain several discrete periods of precipitation and runoff. Parameters which will be computed for each hydrologic event are outlined in Table 3 and respective equations are presented in Table 4. Composite water quality samples will provide event-mean concentrations (EMC) for the tested pollutants. Continuously collected water quality data (i.e. temperature) can also be processed to generate flow-weighted event-mean levels. Using outflow volume data event-based pollutant loads may be computed. A hydrologic and water quality summary should be prepared for each event. Since hydrologic data is collected continuously data should be added to a master record. A step-by-step work plan for data management is presented in Appendix B.

Table 2: Defining hydrologic events

Event type	Beginning	End
Precipitation	Precipitation observed	Outflow from all LIDs < MDL
Thaw	Runoff observed, no precipitation observed	Outflow from all LIDs < MDL
No Outflow	Precipitation and runoff observed, no outflow observed from LIDs	Runoff from asphalt < MDL

Table 3: Hydrologic and water quality parameters

Precipitation	Outflow	Hydrologic evaluation	Water quality	Water Quality evaluation
• Event type • Precipitation depth • Antecedent dry period • Start and end time, duration • Intensity	*LID and asphalt:* • Presence/absence of outflow • Outflow volume • Outflow volume normalized by area • Peak flow rate • Peak flow rate normalized by area • Start and end time, duration • Hydrograph	• Relative volume reduction (using normalized outflow) • Relative peak flow reduction (using normalized peak flow rate) • Lag time • Lag ratio	*Composite samples*: • EMC • Pollutant loads • Presence/ absence of <MDL *Continuously monitored parameters:* • EM • Pollutant loads • Presence/ absence of <MDL	• Efficiency Ratio • Removal Efficiency • Summation of Loads • Irreducible concentration

	centroid *LID specific:* • Presence/absence of saturated conditions in media or aggregate • Start and end of saturated conditions, duration • Degree of saturation (i.e. maximum water level in wells) • Presence/absence of overflow		• Pollutant range	

Table 4: Calculated parameters and performance metrics

Parameter	Notation	Equation
Outflow volume normalized by area	V_n	$V_n = \frac{Volume}{A}$ where A = catchment area
Peak flow rate normalized by area	Q_n	$Q_n = \frac{Peak\ Flow}{A}$
Relative volume reduction	VR	$VR = \frac{V_n(LID)}{V_n(CONTROL)}$ or $VR = \frac{V_n(LID)}{V_n(PRECIPITATION)}$
Relative peak flow reduction	QR	$QR = \frac{Q_n(LID)}{Q_n(CONTROL)}$
Time to centroid	T_E	$T_E = \frac{\sum_{i=1}^{n} V_i x}{\sum_{i=1}^{n} V_i}$ where *x* = measurement time step (10 min), *n* = number of flow measurements, *V* = volume observed for each time step
Lag time	l_t	$l_t = T_E(LID) - T_E(CONTROL)$
Lag ratio	k_l	$k_l = \frac{T_E(LID)}{T_E(CONTROL)}$
Efficiency ratio	ER	$ER = 1 - \frac{average\ EMC(LID)}{average\ EMC(CONTROL)}$ where EMC = event mean concentration
Removal efficiency	RE	$RE_i = 1 - \frac{EMC(LID)}{EMC(CONTROL)}$ where i = event 1, 2,…, n

Pollutant load normalized by area	L	$L = \frac{EMC \times V_n}{A}$
Summation of loads	SOL	$SOL = 1 - \frac{\sum_{i=1}^{n} L_i(LID)}{\sum_{i=1}^{n} L_i(CONTROL)}$
Chloride input (from winter salting)	M_{Cl}	$M_{Cl} = R_a \times A \times x_{Cl}$ where R_a = application rate, x_{Cl} = fraction of chloride

5.5.2 **DATA ANALYSIS**

Statistically significant results will likely not be available until several years of monitoring have been completed. Preliminary results may be subjected to large changes as new monitoring data becomes available and hence, preliminary results should be interpreted with caution. Analysis methods for long-term results remain to-be-determined. A step-by-step work plan for data analysis is provided in Appendix B. For more information on analysis methods refer to Burton and Pitt (2001) *Stormwater Effects Handbook: A Toolbox for Watershed Managers, Scientists, and Engineers*.

Analysis can be conducted using free statistical software such as R or the EPA's Pro.UCL4.1 as well as statistical add-ins available in MSExcel. Quantity and quality performance data is anticipated to follow different distributions and to be subjected to different temporal patterns (Table 5). The distribution of data should be assessed so that appropriate statistical tools are applied during analysis. Data should be inspected for potential outliers. The performance of LID systems will be evaluated using:

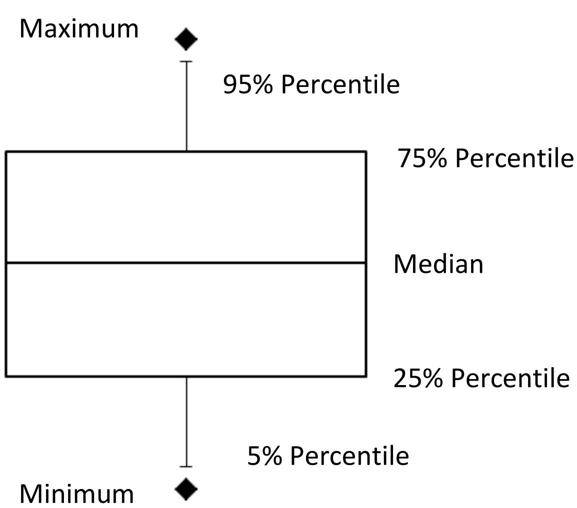
- descriptive statistics for parameters and performance metrics
    - number of events and paired events
    - number of non-detects
    - Range
    - Mean
    - Median
    - Skew
    - Coefficient of variation
- graphical summaries
    - Boxplots
    - Probability plots
    - Time series
    - Correlation plots
- hypothesis testing
    - Paired t-tests

- Sign tests

Currently, graphical summaries are the most widely accepted form of reporting results because they present the entire dataset instead of reducing findings to a single metric. Graphics provide a straightforward and clear picture of stormwater quality allowing results to be easily communicated (Geosyntec Consultants and Wright Water Engineering, Ltd, 2009). Examples of two recommended graphical summaries, boxplots and probability plots, are presented in Figure 13.

Table 5: Anticipated patterns in performance data

Parameter	Anticipated distribution	Time Series Analysis	Rationale
Stormwater Quality	Log Normal	Anticipate seasonal trends	EPA (1983)
Computed ratios (e.g. Volume reduction)	Normal	Anticipate seasonal trends	Central limit theorem
Surface Infiltration rates (i.e. permeability tests)	Normal or Log Normal	Unknown if seasonal trends will be present in data	one-sided boundary (log-normal), central limit theorem (normal)
Pollutant leaching	Non-Normal	Anticipate exponential decay	Inter-annual trends
Pollutants influenced by road salting	Non-Normal	anticipate high variability	Seasonal activities



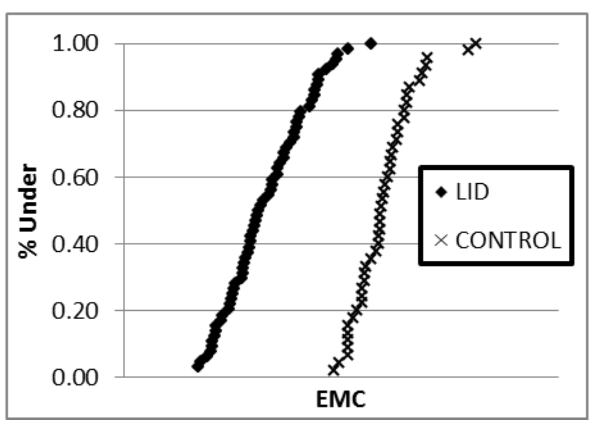


Figure 13: Boxplot (left) and Probability plot (right)

Before using any hypothesis test researchers will need to review the test assumptions. Quantity and quality data for LIDs and asphalt are anticipated to be dependent because results are generated from the same precipitation conditions. Many common statistical hypothesis tests (e.g. two-sample t-tests, ANOVA, Wilcoxon-Mann-Whitney, etc.) assume independence and consequently, these tests should be used with caution as the independence assumption is expected to be invalid. Other tests such as the Wilcoxon-rank-sum test assume that paired data has equal variances. This assumption may also be invalid for stormwater data if LID stormwater quality is found to have less variability than runoff from the control pavement.

For statistical tests, such as paired t-tests, a sample size must be chosen which will ensure an acceptable level of error and significance. A sample size must also be selected so that descriptive statistics (e.g. sample mean) are computed with an acceptable degree of confidence. Equations to estimate sample size are available (shown in Table 6) but most require an estimation of the population's standard deviation (σ). Research of existing hydrologic and water quality data will be required to choose an appropriate σ estimate. Possible sources of environmental data may include CVC, local published data and data available through the International Stormwater BMP database. Sample size equations are approximates and actual confidence intervals should be calculated for all relevant statistics.

Table 6: Sample Size Equation

Objective	Equation	Required information	Source
Estimating individual parameters (e.g. mean)	$n = \left(\frac{COV(Z_{1-\alpha} + Z_{1-\beta})}{\delta}\right)^2$	Estimate or guess of COV Assumes normal distribution	Burton and Pitt (2001)
Simplified estimating individual parameters	$n = \frac{4\sigma^2}{\delta^2}$	Estimate or guess of σ Assumes normal distribution and 95% confidence	Manly (2009)
Evaluating differences between two populations	$n = 2\left(\frac{Z_{1-\alpha} + Z_{1-\beta}}{\mu_1 - \mu_2}\right)^2 \sigma^2$	Estimate or guess of σ Assumes a single σ Assumes normal distribution	Burton and Pitt (2001)
Simplified evaluating differences between two populations	$n = \frac{8\sigma^2}{\delta^2}$	Estimate or guess σ Assumes a single σ Assumes normal distribution and 95% confidence	Manly (2009)
where δ = error, COV = coefficient of variation, Z = Z statistic, α= false positive rate (typically 0.05), β= false negative rate (typically 0.2 or 0.5), σ = standard deviation For more information refer to Burton and Pitt (2001) *Stormwater Effects Handbook: A*			

Toolbox for Watershed Managers, Scientists, and Engineers. CRC Press.

5.5.3 REPORTING RESULTS

For Phase 1, a limited analysis will be performed and only descriptive statistics, totals and graphical summaries will be reported. Phase 1 will only report on individual LIDs and not the collective system. In Phases 2 and 3 a more intensive analysis will be performed (see ` Appendix B work plan) and reported. For all reports, the conditions that were present during the study should be discussed. Any known limitations of the current data and the occurrence of extreme or irregular events should also be explained and reported.

6.0 NEXT STEPS

Construction of the redesigned IMAX parking lot is currently underway and will be completed in spring 2013. Monitoring equipment will be installed in spring 2013 and data collection will begin shortly thereafter. The implementation of the experimental design presented in this report is contingent on the availability of funds for field staffing, lab services and data analysis. Preliminary results will be reported by CVC in December 2013.

The experimental design presented in this report has been developed based on a review of past LID monitoring studies, monitoring manuals/guideline documents and stormwater data management/analysis methods. The objectives were chosen to address current knowledge gaps and expand the current understanding of LID design, performance and best management practices. The methods presented in this report are plans which are intended to maximize research resources. As with most research projects, the final experimental design will be subjected to constraints created by the property owners needs/interests and CVC's staffing and equipment resources. Common challenges of studies involving full-sized stormwater management systems are unforeseen issues which occur when an experimental design is implemented. It is emphasized that the experimental design be regularly re-evaluated and adapted or modified as necessary.

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APPENDIX A

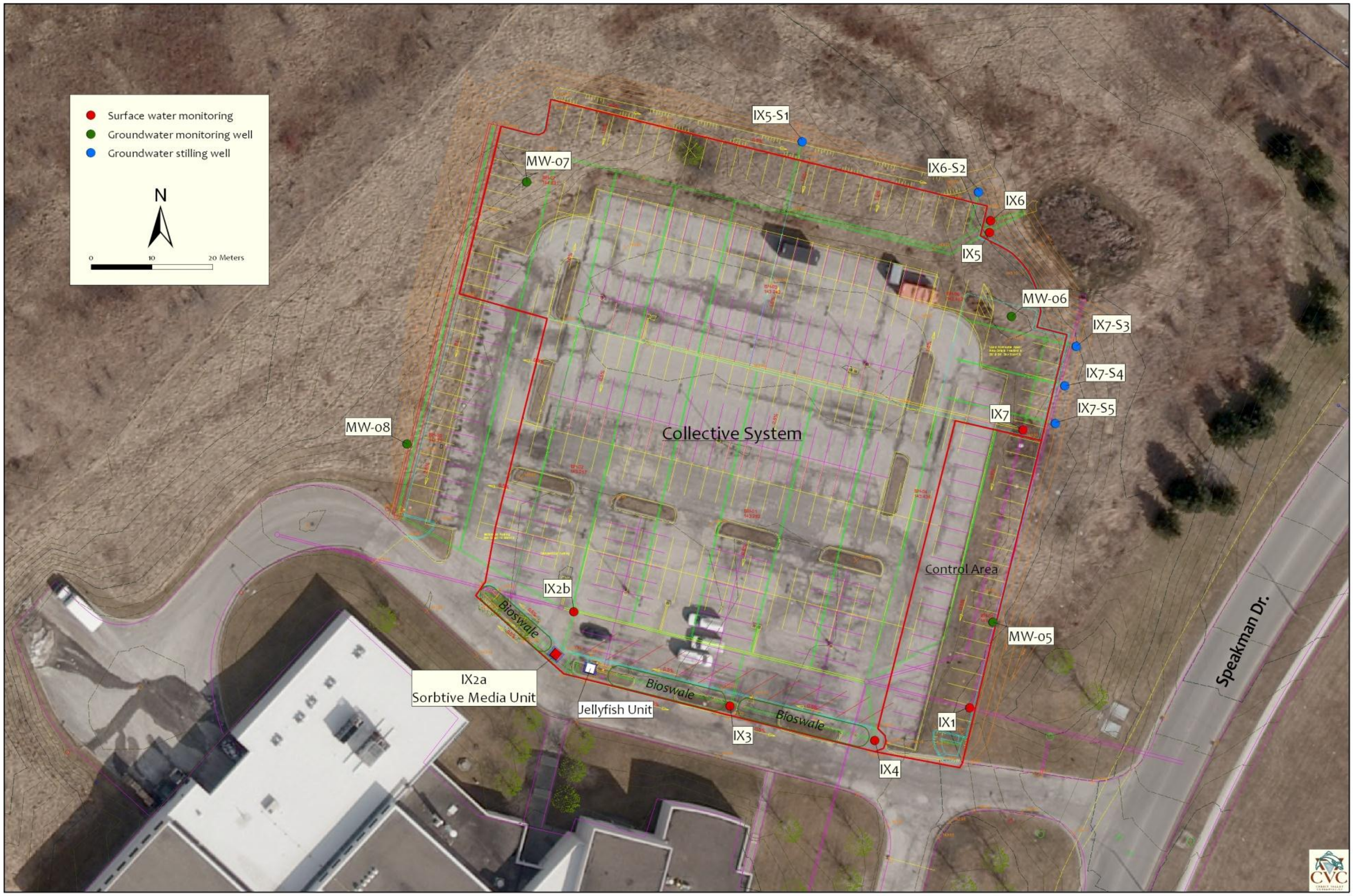

Figure A1: IMAX Collective System Boundary and Monitoring Stations

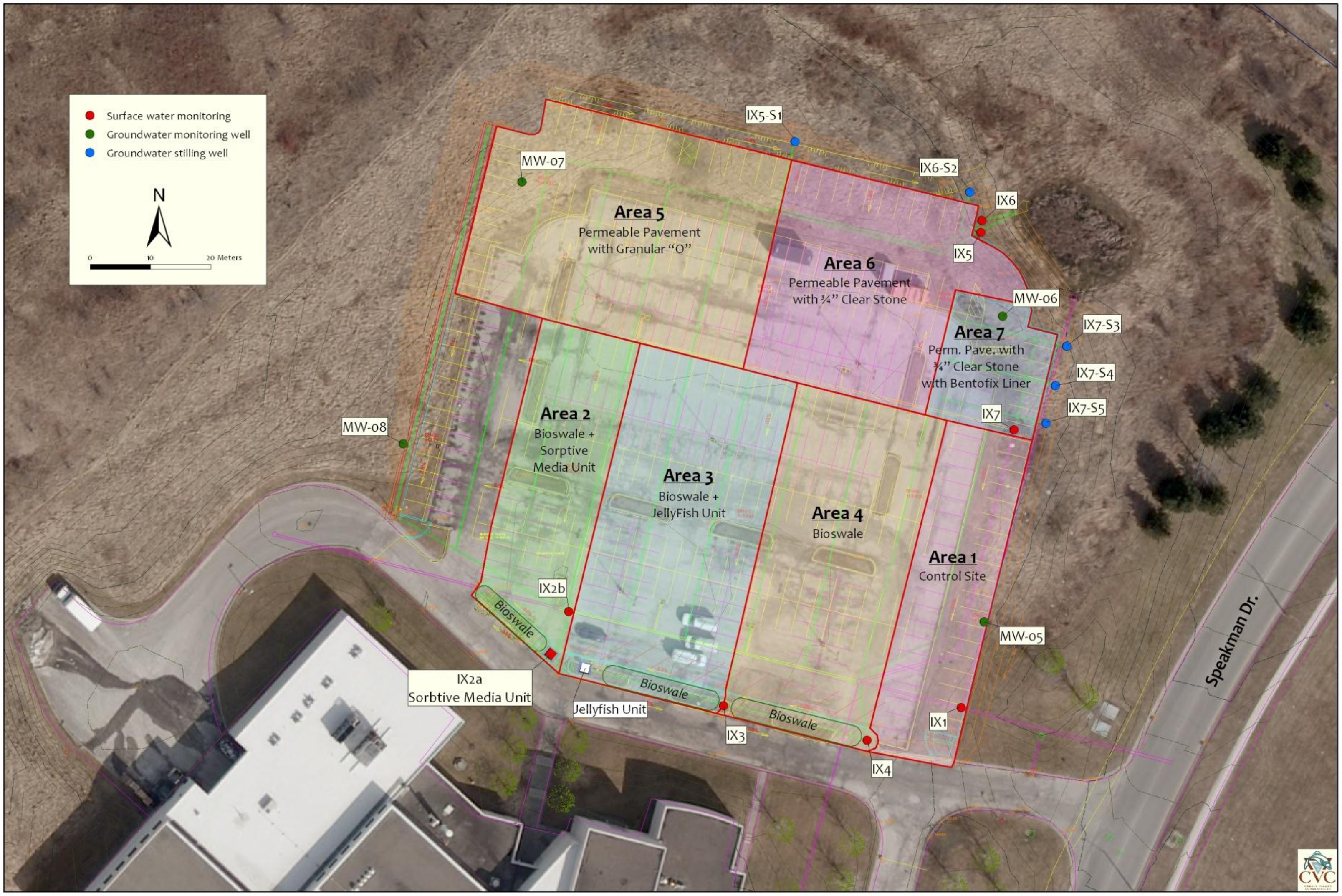

Figure A2: IMAX Individual System Boundaries and Monitoring Stations

Figure A3: Proposed LID systems for the IMAX retrofit

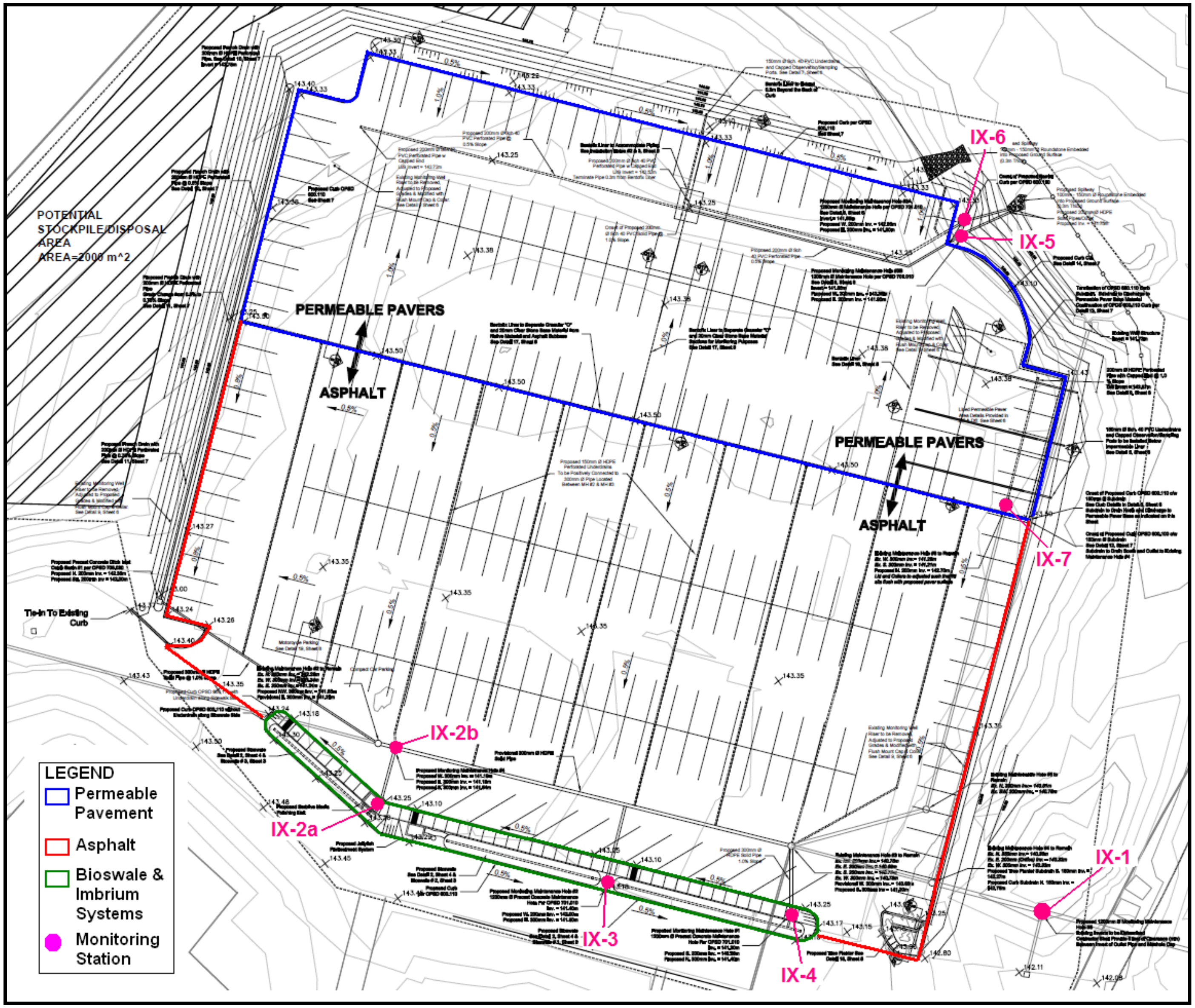

Figure A4: Location of monitoring stations

APPENDIX B

HYDROLOGIC DATA MANAGEMENT WORK PLAN

1 Collect new downloads
2 Export data to .csv format
3 Add data to Master excel files (note: Master file can be broken into multiple files if needed)

Recommendation: master file should have clearly labelled columns for each weir and observational well. Organize flow and precipitation data on one excel page and well data on a second excel page. Master file should also have a summary page. Include summation of all flows for entire dataset so that overall performance metrics can be calculated for the study.

Recommendation: Prepare two master files: collective system and individual systems

4 Inspect flow and precipitation data

Recommendation: Set conditional formatting on columns with flow and precipitation data so that cells with value > 0 are automatically highlighted

5 Review data and identify new hydrologic events
6 Categorize each event and determine the beginning and end date-time for each using definitions:

Event type	Beginning	End
Precipitation	precipitation observed	Outflow from all LIDs < MDL
Thaw	runoff observed, no precipitation observed	Outflow from all LIDs < MDL
No Outflow	precipitation and runoff observed, no outflow observed from LIDs	Runoff from asphalt < MDL

7 For each new event create an individual event file which includes raw hydrologic data during the event.
8 As individual systems determine event details and create event hydrograph

Recommendation: event details should include: start and end, runoff and outflow volumes, peak flows, area-normalized values, lag time, lag ratio, presence/absence of outflow, overflow and saturated conditions, precipitation type, antecedent dry conditions, precipitation duration and intensity, maximum well levels, relative volume and peak flow reductions etc.

Recommendation: for presentation purposes hydrographs may benefit from increasing the time step and averaging raw data. This is essentially smoothing the data so that visually it is easier to present outflows.

9 Calculate flows for collective system, determine event details and create event hydrograph
10 Update Master summary page by adding new event details
11 As desired add data to additional excel files for other time-based analysis (e.g. weekly, monthly, seasonal) or Master summary pages for other organizational schemes (e.g. event classes: Large, small, runoff only etc.)

WATER QUALITY DATA MANAGEMENT WORK PLAN

1 Submit water samples to lab
2 Receive water quality report
3 Add raw data (EMC and lab quality) to Master Water Quality Excel file

Recommendation: Give each event its own excel page but data could alternatively be separated and organized by LID.

Recommendation: Create two Master Files: Winter and Spring/Summer/Fall

4 Update Summary page for each LID and control

Recommendation: Include a method for flagging non-detects or instances of poor lab quality

5 Update Overall summary page

Recommendation: summary page should be set up to calculate event performance metric and water quality descriptive statistics

6 For temperature data follow a similar process as described by the *hydrologic data work plan*.

Recommendation: Set up graphics (time series, boxplots, probability plots etc) which update as data is added to the Master Water Quality file.

MAINTENANCE DATA MANAGEMENT WORK PLAN

1 Collect field permeability measurements, sediment levels in JellyFish and visual inspection of SorbtiveMedia cartridges

2 Add raw data to Master Maintenance Data Excel file
3 Calculate measured infiltration rate
4 Add data to Summary page

Recommendation: set up summary page to automatically average infiltration measurements. Set up graphics (time series, box plots) to automatically update as data is added to the Master Maintenance Data file.

DATA ANALYSIS WORK PLAN FOR SHORT TERM RESULTS

1 Generate descriptive statistics and graphical summaries
2 Determine data distribution
- Review descriptive statistics and graphical summaries
- Perform goodness-of-fit tests

3 Assess sample size
- Evaluate required sample size to ensure representative sample mean for desired confidence
- Evaluate the number of pairs for desired power, confidence interval and percent difference

4 Assess temporal patterns
- Examine time-series plots for seasonal and inter seasonal patterns
- Simple linear regression
- Create box plots grouped by season
- Auto-correlation

5 Performance comparison between LIDs and asphalt
- Report descriptive statistics for observed and calculated quantity and quality parameters (n, max, min, mean, median, skew, standard deviation, coefficient of variance) and relevant totals (e.g. total volume)
- Generate graphics for hydrologic and water quality parameters grouped by stormwater management technique (box plots, time series, probability plots)
- Perform statistical analysis (paired t-tests, sign test, simple linear regression)
- Evaluate confidence intervals
- If appropriate, report perform analysis for complete and seasonally-grouped data

6 System performance
- Calculate overall quantity and quality parameters
- Use methods described above

APPENDIX C

Water Quality Parameters and their respective low method detection limits, analytical method, bottles required, preservatives and hold times.

ANALYSIS BOTTLE IDENTIFICATION

PARAMETER	UNITS	LOWEST MDL	ANALYTICAL METHOD	BOTTLES REQUIRED	PRESERVATIVE	HOLD TIME (D)
Surface Water						
Alkalinity (Total as CaCO3)	mg/L	1	SM 2320B	250 mL - P		14
Orthophosphate (P)	mg/L	0.002	APHA 4500 P-G	250 mL - P		7
Total Kjeldahl Nitrogen (TKN)	mg/L	0.1	EPA 351.2 Rev 2	250 mL - P	Sulphuric Acid	28
pH	pH	0	SM 4500H+ B	250 mL - P		4
Conductivity	umho/cm	1	SM 2510	250 mL - P		4
Total Phosphorus	mg/L	0.02	SM 4500 P,B,F	250 mL - P	Sulphuric Acid	28
Dissolved Phosphorus	mg/L	0.002	APHA 4500 P, B, F	250 mL - P	-	7
Total Ammonia-N	mg/L	0.01	US GS I-2522-90	250 mL - P	Sulphuric Acid	28
Dissolved Chloride (Cl)	mg/L	1	EPA 325.2	250 mL - P		30
Total Suspended Solids (TSS)	mg/L	1	SM 2540D	2 x 500 mL - P		7
Total Dissolved Solids (TDS)	mg/L	10	APHA 2540C	500 mL - P		7
Nitrate + Nitrite	mg/L	0.1	SM 4500 NO3I/NO2B	250 mL - P		7
Nitrate (N)	mg/L	0.1	SM 4500 NO3I/NO2B	250 mL - P		7
Nitrite (N)	mg/L	0.01	SM 4500 NO3I/NO2B	250 mL - P		7
Turbidity	NTU	0.2	APHA 2130B	250 mL - P		1
Total Oil & Grease	mg/L	0.5	EPA 1664A	250 mL - P		28
Escherichia coli	CFU/100mL	10	MOE LSB E3371	250 mL - Sterilized P		48 hrs
Total Metals						
Aluminum (Al)	ug/L	0.5	EPA 6020	500 mL - P	Nitric Acid	6 Months
Chromium (Cr)	ug/L	0.5	EPA 6020	500 mL - P	Nitric Acid	6 Months
Cobalt (Co)	ug/L	0.05	EPA 6020	500 mL - P	Nitric Acid	6 Months
Copper (Cu)	ug/L	0.1	EPA 6020	500 mL - P	Nitric Acid	6 Months
Iron (Fe)	ug/L	5	EPA 6020	500 mL - P	Nitric Acid	6 Months
Lead (Pb)	ug/L	0.05	EPA 6020	500 mL - P	Nitric Acid	6 Months

Lithium (Li)	ug/L	0.5	EPA 6020	500 mL - P	Nitric Acid	6 Months
Magnesium (Mg)	ug/L	5	EPA 6020	500 mL - P	Nitric Acid	6 Months
Manganese (Mn)	ug/L	0.2	EPA 6020	500 mL - P	Nitric Acid	6 Months
Antimony (Sb)	ug/L	0.1	EPA 6020	500 mL - P	Nitric Acid	6 Months
Molybdenum (Mo)	ug/L	0.05	EPA 6020	500 mL - P	Nitric Acid	6 Months
Nickel (Ni)	ug/L	0.1	EPA 6020	500 mL - P	Nitric Acid	6 Months
Potassium (K)	ug/L	20	EPA 6020	500 mL - P	Nitric Acid	6 Months
Selenium (Se)	ug/L	0.2	EPA 6020	500 mL - P	Nitric Acid	6 Months
Silicon (Si)	ug/L	5	EPA 6020	500 mL - P	Nitric Acid	6 Months
Silver (Ag)	ug/L	0.01	EPA 6020	500 mL - P	Nitric Acid	6 Months
Sodium (Na)	ug/L	10	EPA 6020	500 mL - P	Nitric Acid	6 Months
Strontium (Sr)	ug/L	0.1	EPA 6020	500 mL - P	Nitric Acid	6 Months
Arsenic (As)	ug/L	0.1	EPA 6020	500 mL - P	Nitric Acid	6 Months
Thallium (Tl)	ug/L	0.005	EPA 6020	500 mL - P	Nitric Acid	6 Months
Tin (Sn)	ug/L	0.1	EPA 6020	500 mL - P	Nitric Acid	6 Months
Titanium (Ti)	ug/L	0.5	EPA 6020	500 mL - P	Nitric Acid	6 Months
Tungsten (W)	ug/L	0.1	EPA 6020	500 mL - P	Nitric Acid	6 Months
Uranium (U)	ug/L	0.01	EPA 6020	500 mL - P	Nitric Acid	6 Months
Vanadium (V)	ug/L	0.05	EPA 6020	500 mL - P	Nitric Acid	6 Months
Zinc (Zn)	ug/L	0.5	EPA 6020	500 mL - P	Nitric Acid	6 Months
Zirconium (Zr)	ug/L	0.1	EPA 6020	500 mL - P	Nitric Acid	6 Months
Phosphorus (P)	ug/L	5	EPA 6020	500 mL - P	Nitric Acid	6 Months
Barium (Ba)	ug/L	0.2	EPA 6020	500 mL - P	Nitric Acid	6 Months
Tellurium (Te)	ug/L	0.1	EPA 6020	500 mL - P	Nitric Acid	6 Months
Rubidium (Rb)	ug/L	0.02	EPA 6020	500 mL - P	Nitric Acid	6 Months
Beryllium (Be)	ug/L	0.05	EPA 6020	500 mL - P	Nitric Acid	6 Months
Bismuth (Bi)	ug/L	0.1	EPA 6020	500 mL - P	Nitric Acid	6 Months
Cesium (Cs)	ug/L	0.02	EPA 6020	500 mL - P	Nitric Acid	6 Months
Boron (B)	ug/L	1	EPA 6020	500 mL - P	Nitric Acid	6 Months
Cadmium (Cd)	ug/L	0.01	EPA 6020	500 mL - P	Nitric Acid	6 Months
Calcium (Ca)	ug/L	20	EPA 6020	500 mL - P	Nitric Acid	6 Months
Polycyclic Aromatic Hydrocarbons (PAH)						
D10-Anthracene	%		EPA 8270	2 x 500 mL - AG	-	14
D14-Terphenyl (FS)	%		EPA 8270	2 x 500 mL - AG	-	14
D8-Acenaphthylene	%		EPA 8270	2 x 500 mL - AG	-	14

Naphthalene	ug/L	0.05	EPA 8270	2 x 500 mL - AG	-	14
Chrysene	ug/L	0.05	EPA 8270	2 x 500 mL - AG	-	14
Benzo(k)fluoranthene	ug/L	0.05	EPA 8270	2 x 500 mL - AG	-	14
Benzo(a)pyrene	ug/L	0.01	EPA 8270	2 x 500 mL - AG	-	14
Acenaphthylene	ug/L	0.05	EPA 8270	2 x 500 mL - AG	-	14
Indeno(1,2,3-cd)pyrene	ug/L	0.05	EPA 8270	2 x 500 mL - AG	-	14
Dibenz(a,h)anthracene	ug/L	0.05	EPA 8270	2 x 500 mL - AG	-	14
Benzo(g,h,i)perylene	ug/L	0.05	EPA 8270	2 x 500 mL - AG	-	14
2-Methylnaphthalene	ug/L	0.05	EPA 8270	2 x 500 mL - AG	-	14
Acenaphthene	ug/L	0.05	EPA 8270	2 x 500 mL - AG	-	14
Benzo(b/j)fluoranthene	ug/L	0.05	EPA 8270	2 x 500 mL - AG	-	14
Fluorene	ug/L	0.05	EPA 8270	2 x 500 mL - AG	-	14
1-Methylnaphthalene	ug/L	0.05	EPA 8270	2 x 500 mL - AG	-	14
Benzo(a)anthracene	ug/L	0.05	EPA 8270	2 x 500 mL - AG	-	14
Phenanthrene	ug/L	0.03	EPA 8270	2 x 500 mL - AG	-	14
Biphenyl	ug/L	0.05	EPA 8270	2 x 500 mL - AG	-	14
Anthracene	ug/L	0.05	EPA 8270	2 x 500 mL - AG	-	14
Fluoranthene	ug/L	0.05	EPA 8270	2 x 500 mL - AG	-	14
Pyrene	ug/L	0.05	EPA 8270	2 x 500 mL - AG	-	14
NOTE: P - Plastic Bottle, AG - Amber Glass						