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LOW IMPACT DEVELOPMENT PRACTICES FOR STORMWATER MANAGEMENT FOR ROAD RECONSTRUCTION PROJECTS IN SOUTHERN ONTARIO

Senior, Matthew[1,5], Scheckenberger, Ronald[1], Smith, Neal[1] and Stahl, Jason[1]

[1] Amec Foster Wheeler, Canada

[2] matt.senior@amecfw.com

Abstract: Roadway reconstruction projects are one of the most common infrastructure projects in the public sector. These projects often involve a renewal of aging, failing infrastructure, or can be the result of local development pressures which requires a widening of the existing roadway. In all roadway reconstruction projects, stormwater management (SWM) is a key consideration. At a minimum, regulatory authorities typically expect the control of runoff (peak flows) to pre-reconstruction values, as well as water quality treatment of any new paved areas. Increasingly however, regulatory authorities are requiring more stringent SWM controls for reconstruction projects, including requirements for the promotion of on-site retention and infiltration of stormwater runoff (volume controls and water quality). Low Impact Development Best Management Practices (LID BMPs) refer to a suite of SWM controls which promote at-source management of stormwater, and focus on the use of retention, infiltration, and filtration of runoff. LID BMPs are being used increasingly for road reconstruction projects to address the requirements of regulatory authorities, and to promote a more sustainable, resilient, and often more cost-effective solution to SWM requirements. The suite of different LID BMPs provides a variety of options for designers to account for the specific opportunities and constraints of the site in question. Recent road reconstruction projects in various Southern Ontario municipalities are presented as examples. Successful applications of LID BMPs are demonstrated, including innovative approaches. Challenging applications, including high density development areas and areas with relatively impermeable soils and high groundwater levels, are also presented. The differing perspectives of stakeholders are considered, including municipalities (engineering and operations and maintenance groups), regulatory authorities, and designers.

Keywords: low impact development, best management practices, stormwater management, roadway, road reconstruction, infrastructure

1 Introduction

Roads and bridges are among the most common components of government-owned infrastructure, representing approximately 40% of all such items in Canada (Roy, 2008). In Ontario, the stock of infrastructure capital in roads was estimated as some $25 billion as of 2005, and has been rising continuously since the 1960s (Roy, 2008). As the stock of road infrastructure continues to rise and age, roadway reconstruction has become one of the most common infrastructure projects in the public sector. At the municipal level, road reconstruction projects are typically planned based on level of service criteria and/or identified deficiencies or failures of surficial or sub-surface components, or may be the result of local development pressures or increased traffic demand.

Road reconstruction projects require permitting and approvals prior to construction, with environmental approvals forming a primary component of this process. In the Province of Ontario, municipal road reconstruction approvals typically involve multiple agencies. At the Provincial level, the Ministry of the Environment and Climate Change issues Environmental Compliance Approvals (ECAs) for water, wastewater and stormwater infrastructure. Conservation Authorities (watershed-based regulatory agencies in Ontario) provide input and approvals on stormwater management related matters, particular in regulated areas (i.e. watercourse crossings) or as part of broader watershed/subwatershed planning goals and objectives. The Municipality also provides review and approval of designs, particularly given that this level of government is typically charged with the ownership, and ongoing operations and maintenance of roadways and related infrastructure. All parties to the roadway reconstruction project have an interest in supporting a reliable, sustainable roadway design which satisfies regulatory requirements, while not placing undue burden and cost on the municipality, as the ultimate owners and operators of the roadways.

Stormwater management (SWM) is a key consideration in roadway reconstruction projects with respect to approvals and permitting. This relates to both the management of stormwater quantity (i.e. peak flows and volumes in runoff) as well as stormwater quality (i.e. treatment of the increased pollutant loads associated with roadways). Traditional SWM has focused on “grey” infrastructure, such as storm sewers and oil/grit separators to achieve project requirements. Increasingly however, there has been a focus on “green” infrastructure (GI) measures, typically referred to Low Impact Development/Best Management Practices (LID/BMPs) which promote at-source controls. These measures are being promoted not only for broad-based environmental benefits, but in many cases also due to potential cost benefits both in construction and life cycle costs (including operation and maintenance). From a practical perspective, LID/BMPs are increasingly mandated by regulatory authorities as part of the approval process.

This paper reviews recent experiences with the implementation of LID/BMPs for road reconstruction projects in Southern Ontario, including successful applications, and those in challenging conditions. The differing perspectives of stakeholders involved in these projects are also considered, including municipalities (engineering and operations and maintenance groups), regulatory authorities, and designers.

2 Stormwater Management for Roadways

2.1 Traditional Stormwater Management

Approaches to stormwater management (SWM) have evolved steadily over time. Initial efforts were focused largely on conveyance capacity only, with sewers and culverts sized adequately to convey the predicted design flows. Later efforts recognized the need for quantity control, with the standard objective of “post to pre” (control of post-development flow rates to pre-development values). In the last 20 +\- years, there has also been a recognition of the need for quality control, to mitigate the increased pollutant loads (suspended sediments, metals, nutrients, etcetera) associated with urbanization, particularly roadways and associated paved surfaces.

Current requirements for SWM for roadway reconstruction projects in Ontario tend to vary depending on the type of reconstruction being proposed. General design guidelines are provided by the Province of Ontario (Ministry of Transportation Drainage Management Manual, 1997 and Ministry of the Environment Stormwater Management Planning and Design Manual, 2003), however other specific guidelines tend to vary by municipality and Conservation Authority. At a minimum, regulators typically expect quantity control of runoff (“post to pre”), as well as quality treatment of any new paved areas (between 70 and 80% average annual removal of total suspended solids (TSS)) (MOE, 2003, Town of Oakville, 2013, etcetera).

Thus for roadway reconstruction projects which are simply “like for like” (i.e. do not involve any road widening or change in road type), SWM may involve simply replicating what is (or is not) present already, and ensuring adequate capacity in roadway storm sewers or other conveyance infrastructure. Some exceptions may occur however, including cases where approved municipal plans mandate retrofit stormwater quantity or quality controls. In some older areas which pre-date approvals for SWM, the Province of Ontario (MOECC) has required retrofit controls, through the elimination of its previous “grandfathering” clause. In other cases, some form of SWM controls may be required due to existing deficiencies (i.e. insufficient outlet capacity).

Where roadway widening or urbanization is proposed (i.e. transition from a ditched cross-section to a curb and gutter section), some form of quantity and quality control is typically required as noted previously. Given the space limitations associated with the majority of roadway reconstruction projects (i.e. existing urban areas), a surface SWM storage facility is typically not feasible, unless an existing facility is located in close proximity and has sufficient capacity. In other cases, traditional "grey" infrastructure is typically employed; quantity control is typically achieved through the use of sub-surface storage (tanks, or large diameter "super pipes"), and quality control is achieved through the use of oil/grit separators (gravity or hydrodynamic based).

While these approaches to SWM are typically sufficient to meet minimum regulatory criteria and obtain construction permits, there are a number of concerns with this traditional "grey" approach:

- "Like for like" may not account for the lack of SWM consideration in the original design;
- "Post to pre" peak flow management does not account for erosion mitigation for smaller storm events, nor does it mitigate the increase in runoff volume;
- Does not account for changes in the hydrologic cycle, including decreased groundwater recharge and evapotranspiration from previous vegetated areas;
- Underground storage is typically costly and may be onerous to maintain over time;
- Oil/grit separators have a limited treatment capacity, and treat only suspended contaminants (i.e. minimal benefit to reduction of nutrient loadings such as nitrogen and phosphorous); and
- Limited resilience and adaptability of "grey" SWM, particularly in light of climate change concerns.

The preceding concerns (as well as other areas of consideration) have led to an increasing interest of "greener" at source SWM controls.

2.2 Low Impact Development Best Management Practices (LID BMPs)

Low Impact Development Best Management Practices (LID BMPs) refer to a suite of SWM controls which promote at-source management of stormwater, and focus on the use of retention, infiltration, and filtration of runoff. The suite of LID BMPs provides options to account for the specific opportunities and constraints of the subject roadway reconstruction project. Some options include (but are not limited to):

- Roadside bio-retention areas;
- Permeable pavements (permeable asphalt, permeable concrete, paving stones);
- Roadside swales (enhanced grass swales, bio-swales);
- Perforated pipe systems (exfiltration pipes); and
- Prefabricated units (soil retention systems, filter media, etcetera).

Figure 1 presents typical examples of roadside LID BMPs (bio-retention and swales). LID BMPs are being used increasingly for road reconstruction projects to address the requirements of regulatory authorities, and to promote a more resilient and environmentally sustainable SWM strategy. LID BMPs tend to address concerns related to attenuating runoff, enhancing groundwater recharge and runoff volume reduction, mitigation of temperature increases, filtration of contaminants and increased water quality performance.

In Ontario, there are a number of resources available to support LID BMP design and implementation, largely generated by conservation authorities in the Greater Toronto Area (CVC/TRCA, 2010). This also includes guidance documents prepared specifically for roadway reconstruction projects (CVC, 2014) among other types of infrastructure projects. Regulatory authorities are also increasingly requiring that SWM designs incorporate some LID BMPs. Emerging policy direction from the Province of Ontario (in the form of the pending release of an updated Stormwater Management Planning and Design Manual from the MOECC) is anticipated to mandate targets for on-site infiltration and control for all projects, which will require designers to incorporate LID elements into the overall SWM strategy. This is consistent with a policy statement previously released by the MOECC (2015).

Figure 1: Typical Roadside LID BMP Installations (Amec Foster Wheeler)

While regulatory support and design guidance continue to increase to support LID BMP implementation for roadway reconstruction projects, there continue to be a number of different barriers to more extensive implementation. In general, some common barriers and concerns include:

- Performance (surface ponding concerns, aesthetics, winter impacts including salt, potential groundwater impacts in areas serviced by groundwater for drinking water);
- Long-term maintenance (uncertainty as to requirements and effort);
- Site-specific constraints (limited surface space, utility conflicts, feasibility in areas with low permeability soils, high groundwater table, groundwater mounding around buildings and/or infrastructure); and
- Costs (additional construction costs as well as operations and maintenance (O&M) costs);

A number of studies have made a strong business case for LID BMPs in comparison to conventional SWM for roadway reconstruction projects with respect to economics related to both construction costs and long-term operation and maintenance costs (CVC, 2014). Other studies have specifically targeted concerns about long-term O&M costs (STEP, 2013), demonstrating that overall life cycle costs for LID BMPs are equal to or less than those for traditional "grey" SWM infrastructure. Notwithstanding, concerns over cost and effectiveness continue to be a concern for municipalities as owners and operators of roadways. These issues are discussed in subsequent sections as part of a review of actual roadway reconstruction projects.

3 Project Examples

3.1 Project Example 1 (Dundas Street)

Dundas Street (also known as Regional Road 5) is a major arterial roadway which runs parallel to the shore of Lake Ontario, from approximately Highway 6 (City of Hamilton) to Highway 427 (City of Toronto). A large section of this roadway (24 km +\-) is under the jurisdiction of Halton Region, an upper tier municipality which administers Regional Roadways, water and wastewater infrastructure (amongst other services) for its member municipalities, including the City of Burlington, Town of Oakville, Town of Milton, and Town of Halton Hills. Amec Foster Wheeler Environment & Infrastructure (AFW) was retained to undertake the detailed design and contract administration for a 2.7 km +\- portion of Dundas Street within the Town of Oakville (refer to Figure 2). The section of Dundas Street in question is currently a four (4) lane roadway, with two (2) lanes in each direction. The roadway section is primarily rural, with roadside ditches for drainage, generally outletting to storm sewers or watercourses to the south.

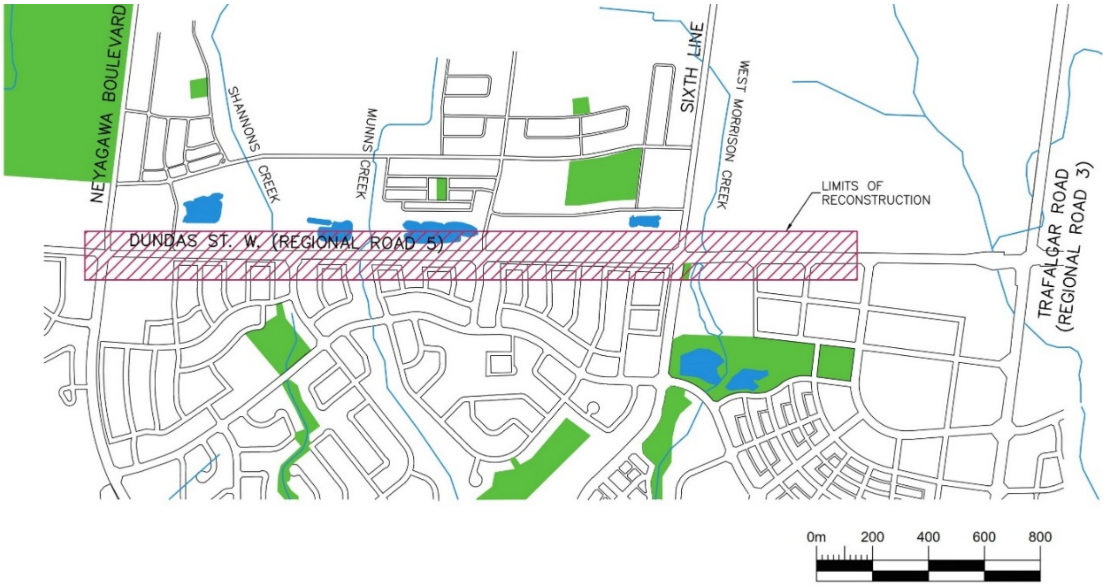


Figure 2: Dundas Street Study Limits (Amec Foster Wheeler)

A preliminary design was conducted as part of a previous Environmental Assessment (MRC, 2013), which determined the need for the widening as well as the preferred cross-section (widening to six (6) lanes and urbanizing to curb and gutter with a solid raised median). With the exception of one section of roadway which was designed to drain to a stormwater management (SWM) facility, the majority of the roadway SWM was recommended to consist of on-site controls (underground storage tanks and oil/grit separators). The Environmental Assessment (EA) indicated that Low Impact Development (LID) measures "should be considered at detailed design" but did propose any specific approaches, locations, or targets. The EA did however note that the highly urbanized nature of the corridor and narrow right-of-way widths would make LID implementation challenging. This was confirmed as part of the preliminary detailed design process, which indicated limited space in the boulevard area for surface-based LID features which may be able to replicate some of the benefits of the existing roadside ditches.

The geotechnical investigation completed in support of detailed design indicated that subsurface soils were predominantly silty clay till, with a very low corresponding rate of saturated hydraulic conductivity (0.1 mm/hr +\-). Elevated groundwater levels were also noted in several locations with levels approaching less than 1 m +\- below ground surface. Both of these findings were considered to be barriers to wide-spread implementation of LID BMPs for the roadway. The subsurface utility engineering (SUE) investigation for the roadway also indicated an abundance of underground utilities in the area, many of which would be expected to interfere with LID BMPs.

Furthermore Halton Region staff expressed a number of concerns with respect to LID BMPs, including:

- Suitability of localized infiltration (LID) measures on a six-lane arterial roadway;
- Potential for long-term maintenance issues (difficulties in maintaining LID BMPs in close proximity to a busy road, potential road salt impacts, uncertainty on how to maintain LID BMPs);
- Functional concerns (given geotechnical report results);
- Additional construction cost implications.

Given the preceding, the initial SWM strategy for the roadway did not include any LID BMPs, but rather focused on more traditional "grey" infrastructure, including oil/grit separators, catchbasin inserts, and underground storage tanks. Regulatory agencies (both the Town of Oakville and Conservation Halton, the local Conservation Authority) however indicated that some form of LID BMPs should be implemented for the project in order to be consistent with the intent of the original Class EA, preferably focused on the more erosion-sensitive receiving watercourses within the limits of work. The regulatory authorities in this case acknowledged the site specific constraints and concerns, however were of the opinion that some limited

LID BMP implementation was feasible and would also be beneficial in promoting LID BMP implementation for other future roadway reconstruction projects.

Based on the feedback received during the detailed design phase, the Project Team generated a long-list of potentially feasible LID BMPs for the roadway, including:

- Pre-fabricated catchbasin units with specialized filter media (i.e. Imbrium Systems);
- Modified catchbasin units with pre-fabricated soil reinforcement grids (i.e. DeepRoot);
- Permeable pavement (asphalt, concrete or paving stones) for the multi-use pathway; and
- Permeable pavement (asphalt, concrete or paving stones) for the bus bay areas.

The long-list of alternatives was reviewed with respect to technical effectiveness, constructability/site feasibility, maintenance requirements, and cost. For instance a permeable multi-use pathway, while feasible and relatively cost effective, would have minimal technical effectiveness with respect to stormwater quality treatment, given the expected low level of sediment loading (no vehicle traffic) and the presence of a vegetated buffer (grass) already in place between the multi-use pathway and the existing roadway. Other factors were also considered. In some cases existing standards were also a barrier to LID BMP implementation: permeable bus bays in particular were not considered acceptable to Region Staff.

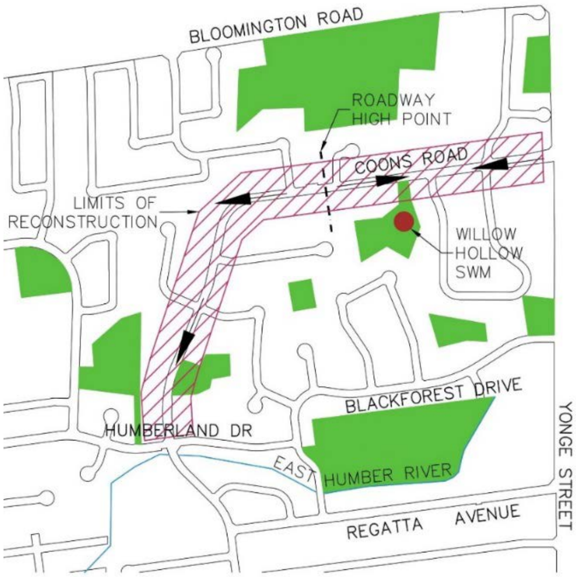
Ultimately, it was determined that modified catchbasin units with pre-fabricated soil reinforcement grids (i.e. DeepRoot) would be the preferred practice in this case. In this system, roadway catchbasins would be modified such that the low flow outlet from the catchbasin is directed into the planter units, while high flows are allowed to bypass the planter units and outlet to the conventional storm sewer. The modular soil reinforcement structures provide structural reinforcement and allow for less compacted soils (no compaction machinery required) below paved surfaces, such as the roadway multi-use pathway. This in turn allows for greater void space for stormwater retention and infiltration, and stormwater uptake by trees, which are planted into cut-outs within the system. The systems therefore provide additional water and higher quality, uncompacted soil for roadside trees, which supports enhanced tree growth. This leads to healthier trees which require less maintenance, which also benefits Region staff, who along with other regulatory authorities, had noted frequent issues with high mortality rates for roadside trees. Currently two (2) different blocks of soil reinforcement grids (supporting approximately 12 trees +\- each) are being proposed for the two most erosion-sensitive watercourses within the limits of reconstruction. Detailed design work for these features is ongoing, with construction planned for later in 2017.

3.2 Project Example 2 (Coons Road)

Coons Road is a local collector road within the community of Oak Ridges, which is part of the Town or Richmond Hill, in York Region (refer to Figure 3). The road connects Yonge Street (a major arterial) with local residential streets, as well as other local collector roads. AFW was retained to undertake the detailed design and contract administration for the proposed reconstruction of a 1.5 km +\- section of the roadway.

The section of Coons Road is a typical local collector road, with two (2) lanes (one in either direction). The roadway has roadside ditches for drainage. Under existing conditions, the roadway is generally split between two (2) different drainage system outlets. The first includes an existing oil/grit separator and a flood control facility (dry pond – Willow Hollow Park), while the second has no controls, and outlets directly to a tributary of the East Humber River (refer to Figure 3). The proposed works involve urbanizing the cross-section (curb and gutter) and widening the roadway slightly (< 1 m) to meet Town standards.

A minor portion of the reconstruction limits (which outlet to a tributary of the East Humber River) are regulated by the Toronto Region Conservation Authority (TRCA), which therefore requires a permit application for the overall project. As part of its general SWM requirements, the TRCA requires that there be zero runoff from the first 5 mm of rainfall (i.e. that all runoff is captured and infiltrated). This requirement essentially mandates the implementation of some form of source control, since conventional “grey” SWM quantity control infrastructure focuses solely on peak flow control and does not promote infiltration or volume reduction. Further, the TRCA also credits only 50% total suspended solids (TSS) removal for oil/grit separator units, which essentially requires a secondary form of treatment (i.e. LID BMPs) to achieve the required overall 80% TSS removal rate (i.e. treatment train approach).



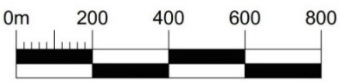


Figure 3: Coons Road Study Limits (Amec Foster Wheeler)

The geotechnical investigation completed for this study indicated variable results along the length of the roadway. Those sections of the roadway draining towards Willow Hollow Park generally had much more pervious sub-soils (silty sands and sandy silts), and no reported groundwater near surface. Those sections of the roadway draining towards the East Humber River tributary however had relatively impermeable soils (silty clays with saturated hydraulic conductivities less than 0.1 mm/hr) and in some cases elevated groundwater levels. As such, while LID BMPs were considered less practical for the north-eastern portion of the roadway, LID BMPs were considered more difficult for the south-western portion of the roadway, particularly given that the reconstruction included an urbanization (i.e. elimination of ditching or other surface conveyance features that could potentially be used).

These concerns were discussed with the TRCA, along with an overall SWM strategy for addressing source controls. It was suggested that scoped LID BMPs be implemented for the less permeable south-western portion of the roadway, while more fulsome LID BMPs be pursued for the more permeable north-eastern portion of the roadway. It was further suggested that the north-eastern LID BMPs would be designed to retain an amount greater than the required 5 mm minimum of rainfall, such that the overall retention for the roadway reconstruction was equivalent to an average retention of 5 mm. This approach was ultimately deemed acceptable to the TRCA, and fully supported by Town staff.

Localized blocks of soil reinforcement grids have been proposed for portions of the boulevard area along the south-western section of the roadway. As noted with respect to the preceding project example, these systems provide a benefit not only with respect to stormwater retention and filtration, but also uptake by new trees and benefits to tree growth and health. An oil/grit separator is also proposed to provide secondary water quality treatment to meet system requirements. An underground storage tank or surface storage feature is also currently being considered to meet quantity control requirements.

For the north-eastern portion of the roadway, a more extensive system of exfiltration pipes has been proposed. In these locations the system has been essentially designed as a “dual” storm sewer system, with a low perforated pipe system placed in a granular surround, and then a standard non-perforated storm sewer for higher flows. An example is shown in Figure 4. Town staff was particularly supportive of this approach, given its positive experience on other road reconstruction projects. In addition, this system has minimal additional construction costs (exfiltration pipes are placed in parallel with traditional storm sewers), and smaller expected maintenance costs as compared to surface-based measures. Currently, this project is advancing through the detailed design and permitting stage, with construction likely scheduled for 2018.

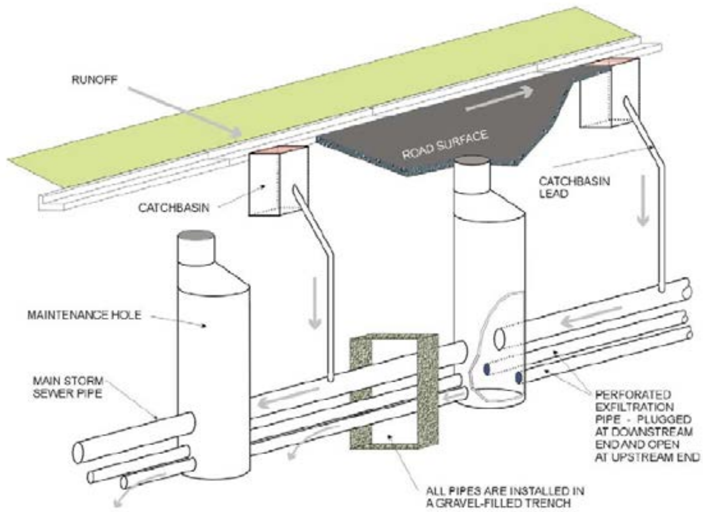


Figure 4: Typical Exfiltration Pipe System (SWAMP, 2004)

3.3 Project Example 3 (Mississauga Road)

Mississauga Road (Regional Road 1) is a major north-south arterial roadway under the jurisdiction of the Region of Peel within the City of Brampton. Mississauga Road extends through the City of Mississauga to the south, and the City of Brampton and the Town of Caledon to the north. Amec Foster Wheeler was retained to complete an environmental assessment and preliminary design for the proposed road widening of a 5 km section of Mississauga Road. Mississauga Road is currently two (2) lanes (one in either direction), and is proposed to be widened to four (4) lanes (two in either direction).

Huttonville Creek runs parallel to the east side of Mississauga road, for approximately 500 m. Huttonville Creek contains several fish species, including Redside Dace (Clinostomus elongates) which was uplisted to endangered in 2009 under Ontario's Endangered Species Act, 2007 (ESA 2007). Redside Dace require cool, clear flowing water with riffle-pool sequences and overhanging streamside vegetation. Due to the impact to Redside Dace, the approved approach was to build the ultimate road section on the east side first, so further widening would not impact the creek or Redside Dace habitat. The drainage system design will need to account for existing drainage as well as drainage for the future roadway widening to the west.

One design concept currently being assessed for the project is a "sewerless road", which has been previously considered on other Regional road projects. A conceptual cross-section is presented in Figure 5. In a "sewerless road", storm drainage is address by using an extensive LID BMP system, rather than the conventional "grey" storm sewer system. Catchbasins outlet to the first section of an underground storage system which has built in sumps to trap sediment. This system is in turn surrounded by clear stone aggregate with a large void space ratio. The system would be constructed with minimal grade to allow stormwater increased infiltration time. During a storm event, the void space within the aggregate would be used and allow for infiltration. Once aggregate storage is maximized, storage space within the underground chambers is used. In the event that all storage is maximized, flows would utilize the major system (overland flow) to a suitable outlet. The "sewerless road" system provides quality and quantity control, erosion control, infiltration and groundwater recharge, and thermal mitigation benefits. It is considered that the optimum location for this system would be underneath the multi-use trail or sidewalk. The system also provides multiple access points for future maintenance (sediment removal), and is considered to be cost effective by eliminating the costs of storm sewer pipes and maintenance holes. The system is considered particularly advantageous for the study area, given the presence of multiple highly permeable sand layers in the surficial soils. The project is still in the alternative assessment phase, with a final road cross-section still to be determined. Road construction is not expected until 2020.

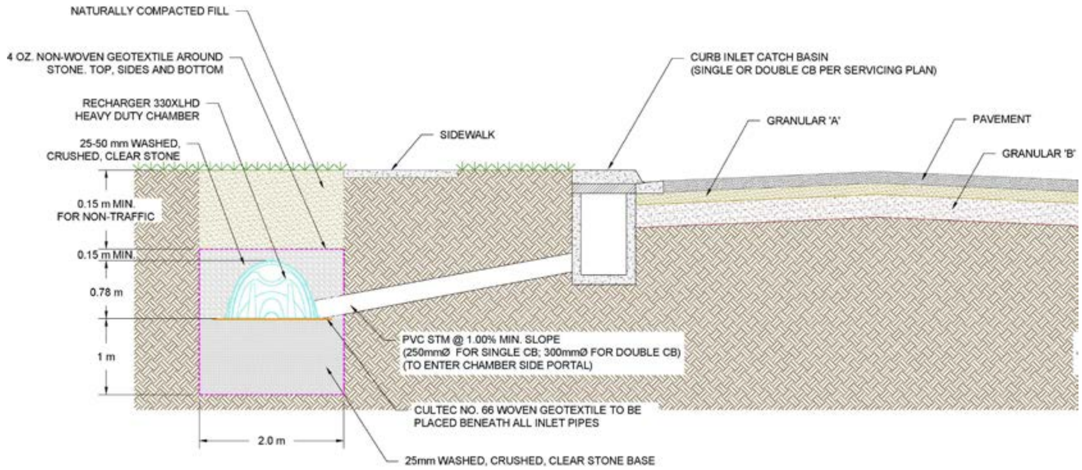


Figure 5: Sewerless Road Conceptual Road Cross-Section (Region of Peel, 2016)

4 Summary and Future Considerations

Roadway reconstruction projects are one of the most common infrastructure projects in the public sector. In all roadway reconstruction projects, SWM is a key consideration. LID BMPs are being used increasingly for road reconstruction projects to address the requirements of regulatory authorities, and to promote a more sustainable, resilient, and often more cost-effective solution to SWM requirements. The suite of different LID BMPs provides a variety of options for designers to account for the specific opportunities and constraints of the site in question.

The roadway reconstruction projects cited in this paper demonstrate the numerous different considerations which must be taken into account when implementing LID BMPs. These include:

- In the first two project examples, the implementation of LID BMPs was largely an afterthought – the roadway layout was already determined by the transportation engineers. Consideration of LID BMP measures should be considered at the outset of the roadway design process.
- The need for roadway urbanizations (i.e. conversion of existing ditched/rural roadways) should be carefully considered. While in some cases they may be necessary (particularly for major roadways or roadways with limited space within the right-of-way), for more local roadways or those with sufficient space in the right-of-way, a rural cross-section incorporating LID/BMP measures may be able to provide a greater environmental benefit, at a lower cost than more traditional “grey” infrastructure”. Municipal concerns with respect to maintenance (ditch sedimentation and erosion and crushed driveway culverts) should however be considered.
- Designers and regulatory authorities need to acknowledge the constraints associated with the physical properties of the sites (i.e. relatively impermeable soils, groundwater conditions, and utility conflicts). While in many cases these constraints can be addressed through scoped measures, in some cases LID BMPs may not be suitable. Attempting to implement LID BMPs in unsuitable conditions will likely lead to failure, which will result in maintenance and operation issues for the municipalities, and potentially less of a willingness to incorporate such measures on future projects.
- Notwithstanding the preceding, LID BMP measures can still be considered in constrained conditions. Implementation should not be totally discarded due to less than ideal conditions, however these conditions need to be taken into account. Small scale projects may also provide an opportunity for all parties involved in the design and approval of roadway reconstruction projects to gain a greater familiarity and level of comfort with these systems, including maintenance requirements. This in turn will likely lead to increased application on future projects.

- Where conditions are not constrained (i.e. highly permeable sandy soils), full implementation of LID BMP measures may be possible, such as the “sewerless road” concept, which will address all SWM requirements and potentially result in cost savings.
- Approval and support by regulatory agencies is key to increasing the implementation of LID BMPs in future roadway reconstruction projects. Designers must know that regulatory authorities will provide full credit for these measures as part of the overall SWM strategy in order to generate a more holistic, cost-effective design. Pending regulatory changes in Ontario will also likely encourage/motivate designers (and owners) in this regard.
- Concerns with respect to long term O&M costs may be valid for initial installations, however studies have shown that these costs tend to reduce over time. Recent studies have also shown that life cycle costs for LID BMPs are frequently less than for conventional “grey” infrastructure. Traditional infrastructure has long-term maintenance requirements, just as LID BMP measures do.

5 Acknowledgements

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