Planning and Design Manual of the Etobicoke Exfiltration System for Stormwater Management

By

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1. Introduction

The Etobicoke Exfiltration System (EES), as depicted in Figure 1, was created, designed and constructed (2.5 km) in the former City of Etobicoke (now part of the City of Toronto) in 1993. Its main objective was to restore the natural hydrologic cycle in a built-up area of the City. In doing so, the City recognized that the following concerns of storm water management be addressed:

- Intensity,
- Volume,
- Quality,
- Duration; and,
- Frequency.

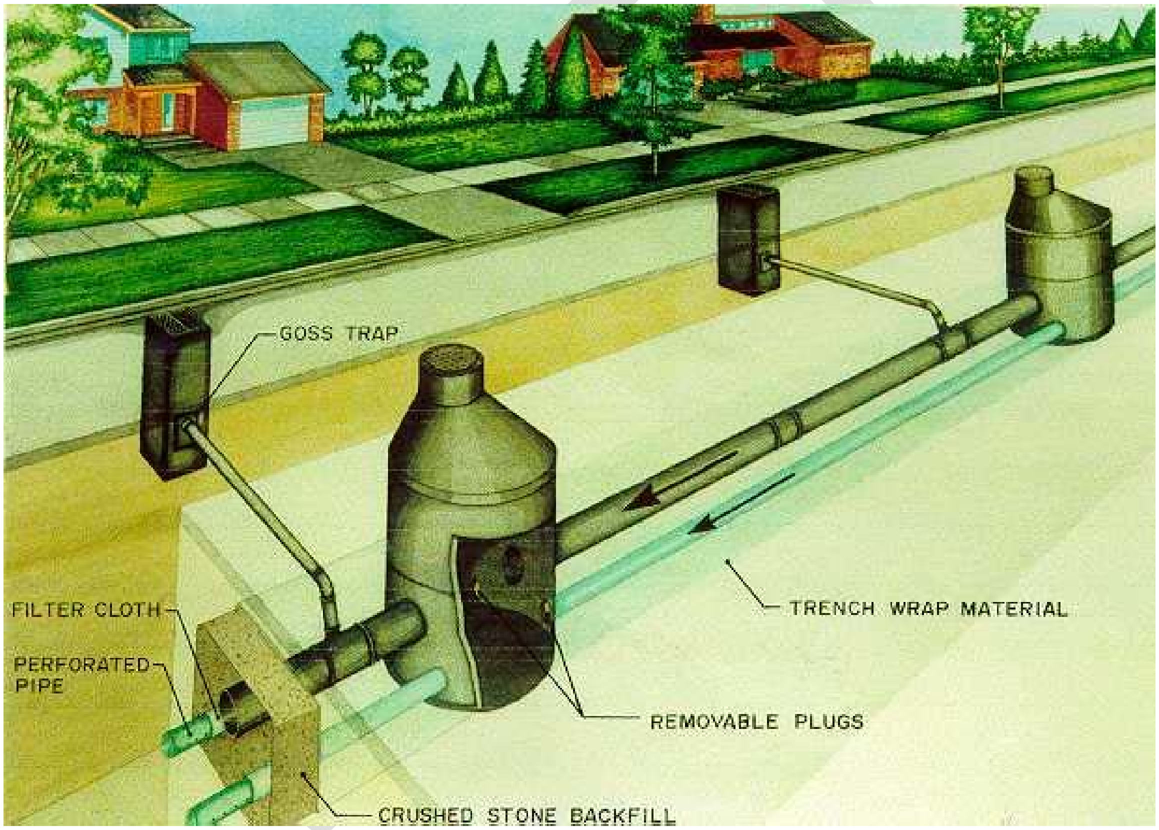


Figure 1 Sketch of the Etobicoke Exfiltration System.

The original design evolved over a long period as it was developed manually. Today with computer simulation models available (e.g. MIDUSS, SWMM), development of various design alternatives can be refined efficiently. Together with appropriate research and field monitoring programs, the design can be improved effectively.

The development of the EES has introduced a new holistic approach to design urban storm water infrastructure. Despite stormwater infrastructure designs often do not receive recognition, the EES was the recipient of the Great Lakes Sustainability Fund's Environmental Award in 1994.

With the EES' ability to infiltrate small and relatively large storms and to address winter/spring runoff, the need for four season storrmwater management is recognized among stormwater management practitioners in Canada, resulting in the development of this document. The following sections describe the principles, objectives, and design process of the EES.

2. Planning of the Etobicoke Exfiltration System.

Although the EES has been in place longer than the majority of quality ponds in Ontario, its design and benefit was not understood until recently. Since its installation under a storm sewer and road in Etobicoke in 1993, the MOECC's 2003 Stormwater Management Planning and Design Manual (MOECC manual) categorizes it as a pervious pipe system. However, the EES was erroneously described as a single perforated pipe under the storm sewer when two perforated pipes were actually recommended and installed in 1993. Section 3 of the MOECC manual describes the objectives of the storm water management criteria are to:

- *"Preserve groundwater and baseflow characteristics;*
- *Prevent undesirable and costly geomorphic changes in watercourses;*
- *Prevent any increase in flood potential;*
- *Protect water quality; and ultimately,*
- *Maintain an appropriate diversity of aquatic life and opportunities for human use."*

The above objectives are much narrower than those of the EES (Appendix G). For example, in promoting the maintenance of the groundwater level, the EES also promotes the maintenance of biodiversity of natural features along stream corridors leading to diversity of birds nesting, of benthic life, and of aquatic food, habitat and species. This was demonstrated at the Queen Mary pilot site where a soil bio-engineering technique was used to rehabilitate a bank failure caused by the road at the top of the bank. Evidence of this type of biodiversity can be found along natural streams which have not been encroached by or modified for human habitat and where the groundwater level has been maintained (e.g. Humber creek, Little Rouge, Grand River in the Greater Toronto area). These are classified as environmental objectives and dealt with in Table 1 (Environmental and Aquatic Objectives). On the other hand, aquatic life and natural features are less impacted by natural flooding and geomorphic changes to streams than by encroaching human habitats. Evidence of creek bed changes dating to the pre-development era can still be seen in many streams in the Greater Toronto area (e.g. Mullet Creek, Don River). Evidence and signs of Hurricane Hazel cannot be found in most urban streams and rivers other than flood structures built after this main event. Flooding and geomorphic changes have resulted in major costly infrastructures (e.g. Clairville reservoir, G Ross Lord reservoir, Black Creek channel) to protect human habitat. These objectives address human benefits in Table 2 (Human Habitat Objectives) which is categorized to be stormwater management objectives associated with human needs and activities. The EES, as a right-of-way low impact development technology, is most beneficial in both the prevention and mitigation of the development foot print.

Finally, a cost saving objective is not and never was the original EES objective of stormwater management. Thus, it is not included in either table.

Table 1- Environmental and Aquatic Objectives (Modified after Ternier 2013)

Environmental Objectives	Suitability	EES-Actions	Comments
Preserve groundwater	Yes	Infiltrate 90% of rainfall events	Includes snowmelt and spring runoff. Also important to the maintenance of uptake by vegetation that depend on groundwater during drought or dry season
Preserve baseflow characteristics	Yes	Recharge groundwater according to duration and frequency dictated by rain events	Of particular importance in small streams, in head water, and in coldwater fishery habitats
Protect water quality	Yes	Lower discharge of pollutants to streams/lakes during four seasons	Better quality of stormwater discharge including lower temperature than end of pipe treatments
Maintain aquatic and terrestrial bio-diversity	Yes	Maintain pre-development groundwater level by enhancing source infiltration	Each vegetation type depends on ground water uptake during the dry season. This diversity is needed as a food supply to aquatic life and for bird nesting, etc…
Protect spawning and rearing grounds	Highly Yes	Maintain baseflow, lower sediment loading, lower temperature	Most aquatic species depend on temperature and river bed substrate for spawning and rearing
Protect migratory corridors	Yes	Maintain natural pools/riffles	EES attenuates runoff peak flow of all storms
Protect wetlands	Highly Yes	Maintain a constant baseflow to the wetland	The EES in Brantford was installed for such reason
Minimize impacts of climate changes	Yes	Underground storage provides cooler temperatures	Preservation of natural features by maintaining groundwater level and baseflow during dry season and long period of drought

Table 2 - Human Habitat Objectives (Modified after Ternier 2013)

Human habitat objectives	Sustainability	EES-Actions	Comments
Drinking water	**No**	Potential contamination of drinking water source	Additional studies needed on quality of groundwater, its ability to dilute various concentrations, and effects of soil chemistry to retain certain pollutant (ie metals)
New Residential sites	Yes	Potential elimination of the need for quality ponds and associated safety concerns	In new developments, EES storage volume may be greater than present quality pond designs
New Industrial sites	**No**	Potential industrial contamination of groundwater	Not enough is known of industrial runoff and uncertainty of type of industry
Combined sewers	Yes	Same installation as storm sewers and reduction of runoff to combined sewers	**Only** as part of sewer separation, must address potential spill (add Goss trap)
Retrofit existing residential sites	Yes	Provide water quality control and flood control where not provided previously	Original design for infrastructure renewal, and done in conjunction with new sanitary, water main and roads
Retrofit existing industrial sites	**No**	Same concerns as new industrial sites	Same comments as New industrial sites
Residential local roads	Yes	Eliminate need for quality ponds and associated safety concerns	In new developments, EES storage volume may be greater than present quality pond designs
Residential collectors	Yes	Eliminate need for quality ponds and associated safety concerns	Same comments as Residential local roads
Residential arterial	**No**	Spill and structural concerns	More difficult to have maintenance access
Industrial roads	**No**	Potential industrial contamination of groundwater	Not enough is known of industrial runoff and uncertainty of type of industry.
Prevent any increase in flood potential	Yes	Reduce peak flow and runoff volume	Negate and reduce post development flood impacts from frequent storms of 2, 5, 10, 25, 50 and 100 years. Minimum impact on Regional type of floods

Prevent geomorphic changes	Yes	Stabilize urban peak flow during four seasons	Baseflow is more constant, minimizing erosive velocity and erosion frequency

Design criteria for pervious pipe systems in the latest MOECC's manual (2003) has the following restrictions:

- Percolation rate of soil to be 15mm/hr or greater;
- Groundwater level to be at least 1m below bedding; and,
- Bed rock to be 1m below bedding.

These criteria are similar to the septic bed design and should not be applicable in the selection of the EES. Different design and selection criteria based on the post evaluation and monitoring of the EES in 1994 (Candaras 1997) and 2004 (SWAMP 2004) should be considered because stormwater flow is different from sanitary flow. The major differences between septic tanks/bed and storm designs are as follows:

- Stormwater has a higher peak per event;
- Stormwater has a larger volume per event;
- Stormwater has a longer duration per event;
- Stormwater has a longer inter-event;
- Stormwater quality is not from a domestic sanitary source; and,
- Rainfall depth, event and frequency are dictated by local rainfall patterns, not by land use.

In addition, the post construction evaluations in 1994 and 2004 have found that these three restriction factors did not reduce the quantity and quality performance of the EES:

- Hydraulic conductivity at the two pilots sites in Etobicoke were much lower than 15 mm/hr;
- Groundwater level was less than 1 m below bedding at one site; and,
- The installation of a relief perforated pipe similar to Queen Mary Dr. would solve the bedrock situation.

As previously discussed, the EES **<u>should not be used</u>** where groundwater is a source of drinking water. For the present time, it is generally **<u>not recommended</u>** in commercial and industrial applications due to spill considerations unless pre-treatment systems are considered. However, an industrial pilot project using an EES in Brandford was undertaken by Dr. A. Smith and Dr. T. Bui (late) recently to save a significant wetland downstream. It is being very carefully monitored and constraints will be developed in the future for industrial and commercial applications.

The two post evaluations of residential applications (Candaris 1994 and SWAMP 2004) have demonstrated that:

- The volume of runoff for most long-duration storms (e.g. 23 mm over 10 hours) could be eliminated, with system overflows being recorded for only three out of 177 (<2%) events monitored between 1996 to 1998 by SWAMP (2004),
- Most runoff pollutants were captured and reduced,
- Groundwater could be recharged; and,
- Local level of flood protection could be maintained.

2.1 Planning Procedure

A two-step evaluation procedure has been developed for the EES. The first step comprises the following most critical screening questions:

1. Is a water supply aquifer absent at the site of interest (reduced ground water contamination)?
2. Is the site of interest a low density residential area (less polluted runoff)?
3. Is the site of interest served by local roads (reduced spill potential by industrial trucks and structural consideration of perforated pipes)?
4. Is the ground water table below the invert of the exfiltration pipes?

All of the first step questions must be answered affirmatively without exception in order to continue to the second step. Regarding Question 4, the EES can still be considered suitable even the ground water table is less than 1 m (typical for infiltration/exfiltration devices) because runoff will be exfiltrated horizontally along the storm sewer trench in addition to vertically downward.

The second step comprises the following secondary questions:

5. Are the roads and/or sewers in poor condition (increased retrofit potential and saved cost)?
6. Is the tree root problem absent at the site of interest (trees with deep roots need relocation to prevent roots from damaging filter cloth and perforated pipes)?
7. Is the required maintenance equipment available at the municipality (reduced long-term maintenance cost)?

All of the second step questions should be answered affirmatively, either with or without implementation of engineering measures designed to remedy the associated environmental impacts. If there are additional environmental impacts associated with the engineering measures, then the EES is not suitable for a site of interest.

3. The Etobicoke Exfiltration System Description

The simplest description of the EES is the addition of two perforated pipes located in the gravel bedding of a standard municipal storm sewer (Figure 2)

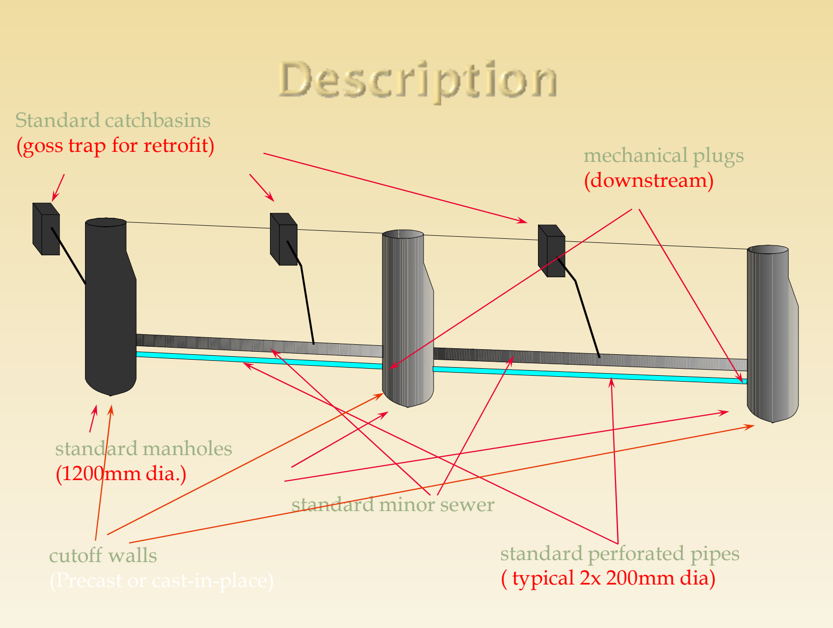


Figure 2. Layout of the EES

In areas of high traffic, such as residential collector roads, a goss trap can be added to the catch basin to trap any floatables and spills resulting from accidents. In older areas of a municipality, residential homes are still serviced with oil furnaces and spill records in Ontario show that furnace oil filling during winter is a major cause. A goss trap is also highly recommended in those areas for floatables and small furnace spills.

The addition of cut-off walls along the sewers is also a common practice in areas of high groundwater to mitigate the migration of bedding material. In the EES, the cut-off wall has the additional functions of forcing the stored stormwater into the surrounding soil, and of preventing the water from migrating to the downstream trench (Figure 3). Road surface inspections show that after nearly 20 years of operations, the three roads where the EES was installed have not been subject to pot holes, cracks or depressions or any particular road failures.

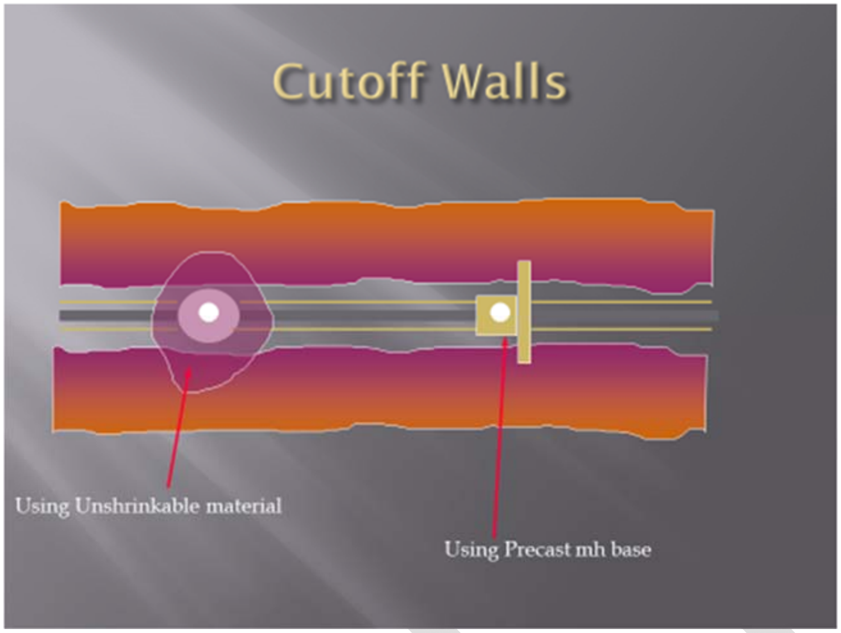

Cutoff Walls

Figure 3. Cut-off walls

A mechanical plug is installed at the downstream maintenance hole of each of the two perforated pipes. During construction, this plug is located in the upstream and downstream ends of the perforated pipe to prevent construction material from plugging the perforations.

3.1 Dynamics

In the Etobicoke Exfiltration System, several infiltration/exfiltration flow paths have been added to the design of a traditional municipal storm sewer (Figure 4).

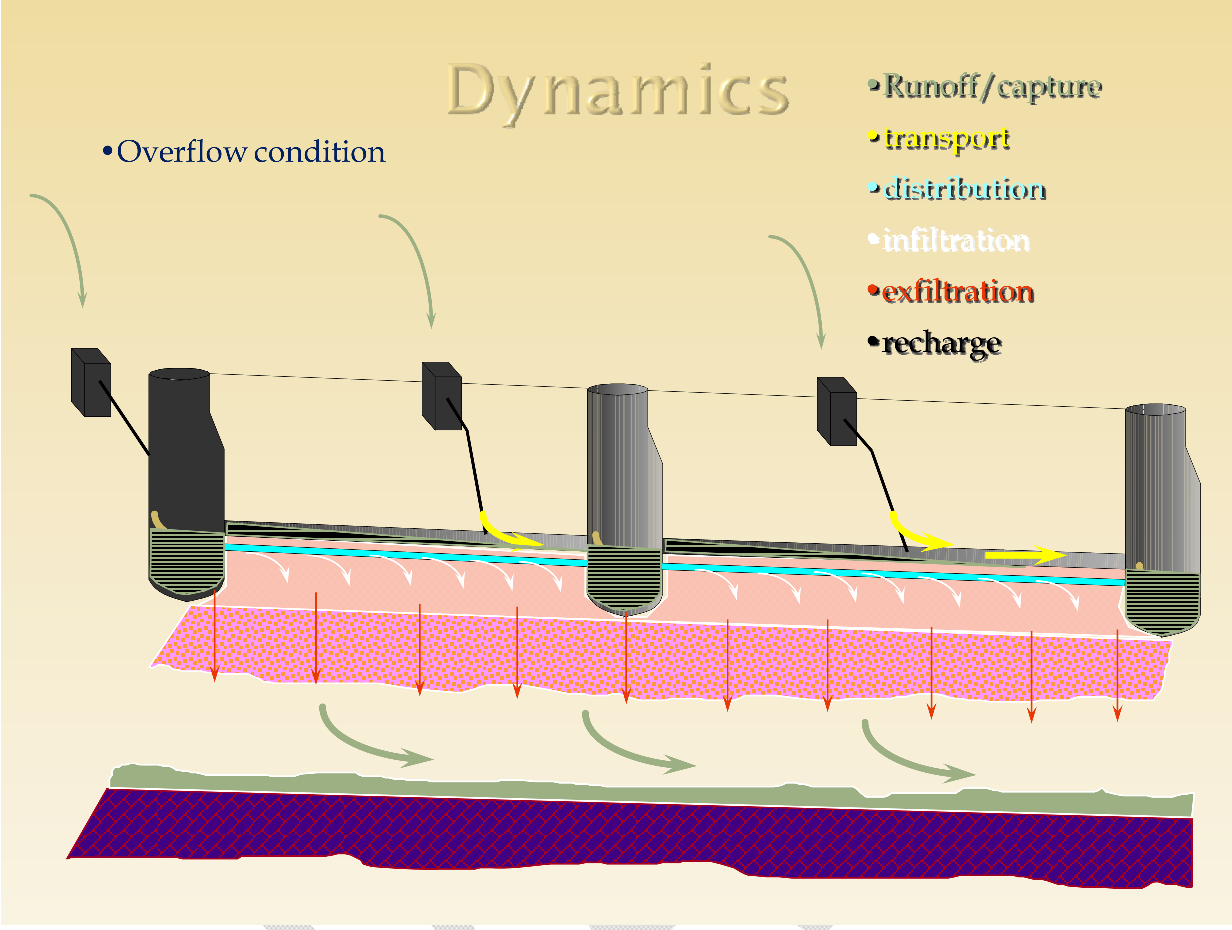


Figure 4. Flow dynamics of the EES

The basic traditional flow paths are runoff on road, flow capture at catch basins and flow transport along storm sewers. Downstream practices such as ponding or storage are added along the storm sewer and at the outfall. In the EES, the flow path includes runoff distribution along the perforated pipes, infiltration to the bedding material, exfiltration to the surrounding soil, groundwater recharge and in some situations, overflow to the sewer (e.g. 10 events/year). Each phase of this path is discussed in the following subsections.

3.2 Runoff

Runoff is produced once the initial abstractions have been met or exceeded. These include interception, soil depression, soil infiltration, evapotranspiration from pervious areas and evaporation from impervious areas. Roof connections are a major runoff contribution to the peak flow and volume of runoff. This is the legacy of the 50's mentality which has led to several present problems. Today, many municipalities are encouraging the disconnection (e.g. rain barrel program) of the roof to minimize downstream flooding and in some cases, the reduction of combined sewer overflow to beaches. Other municipalities are encouraging the harvesting of rain from the roof for flushing toilets and doing laundry, particularly in areas where groundwater is the major source of municipal drinking water.

At the three pilot sites, roof connections were present at the Queen Mary Drive site but were disconnected at the Princess Margaret Blvd. and Breacrest Dr. sites. This explains why the two post construction evaluation studies (Candaris 1994 and SWAMP 2004) agreed that despite the fact that Princess Margaret Blvd. is in clay while Queen Mary Dr. is sandy, the system on Princess Margaret Blvd. and Breacrest Dr. performed better than Queen Mary Dr. Additional peer review also failed to identify this major component.

By disconnecting the roof, the runoff peak flow and volume is reduced, runoff duration and lag time is longer and hydraulic head at the entrance to the two perforated pipes is lower. This has the effect of reducing the number of overflows and maximizing the use of the storage available.

This was clearly demonstrated by the monitoring of the October 5-6, 1995 storm event at the Princess Margaret Blvd. site. This event was 18 hours in duration with an accumulated rainfall depth of 63 mm (100 year storm is approximately 87 mm). Monitoring showed that runoff started at 16:30 pm, peaked at 1:00 am and continued past 10:30 am the following day. Pressure transducers in the trench, both at the upstream and downstream maintenance holes, monitored the water level of the trench. The result showed that the water level in the upstream manhole was more than 100 mm below the overflow level condition (i.e. below the invert of the storm sewer opening).

In the context for climate change, this kind of performance will have a major influence in the design of future stormwater management facilities.

In the Etobicoke Exfiltration System, runoff areas **are not** added when sizing storm sewer pipes (Figure 5). If there is any overflow, the overflow hydrograph is added to the downstream hydrograph. Modeling shows that the additional overflow peak is much lower than, and does not coincide with, the peak flow from the direct contributing area of the downstream section of the EES.

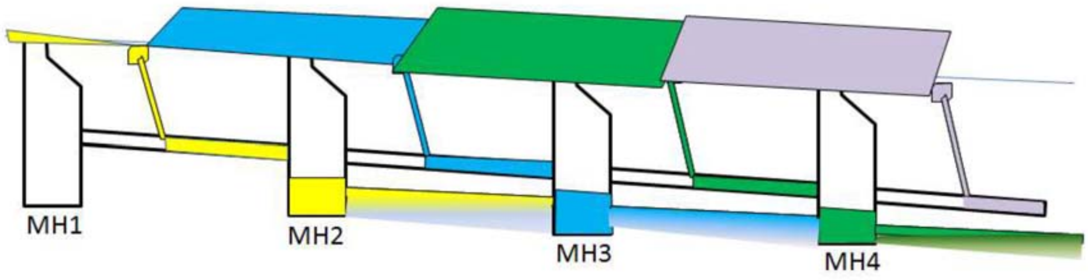


Figure 5. EES inflow associated with non-cumulative drainage area

3.3 Capture

The capture phase is by catchbasins. Their spacing is well documented in any municipal design manual and has no impact on the design of the EES. But it must be pointed out that catchbasins with curb openings must be discouraged as large solids/debris may find its way into the system and become a maintenance problem. Catchbasins have only a certain amount of capture ability. Once this ability is met, additional runoff does not enter into the EES and instead, is transformed into overland flow. This overland flow route must still be designed properly. In the Etobicoke pilot projects, a Goss trap was added to all catchbasins because both Queen Mary Dr. and Breacrest Dr. are older parts of the City and some homes still use oil heating which is a major contribution to residential oil spills during winter refills.

3.4 Transport

Stormwater runoff is transported by storm sewer pipes having design considerations for critical flow, scouring velocity, structural strength of the pipe and the level of convenience specified by the local municipality. These considerations remain valid when considering the use of an EES. At the three pilot sites, it was found safer to design the structural strength of the storm pipe under an embankment condition because the width of the trench may be wider than required under a trench condition.

There are two way of sizing the storm sewer pipes when designing an EES:

3.4.1 Traditional method

At the three pilot sites, the main storm sewer was sized using the Rational Method and Manning's formula. In this method, peak flow is the main consideration and dictates the size of the pipe. As with any pilot project, the City considered the event of a failure which would require it to abandon the system by filling the bottom of the maintenance hole with concrete. Post construction evaluation, including monitoring, sampling and pipe video have shown that in terms of rainfall depth, intensity and duration, the main storm sewer was oversized. Video pictures showed that at the upstream maintenance hole, there was no water mark indicating an overflow. Once past the connections (i.e. catch basins, foundation), the water mark reached below the spring line (i.e. 50% full). This method remains acceptable as far as the Environmental Compliance Approval (ECA) was concerned.

3.4.2 EES method

In this method, the designer sizes the storm sewer pipe to meet the "convenient" peak flow from each individual drainage area. Using this preliminary pipe size as the overflow pipe, the designer will size the bedding storage (design storage) to meet the target rainfall depth, the target rainfall duration and inter-event for the specified stormwater management objectives (see section 'Design objectives'). Finally using the design storage, the designer can analyze the EES under various minor flow conditions and size the main sewer by adding the overflow hydrograph (if any) to the hydrograph of the downstream drainage area. As in the traditional method, the main sewer may not be subject to any surcharge at the convenience (minor) level. Using this method, it was found that except for the first length of sewer, a reduction in pipe size can be achieved. It was also found that the downstream storm sewer pipe may be smaller than the upstream. While this is acceptable hydraulically and hydrologically, municipalities have strict standards in this regard. This method was acceptable as far as the ECA of Etobicoke was concerned.

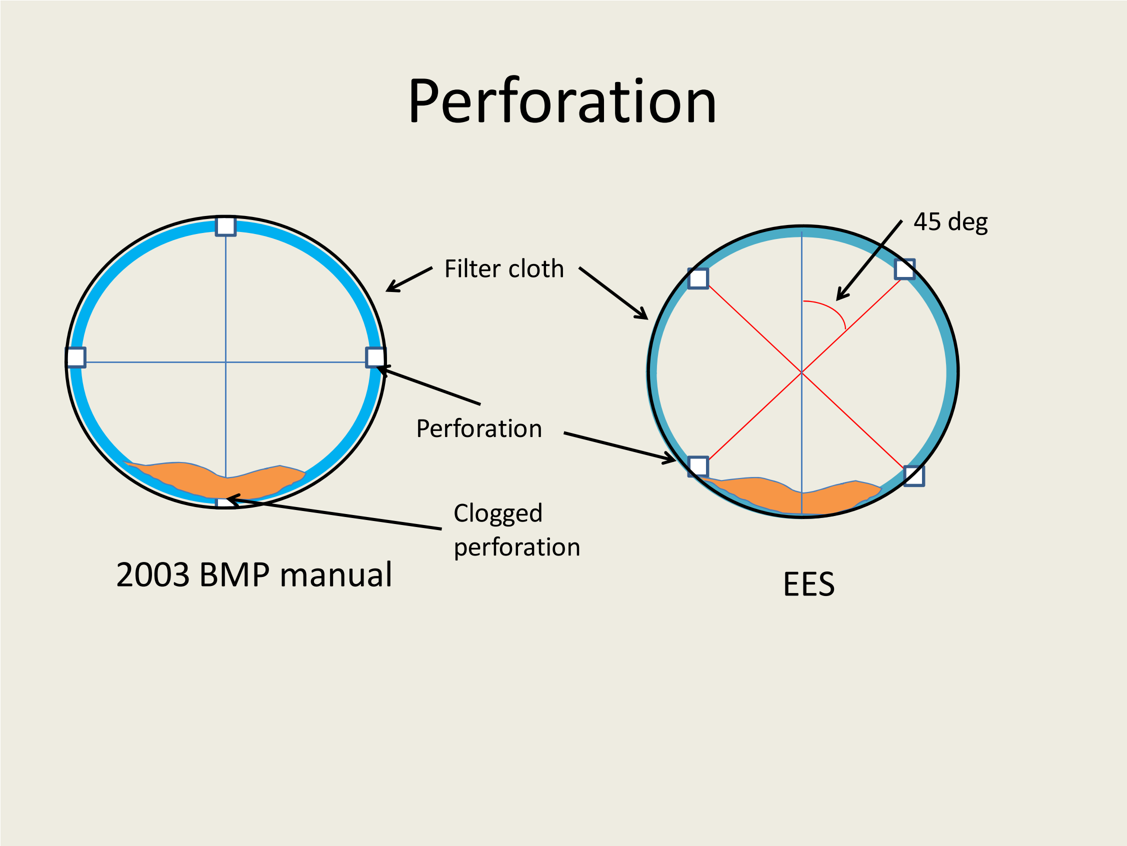
Although this design method may or may not be acceptable for all situations, it will identify the over-design of the conventional minor system (with the EES considered) and the extra level of protection to address other concern such as climatic change impact on service level.

3.5 Distribution

The installation of two perforated pipes under the main sewer is the only addition to the conventional design of storm sewers. Their main purpose is to distribute the runoff over the length of the gravel bed under the main sewer. Wrapped in filter cloth, they also serve the purpose of capturing and trapping solids while allowing for ease of maintenance.

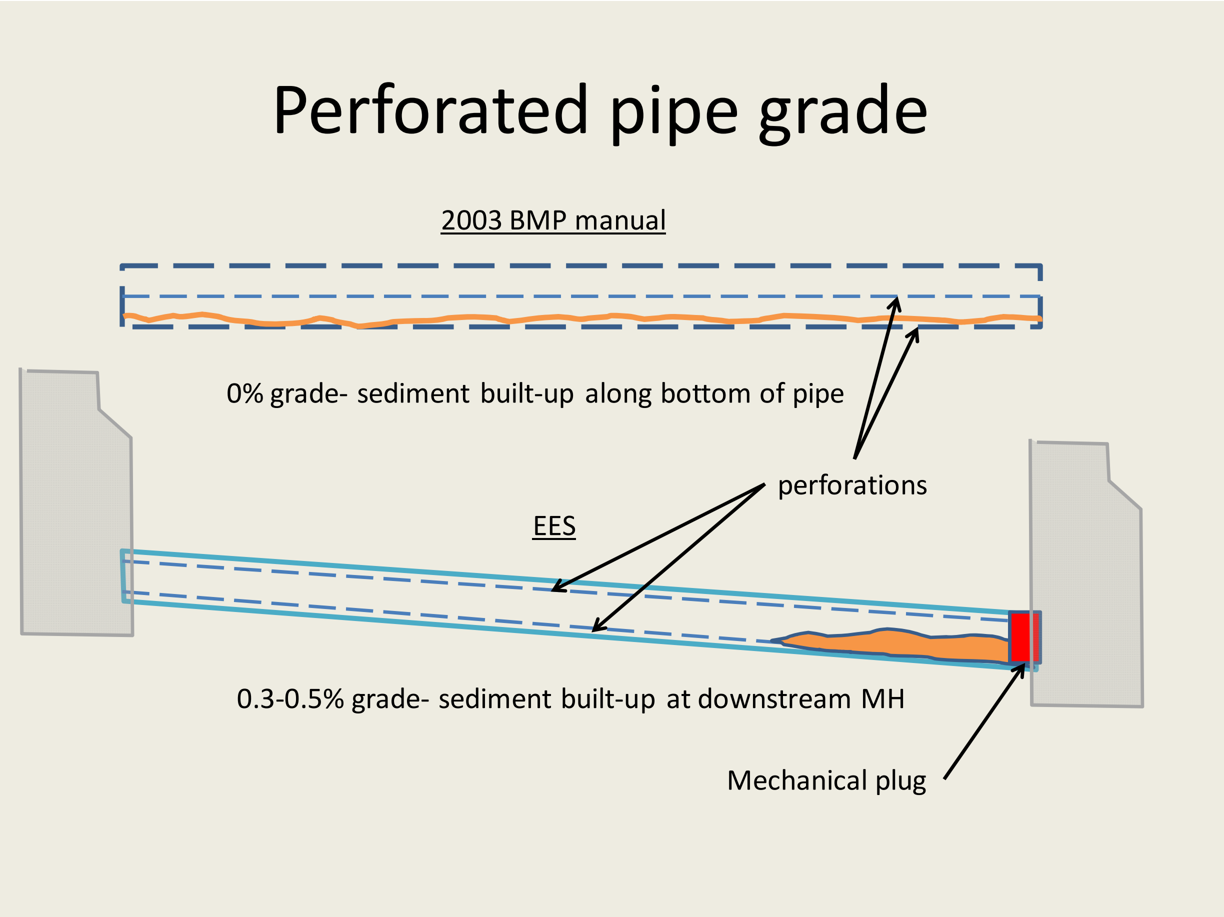
While hydraulic calculations were carried out during the design of the three pilot sites, the inventors of the Etobicoke Exfiltration System took a practical approach to solving the clogging problems which were encountered by many infiltration/exfiltration systems:

- The size of the perforation was dictated by the surrounding bedding material. In this case 19 mm clear stone was specified, therefore the orifice diameter had to be smaller. Holes in the range of 12 -12.5 mm in diameter would prevent the bedding material from entering the pipes.
- A literature review indicated that the orientation of the perforation is to enhance the infiltration of the water into the surrounding material. The left orientation in Figure 5 has the opening at the bottom of the pipes. In the EES, the perforation is rotated 45^0 to the vertical (or horizontal) allowing the bottom to carry the sedimentation downstream without losing any perforations. Video taken five years after installation have confirmed this decision as illustrated in Figure 6.
- A filter cloth was wrapped on the outside of the perforated pipes. Installation of filter cloth inside was tried but it was found to be impractical.



Perforation

Figure 6. Orientation of perforations in exfiltration pipes



Perforated pipe grade

2003 BMP manual

0% grade- sediment built-up along bottom of pipe

perforations

EES

0.3-0.5% grade- sediment built-up at downstream MH

Mechanical plug

Figure 7. Sediment accumulation at the downstream end of the perforated pipes

- Another factor which affects the performance and longevity of perforated pipes is the slope of the pipe. Recent literature reviews show that the perforated pipe should be installed at a flat grade to promote exfiltration (e.g. MOECC's Stormwater Management Planning and Design Manual- March 2003). As shown on Figure 7, the EES took a different approach. Had the perforated pipe been installed flat, the downstream end would have been in conflict with the upper main pipe or ended up **above** the main sewer. Again, the designer of the original EES took a more practical approach. The slope of the pipe follows the same slope as the main pipe for ease of installation and maintenance and to force the sediment to accumulate at the downstream end instead of along the pipe. Post evaluation along with video pictures of the perforated pipes confirmed this decision as illustrated in Figure 7.
- In the Etobicoke projects, the 200 mm diameter perforated pipe was selected because leaves and branches were expected in the runoff. This was confirmed in the sampling of the material found in the perforated pipes, which was highly organic as expected. Rarer, but not unheard of, were larger debris such as plastic bottles and coffee cups. These objects did not have any impact on the performance or the longevity of the EES.

- Hydraulic and entrance head loss were considered at the pilots sites. Short and intense rainfall events will create overflow because of the entrance head loss at the manhole. By using two perforated pipes, the flow is divided and the associated hydraulic head is reduced resulting in fewer number of overflows.
- Since there was no need to transfer flow from the upstream main pipe to the downstream main pipe, the design of the EES did not require benching.

3.6 Infiltration

It must be pointed out that this is the most dynamic phase of the system. Runoff is distributed along the length of the perforated pipes and infiltrates into the gravel bedding where it is stored and slowly exfiltrates into the surrounding soil.

Gravel bedding is a standard requirement to support the storm sewer and to provide horizontal and vertical alignment. This is commonly used at all sewer installations. The uniqueness of the Etobicoke Exfiltration System is the use of this construction material which has always been there and never utilized before.

The selected material must have two properties:

- The ability to store the runoff volume; and,
- A high rate of infiltration.

The sewer bedding used at the three pilot sites was 19 mm clear stone which is commonly used as a bedding material. This material does not require compaction which is also a construction advantage. Tests of the materials used at the three sites confirmed that the void ratio was 40%.

Other material can be used, for example sand, but they may have different physical properties. As to the gravel's chemical properties and ability to provide treatment, it is presently unknown and is lacking scientific research. However, the monitoring and sampling results by the MOECC's SWAMP programs (2004), show that the effluent from the gravel bedding was of better quality than that of the dry weather flow from quality ponds.

The October 5-6, 1995 event with 63 mm rainfall depth was monitored and results showed that infiltration into the gravel bedding occurred almost immediately (Figure 7). The pressure plate transducers in the gravel bed at both the upstream and downstream maintenance holes measured the depth of infiltrated water in the trench. The difference in head of approximately 0.110 m is close to the elevation difference between the upstream and downstream inverts, confirming the decision to slope the two perforated pipes.

Gravel bedding such as the 19 mm clear stone has a very high infiltration rate in the range of 3600 mm/hr compared to the surrounding soil (e.g. sand - 118 mm/hr, clay - 0.3 mm/hr). The backwater effect at the upstream was so minimal that the original calculation and subsequent modeling ignored this additional head loss.

At the pilot sites, the trench width was the sum of the outside diameter (OD) of the main sewer plus 450 mm on both sides. The effective upstream trench depth was 650 mm below the OD of the main sewer. The granular bedding was extended above the main pipe. It was found that at downstream, the water level in the trench storage could rise above the main pipe. Finally the entire granular bedding was wrapped with filter cloth to prevent migration and contamination from the surrounding native soil.

At the present time, it is highly recommended that the same gravel bedding material is used in new installations. A change in the material specifications must address the infiltration rate, the void ratio and any additional head at the upstream maintenance hole.

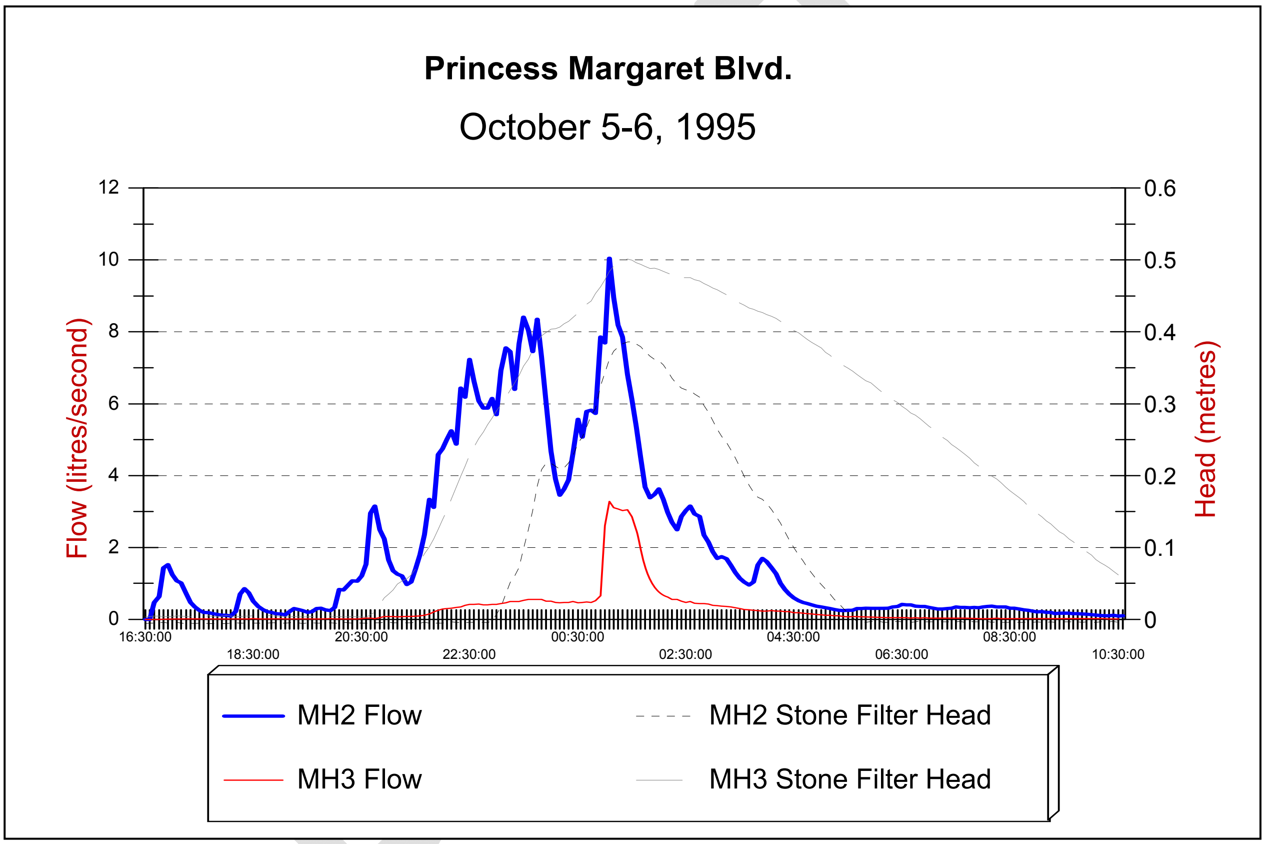


Figure 8 Flows at upstream MH2 and downstream MH3 during the storm event on Oct 5-6, 1995

3.7 Exfiltration

This dynamic phase is the subject to many speculations and misunderstandings of the Etobicoke Exfiltration System. Runoff has to be stored in the gravel **before** it can be exfiltrated into the surrounding soil. The EES's ability to deal with large storms is due to the **storage and infiltration rate of the sewer gravel bedding**, not on the ability of the

surrounding soil to quickly percolate the stored volume. The only factor that is of concern is the duration of drawdown which should be less than the rainfall inter-event. At the three pilot sites, the City targeted two days for the stored runoff volume to completely exfiltrate into the surrounding soil, with the average annual inter-event for that area being three days. In the case of the three pilot sites, it was assumed that the amount of exfiltration was so small (based on the borehole information) that it was ignored during the selection process.
For the monitored event of October 5-6, 1995 (63 mm), the drawdown took slightly over 12 hrs, which was much shorter than anticipated. Figure 8 above shows that even with a hydraulic conductivity field measurement of 1×10^{-7} cm/sec, the surrounding soil was still capable of exfiltrating the storm volume of 63 mm over 12 hours. Dr. Alan Smith (MIDUSS drainage model) peer reviewed the results and concluded that the rate of exfiltration at that location was equivalent to a 30 mm/hr percolation rate.

3.8 Recharge

Very little attention was paid to this part of the system. How much? Where does it go? What is the temperature decrease? How much recharge is becoming baseflow? Is the stream erosion decreasing? Is spring flooding impacted? These are some questions that need to be scientifically answered in a long term and larger scale monitoring; however there are immediate concerns which must be addressed. Drinking water and bank stability are the most common concerns related to groundwater discharge.

Pre-construction groundwater monitoring at Princess Margaret Blvd. found no groundwater even at 14 m below surface. On the other hand, groundwater at Queen Mary Dr. was found between 1.6 m and 2.5 m below surface, but even at that depth, the installation at Queen Mary Dr. still performed very well. However, the Queen Mary Dr. and Kingsway Cr. intersection area was experiencing road failure and bank instability. Groundwater interceptors were installed along Kingsway Cr. to address the impact on the existing groundwater level and to minimize the additional volume of runoff being introduced into the banks. Instead of concrete retaining walls, soil bio-engineering techniques were used to provide bank stabilization and to increase evapotranspiration. Twenty years after construction, no evidence has been found that the road and the banks are failing.

Stormwater quality samplings taken by MOECC's SWAMP in the gravel bedding at Queen Mary Dr., an older area, compared well with dry weather (groundwater) flows entering ponds from newer areas (See Appendix—for more discussion). Sources of dry weather flows are most likely from foundation drains around houses and cracks in pipes.

Drinking water at the three pilot sites is supplied from municipal water treatment plants and therefore, contamination of groundwater was not a critical concern. However, in new areas and in municipalities still served by wells and groundwater, the use of the EES should be done **with caution** and with a full hydro-geological study of the groundwater. In areas of Source Drinking Water Protection Tier 2 and 3, it is recommended that information be obtained from the local Conservation Authority and the local office of the Ministry of the Environment and Climatic Change.

3.9 Overflow

Finally, overflows happen and are expected to happen. From actual flow monitoring, it was observed that the following conditions might create an overflow condition:

- Short and very intense rain events will create a high head loss at the entrance of the two perforated pipes,
- Large storms with runoff volume greater than the designed storage,
- At corners (i.e. 45° bend) where the sewer length is shorter to accommodate for a change in direction,
- A large drainage area flowing to a short section. This can be remedied by equalizing the lengths of sewer; and,
- Short inter-event time (i.e. sewer trench has not completely drained).

Monitoring has also shown that an event with 2-4 mm of rain that follows a series of other events can create an overflow condition for a short period. This is acceptable and expected.

Since the EES was originally designed to capture and treat 90% of annual rainfall events, it is expected that on a typical year, 10-15 overflows will occur. However, monitoring between a four year period by MOECC's SWAMP program found the number of overflows to be less than that, with winter and spring monitoring showing no overflow. Considering that winter and spring runoff account for the majority of the annual runoff volume in rivers and streams, this is significant in reducing development impacts on stream erosion and annual spring flooding.

4 Design Objectives

The prime objective of the Etobicoke Exfiltration System was and is still today, to achieve a sustainable post development hydrologic cycle which provides for continuous baseflow, attenuation of temperature, decreased incidence of flooding and stream erosion all while capturing pollution, and minimizing human footprint on the environment. In doing so, the designer of an EES must recognize that human habitat is also part of the ecosystem which must be protected, as much as fish habitat, from undesirable impacts on drinking water sources, soil stability, and human and wildlife food sources. Mr. Justice J.D. Cameron expressed very well when he said that "*Generally speaking, a riparian owner has the proprietary right to have the water in a natural watercourse flow to him in its natural state, neither increased nor diminished in quantity or quality*."

4.1 Ontario Hydrologic Cycle

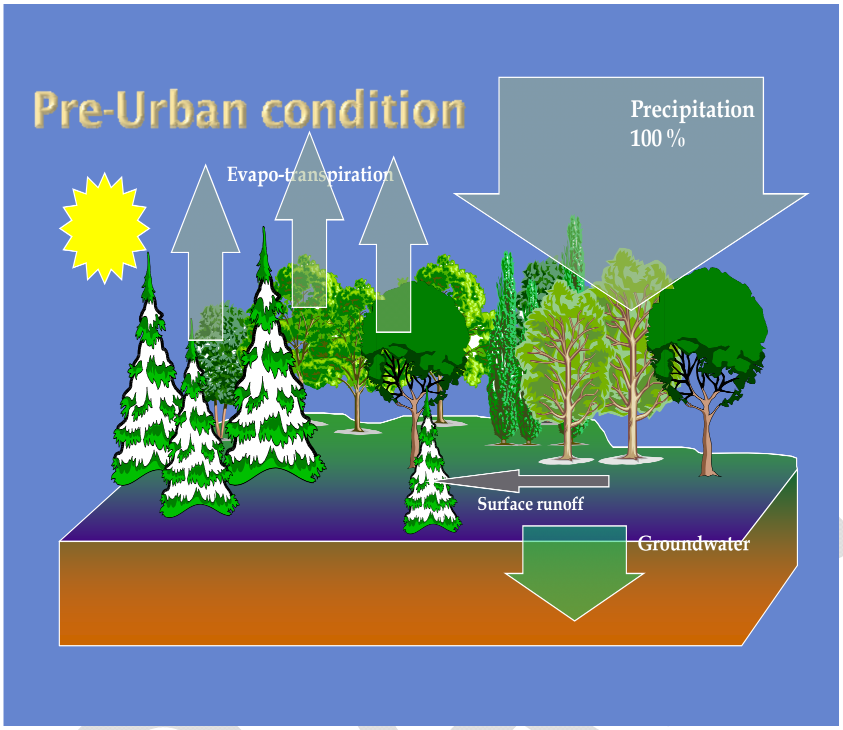


Figure 8 Pre-urban condition of watershed

Ontario is a four season province and the pre-development hydrologic cycle (Figure 8) reflects this climate, with each component of the cycle varying with each season. The Ontario annual precipitation includes snow, rain and hail. In Ontario, the beginning of the evapotranspiration (ET) component is celebrated every year with the Maple syrup festival, a Native custom dating back before the creation of Canada, and is also the first sign of spring. It is characterized by warm days and cold nights, which allows the sap of the maple trees to flow from the roots to the branches. This process will continue until late fall. Each type of vegetation, (i.e. trees, grass and crop) has its own quantity of ET, with trees recognized to evapotranspire more than grass and legumes. After late fall and at the beginning of winter, evapotranspiration is replaced by sublimation. Depending on the local conditions, snow can either melt into liquid or evaporate in a process known as sublimation (water going from solid to vapor, without a liquid phase). Under the snow pack, percolation to the groundwater will continue until the soil temperature reaches a freezing level. Groundwater is recharged over the watershed and discharged along streams, rivers and lakes. In northern Ontario, the Canadian Shield will see a lower level of groundwater infiltration.

Runoff in the pre-development condition is minimal, but does occur. Again in the Canadian Shield, imperviousness area in the form of rocks and rock outcrops provide for greater runoff with minimum evapotranspiration and infiltration.

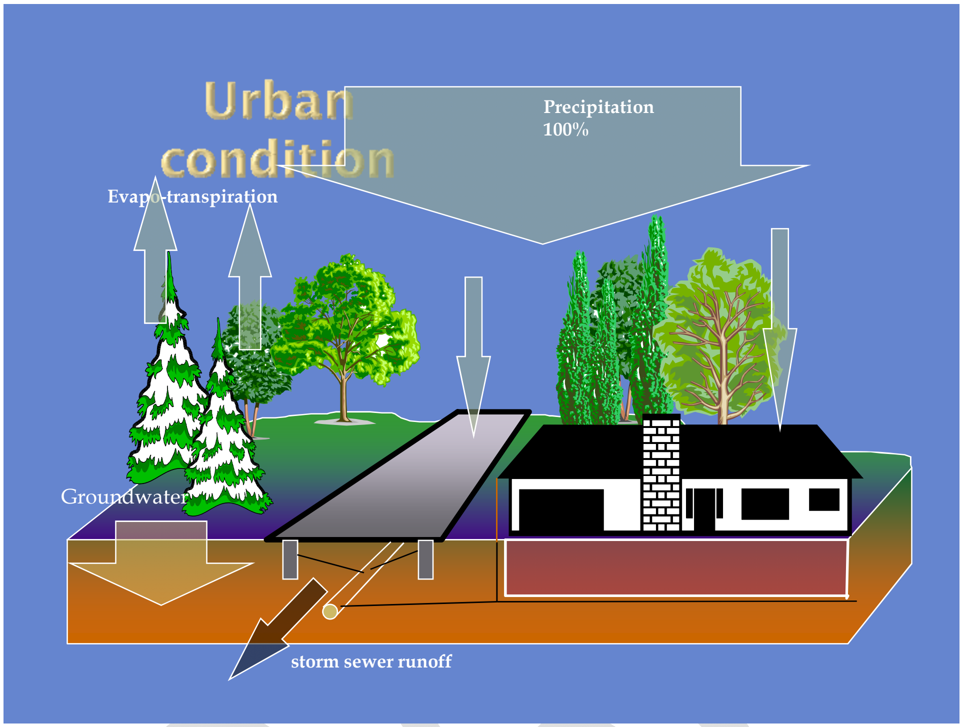


Figure 9 Post-development watershed

Figure 9 above shows a typical residential hydrologic cycle which is also subject to the four season cycle. Compared to 20 years ago, today's residential development sees a larger number of trees and green areas with reintroduced and protected local vegetation, all of which are contributing to the evapotranspiration. However, hard and impervious surfaces are still replacing infiltration areas and continue to deplete the recharge of groundwater. This impact is compounded by foundation weeping tiles which lower the groundwater around dwellings in order to protect foundation and basements. Furthermore, recognizing that Ontario is a four season province, it is deemed incorrect to identify in Figures 8 and 9 how much of the 100% precipitation is runoff, groundwater recharge, evapotranspiration without identifying the season and geographic location.

4.2 Design Criteria

The selected design criteria of the pilot projects recognized local conditions as well as local practices of construction, maintenance and protection. Just as much as the hydrologic cycle reflects the season and the local condition, the design criteria for the use of the EES keeps the same objective.

The following design criteria apply only to **existing and new residential** area having a ratio of no more than **2 ha / 100 m** of storm sewer. A future Addendum will provide for industrial and commercial sites.

Many critiques have been made that the pilot projects were overdesigned. However the only two criteria to be met were 90% of annual rainfall events (15 mm rainfall depth in Toronto) and exfiltration in two days. The rest was standard construction and design practices.

Finally the design criteria are based on the experience gained in the design and construction of the pilot projects and the results of the post evaluation.

4.2.1 Peak Flow Considerations

Municipalities own, operate and maintain storm sewers. Design and approval of these sewers are well documented in their subdivision policies and manuals. The level of convenience and details of the storm sewer design/installation and construction must meet the following local municipal requirements:

- Minor flow design (2, 5, 10 years return) as per present practice, **<u>BUT</u>** peak flow is not cumulative (i.e. main sewer pipes sized on the contributing area without considering upstream area),
- Downstream sewer pipes size smaller than the upstream pipe may be allowed,
- Major overland flow remains the same,
- Perforated pipes **<u>at the same slope</u>** as the main sewer,
- Trench and main pipes designed on embankment conditions for structural pipe design; and,
- All sewers, including perforated pipes, must be located below the local frost line.

This is an area where cost savings can be achieved provided that the reduction of sewer pipe size due to sewer trench storage still meets the local municipal requirements for protection (i.e. basement).

4.2.2 Volume Considerations

The volume of runoff is directly related to initial loss (including evapotranspiration), infiltration, and % of imperviousness. In simple form, the EES meets the following continuity equations:

$$Volume\ of\ runoff = trench\ storage + exfiltrated\ volume + overflow\ volume \tag{1}$$

$$Inflow\ rate = rate\ of\ change\ of\ trench\ volume + exfiltration\ rate + overflow\ rate \tag{2}$$

- Only the flow from the last sewer length is permitted to directly discharge,
- For the 95% annual rainfall event control, the last sewer length will not receive any overflow (i.e. no perforated pipes installed below, last sewer length acts as a typical sewer),

- The average trench storage ratio shall be no less than 30 m^3/ ha for the total sewer drainage area. This is calculated by adding all trench storages and divided by the total drainage area; and,
- Where the hydraulic conductivity of the surrounding soil is found to be less than $1x10^{-7}$ cm/sec, a relief perforated pipe shall be installed at the lower manhole (also see 4.2.4 Duration Considerations below).

As previously indicated, volume of storage available in a standard storm sewer bedding led to the assumption that the original design was oversized. Since this storage was always available, monitoring showed that more than the 90% of annual rainfall events were captured. In modelling the 90% of annual rainfall events, it was found that only 60-65% of the annual total rainfall depth was treated. On the other hand, the criterion of 95% of annual rainfall events would see the capture of 80% or more of the annual total rainfall depth without an increase in storage available. **The 95% of annual rainfall events has been adopted as the criteria to be met for new installation of the EES.**

4.2.3 Water Quality Considerations

Post evaluation samplings of the pilot projects showed that the quality of the runoff in the trench performed very well and exceeded the performance of quality ponds for most parameters including TSS, metal and nutrients. The requirements for a quality pond downstream of the EES have been reviewed and it is not recommended for the following reasons:

1. The EES will treat and store 95% of annual rainfall events,
2. The overflow from the remainder 5% of annual rainfall event will not be sufficient for a permanent pool,
3. The inter-event time between **annual overflows** is greater than that of the annual rainfall events, thus leading to extreme temperatures in the pond, which will have direct negative impacts on the cold and warm water resident fishery; and,
4. Monitoring of quality ponds by SWAMP showed an increase of up to 11°C at the outlet.

In order to maintain this water quality in future new EES projects, the following quality criteria have been developed:

- The EES is restricted to residential applications only,
- Water quality ponds are not required downstream of an EES,
- Wet ponds are not recommended downstream of EES due to temperature concerns,
- Perforated pipes must be wrapped with filter cloth,
- Trenches must be wrapped with filter cloth,
- Trenches must be filled with 40% void washed granular material,
- Minimum perforated pipe size: 200 mm,
- Minimum No. of perforated pipes: 2,
- Minimum 12.5 mm perforation at four locations every 150 mm (Figure 5); and,
- Perforated pipes and main sewer must be located below frost line to treat winter runoff and snow melt.

4.2.4 Duration Considerations

- For peak flow of a minimum 1 hr storm; and
- For volume of a minimum 4 hr storm.

4.2.5 Frequency

- As a minimum, the EES must treat 95% of annual rainfall events on the basis of rainfall depth;
- As a minimum, the EES must treat 90% of annual rainfall events on the basis of rainfall duration;, and,
- Maximum discharge time, 2 days or 48 hrs after peak flow. A relief perforated pipe shall be installed at the downstream if the drawdown time is greater than 48 hrs.

5 Design Process

As previously indicated, the original design of the Etobicoke Exfiltration System (EES) was done manually and was time consuming. The minor sewer system was calculated using the Rational Method for peak flow and Manning's formula for pipe sizing. Trench width was calculated based on City's standards and the exfiltration rate was calculated using Darcy's formula. Individual hydrograph were calculated using Otthymo and MIDUSS programs. All information was then entered into a spreadsheet to calculate the storage. Minor pipe sizing was not reduced because the project was a pilot demonstration and should any failure happens, the bottom of each maintenance hole would have been filled with concrete, leaving the minor system as a traditional installation. A flow chart was developed by the authors of this document which remains valid and is posted in the Ryerson University web page for student information (http://www.civil.ryerson.ca/urban/f-techno.html, source control, Etobicoke Exfiltration System).

The EES Design Process was developed and extensively tested by Dr. T.Bui and J. Tran and is reduced to the following steps:

1. Design minor system
2. Design trench and storage
3. Modify minor as necessary
4. Test system for other storms if necessary

5.1 Design of Minor System

The minor system is also referred to as the convenience system. It provides flooding protection for roads and basement. Its calculation is based on the original design for connection and addresses peak flow and peak intensity (usually 100-120 mm/hr) of frequent storms. For most minor system designs, municipalities have IDF curves and specific time of concentration for use with the Rational Method. Using the peak flows, pipe size can be determined using the Manning's formula.

In the EES design, the minor flow can be estimated using computer models or manually. Using the pipe diameter, the trench width can be estimated. In the original design, the trench width (OD + 900mm) was standardized for ease of construction which in some cases resulted in an embankment condition for pipe structural strength. The structural strength of the two perforated pipes is always calculated based on the depth of the pipe and embankment conditions.

5.2 Design of 95 Percentile Rainfall Event Depth

Once the 95 percentile rainfall event depth and the storm duration have been determined, individual runoff hydrographs can be estimated. The volume of each event is to be stored under the downstream storm sewer. Knowing the width of the trench, the length of downstream sewer and the depth of trench, the trench volume can be determined.

The two pilot projects have demonstrated that storage available in the standard sewer bedding is more than adequate to capture and store the design runoff volume. In the example in Appendix F, the total design runoff event volume is 283.75 m^3 but the storage available is 690.2 m^3. The ratio of volume per hectare is 133.63 m^3/ha which is nearly six time larger than the original design of the EES (See Appendix F). Large upstream runoff will overflow if draining into a short section such as corners. With practice, the designer will be able to equalize the length of sewer with the required storage.

The last section of sewer will not drain into perforated pipes and is permitted to directly discharge into the existing system or stream. In the example, the volume of untreated runoff accounts for approximately 5.37% (15.23 m^3) of the total runoff from a 17 mm of rain. This last section of sewer **will not be permitted** to accept upstream overflow.

5.3 Modifications to Minor System

The EES affects the peak flow, the volume of discharge and the quality of runoff. Subject to municipal approval, a reduction in pipe size can be done. In a design computer model such as MIDUSS, the 95 percentile rainfall event depth is substituted with the minor rainfall. In the example in Appendix F, the comparison is shown in Table 3.

Table 3   Example of sizing storm sewer pipes with the EES

From MH	To MH	Standard minor- pipe size-mm	Modified minor- clay mm	Modified minor-sand-mm
22	21	300	300	300
21	20	375	375	300
23	20	450	450	450

20	13	600	525	450
17	16	250	250	250
16	14	375	375	375
14	13	450	450	375
13	8	675	675	525
12	10	200	200	200
10	9	375	375	300
9	8	450	450	375
8	7	750	675	525

6 Construction

Before construction, all necessary erosion and sediment control devices were installed to prevent sediment laden runoff from leaving the construction sites. The construction procedure of the EES is listed below:

1. Excavation of the trench was undertaken using standard construction techniques.
2. Filter cloth was placed around the trench and held on the sides of the trench by stakes.
3. Granulars of 13-mm size were placed from the bottom of the trench to the design invert of the perforated pipes.
4. Two 200 mm perforated pipes wrapped with filter cloth were placed on the granulars and mechanical plugs were placed on both upstream and downstream ends.
5. Granulars were placed over and around the perforated pipes until the elevation of the invert of the sewer was reached.
6. The storm sewer was laid above the granular layer.
7. Catchbasins were installed with leaders connected to both perforated pipes and sewers
8. Granulars were placed over and around the sewers.
9. The filter cloth was wrapped over the granulars with an overlapping width of 1 metre.
10. The trench was then backfilled with suitable soils.
11. The mechanical plugs at the upstream end of each section of the EES were removed after all construction.

Figures 10 to 16 depict the construction activities of the EES at the pilot site in Etobicoke in 1993.

Figure 10   200 mm perforated pipes with filter cloth socks.

Figure 11   Laying of perforated pipe at sewer trench

Figure 12 Backfilling of perforated pipes

Figure 13 Laying of storm sewers on top of perforated pipes


93 7 5

Figure 14 Backfilling of storm sewers


93 7 5

Figure 15 Wrapping of filter cloth around the stone trench

Figure 16 Mechanical plugs installed at the downstream end of perforated pipes

7 Maintenance

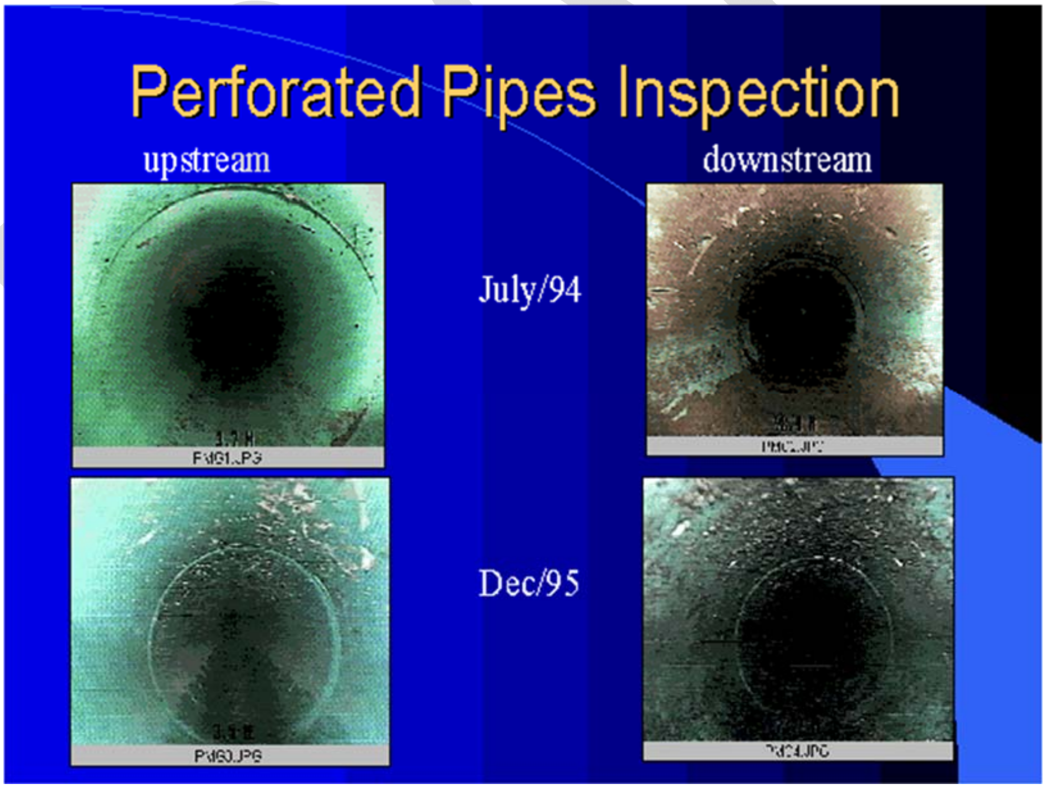
Post-construction maintenance requirements include:

1. A regular maintenance and observation program.

A regular observation and maintenance program was conducted at the two demonstration sites. The working conditions of the EES were assessed periodically and after major storm events. General observations included visual evidence of overflows at the sewer, water marks at the manholes, and the integrity of the mechanical plug at the downstream end of the perforated pipes. If a small storm event has caused an overflow or a high water level at the upstream manhole, the EES may be plugged and need cleaning. If the downstream mechanical plug has been pushed out, a short circuit of flow at that length of perforated pipes may have occurred. Additionally, minor deficiencies such as debris accumulation at catch basins were identified and repaired. Figure 17 shows the water mark at the downstream end of the storm sewer system. Most of the upstream section of the sewer has no overflow which indicates the EES has intercepted the runoff completely. In order to assess the sediment accumulation inside the perforated pipes, a video inspection was conducted one year after the construction (Figure 18). It was observed that a small amount of sediment accumulated at the downstream end of the perforated pipes, and some organic materials such as leaves were hung to the obvert of the perforated pipes. Thus, periodic cleaning of the perforated pipes should be required.

Storm Sewer Inspection Dec/95

Figure 17 Water marks at the downstream end of the storm sewer system



Perforated Pipes Inspection

upstream

downstream

July/94

Dec/95

Figure 18 Sediment accumulation at upstream and downstream perforated pipe sections

2. Power flushing of the perforated pipes to remove accumulated sediments

Although the sediments accumulated inside the perforated pipes was small after the first year, a demonstration of the cleaning techniques was conducted one year after the construction. The downstream mechanical plugs of an upper section of the EES were first removed and a highly pressurized water flusher was inserted at the downstream end. The flusher discharged pressurized jets of water that scourge the walls of the perforated pipes as it travelled upstream. The accumulated sediments were flushed to the downstream manhole of the section which were then pumped out using a vacuum truck. The sediments were then removed from water using a treatment truck equipped with a shear drum separator and disposed of offsite. Figure 19 shows the flushing activities for removal of accumulated sediment in exfiltration pipes. Observation of the perforated pipes after 10 years of operation shows similar accumulation in the downstream sections of the perforated pipes (SWAMP 2004).

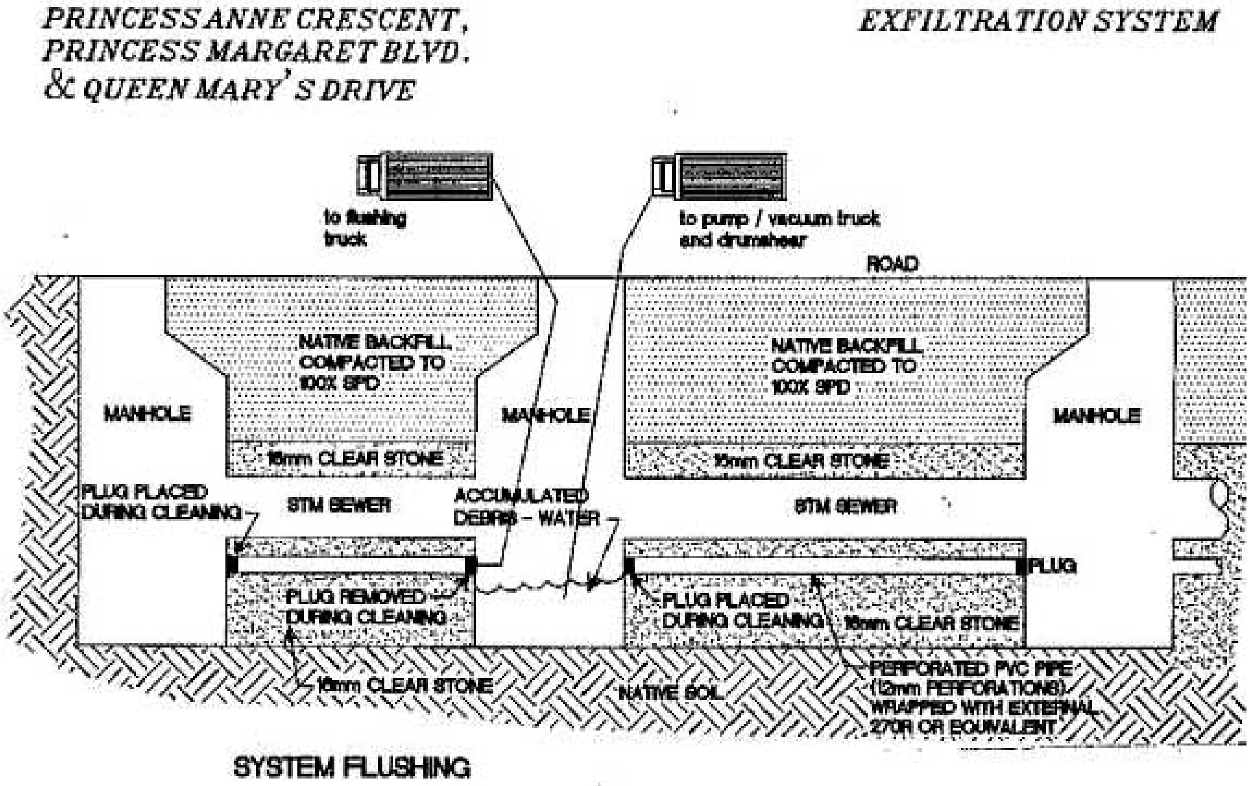


Figure 19 Power flushing of the perforated pipes

8 Performance

The layout of the monitoring program is shown in Figure 20. The upstream flows at MH2 have been reduced significantly in comparison with those downstream at MH3. However, the water in the stone trench downstream at MH3 shows a buildup of infiltrated water. All these observations indicate that the system works effectively for the May 26, 1994 event with a rainfall volume of 28.3 mm (Figure 21). A summary of the monitoring results is shown in Table 4. (Will add SWAMP monitoring results to this table).

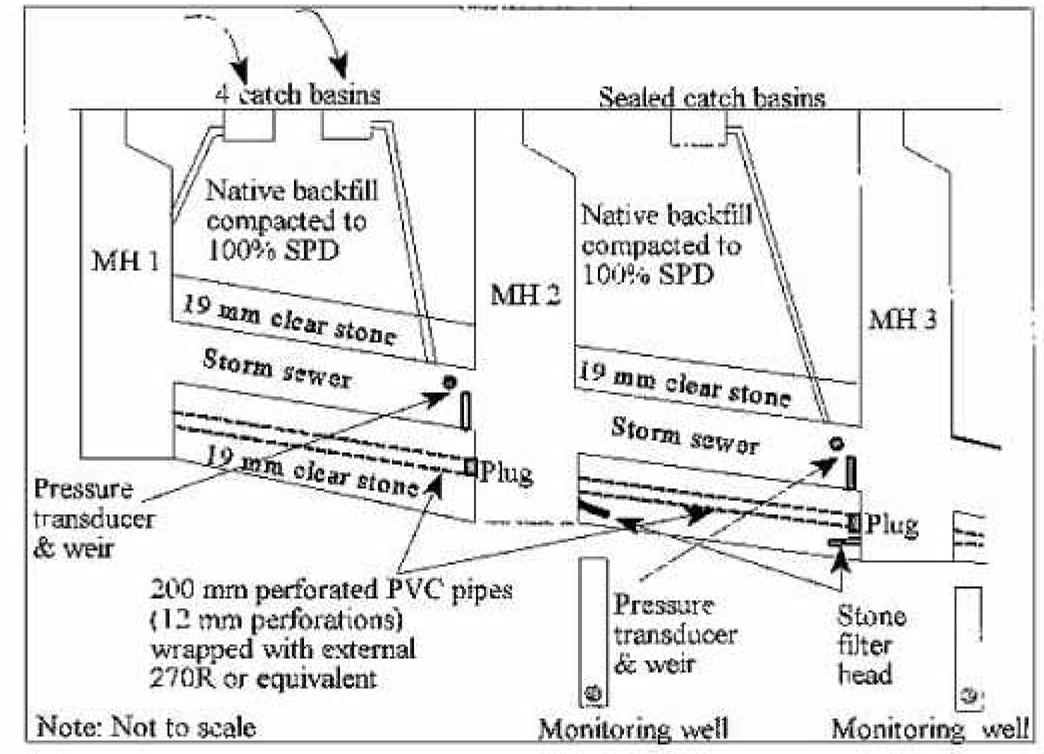


Figure 20 Monitoring of the EES in 1994.

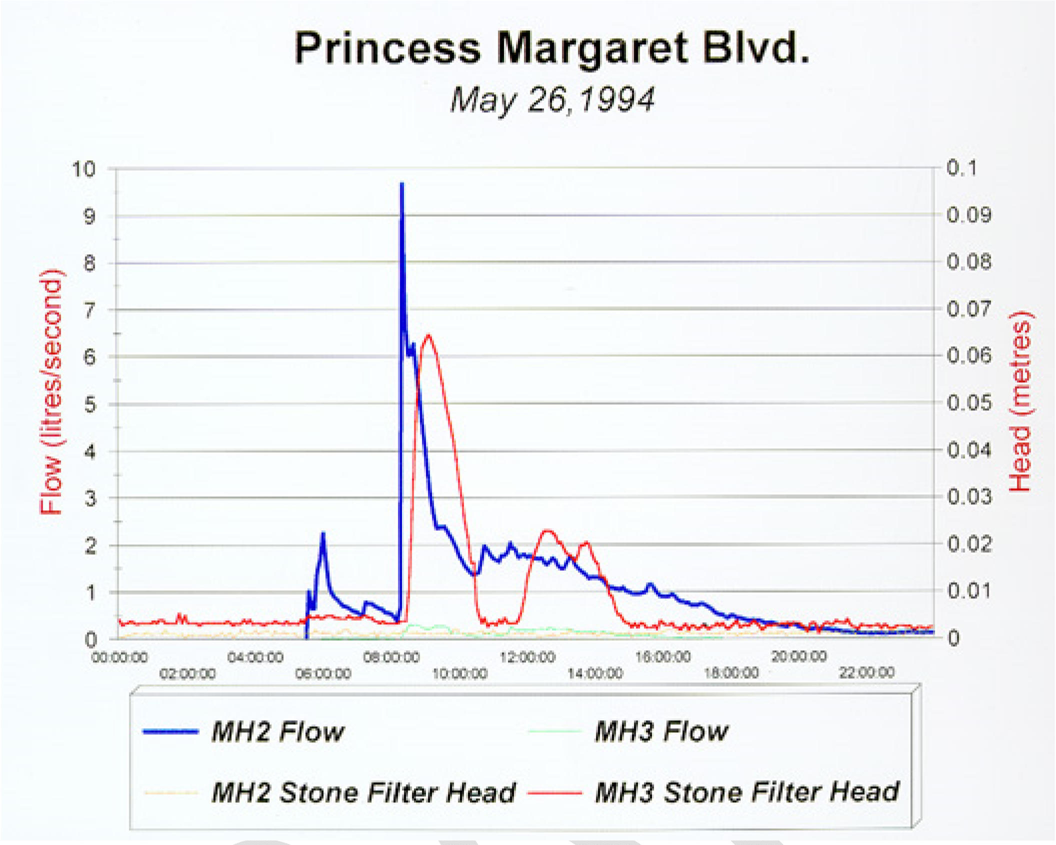


Figure 21 Monitoring results of one storm event.

Table 4 Monitoring results of the EES

Date	**Rainfall (mm)**	**Peak inflow (L/s)**	**Peak outflow (L/s)**	**Upstream filter head (mm)**	**Downstream filter head (mm)**
5/26/94	28.3	9.7	0.3	Nil	65
5/31/94	11.1	8.1	1.5	Nil	5
6/24/94	24.1	2.2	0.1	Nil	3
10/5/95	63.0	10.0	3.0	380	500

9 Construction Cost

The EES is a stormwater management measure which can be integrated into a road construction or reconstruction project. While the following cost analysis focuses on a specific site in the former City of Etobicoke, it demonstrates that the EES is a cost-effective stormwater management measure for both new road construction and reconstruction projects compared to downstream stormwater management practices such as ponds (Karakis 1999).

The case study is based on a 1993 road reconstruction and storm sewer replacement pilot project "A" (with EES) along the Princess Margaret Boulevard between Islington Avenue and Kipling Avenue in the City of Toronto (formerly City of Etobicoke). The storm sewer sizes are 375 mm, 450 mm, 525 mm, and 600 mm. In order to compare the cost of incorporating the EES to a road project, a control site with similar type of construction must be selected. The control site is also a road reconstruction and storm sewer replacement project "B" (without EES) in 1991 along the Princess Margaret Boulevard between Kipling Avenue and Martin Grove Road. The storm sewer sizes are 300 mm, 375 mm, 450 mm, and 525 mm and their inverts are similar to those at the EES pilot site. The additional cost of the EES is derived by comparing and identifying the discrepancies between the two tenders for different sections of roadway along Princess Margaret Boulevard. Since the only correlation between the 1991 control and the 1993 pilot project is the sizes of storm sewers, the cost comparison focuses on the 375 mm, 450 mm, and 525 mm storm sewer sections. The unit rates from the 1993 tender for these sewer sections were converted to 1991 currency by assuming a rate of inflation of 2.5%/year. These converted unit rates are then used to estimate the additional cost of installing the EES at the control site.

As indicated in Table 5, the additional cost for installing the EES is almost consistent for all three sewer sizes. However, the additional cost for the 450 mm sewer is greater than that of 525 mm. Since the perforated pipes are the same for all three sizes of sewer, the difference in cost is attributed to the construction of the sewer and the trench. When excavation surpasses a certain depth, an additional cost is accrued. Due to the installation of the EES, the threshold for extra excavation may be exceeded for all three sizes of storm sewer, resulting in no extraordinary increase in unit rates. When the EES is not installed, the threshold is only surpassed when the 525 mm sewer is initiated. This may result in a lower difference between unit rates and a lower additional cost of the EES. The additional cost for constructing the EES at the control site is summarized in Tables 6 and 7. If a stormwater quality pond was used to control the runoff from the control site (30.5 hectares), the construction cost would be about $130,000 (excluding land cost). Compared to the cost of the EES (≈ $25,000), a saving of about 80% can be realized.

Table 5 Unit rates of storm sewer construction with and without the EES in the Princess Margaret Boulevard.

Concrete Storm Sewer	Construction Cost in 1991$/m		
	375 mm	450 mm	525 mm
With EES	243	254	265
Without EES	164	169	191
Additonal cost of EES	79	85	74

Table 6 Additional cost for installing the EES at the pilot project "A"

Item	Estimated Quantity	Unit Rate	Amount
375 mm sewer	84.7 m	$78/m	$6,606
450 mm sewer	166.0 m	$85/m	$14,110
525 mm sewer	49.0 m	$74/m	$3,626
Mechanical plug	12	$48/m	$576
		Total:	$24,918

Table 7 Cost breakdown for installing the EES at the control site

Cost without EES	Cost to retrofit EES		
Part A – Drainage	$122,531	Part A – Drainage with EES	
Part B – Road	$533,991	Drainage	$122,531
		Additional cost	$ 24,918
Total amount	$656,522	Total Part A	$147,449
		Part B – Road	$533,991
		Total amount	$681,440
		Cost of EES (% total amount)	≈ 4%

The above analysis illustrates that the EES can be a cost-effective stormwater management measures.

Appendix A

Pilot projects Background

Pilot projects background

The Etobicoke Exfiltration System was developed in early 1991 as a stormwater quality control to answer to the 1991 MOE Interim Water Quality Guidelines, but before the MOE 1994 Stormwater Management Practices Planning and Design Manual. As such the EES has been around longer than most quality ponds found in today's subdivisions. Both aforementioned documents did not address the practice of retrofitting and currently, very little attention is given to controlling stormwater quality in existing areas.

The City of Etobicoke (now part of the City of Toronto) was part of the Metro Remedial Action and was committed to improving and minimizing its impacts on the Great Lakes. The Etobicoke Exfiltration System was one of many new ideas introduced by the City at that time. The Rain Barrel, the Yellow Fish Road, the Etobicoke Flow Balancing (at Park Lawn Park), the 1991 Natural Channel Design of Berry Creek and the Etobicoke Exfiltration System were among the few new ideas first introduced in Etobicoke which have made a significant contribution to the management of stormwater.

The City of Etobicoke was fully urbanized and had very little land for new developments. The opportunity to implement quality ponds was not available as urbanized land was and is at premium. Recognizing this, the City searched for other solutions which would be more suitable with its Capital Projects programs of replacing and upgrading its infrastructures. Having found that municipalities throughout North America have done very little in addressing retrofitting its infrastructures for stormwater quality, the Etobicoke Works Department undertook to develop its own ideas. The challenge was to develop and implement a design which must:

- Meet or exceed the 1991 Interim Water Quality Guidelines,
- Must meet present design practices,
- Must meet present construction practices,
- Must meet present maintenance practices; and,
- May not include chemical, biological treatments, nor have any moving parts or require electrical power.

As demonstration/pilot projects, the City selected three locations.

<u>Queen Mary Drive</u>

This site was selected because of the Humber River's bank failure at the intersection of Queen Mary Drive and Kingsway Crescent. The road pavement also showed structural failure as well as the underground infrastructures (storm, sanitary and water main) being in need of replacement. As part of its background monitoring, smoke testing, dye testing and I/I sampling were carried out to determine and locate cross connections and I/I from sanitary sewers. Stormwater sampling showed high concentrations of *E. coli*. Boreholes and groundwater monitoring were carried out at least a year before design and construction. A public meeting was held to advise the local residents of the upcoming construction and to solicit their comments/objections in accordance with the Municipal Class EA. Noise, construction schedule, access and preservation of mature trees were the most common concerns. To address these concerns, the City's Parks department carried out an intensive tree preservation program including injecting nutrients at the roots of all trees along Queen Mary Drive. Instead of using a traditional retaining wall to solve the bank failure, a soil bio-engineering plan was developed which also required high application of nutrients and fertilizer. This reflects in the high concentration of nutrients found in the subsequent groundwater samplings. To further increase the stability of the bank and to minimize the increase of the groundwater level, two perforated groundwater pipes along Kingsway was incorporated in the design of the last maintenance hole, upstream of the outfall. In recognition of the high value of the neighborhood, the City retained the same mason contractor who rebuilt the Old Mill Restaurant, to build the outfall. This area is one of the City's most affluent areas with well maintained landscapes and full mature street trees.

Queen Mary Drive site characteristics:

- Three boreholes were drilled to a depth varying from 2.1 m to 6.7 m,
- Mostly silty sand to clayey silt,
- Hydraulic conductivity measured at 2-7 x 10^{-7} cm/sec for silty sand and 1-4 x 10^{-7} cm/sec for clayey silt, and 6 x 10^{-6} for sand,
- Ground water table 1.6 m to 2.5 m below,
- Total drainage area is 13.3 ha,
- Total length of sewers is 0.44 km,
- Ratio drainage area to sewer length is 3.02 ha/100 m of sewers,
- High income class residential - C=0.30,
- Roof connected,
- Local residential road class,
- Design storage approximately 50 m^3/100m of sewer on average; and,
- Design storage 16.55 m^3 /ha.

Princess Margaret Boulevard

The Princess Margaret Boulevard area, south of Eglinton Ave. West, between Kipling Ave. and Islington Ave. drains to the Humber River and Mimico Creek. As with many parts of the City of Etobicoke, the area was serviced by ditch roads with sanitary sewers and a water main, but no storm sewers. The area is more characteristic of middle to upper income residential neighborhood and is well established with mature trees. This site was selected because the road was in need of replacement and upgrading to curb and gutter cross section, and because it is a residential collector with a higher traffic count and wider cross-section than Queen Mary Drive. Being a residential collector, Princess Margaret Blvd did not have the tree preservation concerns that Queen Mary Drive did. Flow monitoring and sampling was not possible because no storm sewers were installed. However piezometer and groundwater collectors in sanitary maintenance holes were installed at least two years before construction. No evidence of groundwater was found during that period. Seven boreholes were drilled along the 1.3 km of the proposed storm sewer alignment. Depth of drilling ranged from 4.5 m to 14 m with no evidence of groundwater at any depth in any borehole. Soil material varied from silty sand to silty clay, with the measured hydraulic conductivity much lower than the documented range by one or two orders of magnitude. Falling head tests were carried out at each borehole because of the inconsistency of the soil along Princess Margaret Blvd. These tests showed that:

- Hydraulic conductivity for silty sand ranges from 7 x 10^{-7} to 2 x 10^{-7} cm/sec, compared to documented range of 1 x 10^{-3} to 1 x 10^{-5} cm/sec; and,
- Hydraulic conductivity for silty clay was 1 x 10^{-7} cm/sec, compared to the documented range of 1 x 10^{-6} cm/sec or less.

Princess Margaret Boulevard site characteristics

- No groundwater table found above 14 m below surface,
- Hydraulic conductivity lower than documented,
- Total drainage area 30.5 ha.
- Total length of sewer is 1.3km,
- Ratio area to sewer length is 2.35 ha/ 100m,
- Mid density residential C= 0.35-0.45,
- No roof connection,
- Local residential collector,
- Design storage approximately 50m^3 /100 m of sewer; and,
- Design storage 21.3 m^3 /ha.

Breacrest Avenue

A small section of Breacrest Avenue was selected to test a filtration system instead of the exfiltration used at Queen Mary Drive and Princess Margaret Blvd. While the post construction monitoring program indicated that this system performed as well as the exfiltration, the monitoring during the construction showed that it was too complicated for a regular sewer contractor as it required a higher level of inspection. The filtration system is not recommended.

Appendix B

Theory of Etobicoke Exfiltration

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8.5 Theory of Exfiltration Trench Design

An exfiltration trench is a facility that encourages the return of runoff to the ground water. It may be a very simple "soak-away" and comprise only a trench filled with clear stone (i.e. single sized gravel) into which runoff is directed. A more complex facility might be incorporated in-line with a conventional storm sewer and include one or more perforated pipes along the length of the trench to provide more uniform distribution of the inflow over the length of the trench. It is this latter type of facility which is described in the MIDUSS **Trench** command.

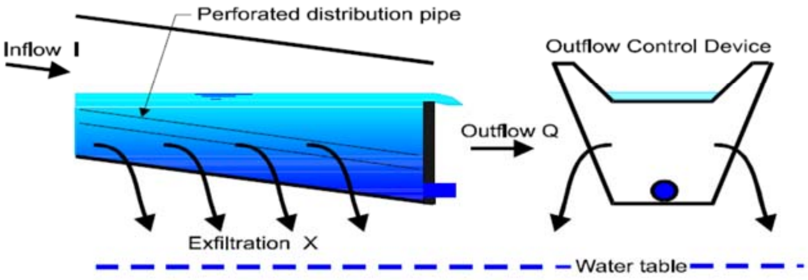


Figure 8.16 A typical exfiltration trench.

Figure 8.16 illustrates a typical arrangement of an exfiltration trench which splits the inflow hydrograph into two components. One fraction is transmitted downstream as an outflow hydrograph that is attenuated by the storage within the voids of the clear stone fill. The balance of the flow is transmitted to the ground water through the pervious walls of the trench. The Trench form has an option to include or exclude the base of the trench in estimating the area contributing to exfiltration.

It is usual to provide some form of outflow control device at the downstream end of the trench to force the free surface in the trench to rise. This causes (1) the volume of voids available for storage to be increased and (2) the surface area along the walls of the trench is increased to allow increased exfiltration. Figure 8.16 shows a typical outflow control device with a small orifice at or near the downstream invert of the trench to allow drainage of accumulated flow in the trench plus an overflow weir to produce high water levels during the maximum inflow rate. The trench may be thought of as a variation of the "super-pipe" facility with a permeable pipe wall.

Analysis of the facility is based on a form of the continuity equation which takes account of the outflow control, the rate of exfiltration and the rate of change of storage within the trench. Thus

Inflow = Outflow + Exfiltration + Rate of change of Storage

or

$$\frac{I_1+I_2}{2}=\frac{Q_1+Q_2}{2}+\frac{X_1+X_2}{2}+\frac{V_2-V_1}{\Delta t} \qquad [8.71]$$

where I = Inflow rate

Q = Outflow rate

X = Exfiltration rate

V = Volume stored

and the subscripts 1 and 2 define values at times t and $(t+\Delta t)$ respectively.

Equation [8.71] can be expanded as:

$$I_1 + I_2 = \left(\frac{2V_2}{\Delta t} + Q_2 + X_2\right) - \left(\frac{2V_1}{\Delta t} + Q_1 + X_1\right) + 2Q_1 + 2X_1 \tag{8.72}$$

or

$$I_1 + I_2 = f(V_2, Q_2, X_2) - f(V_1, Q_1, X_1) + 2Q_1 + 2X_1 \tag{8.73}$$

For any specified outflow control device, the water surface elevation in the trench is dependent on the outflow Q. Both storage volume V and exfiltration X are therefore dependent on Q and a solution for the unknown outflow at time $(t+\Delta t)$ can be obtained from:

$$f(Q_2) = f(Q_1) - 2Q_1 - 2X_1 + I_1 + I_2 \tag{8.74}$$

The method is similar to the graphical solution described in Figure 8.7 *Graphical illustration of equation [8.48]* in topic Theory of Reservoir Routing. One difference is that it is convenient to construct curves (or tables) of both $f(V,Q,X)$ and X as functions of the water surface elevation. In order to do this we must first provide a method of predicting the rate of exfiltration from the trench.

8.5.1 Trench Exfiltration Rate

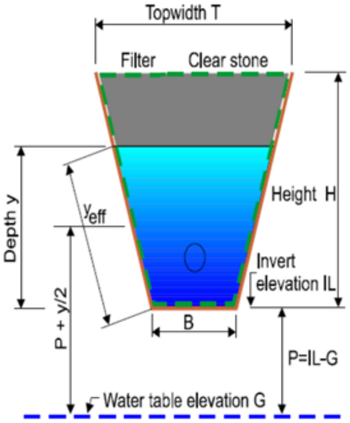


Figure 8.17 Exfiltration Trench Cross-section

Figure 8.17 shows the cross-section assumed in MIDUSS. The shape is a trapezium of height H and top width T tapering symmetrically to a bottom width B. The water table is assumed to be horizontal and located at a depth P=(IL-G) below the downstream invert level of the trench. If the depth of water in the trench voids is y the wetted surface of the trench wall has a length αy where α is given by:

$$[8.75] \qquad \alpha = \sqrt{1 + \left(\frac{T - B}{2H}\right)^2}$$

Flow through the porous soil is assumed to be laminar and can be estimated using Darcy's Law

$$[8.76] \qquad \frac{Q}{A} = q = KS_f$$

where K = hydraulic conductivity of the soil

Sf = friction gradient

Q/A = volumetric flux.

Note that the volumetric flux is much smaller than the actual velocity through the voids since only a fraction of area A is available for flow.

The average driving head between the water in the trench and the water table is P + y/2 and the path length is P so that the available gradient is given by [8.77].

[8.77] $$S_f = \frac{IL - G + {}^{y}\!/_{2}}{IL - G} \quad = \quad 1 + \frac{{}^{y}\!/_{2}}{IL - G}$$

The exfiltration flow through a unit length of trench can then be estimated as:

[8.78] $$dX = (2\alpha y + \beta B) K S_f$$

where β = 1 or 0 depending on whether the 'Include base width' check box is checked or unchecked. Checked is the default condition.

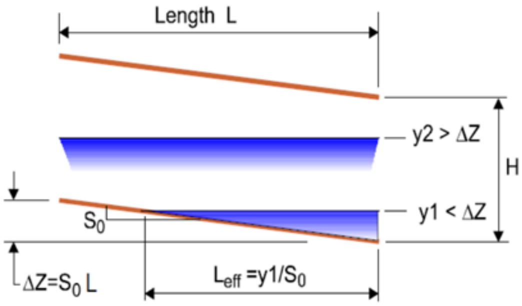


Figure 8.18 **Idealized Longitudinal section on an Exfiltration Trench.**

If the trench invert has a finite slope it is possible that for low flows which can be transmitted by the orifice in the outflow control device, the horizontal free surface does not extend over the full length of the trench. Figure 8.18 shows this situation. Even if the downstream depth is greater than the invert drop ΔZ the available surface for exfiltration must be corrected to allow for the reduced depth at the upstream end. This assumes that the hydraulic gradient along the trench is negligible and that the surface is essentially horizontal. The available wall surface through which exfiltration can occur is therefore given by:[8.79] and [8.80].

[8.79] $$A_X = \alpha\left(y - \frac{\Delta Z}{2}\right)L \quad \text{for} \quad y \geq \Delta Z$$

[8.80] $$A_X = \alpha \frac{y^2}{2S_f} \quad \text{for} \quad y < \Delta Z$$

8.5.2 Estimating the Required Trench Volume

When the Trench command is invoked MIDUSS tries to estimate the required trench volume (i.e. voids plus stone) which is required to achieve the currently defined target peak outflow. The process is similar to that described in the topic Theory of Reservoir Routing; Estimating the

Required Pond Storage. However, an additional level of iteration is required as for each estimate of storage volume the corresponding exfiltration must be computed and the target outflow reduced by this amount.

As with the Pond procedure, the iteration uses the secant method to solve a relationship between *Q* and *K* to yield the required value of *Q* and thus estimate the storage from the corresponding lag *K*.

The algorithm is summarized as follows.

1. Assume maximum exfiltration rate Xmax = 0
2. Set desired Qout = TargetQout - Xmax
3. Initialize values of K and Q for two points on the curve, i.e.

   K1 = Hydrograph Volume/(0.6*Imax)

   K2 = 0.2 Inflow hydrograph timebase

   Q1 = 0.1 Imax

4. Route inflow through a linear reservoir of lag K2 to get maximum outflow Q2
5. Interpolate between points (K1,Q1) and (K2,Q2) to get K3 for required Qout
6. For next iteration set K1 = K2

   K2 = K3

   Q1 = Q2

7. If change in Q2 > ε go to step 4.
8. Solution found for Q2. Estimate storage S = K2.Q2 and convert to trench volume.
9. From trench volume estimate maximum water level Wlmax.
10. For WL calculate exfiltration Xmax.
11. For 5 iterations go to step 2.

Because of the many other quantities which can affect the routing operation the estimate is only an approximate guide and trial and error is normally required.

Appendix C

Background Data Collection

Background data collection

Background work at the three pilot sites was probably more extensive than needed. This was done to ensure the success of the projects and to ensure that the new design did not have negative impacts on other aspects of the projects. These include:

- Preservation of existing trees along the roads,
- Structural road design,
- Bank stabilization,
- Basement flooding,
- Sewer cross connection,
- Sanitary infiltration; and,
- Public acceptance.

To help the drainage designers, the following tables recommend the minimum for data collection.

Table 1–Background for new Development

Data	Reasons	Comments
Source Protection Area	To determine drinking water use of groundwater	Contact local Conservation Authority and MOECC district office for information.
Soil type	To determine suitability	Ontario soil maps can be obtained from------
Rainfall characteristics	To determine intensity, depth, duration and frequency	Using the local IDF curve is not suitable. Select a station with 10-20 years of data.
Groundwater level	To determine location of EES	As part of soil report. Boreholes to at least 0.5m below beddings
Wetland	Certain types of wetland depend on the maintenance of baseflow from groundwater	See Watershed and Subwatershed studies or contact local MNRF office.
Municipal Subdivision design manual	Minor flow design, reduction of sewer pipe, acceptance of EES, roof connection etc.	Contact local municipality
Flood and erosion control	To determine if existing erosion caused by slope/bank stability due to high water table	Contact local CA, refer to soil consultant for analysis if necessary
Existing wells	To determine suitability of EES.	If wells are used for drinking waters - do not use EES without proper hydrogeological studies. Contact MOECC office for record
Existing Wells	To determine pre development groundwater (g/w) quality	If g/w no longer used for drinking, the local MOECC office may still have records of wells and quality of g/w
Mix land use	To determine suitability	If industrial land use located upstream of residential - do not proceed
Environmental Assessment	Public and environment concerns	Follow the Municipal Class EA

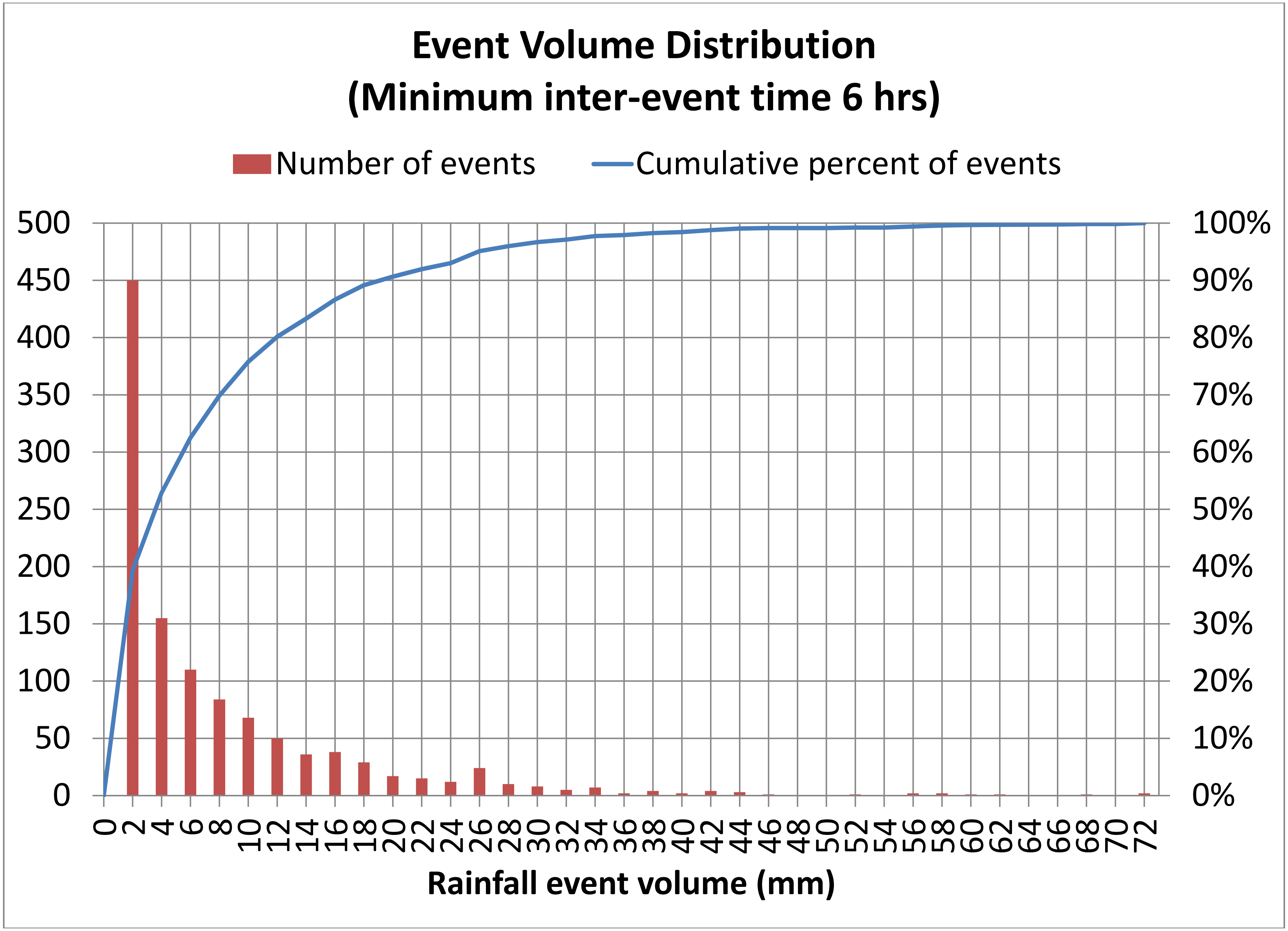
Table 2- Background for existing residential

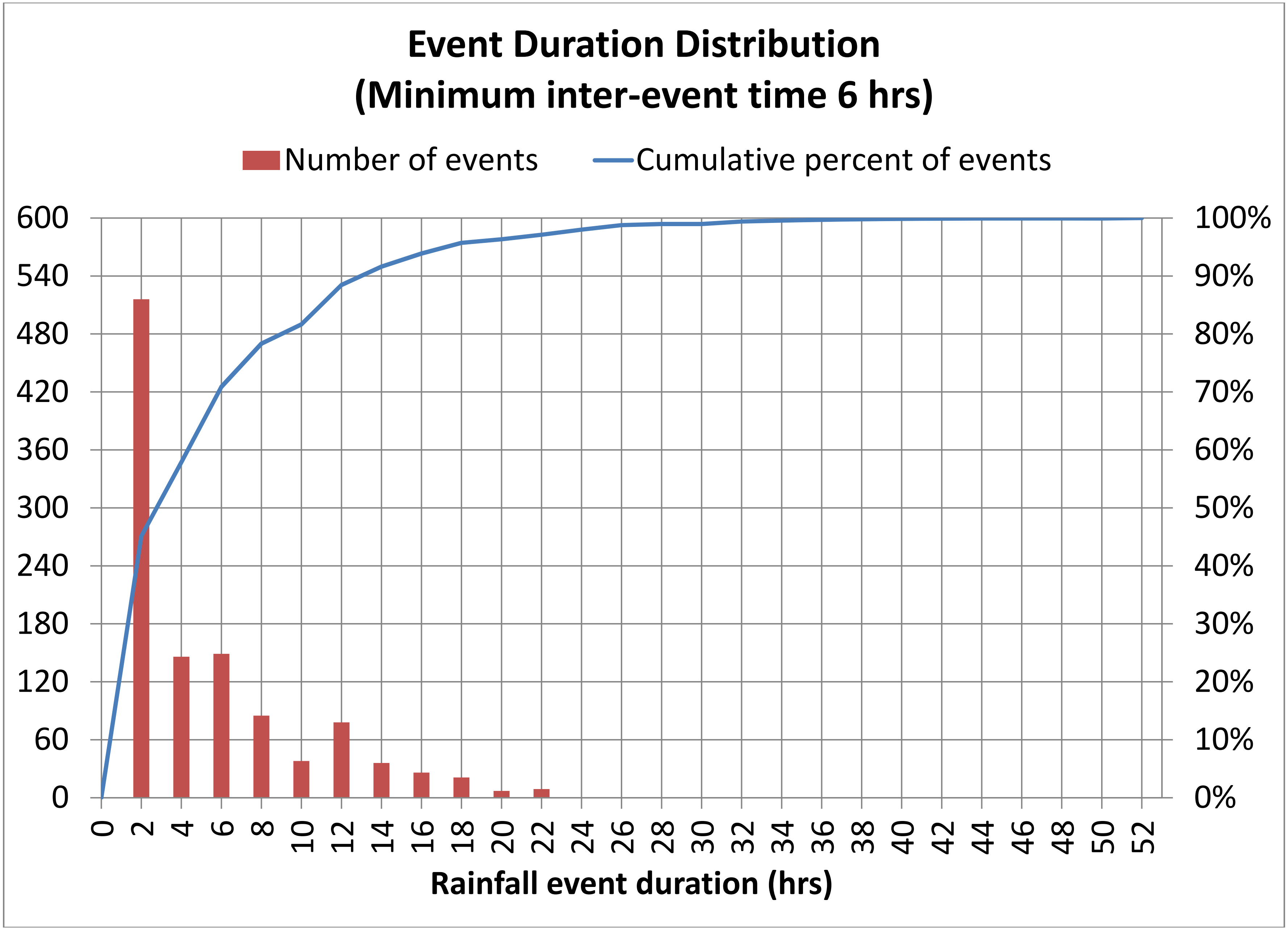
Data	**Reasons**	**Comments**
Basement flooding	To determine suitability	There are many reasons for basement flooding - if high groundwater table is one, do not use EES
Cross connections	To determine source of *E.coli* and other domestic parameters	Very common in older areas - should be identified using smoke tests, dye test and rectified during reconstruction.
Combined Sewer overflow	To determine suitability	As part of a sewer separation program, EES may be suitable
Mature streetscape	Construction practices	Follow normal tree preservation practices during construction
Soil type	See Table 3	See Table 3
Rainfall characteristics	See Table 3	See Table 3
Groundwater level	See Table 3	See Table 3
Wetland	See Table 3	See Table 3
Environmental Assessment	See Table 3	See Table 3

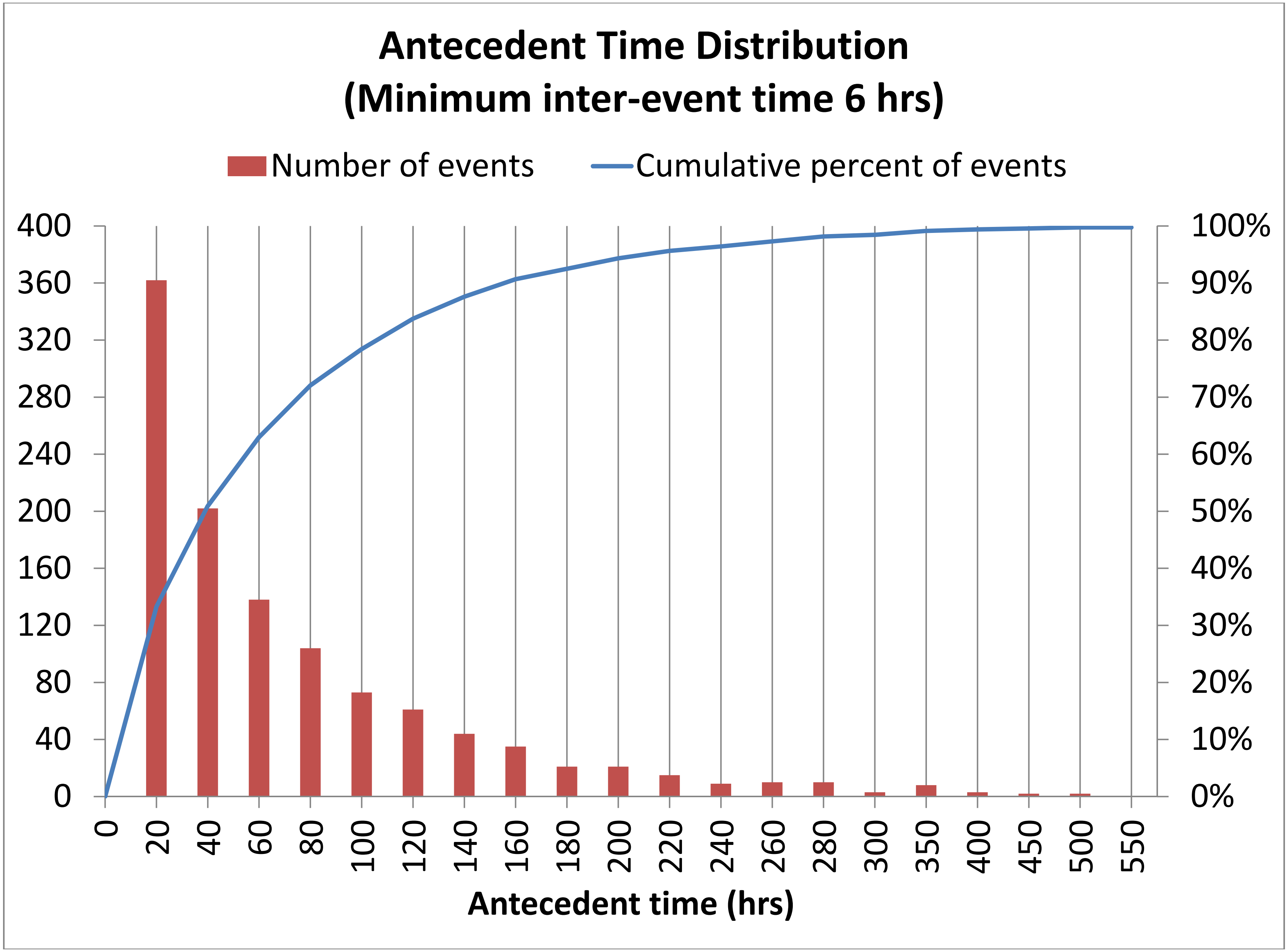
Appendix D

Rainfall Analysis

Buttonville Airport


Event Volume Distribution
(Minimum inter-event time 6 hrs)
Number of events
Cumulative percent of events
500
450
400
350
300
250
200
150
100
50
0
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
38
40
42
44
46
48
50
52
54
56
58
60
62
64
66
68
70
72
Rainfall event volume (mm)


Event Duration Distribution
(Minimum inter-event time 6 hrs)
Number of events
Cumulative percent of events
600
540
480
420
360
300
240
180
120
60
0
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
38
40
42
44
46
48
50
52
Rainfall event duration (hrs)


Antecedent Time Distribution
(Minimum inter-event time 6 hrs)
Number of events
Cumulative percent of events
400
360
320
280
240
200
160
120
80
40
0
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
350
400
450
500
550
Antecedent time (hrs)

Appendix E

Documentation Requirements

for

Potential Review by Approval Agencies

Documentation

For regulatory agency approval, the following information and documents should be attached:

- Ontario soil map number,
- Borehole location and soil information at bedding level,
- Field measured hydraulic conductivity factor, *K* in cm/sec
- Groundwater samplings, depth and seasonal fluctuation,
- Rainfall information including name of closest and longest rain station,
- Rainfall analysis including chosen rainfall depth, duration and inter-event.
- Copy of form EES1 for sizing of minor system piping and trench width,
- Copy of form EES1 for the 95 percentile rainfall event depth,
- Copy of form EES1 for final minor system piping and trench width,
- Relevant correspondence, including consultation with municipality and regulatory agencies,
- Storm Drainage report (i.e. Master drainage plan, etc.)
- Detailed calculation including computer printout.

Form EES1

Name of project:		Storm duration:	hr Page____ of ______
Municipality:		Inter-event:	hr
date:		total drainage area:	Ha
Calculation by:		total storage:	cubic m
design storm		perf. pipe size:	mm

street	from	to	area	length	size	slope	flow	runoff vol	Trench wth	Trench vol.	Overf. Vol	perc.rate
	mh	mh	ha	m	mm	%	m^3/sec	m^3	m	m^3	m^3	mm/hr
confluence												

Appendix F

Example

<u>Example:</u>

The following example is a typical residential subdivision in Ontario.

EES Design Criteria

- Intensity – Minor design, 10 storm return with 15 minutes TC for Residential
- Volume – 95% of annual rainfall events by rainfall depth
- Quality – No overflow of 95 % of annual rainfall events
- Duration – 90 % of annual rainfall event duration
- Frequency – Less than 48 hrs inter-event

- Storage – 30 m^3/ha or more
- Density – Less or equal to 2ha/100m of sewer

Criteria Selected

- Intensity – 10 years storm with Chicago distribution (a = 1010, b = 4.6 and c = 0.78)
- Volume – 100% of 17mm rainfall depth
- Quality – Only the last section to discharge directly
- Duration – 2 hr for minor and 4 hours for quality
- Frequency- Less than 48 hours

Background Information

Municipality: Chelsea, Ontario
Project name: Daleville subdivision
- Source protection: No
- Baseflow protection: yes, Black creek, resident coldwater fishery, and wetland
- Land use: Residential development having 0.4 runoff coefficient with a future high density (c = 0.88) residential block
- Groundwater: 5 m deep at highest over 1 year of monitoring

Soil type at trench:
- Example 1 – silty clay with hydraulic conductivity of 5.5 x10-4 cm/sec
- Example 2 – sandy loam with hydraulic conductivity of 5.5 x 10-3 cm/sec

Results

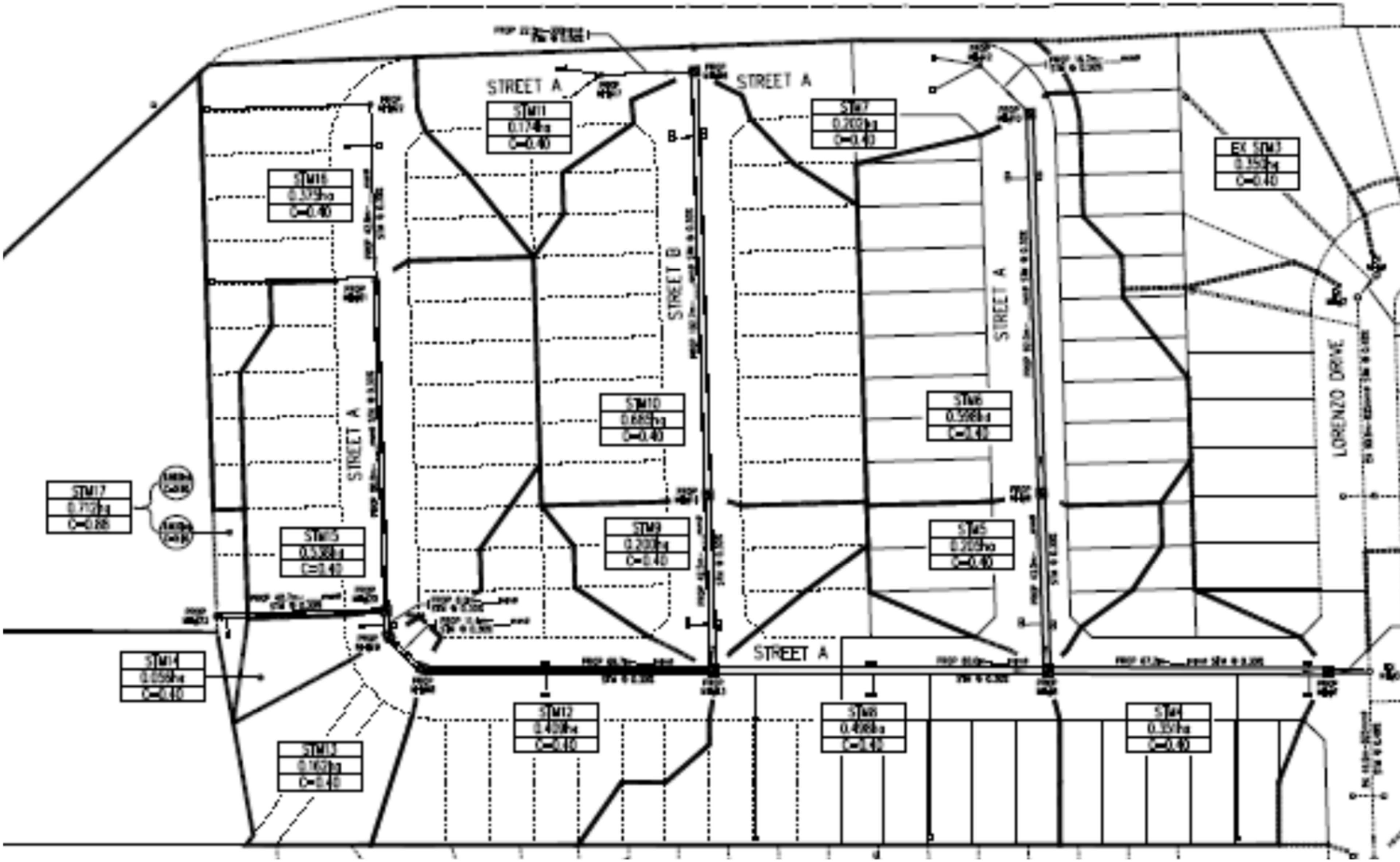
- Total drainage area: 5.165 ha
- Storage: 133.63 cu.m/ha available – ok
- Density: 0.648 ha/100m sewer – ok
- Treatment: 94% of runoff volume treated
- Centroid lag: max 7hrs – ok

- In silty clay, **29**% peak flow reduction and **39**% volume reduction for the 10 year storm.

- In sandy loam, **58**% peak flow reduction and **72** % volume reduction for the 10 year storm

Attachments

- Drainage plan
- Minor data sheet – 10 year storm without EES
- Minor data sheet - 17mm storm with EES – silty clay
- Minor data sheet – 10 year storm with EES – silty clay
- Minor data sheet – 10 year storm with EES – sandy loam


STREET A
STREET A
STREET A
STREET A
STREET A
STREET B
LORENZO DRIVE
STM11
0.174ha
C=0.40
STM16
0.379ha
C=0.40
STM7
0.202ha
C=0.40
EX STM3
0.350ha
C=0.40
STM10
0.685ha
C=0.40
STM6
0.598ha
C=0.40
STM17
0.712ha
C=0.88
STM15
0.538ha
C=0.40
STM9
0.200ha
C=0.40
STM5
0.205ha
C=0.40
STM14
0.059ha
C=0.40
STM13
0.162ha
C=0.40
STM12
0.409ha
C=0.40
STM8
0.408ha
C=0.40
STM4
0.357ha
C=0.40

Name of project:	Daleville	Storm duration:	2 hr Page____ of ____
Municipality:	Chelsea	Inter-event:	hr
Date:		Total drainage area:	5.165 ha
Calculation by:	J. Tran	Total storage:	cubic m
Design storm	10 yr storm - 2hr	Perf. pipe size:	mm

Street	From	To	Run.	Area	Length	Size	Slope	Flow	Runoff Vol.	Trench Width	Trench Vol.	Overf. Vol.	Perc. Rate
	MH	MH	Coeff.	ha	m	mm	%	m^3/sec	m^3	m	m^3	m^3	mm/hr
A	22	21	0.4	0.375	42.80	300	0.3	0.039					
	21	20	0.4	0.538	80.00	375	0.3	0.094					
External	23	20	0.88	0.712	120.00	450	0.3	0.16					
combined at 20													
	20	13	0.4	0.627	87.10	600	0.3	0.291					
B	17	16	0.4	0.174	22.80	250	0.3	0.019					
	16	14	0.4	0.685	102.70	375	0.3	0.088					
	14	13	0.4	0.200	42.50	450	0.3	0.109					
combined		at 13											
	13	8	0.4	0.498	80.00	675	0.3	0.437					
A	12	10	0.4	0.202	16.70	200	0.5	0.022					
	10	9	0.4	0.598	92.00	375	0.3	0.083					
	9	8	0.4	0.205	43.00	450	0.3	0.104					
combined at mh8													
A	8	7	0.4	0.351	67.20	750	0.3	0.576	1228.84				

Name of project:	Daleville	Storm duration:	4	hr	Page____ of ____
Municipality:	Chelsea	Inter-event:	24	hr	
Date:		Total drainage area:	5.165	ha	
Calculation by:	J. Tran	Total storage:	690.2	cubic m	
Design storm	17mm – Silty Clay soil	Perf. pipe size:	200	mm	

Street	From	To	Run.	Area	Length	Size	Slope	Flow	Runoff Vol.	Trench Width	Trench Vol.	Overf. Vol.	Perc. Rate
	MH	MH	Coef.	ha	m	mm	%	m^3/sec	m^3	m	m^3	m^3	mm/hr
A	22	21	0.4	0.375	42.80	300	0.3	0.003	16.27				
	21	20	0.4	0.538	80.00	375	0.3	0.004	23.35	1.4	69.5		20
External	23	20	0.88	0.712	120.00	450	0.3	0.016	90.5	1.5	107.7	3.25	20
combined at 20								0.004	26.6				
	20	13	0.4	0.627	87.10	600	0.3	0.005	27.21	1.6	79.9		20
B	17	16	0.4	0.174	22.80	250	0.3	0.001	7.55				
	16	14	0.4	0.685	102.70	375	0.3	0.005	29.73	1.4	88.1		20
	14	13	0.4	0.200	42.50	450	0.3	0.002	8.68	1.5	39.9	1.45	20
combined		at 13						0.006	37.3				
	13	8	0.4	0.498	80.00	675	0.3	0.004	21.61	1.8	84.7		20
A	12	10	0.4	0.202	16.70	200	0.5	0.002	8.77				
	10	9	0.4	0.598	92.00	375	0.3	0.004	25.95	1.4	79.5		20
	9	8	0.4	0.205	43.00	450	0.3	0.002	8.9	1.5	40.4		20
combined at mh8								0.005	30.5				
A	8	7	0.4	0.351	67.20	750	0.3	0.003	15.23	2	100.5		20

Name of project:	Daleville	Storm duration:	2 hr Page____ of ____
Municipality:	Chelsea	Inter-event:	24 hr
Date:		Total drainage area:	5.165 Ha
Calculation by:	J. Tran	Total storage:	690.2 cubic m
Design storm	Minor EES 10 yr - Silty clay	Perf. pipe size:	200 mm

Street	From	To	Run.	Area	Length	Size	Slope	Flow	Runoff Vol.	Trench Width	Trench Vol.	Overf. Vol.	Perc. Rate
	MH	MH	Coef.	ha	m	mm	%	m^3/sec	m^3	m	m^3	m^3	mm/hr
A	22	21	0.4	0.375	42.80	300	0.3	0.039					
	21	20	0.4	0.538	80.00	375	0.3	0.066		1.4	69.5		20
External	23	20		0.712	80.00	450	0.3	0.162		1.5	107.7		20
combined at 20								0.225					
	20	13	0.4	0.627	87.10	525	0.3	0.236		1.6	79.9		20
B	17	16	0.4	0.174	22.80	250	0.3	0.019					
	16	14	0.4	0.685	102.70	375	0.3	0.069		1.4	88.1		20
	14	13	0.4	0.200	42.50	450	0.3	0.116		1.5	39.9		20
combined		at 13						0.339					
	13	8	0.4	0.498	80.00	675	0.3	0.385		1.8	84.7		20
A	12	10	0.4	0.202	16.70	200	0.5	0.022					
	10	9	0.4	0.598	92.00	375	0.3	0.061		1.4	79.5		20
	9	8	0.4	0.205	43.00	450	0.3	0.106		1.5	40.4		20
combined at mh8								0.468					
A	8	7	0.4	0.351	67.20	675	0.3	0.412	748.74	2	100.5	673.96	20

Name of project:	Daleville	Storm duration:	2	hr	Page____ of _____
Municipality:	Chelsea	Inter-event:	24	hr	
Date:		Total drainage area:	5.165	Ha	
Calculation by:	J. Tran	Total storage:	690.2	cubic m	
Design storm	Minor EES 10 yr - Sandy loam	Perf. pipe size:	200	mm	

Street	From	To	Run.	Area	Length	Size	Slope	Flow	Runoff Vol.	Trench Width	Trench Vol.	Overf. Vol.	Perc. Rate
	MH	MH	Coef.	ha	m	mm	%	m^3/sec	m^3	m	m^3	m^3	mm/hr
A	22	21	0.4	0.375	42.80	300	0.3	0.039					
	21	20	0.4	0.538	80.00	300	0.3	0.055		1.4	69.5	0	200
External	23	20		0.712	80.00	450	0.3	0.162		1.5	107.7	71.79	200
combined at 20													
	20	13	0.4	0.627	87.10	450	0.3	0.115		1.6	79.9	69.59	200
B	17	16	0.4	0.174	22.80	250	0.3	0.019					
	16	14	0.4	0.685	102.70	375	0.3	0.069		1.4	88.1	0	200
	14	13	0.4	0.200	42.50	375	0.3	0.075		1.5	39.9	68.72	200
combined		at 13											
	13	8	0.4	0.498	80.00	525	0.3	0.207		1.8	84.7	187.32	200
A	12	10	0.4	0.202	16.70	200	0.5	0.022					
	10	9	0.4	0.598	92.00	300	0.3	0.061		1.4	79.5	0	200
	9	8	0.4	0.205	43.00	375	0.3	0.067		1.5	40.4	54.88	200
combined at mh8													
A	8	7	0.4	0.351	67.20	525	0.3	0.244	345.85	2	100.5	271.07	200