# Performance Assessment of a Perforated Pipe Stormwater Exfiltration System - Toronto, Ontario

2004

Ministry of the Environment
Ontario

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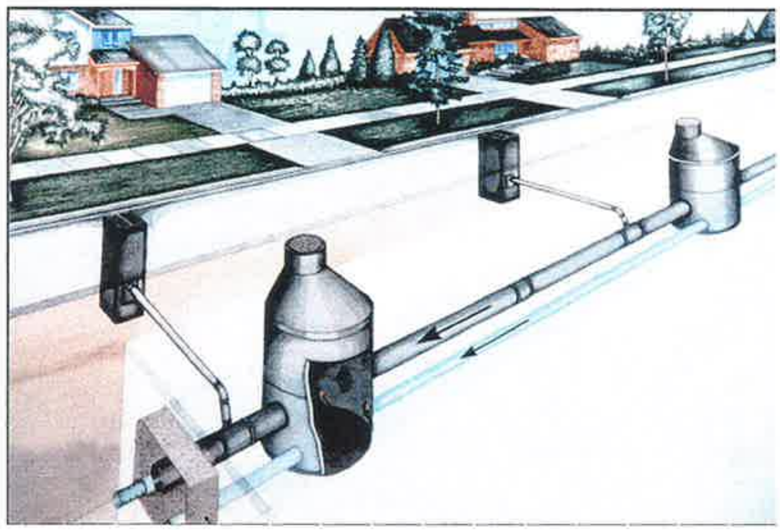

# PERFORMANCE ASSESSMENT OF A PERFORATED PIPE STORMWATER EXFILTRATION SYSTEM

-

# TORONTO, ONTARIO

a report prepared by

STORMWATER ASSESSMENT MONITORING
AND PERFORMANCE (SWAMP) PROGRAM

for

Great Lakes Sustainability Fund of the Government of Canada
Ontario Ministry of the Environment
Toronto and Region Conservation Authority
Municipal Engineers Association of Ontario
City of Toronto

December, 2004

## NOTICE

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The initial version of this report was prepared by SWAMP. Additional data analysis and editing were undertaken by Questor Veritas Inc. under contract to the SWAMP program as represented by the Toronto and Region Conservation Authority.

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# THE SWAMP PROGRAM

The Stormwater Assessment Monitoring and Performance (SWAMP) Program is an initiative of the Government of Canada's Great Lakes Sustainability Fund, the Ontario Ministry of the Environment, the Toronto and Region Conservation Authority, and the Municipal Engineer's Association. A number of individual municipalities and other owner/operator agencies have also participated in the SWAMP studies.

Since the mid 1980s, the Great Lakes Basin has experienced rapid urban growth. Stormwater runoff associated with this growth is a major contributor to the degradation of water quality and the destruction of fish habitats. In response to these environmental concerns, a variety of stormwater management technologies have been developed to mitigate the impacts of urbanization on the natural environment. These technologies have been studied, designed and constructed on the basis of computer models and pilot-scale testing, but have not undergone extensive field-level evaluation in southern Ontario. The SWAMP Program was designed to address this need.

The SWAMP Program's objectives are:

* to monitor and evaluate the effectiveness of new or innovative stormwater management technologies; and
* to disseminate study results and recommendations within the stormwater management industry.

Additional information concerning SWAMP and the sponsoring agencies is included in Appendix A.

## ACKNOWLEDGEMENTS

This report was prepared for the Steering Committee of the Stormwater Assessment Monitoring and Performance (SWAMP) Program. The SWAMP Program Steering Committee is comprised of representatives from:

- the Government of Canada's Great Lakes Sustainability Fund,
- the Ontario Ministry of the Environment,
- the Toronto and Region Conservation Authority,
- the Municipal Engineers Association of Ontario.

Funding support for this project was provided by the Great Lakes 2000 Cleanup Fund (superseded by the Great Lakes Sustainability Fund), the Ontario Ministry of the Environment (OMOE) and the City of Etobicoke (now part of the City of Toronto). The OMOE also provided office facilities and logistic support for the SWAMP program. The Laboratory Services Branch of the OMOE provided laboratory analyses. Administrative support to the SWAMP program was provided by the Toronto and Region Conservation Authority. Staff at the City of Etobicoke provided permission to conduct the monitoring study and provided logistical assistance.

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# EXECUTIVE SUMMARY

## Background and Objectives

This report contains a performance evaluation of a new stormwater management technology that was applied in three demonstration projects in the City of Etobicoke[1], Ontario, Canada.

Various demonstration projects have been built within the Province of Ontario in recent years, under several initiatives, to contribute to the development of stormwater management knowledge. These initiatives have been driven by the realization in the late 1980's that urban stormwater runoff is a significant cause of water quality degradation.

Most of the new stormwater facilities have been constructed in areas of new urban development. Consequently, most of the demonstration projects undertaken to date have addressed technologies suitable for use in "green field" situations. Retrofitting areas of existing development for stormwater management infrastructure is particularly complicated for a number of reasons. The technologies demonstrated in Etobicoke and evaluated in this report represent one class of system that has potential for retrofitting existing city infrastructure. The overall water quantity and quality improvements achieved by these technologies may be equivalent to those obtained with more traditional stormwater management practices.

Stormwater exfiltration and filtration systems are constructed within the road right-of-way, avoiding the need for large areas of public land for ponds or other large facilities. Both systems employ sub-surface perforated pipes and artificial lenses of gravel to hold and transport significant volumes of stormwater. The systems differ in the amount of water that is expected to exfiltrate to become groundwater, and in the particular configuration of the pipe networks.

Several questions have been raised regarding this class of technology, including questions of system capacity, cost and long-term maintenance requirements. The collection and analysis of additional data was recognized as being necessary to address these questions.

This report documents the performance of the Etobicoke stormwater exfiltration and filtration systems for a two-year period between October 1996 and September 1998. Data collected shortly after the facilities were constructed (1994 and 1995) are also taken into consideration in the assessment of the systems. The data obtained provide some answers to the performance and maintenance questions. Since some aspects of performance and long-term maintenance can be measured only over a longer period of time, recommendations are made for an appropriate long-term monitoring program.

[1] now part of the City of Toronto

Three main objectives were established for monitoring the exfiltration and filtration systems:

- to evaluate the performance of the systems;
- to develop guidelines for future implementation and maintenance of these systems;
- to provide recommendations for site selection for future installations, and for monitoring procedures.

## Study Area and Facility Design

Three sites were designed and constructed between 1992 and 1994 as a demonstration project in the City of Etobicoke. The sites were:

- a conveyance pipe-based exfiltration system on Princess Margaret Boulevard;
- a conveyance pipe-based exfiltration system on Queen Mary's Drive;
- a conveyance pipe-based filtration system on Braecrest Avenue.

Both the exfiltration and filtration systems are installed under municipal streets. In addition to conventional sewer pipes that are designed to convey all of the runoff of a standard design storm, the systems include two or more perforated pipes. All pipes are embedded in a gravel-filled trench separated from the local soils by a geotextile fabric.

In the *exfiltration* system, two perforated pipes are located *below* the main sewer pipe (Figure 1). Runoff from catchbasins enters the system by way of catchbasin leads connected to the sewer pipes or maintenance holes (manholes) in the conventional manner. At each maintenance hole, the runoff enters the perforated pipes to be distributed into the gravel bed from where it exfiltrates into the soil and becomes groundwater. If the volume or rate of runoff exceeds the capacity of the exfiltration system, the water level in each maintenance hole increases to the point at which the excess flow is carried by the conventional sewer pipes.

In the *filtration* system, a perforated pipe is located *above* the main sewer pipe (Figure 2). Runoff from the catchbasins is directed to this perforated pipe, from where it is distributed into the gravel bed. The runoff is filtered down through the gravel and some of it may exfiltrate to the local soil. Most of the filtered water is collected by two perforated pipe underdrains located below the main sewer pipe and discharged to the downstream maintenance hole from where it is conveyed by the next leg of the main sewer pipe. The principal effects of the filtration system are to dampen variations in flow rate and to filter pollutants out of the runoff. If the rate of runoff exceeds the throughput capacity of the filtration system, water in the catchbasins rises to a level at which a second catchbasin outlet pipe conveys the excess flow directly to the main sewer pipe, bypassing the gravel filter bed.

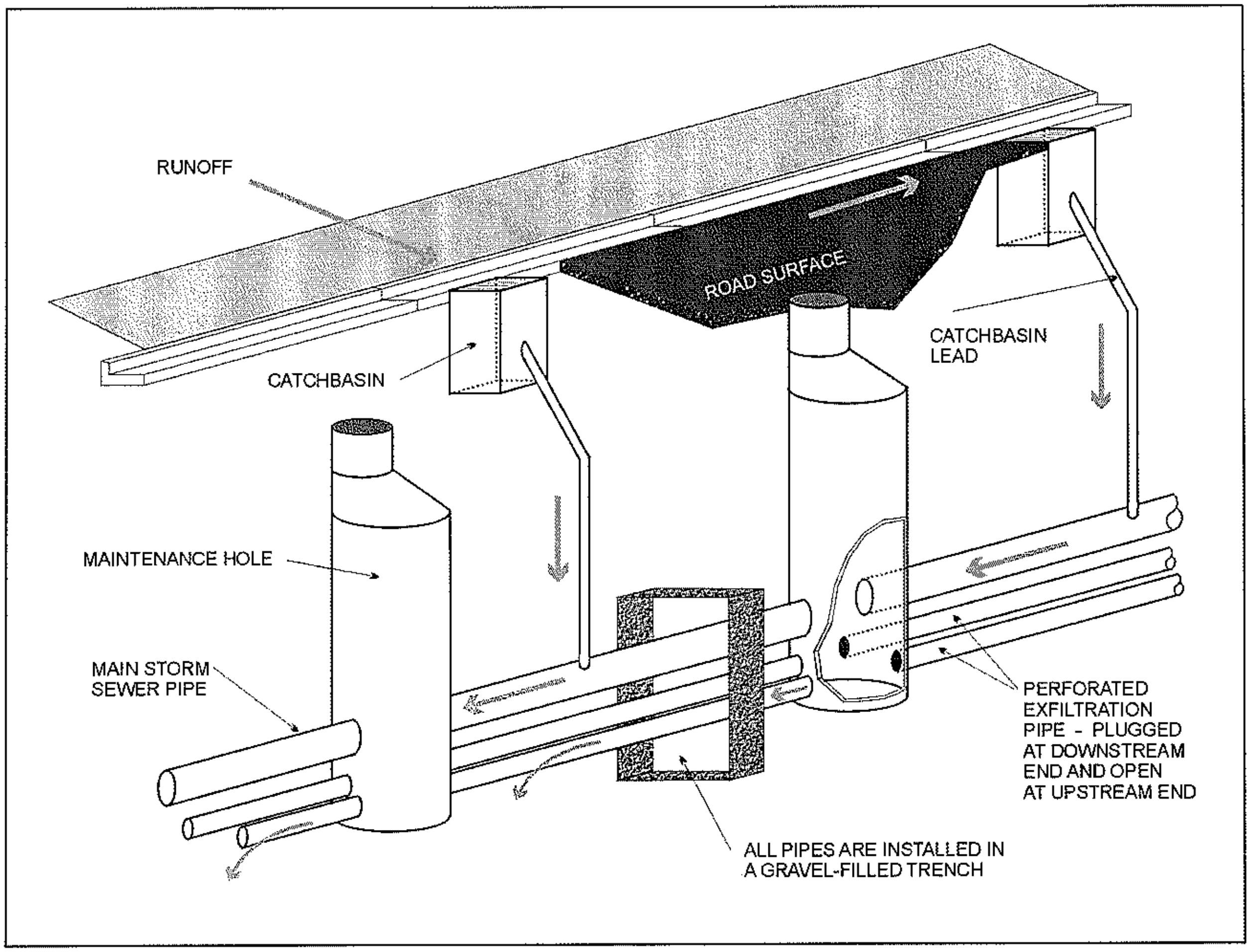


***Figure 1:*** Etobicoke exfiltration system schematic

The Etobicoke exfiltration and filtration systems were designed for use in low-density residential areas where groundwater is not used as a source of water supply. Other criteria include a low groundwater table and low risk of hazardous spills. The exfiltration system requires sandy or silty soil with good hydraulic conductivity. The filtration system was designed for use in areas where percolation rates through local soils are too slow to provide effective exfiltration. For cost-effective implementation, both systems are recommended for consideration where road and sewer reconstruction projects are planned.

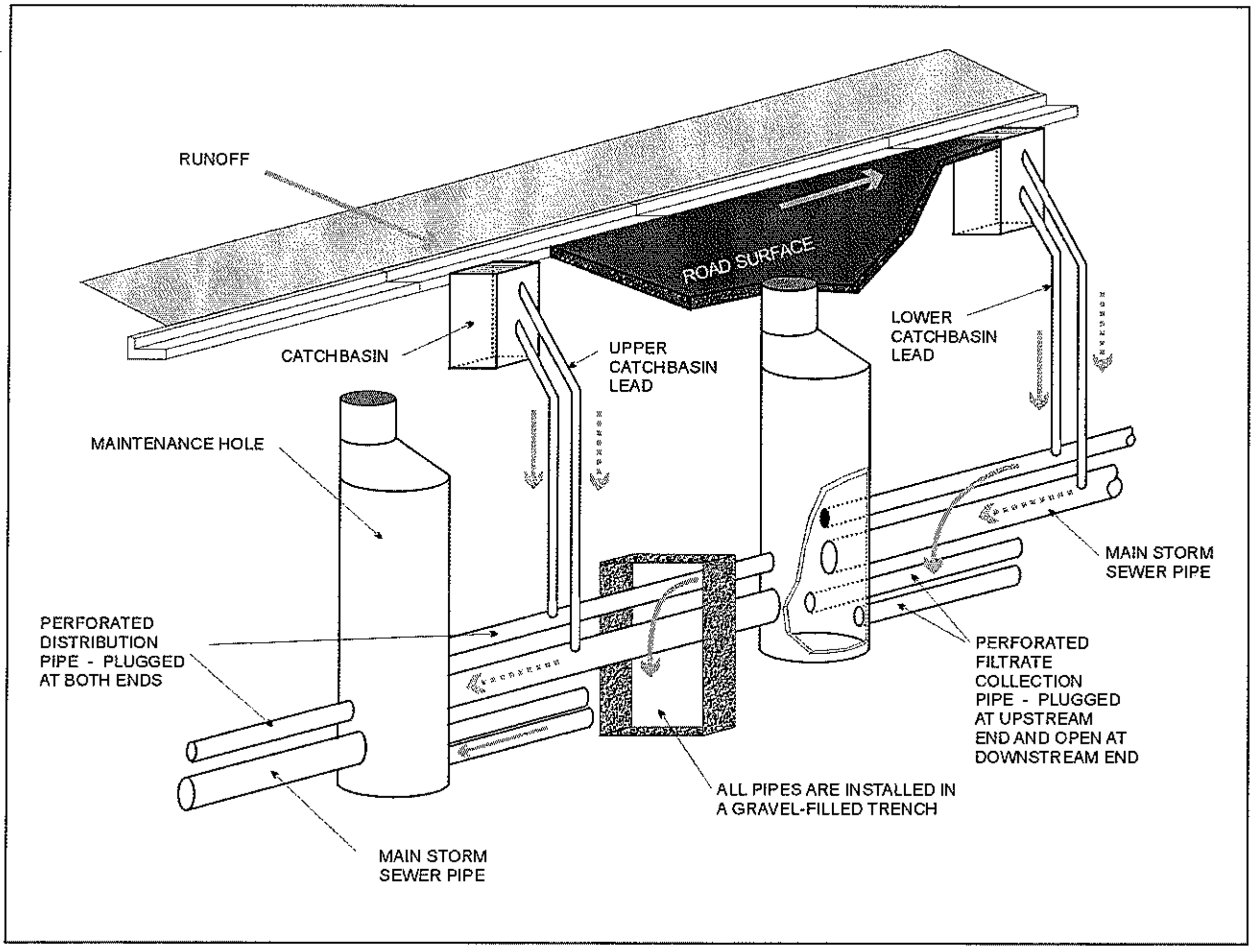


***Figure 2:*** Etobicoke filtration system schematic

## Monitoring Program

The exfiltration and filtration systems were monitored at the downstream ends of each system. Since the gravel trench does not continue past the last maintenance hole in the drainage system, the monitoring stations provided access to all flows exiting the study sites.

Monitoring was initiated in August of 1996. The objectives were to evaluate proposed monitoring procedures and to obtain an initial assessment of the three facilities. Some data had been obtained from all three sites by the end of November.

In 1997 and 1998, monitoring was undertaken primarily at the Princess Margaret Boulevard site. Samples were also collected from a groundwater relief pipe at the Queen Mary's Drive site in order to compile background data on groundwater quality.

Rainfall was measured at school sites in the general area of the study. Additional rainfall data were obtained from L.B. Pearson International Airport. Flows were measured with area-velocity meters, in conjunction with v-notch weirs in some locations. Water level sensors were also employed in maintenance holes. Water quality samples were collected by a combination of automated samplers, grab samples and buckets placed in the maintenance holes.

## Study Findings

The Queen Mary's Drive exfiltration system was found to overflow more frequently than was expected, because rainfall of less intensity than the 15-mm, 1-hour design storm caused overflows. A relatively high groundwater table was thought to be a contributing factor. In addition, examination of the as-built drawings for this site revealed that an appreciable area drained by conventional sewers was discharging to the Queen Mary's Drive sewer. Thus, the hydraulic load placed on the system was greater than it would have been for a system consisting exclusively of the exfiltration design. The runoff coefficients for this site indicated that the system was working well on a volumetric basis, regardless of the number of rainfall events that caused overflow. Most of the runoff coefficients were less than 0.1; all but three were less than 0.2. Assuming that the runoff coefficient for a typical low-density residential area is approximately 0.3 to 0.4, the implication of the observations is that up to two-thirds of the runoff was being exfiltrated.

The Braecrest Avenue filtration system was found to have a much greater exfiltration capacity than had been anticipated. Very few measurable flows were observed. Storm events as large as 66 mm were found to generate very little flow from the filtration system. The soil types in the area include silty clay and sandy loam; deposits of the latter material might have resulted in high percolation rates in some locations.

Monitoring of the Queen Mary's Drive and Braecrest Avenue sites was terminated or abbreviated because the facilities were not considered to be representative of their respective design objectives.

Monitoring of the Princess Margaret Boulevard exfiltration site was continued into the next two runoff seasons. Although flow meters were in place for part of the study, interpretation of the performance of the system was based primarily on water level data that indicated the occurrence of overflow conditions. The system was seen to have the capability of exfiltrating runoff from storms considerably in excess of the 15 mm design criterion. During the monitoring periods, 14 rainfall events exceeded 15 mm in depth but only three events caused system overflows.

However, the exfiltration system was sensitive to the rate of runoff and to antecedent conditions. A prolonged rainfall of large volume would not likely cause overflow in the system, but could saturate the soil such that a subsequent event of less than 15 mm depth (but of greater intensity) may cause an overflow. One event with 15 mm of rainfall in one hour (approximating the design standard) caused a brief overflow because the maximum 5-minute rainfall depth was 10 mm.

Hydraulic tests of the Princess Margaret Boulevard exfiltration facility conducted during an earlier study demonstrated that the system was limited by throughput capacity and not by storage capacity in the gravel bed or the exfiltration rate into the local soil. The water level in the maintenance hole rose appreciably above that in the adjacent gravel bed. Consequently, the problem was one of headloss encountered in getting the flow into the perforated pipes and/or into the gravel bed. If design modifications can overcome this limitation, the number of overflow events would be reduced significantly and more runoff could be exfiltrated.

Examination of outflow hydrographs from the Princess Margaret site has suggested that runoff tends to migrate through the gravel trench to the downstream end of the system, from where it may emerge as delayed overflow. Design modifications that segment the gravel trench may utilize the storage volume to better advantage.

Water quality data from this study were limited by access to the raw runoff and by the small number of overflow events. The lack of measurable flow data in most cases also prevented the calculation of mass balances and removal efficiencies. The available data suggest that the filtrate from the filtration system and the overflow from the exfiltration system are cleaner than the raw runoff. In addition, data on groundwater quality were collected from the Queen Mary's Drive site; the objective was to provide information for comparison to long-term data to assess potential changes in groundwater quality that may result from exfiltration systems.

The Etobicoke exfiltration and filtration systems were intended for use where ground water is not used as a source for water supply systems, acknowledging that some pollutants will eventually enter the aquifer. Site specific concerns and long-term strategies for pollution control may lead to alternative designs.

Overall, when extenuating circumstances are considered, the exfiltration and filtration systems performed very well, exceeding the design objectives. Further attention should be directed to the hydraulic design (i.e., throughput capacity) of the exfiltration system. Long-term monitoring will be required to assess longevity, maintenance requirements and the impact of the systems on groundwater quality.

# Conclusions and Recommendations

## *Conclusions*

1. The Princess Margaret Boulevard exfiltration facility is a good example of an in-street exfiltration system design. Monitoring results have demonstrated that it can exfiltrate all runoff from storms greater than the nominal 15 mm of rainfall, providing that antecedent conditions are dry and that storm intensity is not excessive. Because of limited sample availability, the water quality results did not indicate performance but they are representative of storm sewer effluent quality.

2. The Queen Mary's Drive exfiltration facility is a poor example of an in-street exfiltration system because it receives flow from adjacent conventional sewers and because the groundwater table in the area is relatively high. However, runoff coefficients for the facility indicated that it was exfiltrating a substantial portion of the runoff. Water quality data show that stormwater exiting the system is cleaner (for most constituents) than a mixture of system effluent, conventional sewer effluent and groundwater, but raw runoff samples were not obtained in the study and removal efficiencies can not be determined.

3. The Braecrest Avenue filtration facility was shown to have greater exfiltration capacity than anticipated. A limited water quality database indicated that the filtration system effluent was cleaner than the system influent (catchbasin outflow) for most constituents.

4. This study has provided a preliminary assessment of three stormwater management installations. It has highlighted monitoring constraints associated with such systems and has explored some innovative monitoring methods. Because of the long-term nature of exfiltration and filtration mechanisms, subsequent studies will be required to produce a definitive assessment of performance.

## *Recommendations*

*Site selection:*

- When a site is being examined for possible installation of an exfiltration or filtration system, emphasis should be placed on obtaining accurate information on groundwater conditions and soil types in the area by taking borehole samples and by performing in-situ percolation tests.

*Monitoring programs:*

- Increased emphasis should be placed on the collection of upstream and downstream samples to determine the removal efficiency of the systems. Flow monitoring may be limited by access problems, shallow flow depths and intermittent flow, but should be undertaken as thoroughly as possible to facilitate the calculation of volumetric and mass balances for the systems.

- Future monitoring sites should also include piezometers and sampling wells for the monitoring of system impacts on groundwater quality. Such data should be assessed noting that the potential transmission of some pollutants through the soil, to the groundwater and subsequently to local streams and lakes is within the scope of the designs, and is preferable to the immediate discharge of all of the pollutants directly to the local watercourses. The systems were designed for use where groundwater is not used as a water source.
- Hydraulic tests of the system - using a controlled and monitored flow from a fire hydrant - provide useful data for evaluating the systems. Repeating the tests at approximately 4 to 5 year intervals would allow for the measurement of any change in hydraulic conductivity.

*Maintenance:*

- Closed-circuit television (CCTV) inspection of the perforated pipes is recommended at 5-year intervals to monitor sediment accumulation. Pipe flushing and maintenance hole clean out should be performed if the CCTV inspection finds significant accumulations. Routine catchbasin cleaning should also be emphasized as a means of limiting the requirement for underground maintenance operations.
- When exfiltration pipes are cleaned out during regular maintenance, a measurement of the mass of accumulated sediments should be performed in order to determine the correct maintenance interval.

*Design aspects:*

- Alternative designs of the exfiltration system should be examined to overcome the throughput limitation that causes overflow to occur before the gravel bed is fully utilized. Possible remedies include the installation of air ventilation pipes and the use of increased pipe diameters at the inlets of the perforated pipes.
- Future exfiltration systems should include barriers to the migration of water through the gravel bed toward the downstream end of the system.
- Numerical simulation may be an effective design method for exfiltration and filtration systems. Further model development work should be undertaken after additional data have been acquired from future monitoring work.
- Alternative designs should be considered for application in locations where groundwater contamination is, or will be, of greater concern. Options include the use of adsorbent and ion exchange materials in exfiltration trenches, and placement of the trenches in boulevards were they may be more readily excavated for servicing. Filtration systems may be designed with impervious trench linings to prevent percolation of the runoff into the soil.

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# 1.0 INTRODUCTION

## 1.1 Scope of this Report

This report contains a performance evaluation of a new stormwater management technology that was applied in three demonstration projects in the City of Etobicoke[1], Ontario, Canada.

Various demonstration projects have been built within the Province of Ontario in recent years, under several initiatives, to contribute to the development of stormwater management knowledge. These initiatives have been driven by the realization in the late 1980's that urban stormwater runoff is a significant cause of water quality degradation.

Most of the new stormwater facilities have been constructed in areas of new urban development. Consequently, most of the demonstration projects undertaken to date have addressed technologies suitable for use in "green field" situations. Retrofitting areas of existing development for stormwater management infrastucture is particularly complicated for a number of reasons. The technologies demonstrated in Etobicoke and evaluated in this report represent one class of system that has potential for retrofitting existing city infrastructure. The overall water quantity and quality improvements achieved by these technologies may be equivalent to those obtained with more traditional stormwater management practices.

Stormwater exfiltration and filtration systems are constructed within the road right-of-way, avoiding the need for large areas of public land for ponds or other large facilities. Both systems employ sub-surface perforated pipes and artificial lenses of gravel to hold and transport significant volumes of stormwater. The systems differ in the amount of water that is expected to exfiltrate to become groundwater, and in the particular configuration of the pipe networks. Design and construction of the demonstration projects is documented in Candaras Associates (1997) and D'Andrea and Candaras (1998).

Several questions have been raised regarding this class of technology, including questions of system capacity, cost and long-term maintenance requirements. The collection and analysis of additional data was recognized as being necessary to address these questions.

This report documents the performance of the Etobicoke stormwater exfiltration and filtration systems for a two-year period between October 1996 and September 1998. The data obtained provide some answers to the performance and maintenance questions. Since some aspects of performance and long-term maintenance can be measured only over a longer period of time, recommendations are made for an appropriate long-term monitoring program.

[1] now part of the City of Toronto

## 1.2 Background

Numerous stormwater management options are available for implementation. These options fall into three categories: lot level, conveyance system, and end-of-pipe controls. For new developments, many of the options may be feasible. However, the selection of stormwater management options for use in fully developed areas can be limited for several reasons:

- private property is not accessible to implement lot level controls;
- conveyance systems are well established, making their reconstruction cost-prohibitive;
- publicly owned land is usually not available for end-of-pipe controls.

Consequently, only a limited number of stormwater management alternatives can be implemented in retrofit sites in fully developed areas. Municipalities must therefore take full advantage of opportunities to implement stormwater management practices whenever possible, such as during the plan-approval stage of re-development proposals, or the design-stage of road or drainage reconstruction works. While lot level control alternatives can be incorporated into re-development projects funded by the developer, conveyance system control options that are implemented through road or drainage reconstruction works are supported and funded entirely by the municipality (D'Andrea and Candaras, 1998).

Conveyance system stormwater management options may be designed to achieve some amount of temporary storage to minimize peak flows. Alternatively, or additionally, they may be designed to transfer some of the runoff to the local groundwater by percolating it through the soil. Many of these systems can remove pollutants from the stormwater by filtration[2] through media designed into the system or through the local soil.

Historically, many stormwater management systems have included roadside infiltration trenches, or infiltration ponds where more space was available. The intent of such designs is to utilize a bed of sand and gravel, possibly in conjunction with geotextile or filter cloth material, to filter surface runoff and allow it to percolate to the groundwater table. In road allowances, the infiltration trenches are often placed below shallow roadside ditches or swales.

A Maryland study (Galli, 1992) that investigated the longevity of infiltration trenches indicated that approximately 55% of the trenches were not operating as designed. According to that study, one-third of the trenches were partially or totally clogged and another 20% had significant inflow problems. High groundwater tables, unsuitable soil types and the lack of pretreatment for the influent stormwater were cited as the major factors that contributed to the high clogging failure rates and short life spans (five years) of the systems. To increase the longevity of the infiltration trenches, the Maryland study recommended that several measures be undertaken during the design and construction stages:

[2] Infiltration and exfiltration refer to flow into or out of a specific component of the system. See Appendix B for a glossary of terms.

- field verification of soil infiltration rates and groundwater levels;
- use of pretreatment systems that provide some degree of storage (e.g., sump pits, swales with check dams, plunge pools);
- use of a layer of filter fabric one foot below the ground surface of the trench;
- use of a sand layer rather than filter fabric at the bottom of a trench;
- avoid construction of the infiltration trench until all contributing watershed disturbances and construction activities are completed;
- implementation of erosion control measures suitable for the site and the prevailing soil conditions.

A study conducted through the Environmental Research Program of the Ontario Ministry of the Environment described a more successful application of an infiltration system in the City of Nepean, Ontario (OMOEE, 1994a). This infiltration system, consisting of grass swales and perforated pipes, was approximately six years old when the study was conducted. The subdivisions serviced by the infiltration system were more than 35 years old (i.e., drainage areas were mature and stable). Findings from this study indicated that the infiltration system reduced runoff volume by up to 67% for some storm events. However, analysis of groundwater quality indicated high levels of phosphorus and nitrate nitrogen concentration. Although the study attributed the high levels of these contaminants to the presence of a nearby septic system, contamination caused by the infiltration system can not be ruled out until a follow-up investigation is carried out.

Many municipalities show a preference for the traditional curb-and-gutter drainage systems, arising from public aesthetic concerns. Also, since most municipalities lack experience with new technologies, conventional sewer design is generally selected over alternative drainage approaches for road reconstruction works. This choice is due to concerns regarding potential costly maintenance and operation of these systems, and the potential impact on and reduced life span of roads, as well as safety and liability issues.

The conveyance-based stormwater management systems described in this report were designed to avoid surface-based infiltration by conveying all runoff through catchbasins to underground gravel trenches for storage, filtration and exfiltration to the local soil.

## 1.3 Etobicoke Exfiltration and Filtration Systems

Three sites were designed and constructed between 1992 and 1994 as a demonstration project in the City of Etobicoke. The sites were:

- a conveyance pipe based exfiltration system on Princess Margaret Boulevard;
- a conveyance pipe based exfiltration system on Queen Mary's Drive;
- a conveyance pipe based filtration system on Braecrest Avenue.

The City of Etobicoke constructed the new stormwater management systems in fully developed areas. The technologies were integrated within the design of conventional storm sewer systems to provide stormwater quantity and quality management where land was not available for end-of-pipe treatment.

The systems were designed to address specific practical objectives (D'Andrea and Candaras, 1998) including:

- cost-effective implementation - recognizing that Etobicoke is fully developed and offers little opportunity for end-of-pipe treatment technology;
- no mechanical or chemical treatment components;
- use of conventional materials and components - to ensure good availability of materials and reduced cost;
- meet or exceed existing provincial guidelines - applicable in 1992 - whereby the system design ensures the capture and treatment of runoff from a 13 mm total rainfall (as a minimum), as identified in the Interim Stormwater Quality Guidelines (OMOE & OMNR, 1991);
- maintenance to be provided through the use of existing equipment - minimizing the need for expensive maintenance requirements.

Since these systems were developed with knowledge of the problems experienced with the traditional infiltration technologies, their designs have several inherent advantages over the traditional infiltration facilities with regard to the following considerations:

- *System clogging*

  Clogging of conventional infiltration systems (such as infiltration trenches) over a period of time is a major concern because it reduces the system's functionality. Maintenance, which consists of replacement of the granular media, can be expensive.

  To solve this problem, the perforated pipes in the Etobicoke exfiltration system are wrapped in a filter fabric sleeve to capture suspended particles within the pipes and prevent the clogging of the granular trenches. Sediment that accumulates in the pipes can be removed by standard sewer flushing equipment, and disposed of at a landfill site if necessary.

- *Easy access*

  Standard access chamber (manhole or maintenance hole) spacing facilitates inspection of the extent of sediment accumulation, and flushing/removal of the sediment.

- *Winter operation*

  While conventional infiltration systems usually freeze during the winter and become non-functional, the perforated pipes are placed below the frost line and will continue to function during the winter season to exfiltrate runoff from snowmelt events.

- *Groundwater recharge*

  Rather than concentrating percolation at one location, groundwater recharge is extended over a larger area. This geometry more closely mimics the natural hydrologic cycle and takes better advantage of the storage capacity that may be available in the native soils.

- *Land requirements*

  Unlike conventional systems for which land must be apportioned for implementation, the exfiltration and filtration systems are constructed within the municipal road allowance.

## 1.4 Study Objectives

Three main objectives were established for monitoring the filtration and exfiltration systems:

- to evaluate the performance of the systems;
- to develop guidelines for future implementation and maintenance of these systems;
- to provide recommendations for site selection for future installations and for monitoring alternatives.

This report focuses on the monitoring of system performance over a two-year period (1996-1998), including examination of data collected immediately after the system was constructed. The planning and design for these systems and the results of the initial evaluation of performance are documented in Candaras Associates (1997) and D'Andrea and Candaras (1998).

# 2.0 DESCRIPTION OF THE TECHNOLOGY

## 2.1 Goal of Exfiltration / Filtration Systems

The Etobicoke exfiltration system and the Etobicoke filtration system were developed as new approaches to stormwater management. Planning and design objectives for the exfiltration and filtration systems were established by City of Etobicoke staff, a steering committee, and a design consultant. These objectives were based on a set of interim sizing guidelines developed by the Ministry of the Environment and the Ministry of Natural Resources in 1991, as well as water quality objectives for the local receiving water and site-specific soil conditions. The intent was to eliminate storm runoff discharge at sewer outfalls for frequent rainfall events, while maintaining the conventional level of conveyance capacity such that street flooding would not be increased. The storm magnitude for which runoff should be eliminated was established as 15 mm of rainfall in one hour (AES 1-hour event).

Planning and design guidance for wet pond facilities and other stormwater technologies were developed and documented in a set of guidelines that were released in 1994 as the Stormwater Management Practices Planning and Design Manual (OMOEE, 1994b). Design guidelines for the Etobicoke exfiltration and filtration systems were not included in that document because the infiltration/filtration concept was relatively new[3].

## 2.2 Exfiltration System

The Etobicoke exfiltration system was developed for soils with good percolation rates. A total length of 2.1 km of the exfiltration system was constructed through road reconstruction projects undertaken by the City of Etobicoke in 1993 and 1994. The system consists of two 200 mm diameter PVC perforated pipes wrapped with filter fabric and laid in a gravel trench below a conventional storm sewer (Figure 2.1). The perforated pipes are plugged at the downstream end (Figure 2.2).

During a rainfall event, runoff enters the storm sewer through catchbasins and catchbasin leads as in a conventional storm sewer system. However, each maintenance hole has a sump that directs the stormwater into the perforated pipes rather than into the downstream section of sewer pipe. In the perforated pipes, the stormwater is drained or percolated first into the gravel trench, then into the surrounding soil. Particulate matter carried by the stormwater that does not get trapped in either the catchbasin or the maintenance hole sump is contained within the perforated pipes by the filter fabric.

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[3] A revised edition of the Stormwater Management Practices Planning and Design Manual was released in early 2003. Pervious pipe systems, including the Etobicoke design, are described in the new manual.

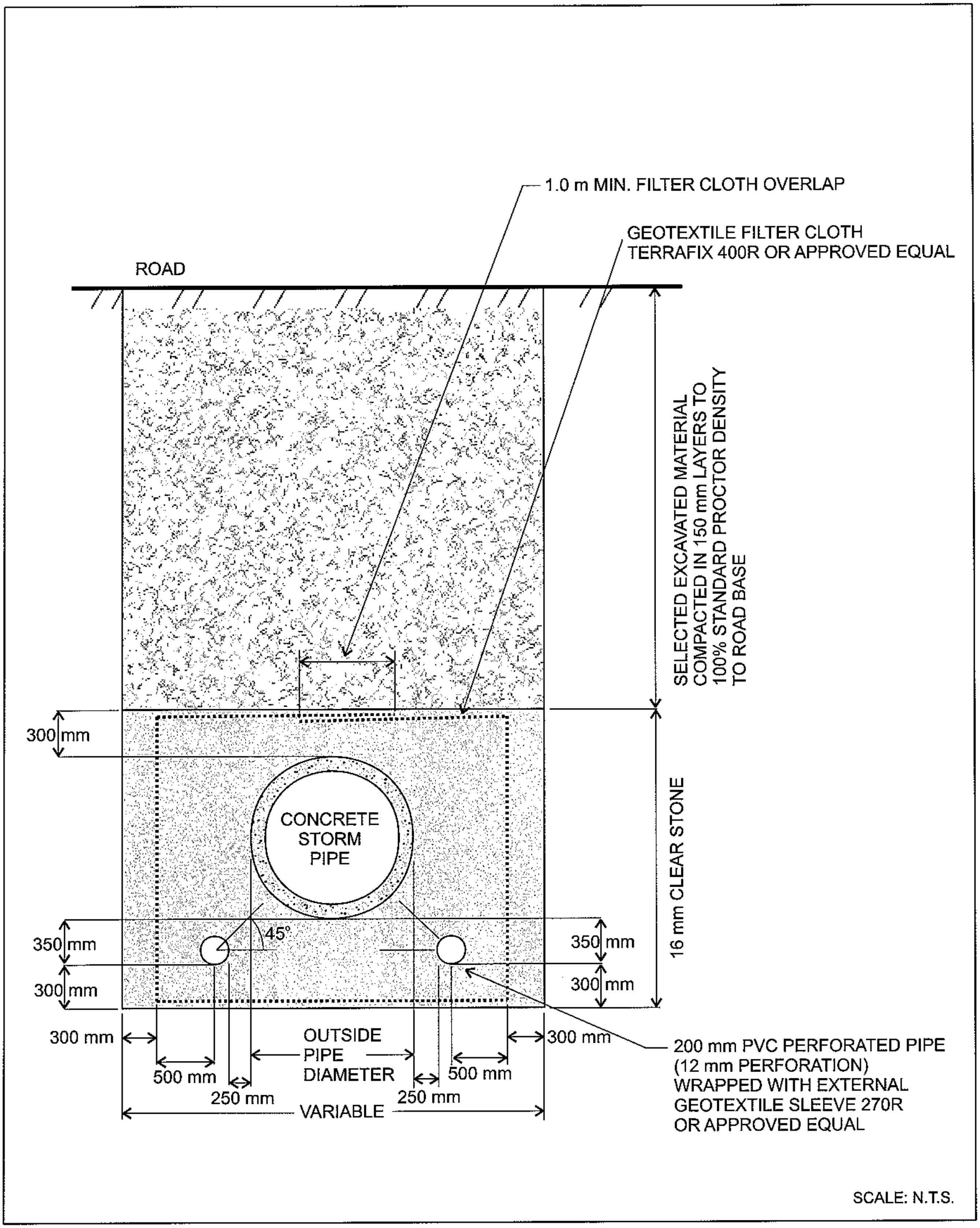


***Figure 2.1:*** Exfiltration system - typical trench cross-section

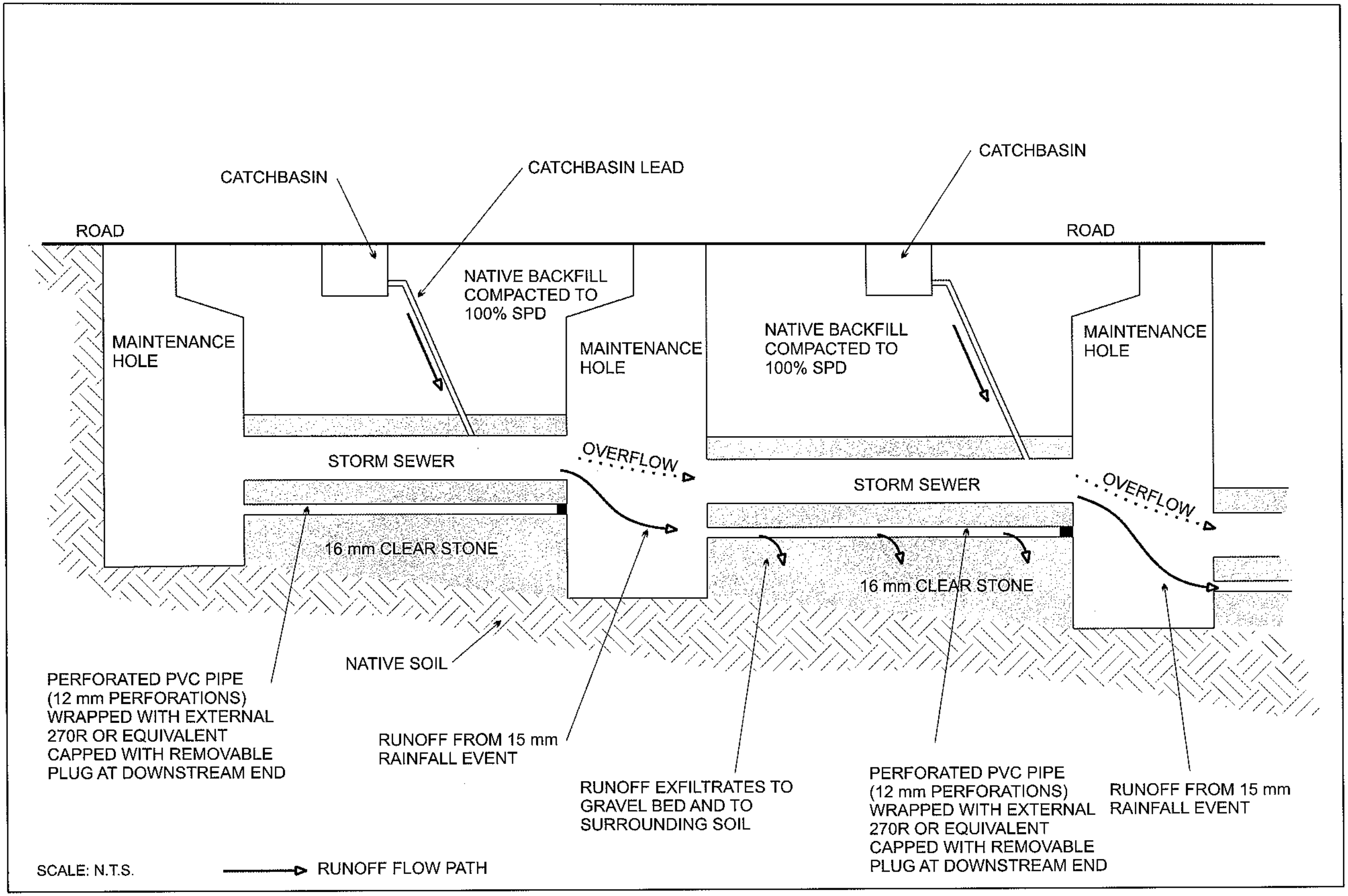


***Figure 2.2:*** Exfiltration system - typical profile

The exfiltration system is designed to provide sufficient storage to capture the runoff from a 15-mm, 1-hour design storm, and is best suited for areas with permeable soils. During large runoff events, excess runoff bypasses the perforated pipe system as overflow and is conveyed through the conventional storm sewer to the downstream maintenance hole.

## 2.3 Filtration System

The Etobicoke filtration system is designed for soils with low percolation rates. This system includes a 200 mm diameter perforated pipe, wrapped in filter cloth and installed above the conventional storm sewer; plus two 100 mm diameter perforated underdrain pipes located beneath the conventional storm sewer (Figure 2.3). The storm sewer and the three perforated pipes are all contained within a gravel-filled trench wrapped in filter cloth. The upper perforated pipe is plugged at both ends. The two lower pipes extend only half the length of the main storm sewer, and are connected to the downstream maintenance hole (Figure 2.4).

Runoff enters the system through catchbasins equipped with two leads. The lower lead is connected to the upper perforated pipe, through which the water enters the gravel. Sediments and associated pollutants present in the runoff may be trapped in the catchbasin or in the perforated pipe. The gravel acts as a granular media filter to remove additional pollutants. This filtered (or treated) runoff will then seep into the two 100 mm diameter perforated underdrain pipes located at the bottom of the gravel trench to be transported the next downstream maintenance hole. Runoff captured in the gravel trench underneath the two underdrain pipes will be retained and allowed to percolate into the surrounding soil. Hence, although the system was not designed to facilitate infiltration of stormwater into the local soils, it is inevitable that some runoff will recharge the groundwater.

When the rate of runoff exceeds the discharge capacity of the lower catchbasin lead, the excess runoff will be drained through the upper catchbasin lead that is connected directly to the storm sewer, similar to the design of a conventional system. Use of the upper catchbasin lead constitutes an overflow condition because runoff is being conveyed downstream "untreated" with no filtering through the gravel trench.

Both the exfiltration and filtration systems may be constructed in conjunction with curb and gutter road designs or roadside ditches or swales. The catchbasin locations vary but the pipe trench is generally under the road surface.

## 2.4 Site Selection Criteria

Although the design concepts of the two systems are different, infiltration of stormwater runoff is expected to occur in both systems. Therefore, site selection criteria for the implementation of the two systems will depend on whether they conform to the following general conditions.

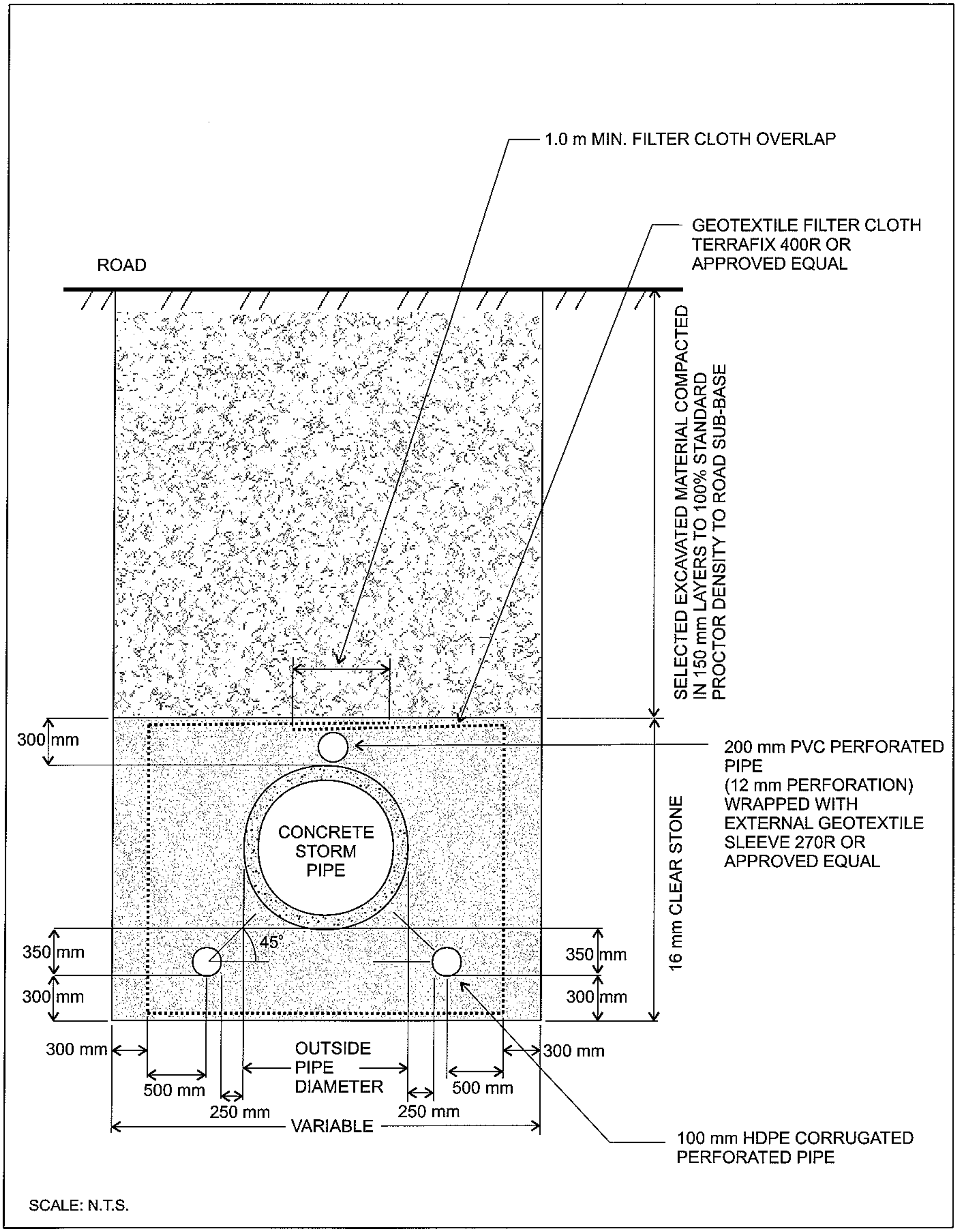


***Figure 2.3:*** Filtration system - typical trench cross-section

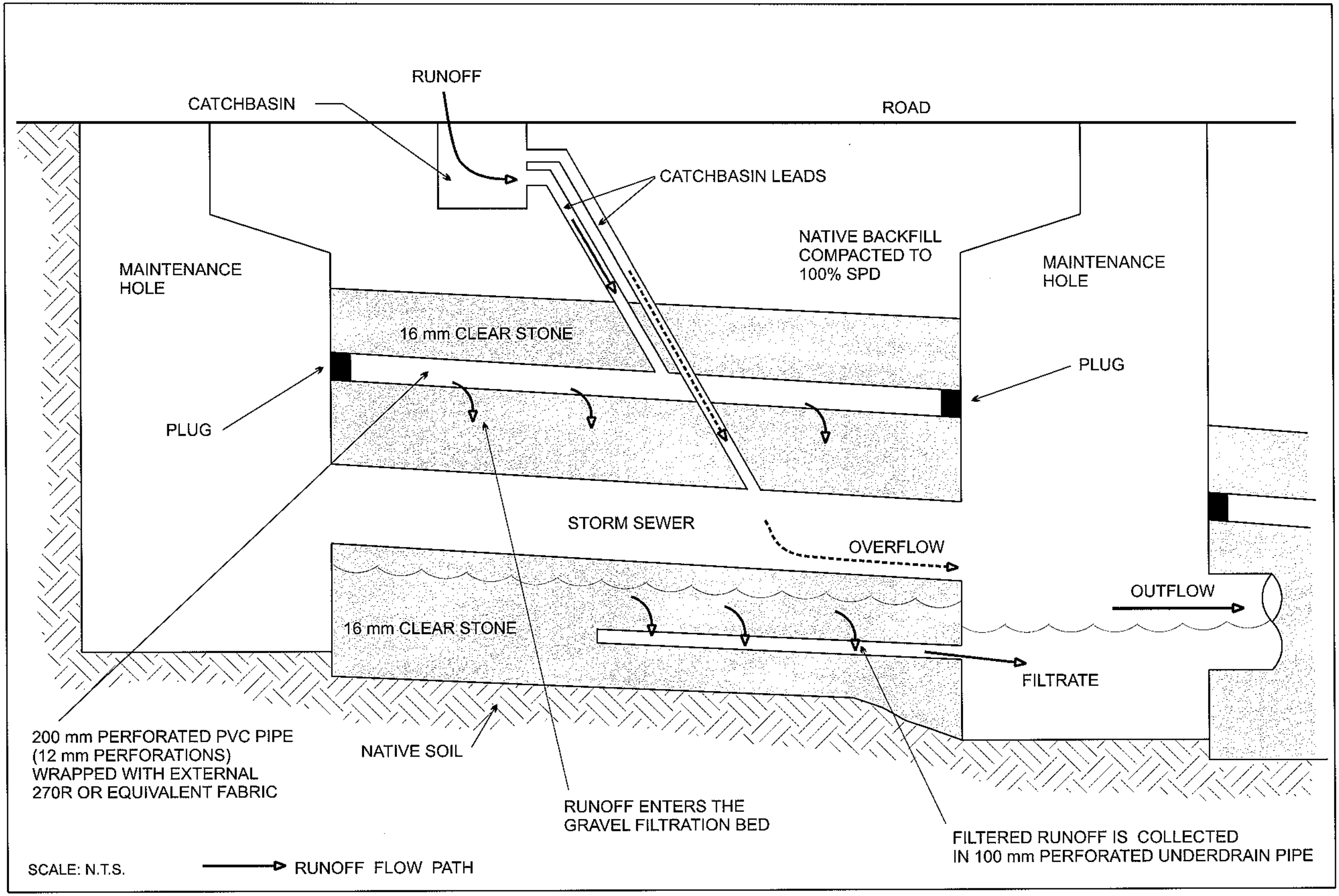


***Figure 2.4:*** Filtration system - typical profile

1. The land use is low-density residential, where:
   - fuel oil is not the main source of home heating;
   - the risk of hazardous spills draining into the system is low (small spills are contained within goss trap fitted catchbasins);
   - traffic volumes are low, minimizing the associated pollutant concentrations and the risk of spills;
   - winter sanding schedules are of a relatively low frequency.
2. Road reconstruction is being considered in the near future (in a fully developed area).
   - Scheduling the implementation of the systems with road reconstruction provides a cost-effective opportunity for installation of the system since installation separate from any road restoration work may be cost prohibitive.
3. Sandy or silty soil is the predominant geological condition (not applicable to the filtration system).
   - Good hydraulic conductivity allows stormwater runoff captured in the gravel trench to be percolated within the average inter-event time.
4. The ground water table is low.
   - System performance will be compromised if the groundwater table is high.
5. The drinking water supply is not taken from a local shallow aquifer.
   - Potential groundwater contamination must be taken into consideration.
6. The sanitary sewer system is in good, watertight condition in order to:
   - minimize the potential for percolated stormwater to infiltrate the sanitary sewer;
   - minimize potential contamination of the exfiltration/filtration system by leaking sewage.
7. Slope stability is not considered to be a problem.
   - Increasing the moisture content of soils is not advisable in areas where slope failure may be caused by soil saturation.

## 2.5 Design Criteria

The distinctive characteristic of the Etobicoke exfiltration and filtration systems is that runoff enters the systems through the catchbasins and is not expected to infiltrate into the soil from the surface. The systems were designed to address the following hydrological objectives:

- to reduce contaminant loadings from stormwater runoff to local receiving waterbodies;
- to reduce peak flow rates of stormwater runoff and minimize erosion of local watercourses;

- to provide a mechanism to recharge local groundwater aquifers and maintain base flow in local watercourses;
- to maintain the full capacity of the conventional storm sewer system for drainage of the local road network to municipal design standards, if the exfiltration system fails.

These objectives were addressed by implementing the following design criteria using 1991 OMOE-OMNR Interim Stormwater Quality Guidelines:

- *Capture and treatment of runoff from a 15 mm rainfall event.*

  The storage volume design criteria was based on a 15 mm design storm (1-hour AES); whereby the required storage is provided within the perforated pipes and the void spaces within the gravel trench.

  Capture of the runoff generated by the first 15 mm of rainfall for larger storm events represents the capture of the "first-flush", which usually contains a higher percentage of contaminants in relation to the remaining runoff volume. The 1991 OMOE-OMNR Interim Stormwater Quality Guidelines suggested stormwater quality control for rainfall depths of 25 mm for the protection of coldwater fisheries, and 13 mm for warmwater fisheries.

- *Percolation to be completed within two days.*

  A review of historical rainfall records indicated that the local average inter-event period was approximately three days. Complete percolation of captured runoff should be accomplished within this period to ensure maximum overall system performance. The percolation rate is dependent on the hydraulic conductivity of the native soil, which was conservatively based on soil saturation conditions in the design of the system.

- *Provide percolation in addition to a conventional municipal storm sewer system.*

  This pilot project was accepted by approving agencies, recognizing that a conventional storm sewer system was also provided and designed to the existing municipal standards (a 2-year design flow based on the Rational Method). This design provides a backup during a worst-case scenario, in which an exfiltration or filtration system became completely plugged or taken out of service, and the conventional storm sewer system would provide the necessary conveyance capacity.

# 3.0 STUDY SITES

Figure 3.1 illustrates the location of the three study sites in Etobicoke and the locations of the rain gauges from which rain data were acquired.

## 3.1 Princess Margaret Boulevard

The Princess Margaret Boulevard study area (Figure 3.2) consists of 30.5 ha of low-density residential housing. The drainage area, covering both Princess Margaret Boulevard and Princess Anne Crescent, is split into two catchments that discharge into the Humber River and Mimico Creek, respectively. A sewer system with a total length of 1.3 km was installed along Princess Margaret Boulevard and Princess Anne Crescent in 1993. The 0.4 km of exfiltration system on Princess Margaret Boulevard between Princess Ann Crescent and Kipling Avenue was the subject of this study.

Princess Margaret Boulevard is classified as a collector road while Princess Anne Crescent is a local residential road. Roadside ditches drain both roads. Geotechnical studies have revealed that the area is underlain by clay to clay-silt till over a silty sand till substrate. Boreholes taken at depths of 4.5 to 14.0 m below ground surface were dry, suggesting no presence of groundwater at any of the depths investigated.

## 3.2 Queen Mary's Drive

The Queen Mary's Drive exfiltration system was completed in the fall of 1994. The drainage area consists of 13.3 ha of low density, mature residential land use (Figure 3.3). The entire area slopes gently to the east toward the Humber River. Road drainage is provided by grass swales created through grade differences between the pavement and boulevard. Upgrading of the drainage system was undertaken because of persistent street flooding problems in the area. In addition, the local sanitary sewer system required replacing. Geotechnical investigations revealed that soils in the area fell generally within the classification of sand to sandy silt.

Conditions at this site presented an opportunity to implement the Etobicoke exfiltration system using a shallow swale drainage system with catchbasins to preserve the character of the streetscape and to minimize the impact of the facility on mature trees lining the street. Groundwater information obtained from a nearby water well indicated that the groundwater elevation at this site was approximately 1.2 m from the surface. A geotechnical investigation measured water levels at 1.6 m to 2.5 m below the ground surface.

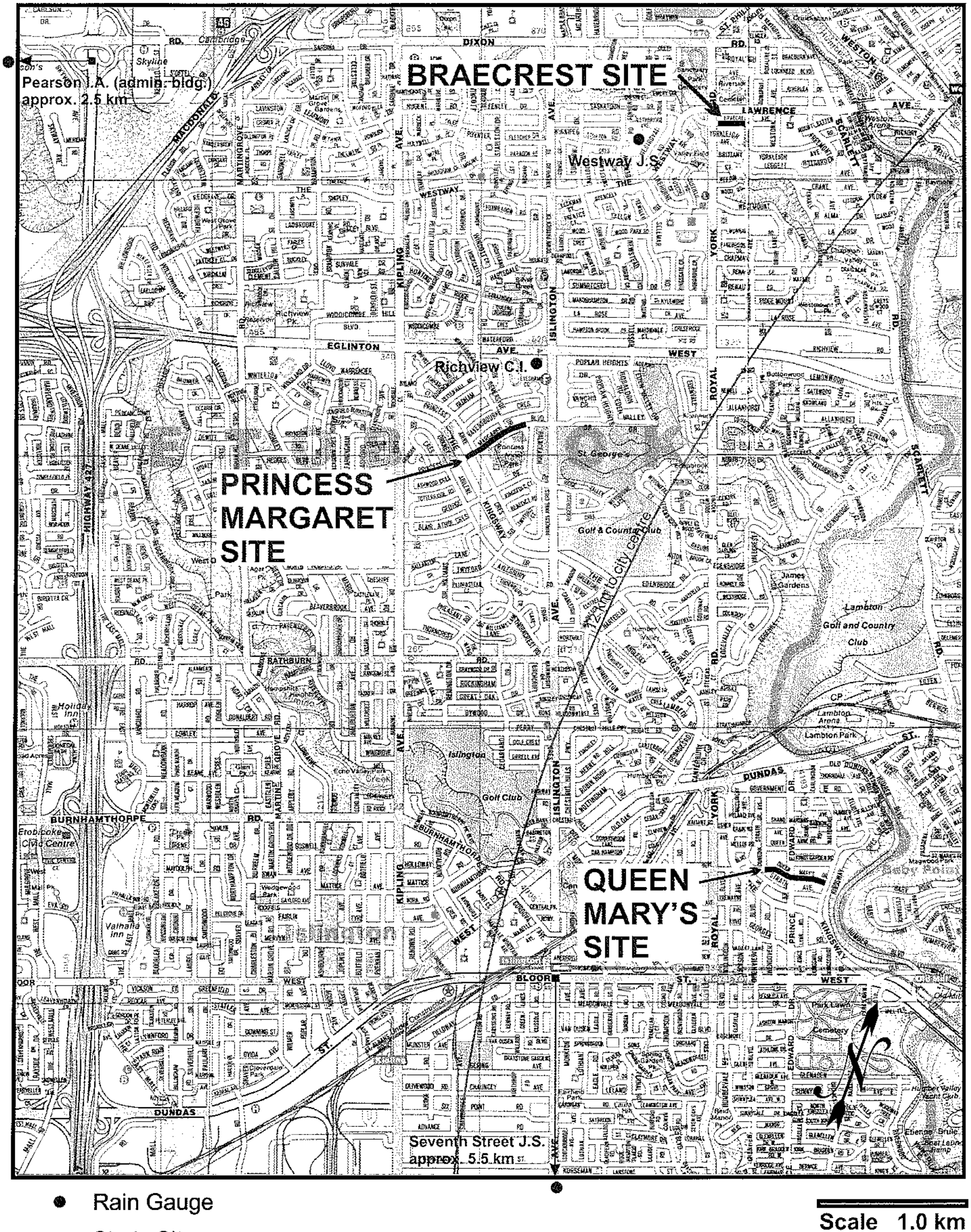


*Figure 3.1:* Location of study sites and rain gauges


***Figure 3.2:*** Princess Margaret Boulevard exfiltration facility


***Figure 3.3:*** Queen Mary's Drive exfiltration facility

Municipal as-built drawings of the Queen Mary's Drive site reveal a complex construction process that included the abandonment of an existing storm sewer and several changes to the proposed new storm sewer. The new exfiltration sewer system starts at maintenance hole 12 (MH 12) near Dunedin Drive at the west end of Queen Mary's Drive. The sewer flows eastward for 0.44 km, including eight more maintenance holes and 32 catchbasins. A short conventional sewer discharges any excess flow through an outfall to the Humber River.

The drainage area directly tributary to the Queen Mary's Drive sewer system is 3.7 ha. In addition, portions of Dunedin Drive (0.6 ha) and Prince Edward Drive (2.5 ha) drain south to Queen Mary's Drive either overland or through conventional storm sewers. A substantial length of conventional storm sewer south of Queen Mary's Drive discharges into the exfiltration system at the intersection of Prince Edward Drive (MH 16), contributing 6.5 ha of land area or 49% of the total tributary area for the system. The system also includes two short sections of "interceptor" exfiltration sewer on Kingsway Crescent, north and south of Queen Mary's Drive that serve a total of 3.8 ha. Those sections drain to maintenance hole 25 and contribute to the total flow at the outfall but not to the hydraulic load on the exfiltration system. The "north interceptor" consists of a 525 mm diameter main sewer pipe, with a single 200 mm diameter perforated exfiltration pipe, north of Queen Mary's Drive; it connects to an existing conventional storm sewer serving Kingsway Crescent and part of Kings Garden Road. The "south interceptor" consists of a 200 mm diameter perforated pipe serving catchbasins on Kingsway Crescent south of Queen Mary's Drive.

The outfall was described in the as-built drawings as discharging to a creek, but the only apparent source of water for the creek is the outfall. This system is discussed further in the monitoring results section of the report and in Appendix G.

## 3.3 Braecrest Avenue

The Braecrest Avenue study site (Figure 3.4) consists of a 2.4 ha drainage area with low-density residential housing. A 0.2 km filtration system was installed in 1993, draining west toward Royal York Road. The highest point of this study site is located approximately at the intersection of Braecrest Avenue and Roxaline Street. A conventional storm sewer was constructed at the same time, serving the eastern part of Braecrest Avenue and draining eastward to Westona Street. The roadway originally had a ditch-type cross-section and was reconstructed to curb-and-gutter during the installation of the filtration system. A geotechnical investigation indicated that the soil types are brown silty clay and dark gray sand loam containing organic matter. Additional soil records available from the City of Etobicoke showed that on Braecrest Avenue, the dominant soils are clay loam. Local well records indicated the upper soils (up to 7 m deep) in the area are brown clay, suggesting the dominance of relatively impervious soils. Consequently, the filtration system was considered to be appropriate at this site.


*Figure 3.4:* Braecrest Avenue filtration facility

# 4.0 MONITORING PROGRAM

## 4.1 General Methodology

The infiltration and exfiltration systems were monitored at the downstream ends of each system. Since the gravel trench does not continue past the last maintenance hole in the drainage system, the monitoring stations provided access to all flows exiting the study sites.

In August of 1996, monitoring equipment was installed at three sites: the exfiltration systems located on Princess Margaret Boulevard and on Queen Mary's Drive, and the filtration system located on Braecrest Avenue. The main purpose of the fall 1996 monitoring was to evaluate new monitoring approaches[4]. The 1996 monitoring program also facilitated an initial assessment of the three facilities.

In 1997-1998, monitoring was undertaken primarily at the Princess Margaret Boulevard site. Samples were also collected from the relief pipe at Queen Mary's Drive site in order to compile background data on groundwater quality.

## 4.2 Rainfall Events and Monitoring Program Summary

Appendix E contains tables summarizing the available data. In 1996, rainfall data were obtained from the L. B. Pearson International Airport, located approximately 7 km west of the most northerly test site (Braecrest Avenue) and approximately 10 km north-west of the most southerly site (Queen Mary's Drive). In 1997 and 1998 rainfall data were obtained from schools. Two of the schools were located closer to the test sites and the third was located near the shore of Lake Ontario approximately 7 km south of Queen Mary's Drive.

## 4.3 Flow Measurement

Area-velocity flow meters were used to monitor flow rates. The application of area-velocity flow meters in storm sewers is convenient due to their portability; reasonably good accuracy can also be expected. However, there are some limitations to these area-velocity flow meters with regard to measuring flow rates at low flow depths. Specifically, the velocity probe can not provide reliable velocity estimates for the calculation of flow rates at flow depths of less than 5 cm. For that reason, only depth readings were recorded for smaller storm events and dry-weather flow conditions. Considering that the purpose of the study was to obtain preliminary results and to provide guidance in refining the monitoring approach, the depth records were considered to be adequate. In some locations, the flow meters were used in conjunction with v-notch weirs.

[4] An earlier study (Candaras Associates, 1997) employed monitoring stations farther upstream in the system (reviewed in Appendix D).

## 4.4 Water Quality Sampling

At the Queen Mary's Drive exfiltration site, time-based composite overflow samples were collected at the most downstream maintenance hole using an automatic wastewater sampler with a liquid level actuator. Grab samples were also collected from the main sewer and from a 100 mm diameter relief pipe that acted as a drain for the gravel trench.

For the infiltration system site at Braecrest Avenue, only limited success was achieved with an automatic wastewater sampler placed in the downstream manhole due to low flow. Efforts were then made to collect composite samples using a covered plastic container that had a slit cut out of the lid to allow water to enter. The container was installed at the downstream end of the main storm sewer, where samples of the stormwater runoff were composited over a period of approximately one hour. This method of collection provided a much better representation of the stormwater, in comparison to the grab sampling approach[5]. This device was also employed at the Princess Margaret Boulevard site to monitor the water quality of the exfiltration system.

Because of the differences in system geometry between the sites, and changes made in the sampling program, additional information on the monitoring methods is provided for each site in the results chapter.

[5] Possible effects of this sampling method are discussed in Appendix C, and in other appendices with respect to specific observations.

# 5.0 MONITORING RESULTS

## 5.1 Princess Margaret Boulevard Exfiltration System

### 5.1.1 Introduction

The total drainage area of the Princess Margaret - Princess Anne exfiltration system is 30.5 ha. Two separate sections of exfiltration sewer were constructed at this site. The easterly section serves Princess Margaret Boulevard and Princess Ann Crescent and drains to the Humber River. The catchment area for this section includes a school and a large park.

The westerly section of exfiltration sewer serves Princess Margaret Boulevard west of Princess Anne Crescent. This catchment drains into Mimico Creek by way of a conventional storm sewer on Kipling Avenue. This system consists of exfiltration piping constructed from MH 68 to MH 73, and drains an area of approximately 3.8 ha. The westerly section of exfiltration sewer was considered to be more representative of a typical suburban residential area than the easterly section and was chosen as the study site

### 5.1.2 Methodology

Monitoring for this site did not commence until mid-October 1996, when monitoring at Queen Mary's Drive was terminated. Flow rates were monitored continuously downstream of MH 72 in October and November of 1996. A plastic container was installed in MH 72 to collect samples directly from the main storm sewer. Grab samples were also collected.

The second phase of monitoring began in June of 1997 and ended in September, 1998. Initially, monitoring consisted of depth measurements and water quality sampling at MH 72, as well as the installation of a weir and flow logger in the main storm sewer line at the upstream end of MH 73 (Figure 5.1). In November 1997, the flow logger was removed because of the risk of damage due to freezing. However, the pressure transducer in MH 72 was located below the frost line and that system was left in place over the winter season and throughout the remainder of the study.

The 22.5 $^{0}$ v-notch weir was installed in the storm sewer upstream of MH 73 in order to enhance the accuracy of flow measurements. This improvement was required because the depths of flow found in the main storm sewer were insufficient to produce a reliable reading from an area-velocity flow meter. The v-notch weir created an upstream pool of water, permitting adequate submergence of the flow sensor such that the depth readings could be used in conjunction with a conventional weir equation to calculate the flow. The flow meter sensor was mounted on a steel ring, which was fixed at a location approximately 2 m upstream of the weir. At a sewer slope of 1.65%, the water level retained behind the weir was measured at a constant 170 mm from the invert of the storm sewer.

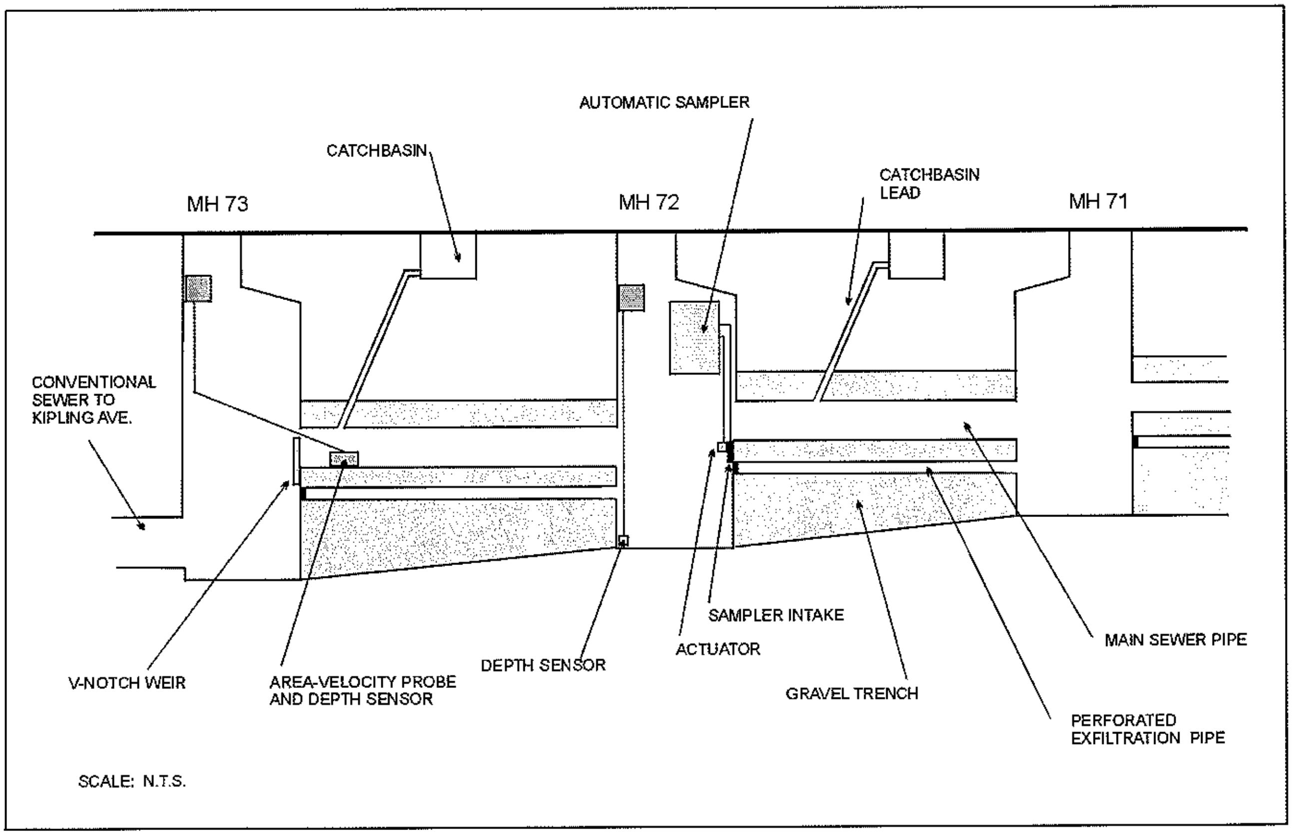


***Figure 5.1:*** Princess Margaret Boulevard monitoring setup

### 5.1.3 Flow Monitoring Results

All results for this monitoring period are included in Appendix F. No measurable flow rates were recorded during the period from October to November 1996. Most precipitation events were small but one day had a total rain depth of 15 mm and one a depth of 27 mm. The storm sewer was found to be free of sediment throughout the monitoring period, and no signs were observed of groundwater entering the system during dry weather. Very low flow rates could occasionally be seen in the main storm sewer during storm events due to direct catchbasin connections.

No overflows occurred between June and November 1997 (i.e., the water level at MH 72 did not rise to the invert of the storm sewer, which was located 365 mm above the measuring point of the depth sensor). The highest water level was recorded as 240 mm on July 15. During that time, seven daily rainfalls equaled or exceeded 15 mm total depth.

No overflows were observed during the winter season. However, on February 17, 1998, a rainfall event nearly triggered an overflow. Based on rainfall data from a site in Scarborough, several kilometers to the east of Princess Margaret Boulevard, the total rainfall for this storm event was 28 mm, approximately twice the design storage volume of the gravel trench. The storm event lasted for 42 hours and had a maximum rainfall intensity of 6.8 mm/hr. The water level at MH 72 rose to approximately 345 mm, or 20 mm below the depth needed to cause an overflow.

In the summer/fall period, beginning in May 1998, five days had rainfall depths equal to or greater than 15 mm. Overflows were measured at MH 72 at the Princess Margaret site on June 13, June 30 and September 6. Hyetographs and depth hydrographs for these events are included in Appendix F. Because the flow monitor had not been re-installed in MH 73, no flow data are available. A chronological summary of the three events and some interpretive notes follow:

- Significant rainfall (20.2 mm) occurred between 22:30 on June 11 and 07:10 on June 12 but did not cause an overflow. On June 13th, 3.6 mm of rain fell between 14:15 and 15:15 causing a small overflow. The total rainfall and maximum intensity of the event on the 13th were small, and the system had more than 24 hours to recover after the previous rainfall. Soil saturation resulting from the earlier event may have been a contributing factor on the 13th, but was probably not solely responsible for the overflow condition. A highly localized rainfall event or extraneous sources of water such as flows from watermain flushing, the draining of private swimming pools, street cleaning or fire hydrant tests may have been contributing factors.
- On June 30, an intense rain event with a total rainfall of 14.9 mm was followed five hours later by another intense rain event of 11.9 mm. The first period of rain did not cause an overflow, but the second period caused a peak depth of 437 mm in MH 72. In this case, soil saturation and water storage in the gravel bed probably contributed to the overflow condition.
- On September 6, a single storm event (15.3 mm total) with the greatest hourly rainfall intensity (14.8 mm/h) and the greatest 5-minute intensity (9.7 mm) raised the depth in MH 72 to 385 mm. This depth was observed for only 10 minutes, resulting in a minor overflow[6]. The preceding three days had been dry.

### 5.1.4 Water Quality Results

Table 5.1 presents the water quality results collected over the monitoring period between October 1996 and September 1998. Water quality analysis was conducted only for samples collected from the main storm sewer. As previously discussed, only three overflow events were detected. Furthermore, only one sample (June 30, 1998) was taken during an overflow event. Consequently, these samples consist principally of local catchbasin effluent. A total of 36 samples were obtained, 18 from the summer/fall period and 18 from the winter/spring period.

[6] The hydrograph shape for this event was also different than those of previous events. Implications of this observation are discussed in Appendix F and in Chapter 6.

***Table 5.1*** Princess Margaret Boulevard -- water quality results

| Parameter & Units \ Period | MDL | PWQO | average, summer (n = 18) | average, winter (n = 18) |
|---|---|---|---|---|
| **General Water Chemistry** | | | | |
| Suspended Solids mg/L | 2.5 | | 164.2 | 81.6 |
| Turbidity FTU | 0.01 | | 42.05 | 68.58 |
| pH | N/A | 6.5 - 8.5 | 7.59 | 7.67 |
| Alkalinity mg/l CaCO3 | 0.25 | | 76.29 | 63.06 |
| Chloride mg/L | 0.2 | | 62.7 | 975.9 |
| Conductivity μS/cm | 1 | | 422 | 3,037 |
| **Nutrients** | | | | |
| Total Ammonium mg/L | 0.002 | | 0.350 | 0.293 |
| Nitrite mg/L | 0.001 | | 0.116 | 0.074 |
| Nitrate + nitrite mg/L | 0.005 | | 1.705 | 0.889 |
| Total Kjeldahl Nitrogen mg/L | 0.02 | | 3.04 | 1.30 |
| Total Phosphorus mg/L | 0.002 | 0.01 - 0.03 | 0.485 | 0.240 |
| Phosphate mg/L | 0.0005 | | 0.1423 | 0.0939 |
| **Organics** | | | | |
| Carbon, Dissolved Organic mg/L | 0.1 | | 8.7 | 3.4 |
| Solvent extractable mg/L | 1 | | 11.2 | 6.5 |
| **Inorganics** | | | | |
| Aluminum μg/L | 11 | 75 | 615 | 504 |
| Arsenic mg/L | 0.001 | 0.1 | 0.001 | 0.001 |
| Barium μg/L | 0.2 | | 23.3 | 25.2 |
| Beryllium μg/L | 0.02 | | 0.06 | 0.04 |
| Cadmium μg/L | 0.6 | 0.2 | 0.8 | 0.5 |
| Calcium mg/L | 0.005 | | 42.900 | 48.511 |
| Carbon, Dissolved Inorganic mg/L | 0.2 | | 17.7 | 14.4 |
| Chromium μg/L | 1.4 | 8.9 as $Cr^{III}$ | 4.1 | 5.2 |
| Cobalt μg/L | 1.3 | 0.9 | 1.1 | 0.7 |
| Copper μg/L | 1.6 | 5 | 21.0 | 20.7 |
| Iron μg/L | 0.8 | 300 | 1009.1 | 848.8 |
| Lead μg/L | 10 | 25 | 16 | 21 |
| Magnesium mg/L | 0.008 | | 7.795 | 6.487 |
| Manganese μg/L | 0.2 | | 139.2 | 111.7 |
| Mercury μg/L | 0.02 | 0.2 | 0.03 | 13.44 |
| Molybdenum μg/L | 1.6 | 40 | 0.3 | 0.1 |
| Nickel μg/L | 1.3 | 25 | 3.0 | 2.1 |
| Selenium mg/L | 0.001 | 0.1 | | |
| Silicon mg/L | 0.02 | | 1.57 | 0.85 |
| Strontium μg/L | 0.1 | | 142.1 | 315.3 |
| Titanium μg/L | 0.5 | | 9.6 | 5.4 |
| Vanadium μg/L | 1.5 | 6 | 4.1 | 2.5 |
| Zinc μg/L | 0.6 | 30 | 129.3 | 116.0 |
| **Bacteria** | | | | |
| Escherichia coli c/100mL | N/A | 100 | 2,088 | 62 |
| Fecal streptococcus c/100mL | N/A | | 23,785 | 4,627 |
| Pseudomonas aeruginosa c/100mL | N/A | | 1,554 | 16 |
| **Organics** | | | | |
| 2,4-dichlorophenol, ng/L | 2,000 | 4,000 | | |
| 2,4,6-trichlorophenol, ng/L | 20 | 18,000 | | |
| 2,4,5-trichlorophenol, ng/L | 100 | 18,000 | | |
| 2,3,4-trichlorophenol, ng/L | 100 | 18,000 | | |
| 2,3,4,5-tetrachlorophenol, ng/L | 20 | 1,000 | | |
| 2,3,4,6-tetrachlorophenol, ng/L | 20 | 1,000 | | |
| Pentachlorophenol, ng/L | 10 | 500 | 17 | 14 |
| Dicamba, ng/L | 50 | 200,000 | 203 | 64 |
| Bromoxynil, ng/L | 50 | | | |
| 2,4-D-propionic acid, ng/L | 100 | | | |
| 2,4-D, ng/L | 100 | 4,000 | 3,380 | 188 |
| Silvex, ng/L | 20 | | | |
| 2,4,5-T, ng/L | 50 | 18,000 | | |
| 2,4-DB, ng/L | 200 | | | |
| Picloram, ng/L | 100 | | | |
| Diclofop-methyl, ng/L | 100 | | | |

Relative to the summer season, samples collected during the winter season were found to have lower concentrations of total suspended solids but greater turbidity. In winter, the chloride concentration and conductivity were greatly increased, organics and nutrient concentrations were reduced, bacterial concentrations were greatly reduced, and biocide concentrations were reduced. Metal concentrations increased or decreased but the values included many observations less than the method detection limit.

Table 5.1 includes a summary of the Provincial Water Quality Objectives (PWQO) (OMOEE, 1999). The PWQO values apply to receiving waters and not to stormwater runoff. However, a comparison of the runoff quality to PWQO criteria is indicative of the relative quality of the runoff. The PWQO values for some chemicals are dependent upon pH, alkalinity, hardness or valence because the toxic effects of the materials depend on their specific form and availability to biota. For simplicity, Table 5.1 lists the values thought to be most appropriate for the conditions at the study sites. The table also uses the revised or interim PWQO values specified in the OMOEE document.

Figure 5.2 shows the average particle size distributions for the suspended particles found in the main pipe samples. As would be expected, the particulates were more coarse in summer than in winter, with the summer/fall average size being between 10 and 20 $\mu m$ and the winter/spring average size being between 3 and 4 $\mu m$.

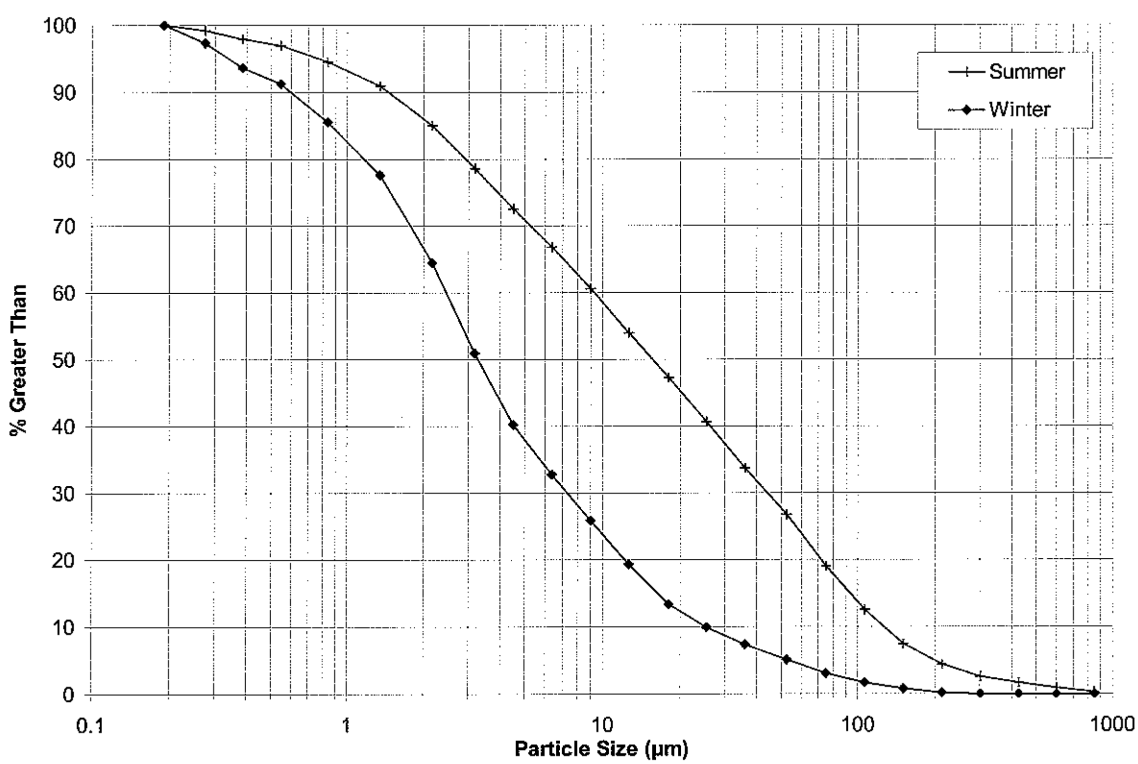


***Figure 5.2:*** Princess Margaret Boulevard average particle size distributions

### 5.1.5 Sediment Quality Study

A sample of sediment was obtained from the perforated exfiltration pipes at MH 3 at the Princess Margaret Boulevard site on April 17, 1996 (Candaras Associates, 1997). In February of 1998, a single sediment core was extracted from the Princess Margaret site (Rochfort and Marsalek, 1998)[7]. The core was divided longitudinally into three separate 1-m sections. The three samples were then homogenized and sub-samples were collected for analysis. The metals results of both studies are summarized in Table 5.2. Additional data for nutrients and PAH's were obtained from the 1998 samples, and particle size data were obtained for both years.

Metal concentrations were fairly high, with cadmium, chromium, manganese, mercury and nickel equal to or elevated slightly above the Lowest Effect Level (LEL), although well below the Severe Effect Level (SEL), as defined in the Ministry of the Environment's Sediment Quality Guidelines (OMOE, 1997). Lead and zinc samples yielded results half-way between the LEL and SEL, while copper was the only constituent to exceed the SEL. The concentrations for most constituents measured in 1998 were more than 50% lower than the values measured from the samples analyzed in 1996. The analytical results may have been influenced by sampling methods, sampling locations, solvents used for extraction and other laboratory methods, in addition to changes in the catchment and exfiltration system that took place between the sampling programs.

In the 1998 sample, most PAH compounds were found in concentrations above the LEL but well below the SEL. The presence of PAH compounds with heavier molecular weights may possibly be explained by the presence of motor oils, lubricants and similar products that may be found in road runoff.

In the 1998 sample, total phosphorus, total organic carbon (TOC) and total nitrogen (TN) were measured as indicators of the presence of nutrients in the sediment. Two of the three sub-samples for TOC and TN were at or above the SEL. Total phosphorus values were half-way between the LEL and SEL. Taking into consideration the flow path within the exfiltration system and high nutrient values in the sediment, it would appear that the sediments acted as a sink for these nutrients (Rochfort and Marsalek, 1998).

Both the 1996 and 1998 samples were dominated by silt-sized particles (54 to 60% by mass). However, the 1996 sample contained a large fraction of sand and very little clay, whereas the 1998 sample had a large percentage of clay and very little sand. As previously discussed with respect to the metals data, several factors may have contributed to the differences between the sediment characterization results.

[7] The Rochfort and Marsalek report did not state the precise source of this sample.

***Table 5.2:*** Sediment sample data -- Princess Margaret Boulevard exfiltration site

| Parameter | Units[3] | NWRI Samples[1] Sample A | Sample B | Sample C | Candaras Samples[2] | Severe Effect Level |
|---|---|---|---|---|---|---|
| Aluminum | pct | 0.85 | 0.82 | 0.81 | 1.14 | |
| Antimony | µg/g | | | | n/a | |
| Arsenic | µg/g | | | | n/a | 10 |
| Barium | µg/g | 47 | 51 | 51 | 82 | |
| Beryllium | µg/g | 0.4 | 0.4 | 0.4 | 0.1 | |
| Bismuth | µg/g | | | | 9.5 | |
| Cadmium | µg/g | | | | 4.4 | 10 |
| Calcium | pct | 4.63 | 4.98 | 5.54 | 6.32 | |
| Chromium | µg/g | 40 | 45 | 51 | 88 | 110 |
| Cobalt | µg/g | 4 | 3 | 4 | 8 | |
| Copper | µg/g | 110 | 125 | 135 | 263 | 110 |
| Iron | pct | 1.77 | 1.79 | 1.82 | 4.02 | 4 |
| Lead | µg/g | 79 | 96 | 109 | 214 | 250 |
| Lithium | µg/g | 13 | 14 | 13 | n/a | |
| Mercury | µg/g | 0.226 | 0.279 | 0.281 | n/a | 2 |
| Magnesium | pct | 3 | 3.39 | 3.72 | 3.37 | |
| Manganese | µg/g | 496 | 576 | 589 | 807 | 1100 |
| Molybdenum | µg/g | 2 | | | 5 | |
| Nickel | µg/g | 19 | 20 | 20 | 30 | 75 |
| Niobium | µg/g | | | | n/a | |
| Potassium | pct | 0.15 | 0.13 | 0.13 | 0.242 | |
| Silver | µg/g | | | | 5 | |
| Sodium | pct | 0.1 | 0.12 | 0.12 | 0.207 | |
| Strontium | µg/g | 48 | 49 | 51 | n/a | |
| Tin | µg/g | | | | n/a | |
| Titanium | µg/g | 239 | 236 | 241 | n/a | |
| Tungsten | µg/g | | | | n/a | |
| Vanadium | µg/g | 25 | 26 | 26 | 56 | |
| Yttrium | µg/g | 7 | 7 | 7 | n/a | |
| Zinc | µg/g | 479 | 570 | 615 | 1001 | 820 |

Notes: [1] data from Rochfort & Marsalek, 1998
[2] data from Candaras Associates, 1997
[3] pct = percentage

### 5.1.6 Summary – Discussion

The monitoring results show that very few overflow conditions occurred, although some rainfall events had volumes greater than the 15 mm design specification. A brief overflow was caused by a 15 mm 1-hour event that had a high peak flow of 9.7 mm in 5 minutes. An overflow also occurred in the second of two intense back-to-back rainfall events that had rain depths of 15 and 12 mm respectively. The results suggest that the exfiltration system has adequate volumetric capacity, and that the limiting factor is throughput capacity. Also, antecedent conditions can influence performance if there is insufficient time available for the stored runoff to percolate into the soil.

Water quality data were obtained for only one overflow event. However, overflows result because the total volume of catchbasin effluent exceeds the storage/exfiltration/throughput capacity of the system. Most of the samples consisted of catchbasin effluent that entered the sewer between MH 71 and MH 72 and should be representative of overflow conditions. Therefore, the data obtained from this site contribute to the general database on storm sewer effluent quality.

## 5.2 Queen Mary's Drive Exfiltration System

### 5.2.1 Site Instrumentation

Figure 5.3 is an illustration of maintenance hole 25 (MH 25), which was the downstream point of access to the exfiltration system. In mid-August 1996, an area velocity flow logger was installed in the 825 mm diameter main storm sewer of the Queen Mary's Drive exfiltration system at MH 25. Further inspection revealed that there was additional flow entering the maintenance hole from a 100 mm diameter relief drain located approximately 2.5 m below the perforated pipes of the exfiltration system. There were also a number of cracks within the maintenance hole, which were observed to contribute additional flows. The 100 mm diameter relief drain was apparently installed to drain down the high water table in this area, with the intention of preventing the failure of the bank along the Humber River. The relief pipe was observed to drain continuously during dry weather at a rate of about 0.4 l/s. Therefore, in order to quantify the additional flows contributed by the relief pipe and the cracks in the maintenance hole wall, flow monitoring equipment was installed in the Kingsway Crescent sewer and in the outfall sewer. The Kingsway Crescent pipe was equipped with a flow logger at the end of September 1996. Monitoring of flow at the 975 mm diameter outfall sewer commenced in October 1996.

An automatic sampler and a liquid level actuator were installed to collect samples from the bottom of MH 25. In addition, grab samples were collected from the main storm sewer of the exfiltration system and the 100 mm diameter relief drain. Water quality sampling began in mid-November of 1996. Table G.1 in Appendix G provides the chronology of the monitoring program.

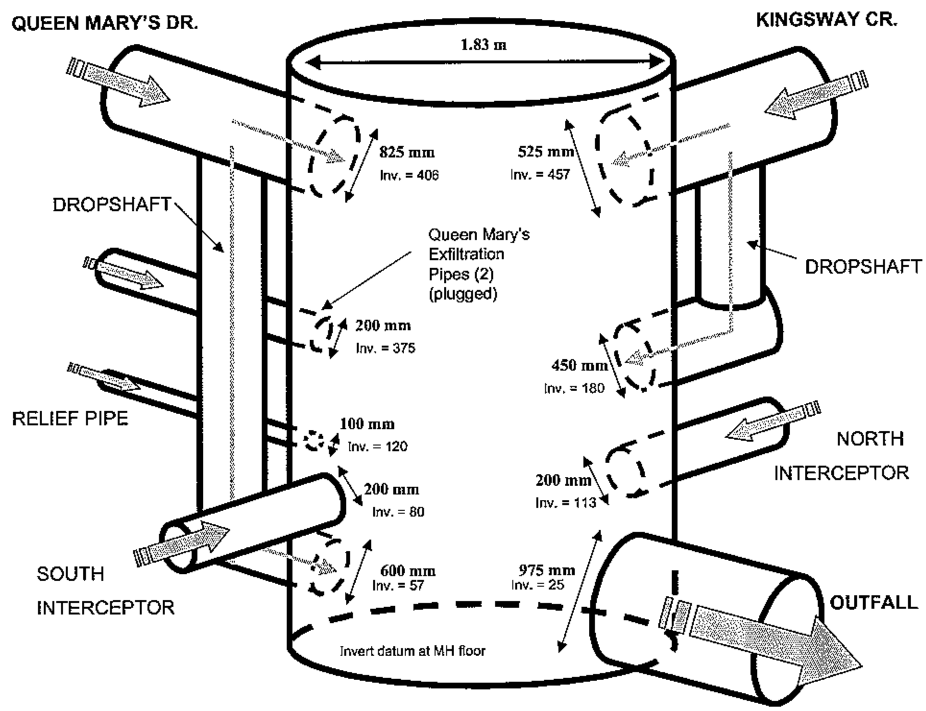


***Figure 5.3:*** Schematic diagram of maintenance hole 25

### 5.2.2 1996 Flow Monitoring Results

The main storm sewer along Queen Mary's Drive was completely dry under dry-weather conditions; flow was observed during many storm events. Appendix G contains rainfall and runoff graphs plotted on a monthly basis.

Flow was observed in the main storm sewer for storm events with total rainfall volumes of less than 15 mm, which was the design storm for the system. Several inspections were conducted, both during the storm events and shortly after the termination of the runoff. Those observations led to the conclusion that flow in the main storm sewer was generated by overflow from the next upstream maintenance hole as well as by infiltration from the gravel bed through visible cracks in the wall of the sewer. Those observations indicated that - for at least the lower part of the Queen Mary's Drive's system - the water level in the gravel bed was sufficiently high to at least partly submerge the sewer pipe. Dry weather flow was observed on numerous occasions from the relief drain and cracks in the walls of the maintenance hole.

Figure 5.4 contains the hyetograph and hydrographs for the event of October 9-10, 1996. The first rain event on the morning of the 9th had a total depth of 2.0 mm. The second event had a total depth of 9.2 mm. In the figure, the outlet sewer is seen to have a relatively uniform baseflow of approximately 1.8 l/s. Rainfall was measured approximately 10 km from the study site and a 1-hour difference between the rainfall and flow time scales likely resulted from the use of daylight savings time in the flow sensors. However, the flows in the three sewers are seen to respond to the rainfall pattern. As previously stated, the sensors were not capable of measuring low flows and the hydrographs consequently start and end abruptly. In addition, the sensor in the Kingsway Crescent sewer appears to have stopped reporting after the initial few observations. The measured inflow was only 33% of the measured outflow during this period. Because additional, unmeasured flows would have come from the north and south interceptor sewers, a volumetric balance could not have been obtained from the data set.

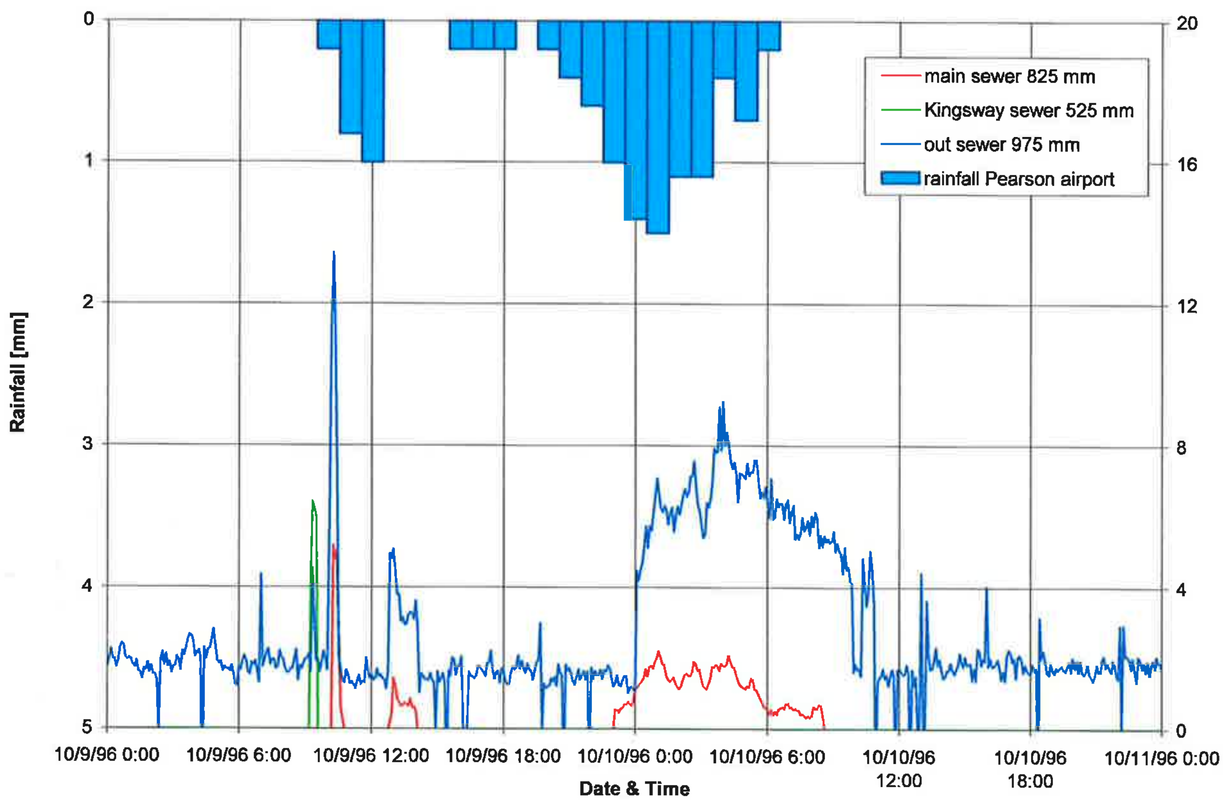


***Figure 5.4:*** Queen Mary's Drive event of October 9-10, 1996

The Queen Mary's Drive exfiltration facility is actually a hybrid of exfiltration sewers and conventional sewers. The drainage area directly tributary to the new exfiltration sewer is approximately 3.7 ha. The total drainage area is 13.3 ha. According to available plans:

- part of Dunedin Drive (0.6 ha) drains to MH 12,
- part of Prince Edward Drive north of Queen Mary's Drive, including a portion of Kings Garden Road, (2.5 ha) drain southward to MH 16,

- part of Prince Edward Drive south of Queen Mary's Drive, including parts of The Kingsway, Grenview Blvd. N. and Strath Ave., (6.5 ha) drain northward to MH 16.

The consequence of this geometry is that the exfiltration sewer system was treating flows from an area that is much larger than that tributary to the exfiltration system itself. This factor, in combination with the apparently high water table in the area, make the facility unsuitable for assessing performance on a quantitative basis.

### 5.2.3 Water Quality Results

Water samples were collected from the main storm sewer upstream of MH 25. Those samples represented flows entering the last leg of the system directly from the catch basins, roof leaders and foundation drains, plus overflows from the maintenance hole immediately upstream (MH 20) and infiltration from the gravel trench. Composite samples collected from the bottom of MH 25 represented flows from the Queen Mary's Drive main sewer, the Kingsway Crescent sewers, the relief drain and infiltration through the maintenance hole walls from the gravel trench and surrounding soil. Table 5.3 summarizes the water quality results for both the main storm sewer and the sampling station at the bottom of MH 25. Data from individual events are included in Appendix G.

Following assessment of data collected in the initial monitoring period, a limited monitoring program was recommended for the Queen Mary's Drive site. In 1997, grab samples were collected from the sampling stations, with only the relief drain being sampled from November 1997 to the end of the program. The relief drain was monitored to provide some insight into the impact of the exfiltration system on the groundwater quality. A total of 20 groundwater grab samples[8] were taken from the 100 mm diameter relief pipe at MH 25 between February 1997 and August 1998. The intent was to determine what effect, if any, the exfiltration system had on local groundwater. A summary of the results is included in Table 5.3.

On average, for the majority of pollutants measured, water samples collected from the bottom of maintenance hole 25 had greater pollutant concentrations than those collected from the main sewer on Queen Mary's Drive. The samples collected from the relief pipe had lesser pollutant concentrations than those collected from both the bottom of the maintenance hole and the Queen Mary's Drive main pipe. These observations are consistent with the physical nature of the system. The groundwater sampled at the relief pipe would have been filtered in passing through the gravel trench and soil. The exfiltration system overflow would not have included the more polluted first flush of runoff, which would have been retained and exfiltrated. The bottom samples would have included some conventional sewer runoff that had little opportunity to exfiltrate.

[8] Two samples were analyzed only for bacteria. For most parameters, n = 18.

*Table 5.3:* Queen Mary's Drive -- water quality results

| Parameter & Units \ Location | RMDL | PWQO | QM Main Pipe (n = 7) | MH 25 Bottom (n= 6) | Relief Pipe (n = 18) |
|---|---|---|---|---|---|
| **General Water Chemistry** | | | | | |
| Solids, suspended, mg/L | 2.5 | | 124.4 | 196.0 | 16.1 |
| Turbidity, FTU | 0.01 | | 107.43 | 174.63 | 8.74 |
| pH | n/a | 6.5 - 8.5 | 7.5 | 7.8 | 7.8 |
| Alkalinity, mg CaCO3/L | 0.25 | | 49.00 | 119.40 | 184.33 |
| Chloride, mg/L | 0.2 | | 1059.0 | 1600.3 | 367.9 |
| Conductivity, µS/cm | 1.0 | | 3195.6 | 4955.0 | 1549.4 |
| **Nutrients** | | | | | |
| Nitrogen; ammonia + ammonium, mg/L | 0.002 | | 1.751 | 2.829 | 0.177 |
| Nitrogen; nitrite, mg/L | 0.001 | | 0.111 | 0.117 | 0.014 |
| Nitrogen; nirate + nitrite, mg/L | 0.005 | | 1.024 | 2.293 | 2.861 |
| Nitrogen; total Kjeldahl, mg/L | 0.02 | | 4.14 | 7.19 | 0.77 |
| Phosphorus; total, mg/L | 0.002 | 0.01 - 0.03 | 0.573 | 0.438 | 0.155 |
| Phosphorus; phosphate, mg/L | 0.0005 | | 0.2134 | 0.1632 | 0.0739 |
| **Organics** | | | | | |
| Carbon; dissolved organic, mg/L | 0.1 | | 7.2 | 10.7 | 2.5 |
| Solvent extractable, mg/L | 1.0 | | 14.8 | 13.3 | 1.5 |
| **Inorganics** | | | | | |
| Aluminum, µg/L | 11 | 75 | 483 | 524 | 103 |
| Arsenic, mg/L | 0.0005 | 0.1 | 0.0016 | 0.0015 | |
| Barium, µg/L | 0.2 | | 23.2 | 50.2 | 35.0 |
| Beryllium, µg/L | 0.02 | | 0.03 | 0.05 | 0.01 |
| Cadmium, µg/L | 0.6 | 0.2 | 0.5 | 0.5 | 0.3 |
| Calcium, mg/L | 0.005 | | 52.100 | 105.767 | 86.978 |
| Carbon; dissolved inorganic, mg/L | 0.2 | | 11.3 | 26.5 | 44.2 |
| Chromium, µg/L | 1.4 | 8.9 as $Cr^{III}$ | 7.1 | 7.4 | 2.5 |
| Cobalt, µg/L | 1.3 | 0.9 | 1.1 | 1.3 | 0.5 |
| Copper, µg/L | 1.6 | 5 | 23.0 | 30.3 | 7.5 |
| Iron, µg/L | 0.8 | 300 | 909.4 | 996.3 | 177.2 |
| Lead, µg/L | 10 | 25 | 35 | 36 | 4 |
| Magnesium, mg/L | 0.008 | | 12.531 | 18.853 | 9.102 |
| Manganese, µg/L | 0.2 | | 146.5 | 196.7 | 28.2 |
| Mercury, µg/L | 0.02 | 0.2 | 0.03 | 0.03 | 2.90 |
| Molybdenum, µg/L | 1.6 | 40 | 0.2 | 0.3 | 0.3 |
| Nickel, µg/L | 1.3 | 25 | 2.2 | 2.7 | 0.8 |
| Selenium, mg/L | 0.0005 | 0.1 | <MDL | <MDL | 0.0005 |
| Silicon, reactive silicate, mg/L | 0.02 | | 0.46 | 1.45 | 2.60 |
| Strontium, µg/L | 0.1 | | 315.0 | 464.0 | 242.9 |
| Titanium, µg/L | 0.5 | | 4.8 | 2.7 | 2.0 |
| Vanadium, µg/L | 1.5 | 6 | 2.0 | 2.5 | 0.6 |
| Zinc, µg/L | 0.6 | 30 | 114.1 | 129.9 | 29.9 |
| **Bacteria** | | | | | |
| Escherichia coli, c/100mL | N/A | 100 | 3,588 | 1,530 | 3,690 |
| Fecal streptococcus, c/100mL | N/A | | 9,360 | 4,900 | 11,794 |
| Pseudomonas aeruginosa, c/100mL | N/A | | 13 | 20 | 16 |
| **Toxic Organics** | | | | | |
| 2,4-dichlorophenol, ng/L | 2,000 | 4,000 | | | |
| 2,4,6-trichlorophenol, ng/L | 20 | 18,000 | | | |
| 2,4,5-trichlorophenol, ng/L | 100 | 18,000 | | | |
| 2,3,4-trichlorophenol, ng/L | 100 | 18,000 | | | |
| 2,3,4,5-tetrachlorophenol, ng/L | 20 | 1,000 | | | |
| 2,3,4,6-tetrachlorophenol, ng/L | 20 | 1,000 | | | |
| Pentachlorophenol, ng/L | 10 | 500 | 63 | 65 | 39 |
| Dicamba, ng/L | 50 | 200,000 | | | |
| Bromoxynil, ng/L | 50 | | | | |
| 2,4-D-propionic acid, ng/L | 100 | | | | |
| 2,4-D, ng/L | 100 | 4,000 | 167 | 220 | |
| Silvex, ng/L | 20 | | 42 | | |
| 2,4,5-T, ng/L | 50 | 18,000 | | | |
| 2,4-DB, ng/L | 200 | | | | |
| Picloram, ng/L | 100 | | | | |
| Diclofop-methyl, ng/L | 100 | | | | |

Exceptions to the above general relationships provide some insight into the functioning of the system. The groundwater had elevated concentrations of alkalinity, dissolved inorganic carbon and silicon because of leaching from the gravel or local soils. The groundwater also had elevated concentrations of bacteria and nitrogen, suggesting that local sanitary sewers were leaking. Sanitary sewer replacement was one of the reasons for the reconstruction project on this street. The groundwater had an elevated concentration of mercury, but that was the result of one anomalous sample; all other observations were less than the detection limit.

The greatest concentrations of phosphorus and solvent extractables were measured in the exfiltration system main sewer pipe. The groundwater concentrations for these constituents were less and the bottom sample concentrations appear to result from dilution.

Only three of the complex organic compounds - pentachlorophenol, 2,4-D and Silvex - appeared at concentrations greater than their respective detection limits. Several of the metals were found to have concentrations less than the detection limits, particularly in the groundwater samples.

At the Queen Mary's Drive site, the *E. Coli* concentrations exceeded PWQO values, as did total phosphorus and several metals (aluminum, cobalt, copper, iron, lead and zinc). The chromium concentrations were close to the objective set for trivalent chromium and exceeded the objective of 1.0 $\mu$g/L for the hexavelent form.

The average particle size distributions for the three sampling locations are shown in Figure 5.5. As might be expected, the largest average particle size was associated with the maintenance hole bottom samples, and the smallest average particle size was associated with the groundwater (relief pipe) samples.

### 5.2.4 Summary – Discussion

The exfiltration system constructed along Queen Mary's Drive was reported to have been designed to exfiltrate runoff from a 15 mm, 1-hour rainfall event. That specified capacity is interpreted in this report as pertaining to a typical catchment area surrounding the exfiltration system, without any extraneous sources of flow. As constructed, the Queen Mary's Drive system received flow, either overland or through conventional storm sewers, from an external area 2.6 times greater than that of the lots draining directly to the street containing the exfiltration sewer. The hydraulic load created by that drainage area would presumably be out of proportion to the exfiltration system infrastructure. In addition, the relatively high groundwater table in the area may have been responsible for limiting system capacity.

The data obtained between August 15 and November 30, 1996 include 31 individual rainfall-runoff events. Rain depths ranged between 0.2 mm and 66.7 mm for these events. Only three of the events had no measurable overflow. The largest event that produced no overflow had a rainfall depth of 1.4 mm, but the system was seen to overflow for lesser rainfall depths. Antecedent effects must be taken into consideration in this analysis; a small rainfall event following closely behind a larger event could easily cause overflow. Also, the fact that the rainfall data came from a gauge located approximately 10 km from the test site suggests that the rain depths may not have been correct for the site.

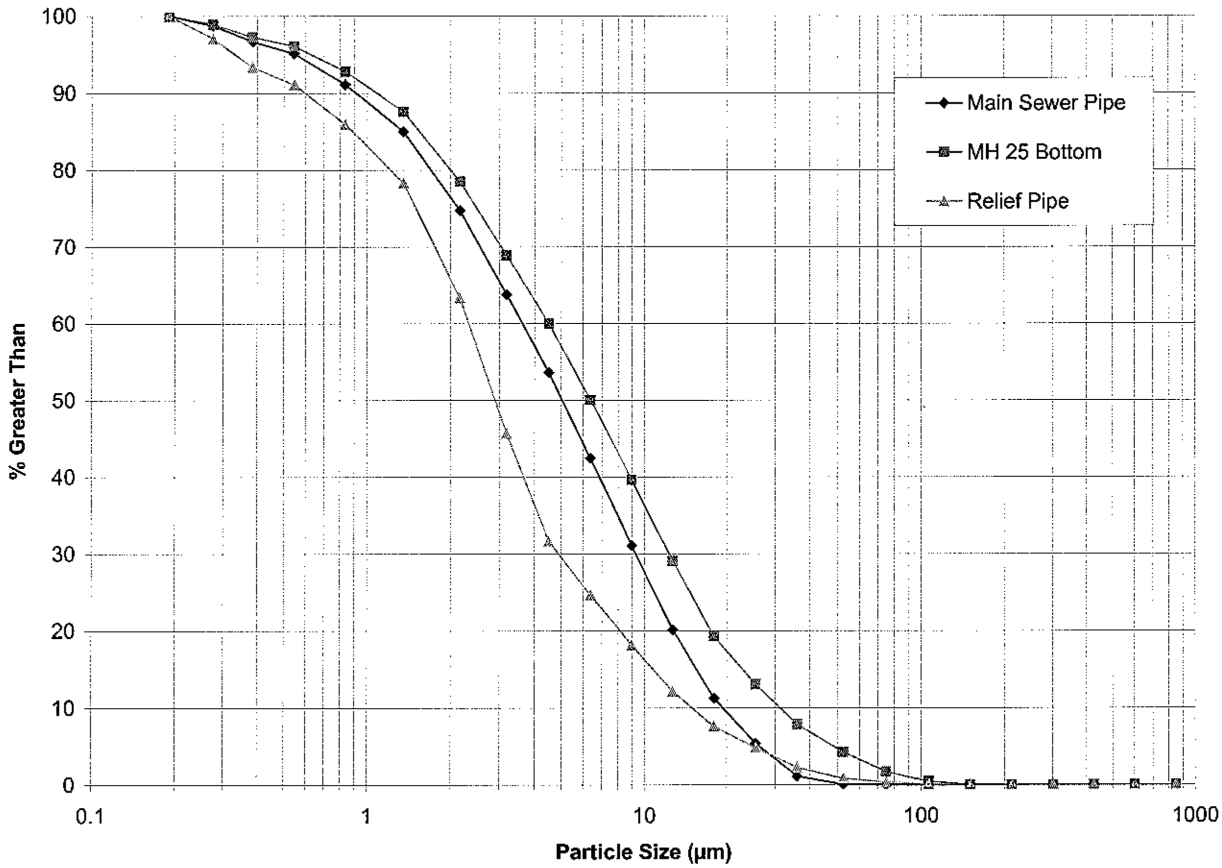


***Figure 5.5:*** Queen Mary's Drive average particle size distributions

The runoff coefficients for the Queen Mary's Drive exfiltration sewer, and for the outfall, indicate that the system was working well regardless of the number of events that caused overflow. Most of the coefficient values were less than 0.1; all but three were less than 0.2. The largest coefficient value (0.34) was obtained from an event that followed very closely behind a large event (26.9 mm rainfall) when the exfiltration system and local soils were presumably saturated with water. That occurrence also supports the validity of the data, since a coefficient of 0.34 would be appropriate for a conventional storm sewer system in that area.

In general, the water quality data appear to be in the low end of ranges generally reported for pollutant concentrations in runoff from urban areas. There was no evidence of dry-weather flow in the main storm sewer and no independent evidence (e.g., through borehole data) that any part of the gravel trench was permanently below the water table. Hence, dilution of the runoff with groundwater may be assumed to be minimal as observed in the system overflow, and the exfiltration system was apparently contributing to water quality improvement as well as providing volume control[9].

## 5.3 Braecrest Avenue Filtration System

### 5.3.1 1996 Site Instrumentation

Flow monitoring was undertaken initially in second-to-last maintenance hole (MH 4), but the instrument was moved to MH 5 later in the program. An automatic sampler with a liquid level actuator was installed in MH 5 to collect samples from the bottom of the maintenance hole. Water quality samples collected at this station were deemed to be representative of the system output; the samples consisted of filtrate plus the output of a catchbasin directly connected to the maintenance hole and any catchbasin overflow to the final leg of the main sewer. A bucket was used to collect samples from a catch basin lead at the upstream end of the system; these samples were considered to be representative of system inflow. In addition, grab samples were also collected when feasible. A more detailed chronological summary of the monitoring program is included in Appendix H.

### 5.3.2 1996 Flow Monitoring

During the period from mid-August until the end of November, 1996, almost no measurable flows were recorded in the storm sewer. During dry weather conditions, the storm sewer was found to be dry and completely free of any sediment accumulation. No flows were observed infiltrating into the storm sewer or the maintenance hole through any cracks during regular field sampling and maintenance. This observation suggested that, unlike the situation at Queen Mary's Drive, the groundwater table was probably below the invert of the storm sewer.

*September 7$^{th}$ storm event:*

Some measurable flows were recorded in the first half of September during the largest storm event of the year (66.9 mm). The runoff analysis for the storm event on September 7, 1996 is shown in Figure 5.6. Despite the large rainfall volume with relatively high intensity (66.9 mm in less than 24 hours), measurable flow rates occurred only occasionally in the storm sewer. The total runoff volume measured in the main storm sewer for this event was 19.7 $m^3$, approximately 1% of the total rainfall volume for the whole drainage area. These results indicate that the percolation capacity of the surrounding soils had been underestimated.

An alternative hypothesis concerning the small volume of runoff observed in the sewer is that clogging in either or both the catchbasin leads or the perforated pipes restricted the total conveyance capacity of the filtration system. However, both catchbasin leads would have to be blocked, with surface runoff bypassing the sewer system, to result in low flows in the storm sewer. Such conditions were not observed in numerous field inspections.

[9] Comparisons between various studies will be the subject of a separate report.

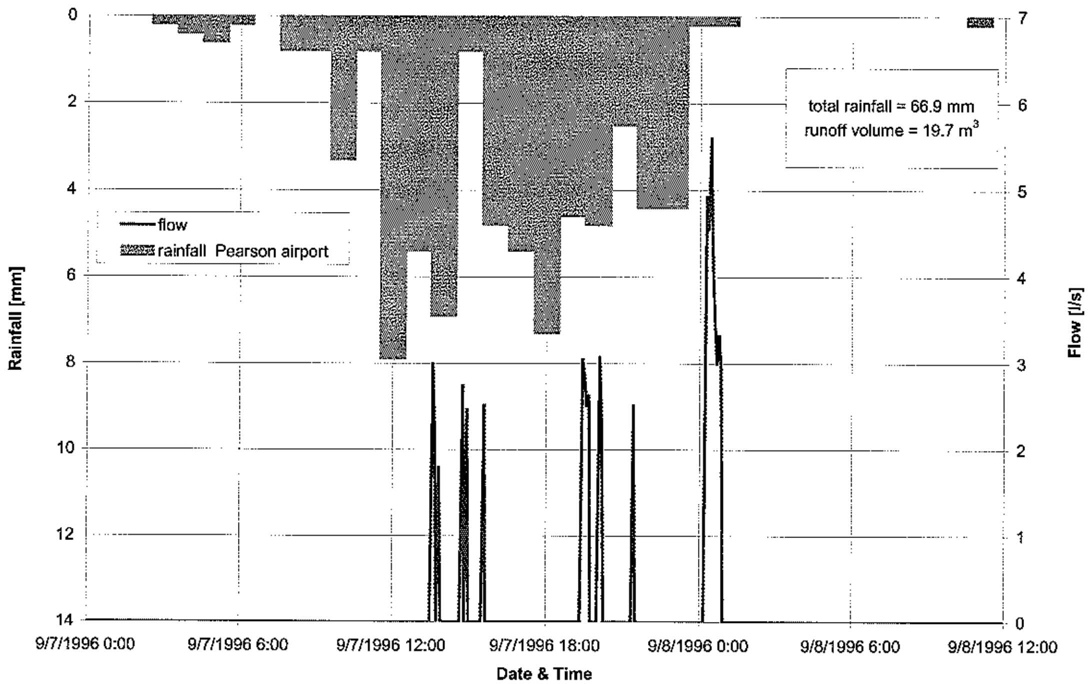


***Figure 5.6:*** Braecrest Avenue event of September 7, 1996

*Other results:*

In the previous study (Candaras Associates, 1997), a test was conducted to calibrate flow monitoring equipment and to observe the performance of the system. A summary of the results is included in Appendix D. Flow from fire hydrants was introduced into the catchbasins upstream of MH 2 using fire hoses. Flow was introduced into the system for approximately 1 hour and 40 minutes and was gradually increased from 600 l/min to 1,400 l/min in increments of 300 l/min. Hydraulic head was measured at various locations in the system.

In the calibration test, the filtration system showed that it could conduct a constant flow rate of approximately 15 l/s, to possibly as much as 17 l/s, with no discharge into the conventional storm sewer. The hydraulic capacity of the system is nominally the balance between the driving head (difference in water levels between influent and effluent) and the resistance created by the pipes and gravel bed. However, in this case, some of the water would have infiltrated the surrounding soil and may have moved downstream in the gravel rather than exiting the system through the perforated filtrate collection pipes.

Field observations made when collecting water samples at MH 5 during small snowmelt events in mid-winter revealed that there were some "overflows" into the storm sewer from the upper catchbasin lead. Overflows into the conventional storm sewer are not expected during the winter because flow rates resulting from snowmelt are relatively small. The occurrence of overflows may indicate possible clogging in the lead between the upper perforated pipe and the catchbasin due to water frozen in the catchbasin lead. Flow rates in the storm sewer were continuously monitored at the downstream side of the maintenance hole only until the end of November 1996.

### 5.3.3 1996 Water Quality

Water quality samples were collected at three sampling stations within the Braecrest Avenue filtration system during 1996-1997. Samples were collected by composite sampler at the most downstream location in the system (MH 5) during the summer/fall monitoring period to define the water quality of the system's effluent. A single sample collected from a catchbasin lead upstream in the system represents the water quality of untreated runoff. Grab samples were also collected from the main sewer pipe entering MH 5 during the winter/spring monitoring period; these samples include both filtered water from upstream and any unfiltered flow from the upper catchbasin leads, but exclude flow from the catchbasin discharging directly to MH5 and filtrate entering MH 5 through the perforated pipes. Laboratory results for the analysis of the samples are summarized in Table 5.4. Individual results are included in Appendix H.

The results of the summer/fall monitoring program show that most of the pollutant concentrations in the outlet were appreciably less than those in the inlet. Exceptions were chloride and nitrogen (as ammonia and nitrate). The increased chloride concentration may have resulted from the leaching of salt deposited during previous winter periods. The increased nitrogen concentrations may have resulted from leaking sanitary sewers, illegal connections or rodents in the sewer system. However, the conductivity data did not support the chloride data and this comparison was based on a single inlet sample.

The average outlet pollutant concentrations measured in the winter/spring period were generally greater than those from the summer/fall period. These outlet grab samples were taken from the main sewer entering MH 5, and did not include the contribution from the catchbasin discharging directly to MH 5, or the filtrate entering MH 5 through the two perforated underdrains. The TSS concentration was less in winter than in summer but the turbidity was greater, suggesting that the particle size distribution was finer in winter. All nitrogen and phosphorus concentrations were greater in winter. With reduced runoff in winter, the dilution of sanitary or animal waste (from whatever source) would be reduced resulting in the observed concentration increases.

Figure 5.7 summarizes the particle size distributions for the Braecrest Avenue facility. As would be expected, the coarsest sizes were observed in the inlet sample. The finest sizes were obtained from the main sewer where the majority of the runoff would have been filtered through the gravel bed. The average distribution observed in the maintenance hole bottom samples was of intermediate size, which is also logical since one catchbasin drains directly to MH 5. Superimposed on this spatial relationship is the seasonal effect. The MH 5 samples were from the summer/fall period and the main sewer samples were from the winter/spring period. The seasonal relationship is consistent with the TSS and turbidity data discussed previously.

***Table 5.4:*** Braecrest Avenue -- water quality results

| Parameter & Units \ Location | RMDL | PWQO | Average Outlet, summer/fall period (n = 4) | Inlet Sample, 13/11/96 | Average Main Pipe, winter/spring period (n = 7) |
|---|---|---|---|---|---|
| **General Water Chemistry** | | | | | |
| Solids, suspended, mg/L | 2.5 | | 66.7 | 926.0 | 49.4 |
| Turbidity, FTU | 0.01 | | 17.05 | 24.20 | 55.04 |
| pH | n/a | 6.5 - 8.5 | 7.67 | 7.76 | 7.64 |
| Alkalinity, mg $CaCO_3$/L | 0.25 | | 49.47 | 82.40 | 51.20 |
| Chloride, mg/L | 0.2 | | 20.1 | 8.4 | 1,678.3 |
| Conductivity, µS/cm | 1 | | 187 | 211 | 4,921 |
| **Nutrients** | | | | | |
| Nitrogen; ammonia + ammonium, mg/L | 0.002 | | 0.057 | 0.042 | 0.379 |
| Nitrogen; nitrite, mg/L | 0.001 | | 0.025 | 0.070 | 0.095 |
| Nitrogen; nirate + nitrite, mg/L | 0.005 | | 0.902 | 0.340 | 0.959 |
| Nitrogen; total Kjeldahl, mg/L | 0.02 | | 0.74 | 3.38 | 1.75 |
| Phosphorus; total, mg/L | 0.002 | 0.01 - 0.03 | 0.177 | 0.676 | 0.186 |
| Phosphorus; phosphate, mg/L | 0.0005 | | 0.0533 | 0.0795 | 0.1013 |
| **Organics** | | | | | |
| Carbon; dissolved organic, mg/L | 0.1 | | 2.3 | 8.0 | 3.2 |
| Solvent extractable, mg/L | 1 | | 2.3 | 34.0 | 4.1 |
| **Inorganics** | | | | | |
| Aluminum, µg/L | 11 | 75 | 271 | 431 | 439 |
| Arsenic, mg/L | 0.001 | 0.1 | <MDL | <MDL | 0.001 |
| Barium, µg/L | 0.2 | | 18.3 | 47.6 | 25.1 |
| Beryllium, µg/L | 0.02 | | 0.03 | 0.08 | 0.03 |
| Cadmium, µg/L | 0.6 | 0.2 | 0.9 | 0.7 | 0.3 |
| Calcium, mg/L | 0.005 | | 25.400 | 94.000 | 39.743 |
| Carbon; dissolved inorganic, mg/L | 0.2 | | 11.4 | 20.0 | 11.5 |
| Chromium, µg/L | 1.4 | 8.9 as $Cr^{III}$ | 2.1 | 1.0 | 3.7 |
| Cobalt, µg/L | 1.3 | 0.9 | 0.9 | 3.6 | 0.6 |
| Copper, µg/L | 1.6 | 5 | 8.4 | 22.0 | 15.6 |
| Iron, µg/L | 0.8 | 300 | 619.7 | 599.0 | 600.1 |
| Lead, µg/L | 10 | 25 | 10 | 17 | 13 |
| Magnesium, mg/L | 0.008 | | 3.980 | 19.400 | 4.243 |
| Manganese, µg/L | 0.2 | | 69.0 | 633.0 | 70.5 |
| Mercury, µg/L | 0.02 | 0.2 | <MDL | <MDL | <MDL |
| Molybdenum, µg/L | 1.6 | 40 | 0.1 | <MDL | 0.0 |
| Nickel, µg/L | 1.3 | 25 | 1.3 | 4.8 | 1.8 |
| Selenium, mg/L | 0.001 | 0.1 | <MDL | <MDL | <MDL |
| Silicon, reactive silicate, mg/L | 0.02 | | 0.87 | 1.58 | 0.71 |
| Strontium, µg/L | 0.1 | | 56.4 | 205.0 | 302.3 |
| Titanium, µg/L | 0.5 | | 2.5 | 2.0 | 3.9 |
| Vanadium, µg/L | 1.5 | 6 | 1.3 | 1.9 | 1.8 |
| Zinc, µg/L | 0.6 | 30 | 43.3 | 212.0 | 74.0 |
| **Bacteria** | | | | | |
| Escherichia coli, c/100mL | n/a | 100 | 1,900 | | 312 |
| Fecal streptococcus, c/100mL | n/a | | 500 | | 1,066 |
| Pseudomonas aeruginosa, c/100mL | n/a | | 136 | | 21 |
| **Toxic Organics** | | | | | |
| 2,4-dichlorophenol, ng/L | 2,000 | 4,000 | | <MDL | |
| 2,4,6-trichlorophenol, ng/L | 20 | 18,000 | | <MDL | 45 |
| 2,4,5-trichlorophenol, ng/L | 100 | 18,000 | | <MDL | |
| 2,3,4-trichlorophenol, ng/L | 100 | 18,000 | | <MDL | |
| 2,3,4,5-tetrachlorophenol, ng/L | 20 | 1,000 | | <MDL | |
| 2,3,4,6-tetrachlorophenol, ng/L | 20 | 1,000 | | <MDL | |
| Pentachlorophenol, ng/L | 10 | 500 | 35 | <MDL | 22 |
| Dicamba, ng/L | 50 | 200,000 | | <MDL | |
| Bromoxynil, ng/L | 50 | | | <MDL | |
| 2,4-D-propionic acid, ng/L | 100 | | | <MDL | |
| 2,4-D, ng/L | 100 | 4,000 | | <MDL | 330 |
| Silvex, ng/L | 20 | | 57 | <MDL | 36 |
| 2,4,5-T, ng/L | 50 | 18,000 | | <MDL | |
| 2,4-DB, ng/L | 200 | | | <MDL | |
| Picloram, ng/L | 100 | | | <MDL | |
| Diclofop-methyl, ng/L | 100 | | | <MDL | |

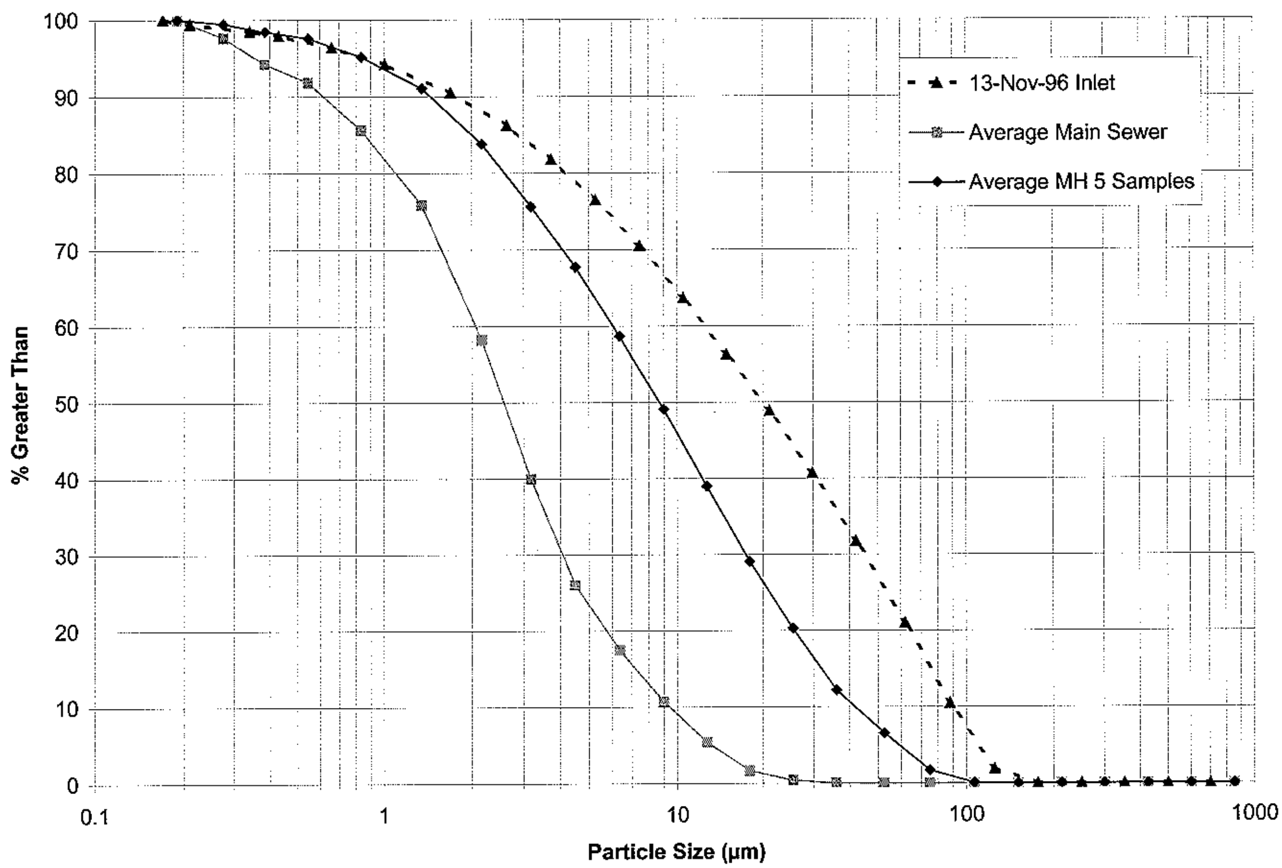


***Figure 5.7:*** Braecrest Avenue average particle size distributions

### 5.3.4 Summary – Discussion

The Braecrest Avenue infiltration system appears to have successfully contained and infiltrated a significant portion of the runoff generated from storm events larger than 15 mm. Field data suggest the infiltration capacity of the surrounding soil had been underestimated because storm events as large as 66.9 mm were found to generate very little flow in the drainage system. Although overflows directly from the catchbasins were observed during some snowmelt events, it is believed the overflows that occurred in the winter season could have been due to the clogging of the catchbasin leads as a result of freezing. Since the design concept of this filtration system is to provide treatment to the storm runoff and not to promote infiltration of runoff into the surrounding soils, this study site was considered unsuitable for the assessment of the design concept of the filtration system.

# 6.0 SUMMARY - DISCUSSION

## 6.1 Hydraulic Performance

Monitoring of the Princess Margaret Boulevard exfiltration site included both level and flow sensors at various times. However, the assessment of performance has been based primarily on level data that indicated when system overflow conditions occurred. The system was seen to have the capability of exfiltrating runoff from storms considerably in excess of the 15 mm design criterion. During the monitoring periods, 14 rainfall events exceeded 15 mm in depth but only three events caused system overflows. However, the exfiltration system was sensitive to the rate of runoff and to antecedent conditions. A prolonged rainfall of large volume would not likely cause overflow in the system, but could saturate the soil such that a subsequent event of less than 15 mm depth (but of greater intensity) may cause an overflow. One event with 15 mm of rainfall in one hour (approximating the design standard) caused a brief overflow because the maximum 5-minute rainfall depth was 10 mm. Low intensity storms with rain depths greater than 15 mm did not cause overflows, for example: 40 mm of rainfall over a period of 19 hours.

Runoff coefficients calculated for the Queen Mary's Drive exfiltration site indicate that the system was reducing the quantity of runoff substantially. The fact that some outlet flow occurred for events smaller than the 15 mm design rainfall can be attributed to the design of the system, which consisted of a combination of exfiltration sewers and conventional sewers, possibly in combination with the high groundwater table in the area. The hydraulic monitoring program was of limited duration and operational problems prevented the attainment of complete data sets and volumetric balances.

Monitoring of the Braecrest Avenue filtration site demonstrated that flows were less frequent and of lesser magnitude than would be expected for a filtration facility. The percolation capacity of the soils had apparently been underestimated. The local soils were reported to vary from silty clay to sandy loam, and one may speculate about the existence of areas having high percolation rates associated with the latter soil type.

## 6.2 Water Quality Data Comparison

Table 6.1 summarizes the average water quality data from the three sites.

Runoff quality data are generally not available because of the configuration of the exfiltration and filtration facilities. Such samples would have to be taken from the street surface or from within catchbasins, and sampling strategies had not been developed for those locations. In at least one case, some catchbasins drained directly to maintenance holes, rather than to the sewer pipes, and the catchbasin leads were accessible for sampling. One such sample was reported from the Braecrest site; the suspended solids concentration was found to be substantial (926 mg/L).

*Table 6.1:* Summary of water quality data

| Parameter & Units \ Location & Period | MDL | PWQO | Princess Margaret: Average - Summer | Princess Margaret: Average - Winter | Queen Mary's Drive: Main Pipe (winter/spring) | Queen Mary's Drive: MH25 Bottom (winter/spring) | Queen Mary's Drive: Groundwater (relief pipe) | Braecrest Avenue: Average Outlet, summer/fall period | Braecrest Avenue: Inlet Sample, 13/11/96 | Braecrest Avenue: Average Main Pipe, winter/spring period |
|---|---|---|---|---|---|---|---|---|---|---|
| **General Water Chemistry** | | | | | | | | | | |
| Suspended Solids mg/L | 2.5 | | 164.2 | 81.6 | 124.4 | 196.0 | 16.1 | 66.7 | 926.0 | 49.4 |
| Turbidity FTU | 0.01 | | 42.05 | 68.58 | 107.43 | 174.63 | 8.74 | 17.05 | 24.20 | 55.04 |
| pH | N/A | 6.5 - 8.5 | 7.59 | 7.67 | 7.5 | 7.8 | 7.8 | 7.67 | 7.76 | 7.64 |
| Alkalinity mg/l CaCO3 | 0.25 | | 76.29 | 63.06 | 49.00 | 119.40 | 184.33 | 49.47 | 82.40 | 51.20 |
| Chloride mg/L | 0.2 | | 62.7 | 975.9 | 1059.0 | 1600.3 | 367.9 | 20.1 | 8.4 | 1,678.3 |
| Conductivity μS/cm | 1 | | 422 | 3,037 | 3195.6 | 4955.0 | 1549.4 | 187 | 211 | 4,921 |
| **Nutrients** | | | | | | | | | | |
| Total Ammonium mg/L | 0.002 | | 0.350 | 0.293 | 1.751 | 2.829 | 0.177 | 0.057 | 0.042 | 0.379 |
| Nitrite mg/L | 0.001 | | 0.116 | 0.074 | 0.111 | 0.117 | 0.014 | 0.025 | 0.070 | 0.095 |
| Nitrate + nitrite mg/L | 0.005 | | 1.705 | 0.889 | 1.024 | 2.293 | 2.861 | 0.902 | 0.340 | 0.959 |
| Total Kjeldahl Nitrogen mg/L | 0.02 | | 3.04 | 1.30 | 4.14 | 7.19 | 0.77 | 0.74 | 3.38 | 1.75 |
| Total Phosphorus mg/L | 0.002 | 0.01 - 0.03 | 0.485 | 0.240 | 0.573 | 0.438 | 0.155 | 0.177 | 0.676 | 0.186 |
| Phosphate mg/L | 0.0005 | | 0.1423 | 0.0939 | 0.2134 | 0.1632 | 0.0739 | 0.0533 | 0.0795 | 0.1013 |
| **Organics** | | | | | | | | | | |
| Carbon, Dissolved Organic mg/L | 0.1 | | 8.7 | 3.4 | 7.2 | 10.7 | 2.5 | 2.3 | 8.0 | 3.2 |
| Solvent extractable mg/L | 1 | | 11.2 | 6.5 | 14.8 | 13.3 | 1.5 | 2.3 | 34.0 | 4.1 |
| **Inorganics** | | | | | | | | | | |
| Aluminum μg/L | 11 | 75 | 615 | 504 | 483 | 524 | 103 | 271 | 431 | 439 |
| Arsenic mg/L | 0.001 | 0.1 | 0.001 | 0.001 | 0.0016 | 0.0015 | | <MDL | <MDL | 0.001 |
| Barium μg/L | 0.2 | | 23.3 | 25.2 | 23.2 | 50.2 | 35.0 | 18.3 | 47.6 | 25.1 |
| Beryllium μg/L | 0.02 | | 0.06 | 0.04 | 0.03 | 0.05 | 0.01 | 0.03 | 0.08 | 0.03 |
| Cadmium μg/L | 0.6 | 0.2 | 0.8 | 0.5 | 0.5 | 0.5 | 0.3 | 0.9 | 0.7 | 0.3 |
| Calcium mg/L | 0.005 | | 42.900 | 48.511 | 52.100 | 105.767 | 86.978 | 25.400 | 94.000 | 39.743 |
| Carbon, Dissolved Inorganic mg/L | 0.2 | | 17.7 | 14.4 | 11.3 | 26.5 | 44.2 | 11.4 | 20.0 | 11.5 |
| Chromium μg/L | 1.4 | 8.9 as $Cr^{III}$ | 4.1 | 5.2 | 7.1 | 7.4 | 2.5 | 2.1 | 1.0 | 3.7 |
| Cobalt μg/L | 1.3 | 0.9 | 1.1 | 0.7 | 1.1 | 1.3 | 0.5 | 0.9 | 3.6 | 0.6 |
| Copper μg/L | 1.6 | 5 | 21.0 | 20.7 | 23.0 | 30.3 | 7.5 | 8.4 | 22.0 | 15.6 |
| Iron μg/L | 0.8 | 300 | 1009.1 | 848.8 | 909.4 | 996.3 | 177.2 | 619.7 | 599.0 | 600.1 |
| Lead μg/L | 10 | 25 | 16 | 21 | 35 | 36 | 4 | 10 | 17 | 13 |
| Magnesium mg/L | 0.008 | | 7.795 | 6.487 | 12.531 | 18.853 | 9.102 | 3.980 | 19.400 | 4.243 |
| Manganese μg/L | 0.2 | | 139.2 | 111.7 | 146.5 | 196.7 | 28.2 | 69.0 | 633.0 | 70.5 |
| Mercury μg/L | 0.02 | 0.2 | 0.03 | 13.44 | 0.03 | 0.03 | 2.90 | <MDL | <MDL | <MDL |
| Molybdenum μg/L | 1.6 | 40 | 0.3 | 0.1 | 0.2 | 0.3 | 0.3 | 0.1 | <MDL | 0.0 |
| Nickel μg/L | 1.3 | 25 | 3.0 | 2.1 | 2.2 | 2.7 | 0.8 | 1.3 | 4.8 | 1.8 |
| Selenium mg/L | 0.001 | 0.1 | | | <MDL | <MDL | 0.001 | <MDL | <MDL | <MDL |
| Silicon mg/L | 0.02 | | 1.57 | 0.85 | 0.46 | 1.45 | 2.60 | 0.87 | 1.58 | 0.71 |
| Strontium μg/L | 0.1 | | 142.1 | 315.3 | 315.0 | 464.0 | 242.9 | 56.4 | 205.0 | 302.3 |
| Titanium μg/L | 0.5 | | 9.6 | 5.4 | 4.8 | 2.7 | 2.0 | 2.5 | 2.0 | 3.9 |
| Vanadium μg/L | 1.5 | 6 | 4.1 | 2.5 | 2.0 | 2.5 | 0.6 | 1.3 | 1.9 | 1.8 |
| Zinc μg/L | 0.6 | 30 | 129.3 | 116.0 | 114.1 | 129.9 | 29.9 | 43.3 | 212.0 | 74.0 |
| **Bacteria** | | | | | | | | | | |
| Escherichia coli c/100mL | N/A | 100 | 2,088 | 62 | 3,588 | 1,530 | 3,690 | 1,900 | | 312 |
| Fecal streptococcus c/100mL | N/A | | 23,785 | 4,627 | 9,360 | 4,900 | 11,794 | 500 | | 1,066 |
| Pseudomonas aeruginosa c/100mL | N/A | | 1,554 | 16 | 13 | 20 | 16 | 136 | | 21 |
| **Organics** | | | | | | | | | | |
| 2,4-dichlorophenol, ng/L | 2,000 | 4,000 | | | | | | | <MDL | |
| 2,4,6-trichlorophenol, ng/L | 20 | 18,000 | | | | | | | <MDL | 45 |
| 2,4,5-trichlorophenol, ng/L | 100 | 18,000 | | | | | | | <MDL | |
| 2,3,4-trichlorophenol, ng/L | 100 | 18,000 | | | | | | | <MDL | |
| 2,3,4,5-tetrachlorophenol, ng/L | 20 | 1,000 | | | | | | | <MDL | |
| 2,3,4,6-tetrachlorophenol, ng/L | 20 | 1,000 | | | | | | | <MDL | |
| Pentachlorophenol, ng/L | 10 | 500 | 17 | 14 | 63 | 65 | 39 | 35 | <MDL | 22 |
| Dicamba, ng/L | 50 | 200,000 | 203 | 64 | | | | | <MDL | |
| Bromoxynil, ng/L | 50 | | | | | | | | <MDL | |
| 2,4-D-propionic acid, ng/L | 100 | | | | | | | | <MDL | |
| 2,4-D, ng/L | 100 | 4,000 | 3,380 | 188 | 167 | 220 | | | <MDL | 330 |
| Silvex, ng/L | 20 | | | | 42 | | | 57 | <MDL | 36 |
| 2,4,5-T, ng/L | 50 | 18,000 | | | | | | | <MDL | |
| 2,4-DB, ng/L | 200 | | | | | | | | <MDL | |
| Picloram, ng/L | 100 | | | | | | | | <MDL | |
| Diclofop-methyl, ng/L | 100 | | | | | | | | <MDL | |

Two sites, Princess Margaret and Braecrest, provided comparisons between outlet water quality during the summer/fall and winter/spring monitoring periods. However, the summer and winter sampling locations were different in the case of the Braecrest site. At both sites, the TSS concentrations were less in winter than in summer, but the turbidities were greater in winter. Reduced average particle sizes in winter at both sites help to explain the TSS-turbidity relationship. Also at both sites, the chloride concentrations and conductivity were substantially increased in winter because of road salt applications. The concentrations of organic material - measured as dissolved organic carbon and solvent extractables - were less in winter than in summer. The concentrations of inorganic constituents increased or decreased with no specific patterns evident. At the Princess Margaret site the concentrations of nutrients decreased from summer to winter. At the Braecrest site, the opposite trend in nutrient concentrations was observed. A number of factors could have contributed to the latter case, including a leaking sanitary sewer, rodents in the storm sewer, or seepage from old septic systems. However, only one of the three bacteria species increased in concentration, so that evidence of fecal contamination remained inconclusive.

The data obtained from the system outlets and the groundwater (relief pipe samples) provide a valuable baseline from which long-term performance may be assessed after subsequent sampling programs.

## 6.3 Design Considerations - Capacity

The Etobicoke exfiltration and filtration systems were designed to accommodate a 15 mm, 1-hour storm event. In this section, simple capacity calculations are used to approximate the storage capacity of the exfiltration system. The original design calculations were not reviewed as part of the SWAMP study. A subsequent draft report describing the development of a numerical simulation program (Smith, 1999) was examined.

The geometry of the exfiltration and filtration systems is complex because of the slope of the gravel bed and the pipes, and because the pipes occupy space in the gravel bed. The storage capacity of the exfiltration system can be approximated by making simplifying assumptions:

- consider a 1-metre length of sewer with the water depth limited by the invert of the main sewer pipe (i.e., applies to the upstream end of the trench or to a level trench),
- assume a main sewer pipe of 500 mm outside diameter (i.e., set the trench width at 2.60 m),
- assume a road right-of-way width of 10 m and lot depths of 35 m on each side of the road,
- assume a gravel bed void ratio of 0.4 (assumes uniform grain size),
- assume a runoff coefficient of 0.4 for the tributary area.

Per linear metre of sewer, the 15 mm rainfall would be expected to produce 0.48 $m^3$ of runoff. Also per linear metre and using the dimensions given in Figure 2.1, the storage capacity of the gravel bed plus perforated pipes is 0.68 $m^3$. Therefore, the system has approximately 1.4 times the storage capacity needed to accommodate the runoff. If the gravel is not mono-sized the void ratio would be less, perhaps 0.3 rather than 0.4, but the slope of the trench would also provide downstream storage that is situated above the main sewer pipe invert elevation. Also, percolation into the surrounding soils would be removing some of the runoff volume continuously. These additional factors would at least balance each other, if not provide greater effective storage capacity. These calculations support the hypothesis that the capacity limitations seen in the monitoring data result from flow rate restrictions and not from storage capacity.

Another characteristic that may be of interest is the ratio of tributary area to pipe length, or the number of square metres drained by each metre of pipe. These values are summarized in Table 6.2 for three Etobicoke sites and the hypothetical case above. The hypothetical case was intended to represent a local residential street. Although Queen Mary's Drive has a wider road allowance, the area immediately adjacent to the sewer system provides a similar area-to-length ratio. The west portion of the Princess Margaret site is also similar but presumably has a slightly wider road allowance (as a local collector street) and deeper lots. The east portion of the Princess Margaret site includes a school and park and, although the ratio of tributary area to sewer length is greater, the average runoff coefficient would be reduced.

***Table 6.2:*** Tributary areas per unit length of sewer

| Site or test case | Sewer Length (m) | Tributary area ($m^2$) | Area/length ratio |
|---|---|---|---|
| Hypothetical case (10 m road allowance, 35 m lot depth) | 1 | 80 | 80 |
| Princess Margaret – Princess Anne (total site) | ≈ 1,300 | $30.5 \times 10^4$ | ≈ 235 |
| Princess Margaret – Princess Anne (east portion) | ≈ 885 | $26.7 \times 10^4$ | ≈ 302 |
| Princess Margaret (west portion – test site) | 415 | $3.8 \times 10^4$ | 92 |
| Queen Mary's Drive – total tributary area | 443 | $13.3 \times 10^4$ | 300 |
| Queen Mary's Drive – adjacent to exfiltration sewer | 443 | $3.7 \times 10^4$ | 84 |
| Braecrest | 209 | $2.4 \times 10^4$ | 115 |

The draft report on numerical simulation by Smith (1999) described changes made to the stormwater runoff simulator MIDUSS 98 to accommodate the exfiltration system. Algorithms were developed to represent the hydraulic gradient through the sloping pipe and gravel bed system. However, some problems of numerical instability were encountered and the data used for model fitting (Candáras Associates, 1997) were lacking in some respects. The report recommended that additional data be obtained from future monitoring.

## 6.4 Design Considerations - Exfiltration System

The exfiltration system has been shown to be limited by its throughput capacity. Consequently, the gravel bed is being under-utilized and overflows can occur during events of less volume than the design storm. The hydraulic limitation may be the result of inlet conditions, or the inability of the gravel bed to displace air when filling, or both factors.

The gravel bed extends 300 mm above the sewer pipe. Depending on the slope of the pipes and gravel bed, any gravel appreciably above the invert of the sewer would be of little use for the storage of runoff, since the system would have to be surcharged for water to reach above the sewer pipe obvert and few storm events would fill the pipe. Much of the gravel therefore serves as air space to adsorb the air displaced by the runoff.

Several options may be considered:

- increase the diameter of the perforated exfiltration pipes, for a least a few metres downstream of each maintenance hole, to minimize inlet headloss,
- provide one or two vent pipes in the upper portion of the gravel bed to facilitate displacement of the air as the runoff enters the bed from below,
- employ a porous or perforated section in the maintenance hole itself, with geotextile wrapping, such that water in the maintenance hole can flow into the gravel bed with little associated headloss (may also work for air venting),
- do not install granular material any higher than the top of the sewer pipe (adjusted as appropriate for venting, the slope of the trench and construction methods).

Figure 6.1 is a schematic diagram illustrating these options. A further option may be to employ precast rectangular sections for the maintenance hole. A flat wall would facilitate multiple pipe connections and the creation of porous areas.

Both the inlet headloss and the potential air locking problem could be checked theoretically, but the construction of an experimental section of sewer would be advisable before a revised design is recommended for general use. A test section could be created in a hydraulic laboratory or constructed on public property in some location where intensive monitoring and modification would be feasible.

Hydrographs for two events at the Princess Margaret site (Figures F.20 and F.21, Appendix F) have indicated that water in the gravel bed may be migrating to the downstream end of the system and exiting as a delayed overflow. In future systems, consideration should be given to the inclusion of flow barriers at strategic locations to make optimum use of the storage capacity of the gravel bed. An alternative design might consist of lengths of conventional sewer interspersed throughout the exfiltration sewer system.

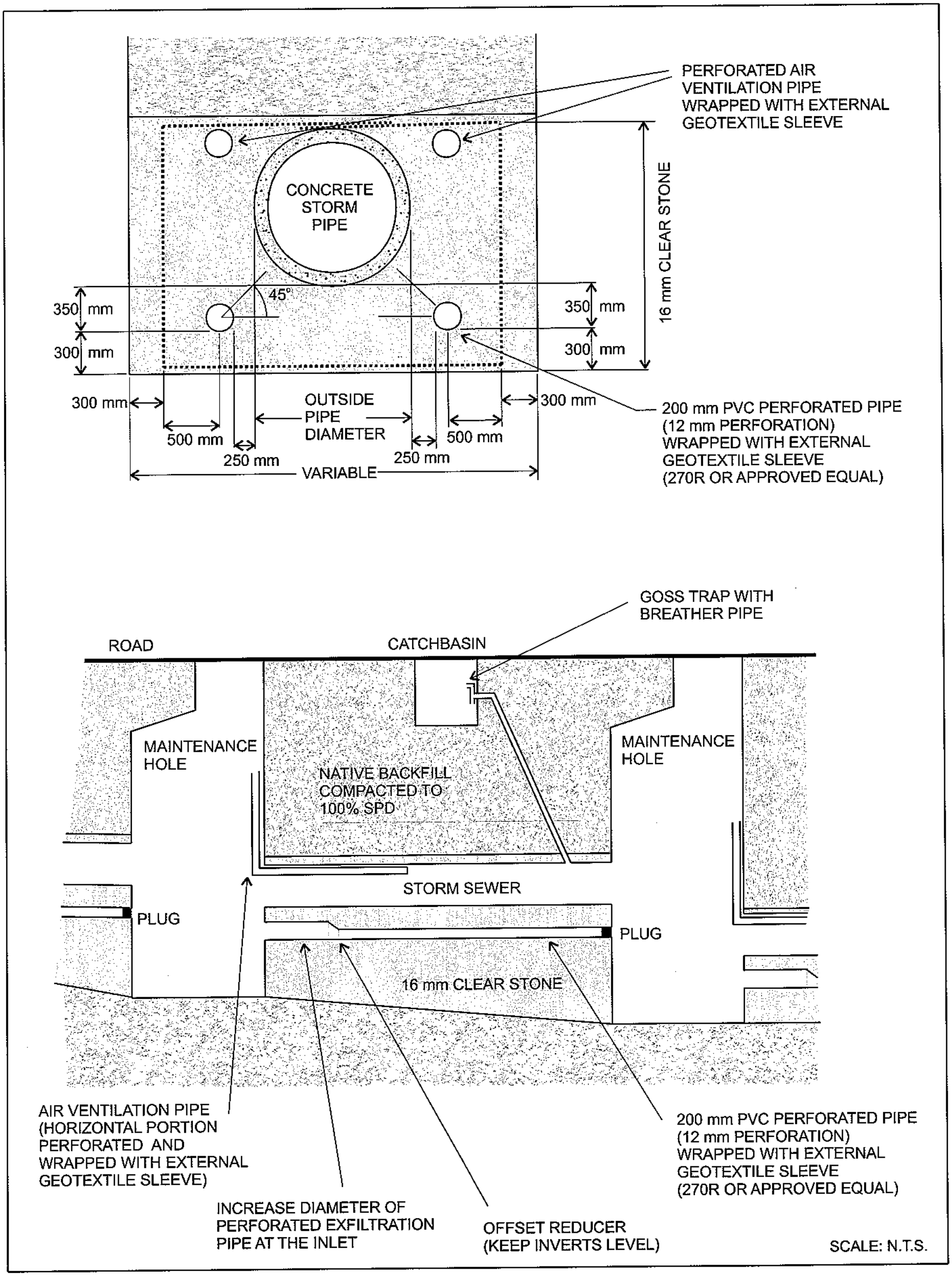


***Figure 6.1:*** Exfiltration system -- suggested revisions

## 6.5 Design Considerations - Filtration System

Unlike the exfiltration system, the upper portion of gravel bed in the filtration system is open to the atmosphere, being vented through the catchbasin leads. The hydraulic tests indicated that up to 15 L/s could be processed through the system. However, the filter bed throughput decreased when overflow occurred. The design of the goss traps should be examined to determine if air entrapment or other hydraulic phenomena may be a problem under some circumstances.

## 6.6 Monitoring Considerations

Monitoring of conveyance-based control facilities is limited by the diffuse nature of the influent. In this study, no raw influent samples were collected and those samples representing influent were actually catchbasin effluent samples. Stormwater monitoring practices would be enhanced by the development of a runoff sampling method. For example, a trailer-mounted facility could be parked on a street and could draw samples from the gutter or catchbasin, or a bucket-type sampler could be developed for use in a catchbasin.

Measurement of the water depth in the gravel trench was included in the earlier study (Candaras Associates, 1997) by insertion of pressure transducers into the gravel through the walls of the maintenance holes. Some of the resulting data were difficult to interpret and, as stated in the report by Smith (1999), the installation method created some uncertainty about the positions of the sensors relative to the trench bottom. In future demonstration projects, piezometers should be included in the design to provide continuous records of the water depths at various locations.

In this study, groundwater monitoring could be undertaken at the Queen Mary's Drive site because a relief pipe had been included in the last maintenance hole. In future demonstration projects, sampling wells should be provided to facilitate sampling of the water in the gravel trench and sampling of the groundwater at various depths and distances from the exfiltration site.

## 6.7 Design Strategy – Water Quality Control

The Etobicoke exfiltration system was designed primarily to minimize the hydraulic impact of urban runoff. The system removes contaminants to the extent that they are trapped in the catchbasins, maintenance holes and perforated pipes. Contaminants are also assumed to be removed by filtration and sorptive processes in the gravel and in the surrounding soil, and some contaminants will be degraded by bacteria in the soil. However, the designers recognized that contaminants would eventually migrate down through the soil to the water table; they specified that the exfiltration system was not intended for use where groundwater is used for water supply. With regard to the fate of pollutants, the Etobicoke exfiltration system is similar to other exfiltration designs and to most (i.e., unlined) stormwater ponds.

Site specific concerns and long-term strategies for pollution control may lead to alternative designs. The dual goals are to allow much of the runoff to percolate into the soil and to contain the pollutants such that they may be destroyed or disposed of at an appropriate site. In most cases, additional research will be necessary to test the feasibility of some of the concepts. For exfiltration systems, the options include the use of beds of natural adsorbent and ion exchange materials in addition to filtration materials, and location of the exfiltration trench where it can eventually be excavated and the materials replenished.

The Etobicoke filtration system could be employed in areas where groundwater quality protection is required if the trench were lined with an impervious membrane rather than filter cloth. Groundwater recharge would be prevented but the system would have all of the flow regulation properties intended by the original design.

## 6.8 Maintenance and Longevity Considerations

The Etobicoke exfiltration and filtration systems require periodic cleaning. The frequency of cleaning can not be determined from the monitoring data available to date and will be a function of other municipal practices. If street sanding is minimized in winter, if street sweeping is undertaken frequently, and if catchbasin cleaning is undertaken frequently the need for underground maintenance will be minimized. Underground maintenance consists of the removal of the plugs from the perforated pipes and flushing of the retained sediment into the downstream maintenance hole from where it may be removed by vacuum truck.

The exfiltration and filtration systems were designed using standard construction materials to minimize cost. One possible weakness of the designs is the use of a filter fabric on the outside of the perforated pipes. Fine particles may clog the fabric, and flushing of the pipes may not cause enough turbulence to dislodge those particles. An alternative failure mode may be filling of the void spaces in the gravel by fine particles. Data available to date do not support estimates of the life span of the systems, and the life span will be influenced by the amount of effort applied to routine maintenance.

# 7.0 CONCLUSIONS & RECOMMENDATIONS

## 7.1 Conclusions

1. The Princess Margaret Boulevard exfiltration facility is a good example of an in-street exfiltration system design. Monitoring results have demonstrated that it can exfiltrate all runoff from storms greater than the nominal 15 mm of rainfall, providing that antecedent conditions are dry and that storm intensity is not excessive. Because of limited sample availability, the water quality results did not indicate performance but they are representative of storm sewer effluent quality.

2. The Queen Mary's Drive exfiltration facility is a poor example of an in-street exfiltration system because it receives flow from adjacent conventional sewers and because the groundwater table in the area is relatively high. However, runoff coefficients for the facility indicated that it was exfiltrating a substantial portion of the runoff. Water quality data show that stormwater exiting the system is cleaner (for most constituents) than a mixture of system effluent, conventional sewer effluent and groundwater, but raw runoff samples were not obtained in the study and removal efficiencies can not be determined.

3. The Braecrest Avenue filtration facility was shown to have greater exfiltration capacity than anticipated. A limited water quality database indicated that the filtration system effluent was cleaner than the system influent (catchbasin outflow) for most constituents.

4. This study has provided a preliminary assessment of three stormwater management installations. It has highlighted monitoring constraints associated with such systems and has explored some innovative monitoring methods. Because of the long-term nature of exfiltration and filtration mechanisms, subsequent studies will be required to produce a definitive assessment of performance.

## 7.2 Recommendations

*Site selection:*

- When a site is being examined for possible installation of an exfiltration or filtration system, emphasis should be placed on obtaining accurate information on groundwater conditions and soil types in the areas by taking borehole samples and by performing in-situ percolation tests.

*Monitoring programs:*

- Increased emphasis should be placed on the collection of upstream and downstream samples to determine the removal efficiency of the systems. Flow monitoring may be limited by access problems, shallow flow depths and intermittent flow, but should be undertaken as thoroughly as possible to facilitate the calculation of volumetric and mass balances for the systems.

- Future monitoring sites should also include piezometers and sampling wells for the monitoring of system impacts on groundwater quality. Such data should be assessed noting that the potential transmission of some pollutants through the soil, to the groundwater and subsequently to local streams and lakes is within the scope of the designs, and is preferable to the immediate discharge of all of the pollutants directly to the local watercourses. The systems were designed for use where groundwater is not used as a water source.
- Hydraulic tests of the system - using a controlled and monitored flow from a fire hydrant - provide useful data for evaluating system design. Repeating the tests at approximately 4 to 5 year intervals would allow for the measurement of any change in hydraulic conductivity.

*Maintenance:*

- Closed-circuit television (CCTV) inspection of the perforated pipes is recommended at 5-year intervals to monitor sediment accumulation. Pipe flushing and maintenance hole clean out should be performed if the CCTV inspection finds significant accumulations. Routine catchbasin cleaning should also be emphasized as a means of limiting the requirement for underground maintenance operations.
- When exfiltration pipes are cleaned out manually during regular maintenance, a measurement of the mass of accumulated sediments should be performed in order to determine the correct maintenance interval.

*Design aspects:*

- Alternative designs of the exfiltration system should be examined to overcome the throughput limitation that causes overflow to occur before the gravel bed is fully utilized. Possible remedies include the installation of air ventilation pipes and the use of increased pipe diameters at the inlets of the perforated pipes.
- Future exfiltration systems should include barriers to the migration of water through the gravel bed toward the downstream end of the system.
- Numerical simulation may be an effective design method for exfiltration and filtration systems. Further model development work should be undertaken after additional data have been acquired from future monitoring work.
- Alternative designs should be considered for application in locations where groundwater contamination is, or will be, of greater concern. Options include the use of adsorbent and ion exchange materials in exfiltration trenches, and the location of the trenches in boulevards were they may be more readily excavated for servicing. Filtration systems may be designed with impervious trench linings to prevent percolation of the runoff into the soil.

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# APPENDIX A

# Historical Context of the SWAMP Program

# HISTORICAL CONTEXT OF THE SWAMP PROGRAM

In the latter part of the 20th century, the Great Lakes Basin experienced rapid urban growth. Stormwater runoff associated with this growth has been identified as a major contributor to the degradation of water quality and the destruction of fish habitats. In response to these concerns, a variety of stormwater management programs have been developed in the Great Lakes basin.

A number of complementary programs have been established at the international, national, provincial and municipal levels to protect the Great Lakes ecosystem. The SWAMP program and the study that is the subject of this report are parts of the overall effort.

## International Joint Commission

The International Joint Commission (IJC) prevents and resolves disputes between the United States of America and Canada under the Boundary Waters Treaty of 1909. The IJC pursues the common good of both countries as an independent and objective advisor of the two governments.

In particular, the IJC rules upon applications for approval of projects affecting boundary or transboundary waters and may regulate the operation of these projects; it assists the two countries in the protection of the transboundary environment. Among the responsibilities of the IJC is the implementation of the Great Lakes Water Quality Agreement.

## Great Lakes Water Quality Agreement

The first Great Lakes Water Quality Agreement (GLWQA) between Canada and the United States was signed in 1972 in recognition of the urgent need to improve environmental conditions in the Great Lakes. The focus of the agreement was to improve water quality through pollution control programs. Objectives included the reduction of nuisance conditions and control of toxic substances. Specific numerical targets were included for the reduction of phosphorus loadings.

The Great Lakes Water Quality Agreement was amended in 1978 to include the objective of controlling persistent toxic substances. The new agreement also incorporated the ecosystem approach to environmental management.

In 1987, the Canadian and U.S. governments signed a protocol that identified local Areas of Concern (AOC's) where beneficial uses of the ecosystem had been significantly degraded. Remedial Action Plans (RAP's) were to be prepared by various levels of government for the AOC's. The plans would contain strategies to clean up problem areas in the Great Lakes region. In addition, the 1987 protocol included annexes addressing specific subjects such as non-point contaminant sources and contaminated sediments.

In total, 43 Areas of Concern were identified throughout the Great Lakes basin. Of the total, 17 AOC's were in Canada.

## Great Lakes Sustainability Fund

The Canadian federal government's commitment to the Great Lakes ecosystem was initially managed through the Great Lakes Action Plan (GLAP). In 1990, the Great Lakes Cleanup Fund (GLCuF) was created to provide support for environmental projects designed to benefit the Great Lakes basin ecosystem.

In 1994, GLAP was replaced by the Great Lakes 2000 Program. GLCuF was extended and renamed the Great Lakes 2000 Cleanup Fund. In 2000, the Great Lakes Basin 2020 Action Plan was introduced in addition to the successor to the GLCuF, the Great Lakes Sustainability Fund (GLSF). The new plan and fund place priority on the restoration of environmental quality in Canada's remaining 16 Areas of Concern.

The GLSF supports the implementation of remedial actions falling within federal responsibilities that will lead to the restoration of beneficial uses in the Canadian Great Lakes Areas of Concern. The five-year, $30 million GLSF builds on past successes and is administered by Environment Canada on behalf of eight Government of Canada departments.

To restore these beneficial uses in the Great Lakes Areas of Concern, joint Canada-Ontario teams work in consultation with local Public Advisory Committees to develop Remedial Action Plans (RAPs) aimed at eliminating or reducing the major sources of contamination in these areas. When all beneficial uses in an AOC have been restored, the area is delisted. The RAPs have had some important successes. Collingwood Harbour was delisted in 1994, and Spanish Harbour was designated an Area of Recovery in 1999.

## Canada – Ontario Agreement

Canada and Ontario have had Great Lakes environmental agreements in effect since 1971. The latest version of the Canada-Ontario Agreement Respecting the Great Lakes Basin Ecosystem (COA) was signed in June, 2002. The agreement provides the framework for systematic and strategic coordination of shared federal and provincial responsibilities for environmental management in the Great Lakes basin. The main objectives are to restore degraded areas, to prevent and control pollution, and to conserve and protect human and ecosystem health.

## Ontario Ministry of the Environment

The Ontario Ministry of the Environment (OMOE) manages a number of programs that contribute to the protection and clean-up of the Great Lakes basin. The Provincial Water Protection Fund assists municipalities to address water and sewage treatment problems and to undertake related studies. The Ontario Great Lakes Renewal Foundation, established in 1998, provides seed money to support local projects that include habitat restoration and stormwater management. The OMOE works in partnership with federal and state agencies and municipal governments to achieve numerous environmental goals; the Great Lakes Remedial Action Plans have been a prominent example of such work.

## Toronto and Region Conservation Authority

The Toronto and Region Conservation Authority (TRCA) is one of 38 conservation authorities in Ontario that develop and implement programs for the management of water and natural resources on a watershed basis. Conservation authorities are created and given their mandate under the Conservation Authorities Act and involve a partnership of the municipalilties within a watershed and the Province of Ontario. The TRCA jurisdiction includes nine watersheds in the Toronto Region.

The TRCA and the Waterfront Regeneration Trust are the local coordinating agencies for the Toronto and Region Remedial Action Plan. The two agencies help the provincial and federal governments fulfill their obligations under the Great Lakes Water Quality Agreement and the Canada-Ontario Agreement. The TRCA's general RAP role is to focus implementation activities on an individual watershed basis and provide technical expertise to its implementation partners. Stormwater management and the remediation of combined sewer overflows are integral to the restoration of the Toronto and Region Area of Concern.

## SWAMP

In 1995, the Storm Water Assessment Monitoring and Performance Program (SWAMP) was created as a cooperative initiative of agencies interested in monitoring and evaluating the performance of various stormwater management technologies. The SWAMP program acts as a vehicle whereby federal, provincial, municipal and other interested agencies can pool their resources in support of shared research interests.

The objective of SWAMP is to collect data and report on the performance of stormwater treatment facilities. SWAMP is supported by the Great Lakes Sustainability Fund, the Ontario Ministry of the Environment, the Toronto and Region Conservation Authority, the Municipal Engineers Association, a number of individual municipalities in Great Lakes Areas of Concern, and other owner/operator agencies.

A variety of stormwater management technologies have been developed to mitigate the impacts of urbanization on the natural environment. Prior to the creation of SWAMP, these technologies had been studied using computer models and pilot-scale testing, but had not undergone extensive field-level evaluation in southern Ontario.

The objectives of the SWAMP Program are:

- to monitor and evaluate the effectiveness of new or innovative stormwater management technologies,
- to disseminate study results and recommendations within the stormwater management community.

Technologies that have been addressed by the SWAMP program include:

- wet ponds and constructed wetlands,
- underground storage tanks,
- flow balancing systems,
- oil and grit separators,
- conveyance exfiltration systems.

A number of people have been part of the SWAMP team since the inception of the program. In alphabetical order, the staff members have been:

| | |
|---|---|
| David Averill | Program Co-ordinator [July 2001 to May 2003] |
| David Fellowes | |
| Rene Gagnon | |
| Dajana Grgic | |
| Weng Liang | Program Co-ordinator [1995 to 2000] |
| Serge Ristic | |
| Derek Smith | |
| Sheldon Smith | |
| William Snodgrass | Program Co-ordinator [December 2000 to June 2001] |
| Michael Thompson | |
| Tim Van Seters | |

In addition, several student employees contributed to the success of the projects. Staff of the Ontario Ministry of the Environment, Standards Development Branch, provided administrative and facility support. In addition, Standards Development Branch staff have contributed their technical expertise through informal advice and review of draft reports.

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# APPENDIX B

# Glossary

# GLOSSARY

**adsorption:** The adhesion of a liquid, gaseous or dissolved substance to a solid, resulting in a higher concentration of the substance (Raven *et al.*, 1992).

**best management practice (BMP):** A device, practice, or method for removing, reducing, retarding, or preventing targeted stormwater runoff constituents, pollutants, and contaminants from reaching receiving waters (ASCE, 1999).

**catchment:** That area determined by topographic features within which falling rain will contribute to runoff to a particular point under consideration. The area tributary to a lake, stream, sewer or drain. See also drainage area, drainage basin, river basin, catchment area, watershed (James and James, 2000).

**evapotranspiration:** The combined processes of evaporation from the water or soil surface and transpiration of water by plants (IWA, 2000).

**filtration:** The separation of a fluid-solids mixture involving the passage of most of the fluid through a porous barrier which retains most of the solid particles contained in the mixture (Perry, et al., 1984)

**geotextile:** A woven or nonwoven fabric manufactured from synthetic fibres or yarns that is designed to serve as a continuous membrane between soil and aggregate in a variety of earth structures.

**glacial till:** Unsorted and unstratified drift consisting of a heterogeneous mixture of clay, sand, gravel and boulders which is deposited by and underneath a glacier (Parker, 1989).

**groundwater recharge:** Replenishment of groundwater naturally by precipitation or runoff or artificially by spreading or injection (James and James, 2000).

**groundwater table:** The upper surface of groundwater, or the surface below which the pores of rock or soil are saturated (James and James, 2000).

**hydraulic conductivity:** The rate of water flow through a cross section under a unit hydraulic gradient (Parker, 1989).

**hydrograph:** A graph showing, for a given point on a stream or conduit, the discharge, stage, velocity, available power, or other property of water with respect to time (James and James, 2000)

**hyetograph:** A graphical representation of the variation in rate of rainfall over time (James and James, 2000).

**infiltration rate:** The rate at which water enters the soil or other porous material under a given condition (James and James, 2000) (also see hydraulic conductivity and permeability)

**invert:** The lowest point on the inside wall of an essentially horizontal pipe, at any given position along the length of the pipe.

**mass balance:** An accounting for all identified materials entering, leaving, or accumulating within a defined region.

**obvert:** The highest point on the inside wall of an essentially horizontal pipe, at any given position along the length of the pipe.

**peak discharge:** The maximum instantaneous flow at a specific location resulting from a given storm condition (James and James, 2000).

**peak-shaving:** Reduction of peak discharge rates by providing temporary detention in a BMP. Also called peak flow attenuation (adapted from James and James, 2000).

**percolation:** The downward flow of water through the pore spaces of soil, due to gravity.

**performance:** A measure of how well a BMP meets its goals for stormwater that the BMP is designed to treat. (ASCE, 1999)

**permeability (of soil):** property of soil which governs the rate at which water moves through it (James and James, 2000) (also see infiltration rate and hydraulic conductivity)

**porosity:** The fraction of a solid, as a percent of its total volume, occupied by minute channels or open spaces (Parker, 1989).

**removal efficiency:** A percentage reduction in a specific contaminant or constituent of the wastewater or runoff, as measured across a treatment system or an individual treatment unit.

**runoff:** That part of the precipitation which runs off the surface of a drainage area and reaches a stream or other body of water or a drain or sewer (James and James, 2000).

**runoff coefficient:** The ratio of the depth of runoff from the drainage basin to the depth of rainfall (James and James, 2000)

**transpiration:** The transport of water vapour from the soil to the atmosphere through actively growing plants (IWA, 2000).

**watercourse**: A natural or artificial channel for passage of water (James and James, 2000).

**watershed:** A topographically defined area drained by a river or a stream or a system of connecting rivers and streams such that all outflow is discharged through a single outlet (James and James, 2000).

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# APPENDIX C

# Sampling and Analytical Procedures

# SAMPLING AND ANALYTICAL PROCEDURES

## C.1 Sampling and Flow Monitoring

At some locations, samples of storm sewer pipe effluent were collected by placing a bucket in the maintenance hole beneath the pipe. A slit was cut in the bucket lid to extract a portion of the flow exiting the sewer pipe. This procedure was adopted because the flows were intermittent and the liquid depth in the pipe was often too shallow to facilitate conventional flow detection and sample extraction methods. The bucket would be expected to capture the first flush of the runoff and - relative to grab samples that are taken when staff can reach the site - would tend to produce samples with greater pollutant concentrations. Ideally, the buckets would be retrieved as soon after the start of the event as possible. However, if the bucket remained in place throughout the event, the potential effect on the sample is not clear. Dilution of the first flush sample by flows later in the event is possible, as soluble pollutants and light suspended particles are flushed out of the bucket. Simultaneously, heavier particles may tend to be preferentially captured, increasing the suspended solids concentration and average particle size of the sample.

## C.2 Analytical

Samples were analyzed by the Ontario Ministry of the Environment using their standard procedures. Table C.1 contains the OMOE method codes and brief summaries of each procedure.

***Table C.1:*** Analytical procedures employed in the Etobicoke exfiltration/filtration study

| Method Number | Product Number | Constituent | Procedure | Comments |
|---|---|---|---|---|
| E3016A | CL3016 | Chloride | Colourimetry following two-stage reaction with mercuric thiocyanate and ferric iron | interferences from bromide, iodide, sulphide, cyanide, thiosulphate |
| E3060B | HG3060 | Mercury | Cold vapour flameless atomic adsorption spectrophotometry (CV-FAAS) at 253.7 nm following acid digestion and reduction with stannus chloride solution | method is suitable for "clean" waters |
| E3089A | ASSE3089 | Arsenic, Selenium | Flameless atomic adsorption spectroscopy (FAAS) following acid digestion and hydride generation | |
| E3119A | CPA3119 | Chlorophenols and phenoxyacid herbicides | Solid phase extraction (SPE) using pre-conditioned $C_{18}$ cartridges followed by elutriation with solvent, treatment with diazomethane and analysis gas chromatography with electron capture detectors (GC-ECD) | 16 compounds |
| E3188B | TSD3188 | Total, Suspended and Dissolved Solids | Suspended solids are determined as the material removed from suspension by a 1.5 to 2.0 $\mu$m glass fibre filter, after drying at 103° ±2°C. Dissolved solids is the material that remains in solution after suspended solids are filtered out, as determined by evaporating to dryness at 103±2°C. Total solids is the sum of suspended and dissolved solids. | This method was employed beginning October 2, 1997. See method E3365 for earlier samples. |
| E3201B | SXT3201 | Organic Solvent Extractable Matter | Liquid-liquid extraction using dichloromethane as the extraction solvent. | includes non-volatile petroleum hydrocarbons, vegetable oils, animal fats, soaps, greases and waxes |
| E3289A | PHALCO 3289 | Conductivity, pH, Alkalinity | Automated system using electrodes in a constant temperature bath for conductivity, a calibrated potentiometric system for pH and titration for TFE alkalinity (to an end-point of pH 4.5) | Supernatant or filtrate is analyzed. Gran alkalinity by special request only |
| E3311A | TURB3311 | Turbidity | Measurement of light scattering at 90° ±30° by nephelometry calibrated to Formazin turbidity standards | |
| E3328A | PART3328 | Particle size | Optical – laser light diffraction (Coulter LS130 Particle Size Analyzer) | 0.1to 900 $\mu$m in 27 size channels. Reported as % by volume (no count data) |

| | | | | |
|---|---|---|---|---|
| E3364A | DISNUT<br>3364 | Dissolved nutrients:<br>ammonia + ammonium<br>nitrite<br>nitrate + nitrite<br>phosphate | Simultaneous, automated analysis of one aliquot of sample:<br>- ammonia by conversion to indophenol blue with sodium nitroprusside as a catalyst<br>- nitrite by colourimetric method after reaction with sulphanilamide and N(1-napthyl) ethylenediamine dihydrochloride<br>- nitrate + nitrite by colourimetric method following conversion of nitrate to nitrite<br>- phosphorus, as orthophosphate, by colourimetric method following reaction with ascorbic acid | |
| E3365A | SS3365 | Suspended Solids | Suspended solids are determined as the material removed from suspension by a 1.5 to 2.0 $\mu$m glass fibre filter, after drying at 103° ±2°C. | |
| E3367A | TOTNUT<br>3367 | Total nutrients:<br>total P<br>TKN | Total P: digestion in sulphuric acid, mercuric oxice, potassium sulphate media followed by reduction with ascorbic acid – measured a orthophosphate<br>Total Kjeldahl Nitrogen: digestion with Kjeldahl's reagent, neutralization and analysis for ammonia species by colourimetry | |
| E3370A | DCSI3370 | Silicon: reactive silicate<br>Dissolved organic carbon<br>Dissolved inorganic carbon | Molybdate reactive silicates: dissolved reactive silicate ions are measured through the formation of molybdenum heteropoly blue complex<br>Dissolved inorganic carbon (+ carbon dioxide) are measured by acidifying the sample supernatant, extracting the $CO_2$ through a dialysis membrane and reacting it with phenolphthalein and colourimetric measurement<br>Organic carbon is measured in the sample supernatant by acidification followed by nitrogen flushing to remove inorganic carbon and UV digestion in an acid-persulphate medium. The resulting $CO_2$ is analyzed as above. | |
| E3371A | ECFSPS<br>3371 | *Escherichia coli*<br>*Fecal streptococcus*<br>*Pseudomonas aeruginosa* | Membrane filtration procedures are used to recover and enumerate several bacteria or bacterial groups. The culture media, incubation temperatures and incubation periods are specific to each bacterial analyte. | |
| E3386A | MET3386 | Metals | Inductively coupled plasma (ICP) following ultrasonic nebulizer | Digestion is not used. |

# APPENDIX D

# Review of Earlier Study

# REVIEW OF EARLIER STUDY

## D.1 Introduction

The exfiltration and filtration demonstration facilities were constructed in 1993 and 1994. The City of Etobicoke conducted a post-construction monitoring study in 1994 and 1995 to evaluate the performance of the systems. A subsequent report prepared for the City (Candaras Associates, 1997) described the results of the monitoring program and provided a description of the exfiltration and filtration systems, including documentation of the site assessment procedure, design protocols and construction method.

The objectives of the 1994-1995 study were to assess the hydraulic performance of the systems and to monitor effluent water quality. Because the hydraulic performance was to be compared to the design objectives, the monitoring equipment was set up in upstream legs of the sewer systems where both inflow and outflow could be observed. Water quality monitoring was undertaken at the downstream ends of the systems, but a combination of equipment problems and limited outflow resulted in failure of that part of the study. Rainfall data were obtained from several municipal rain gauges, as well as from Pearson International Airport. The report selected rainfall events equal to or greater than 10 mm for analysis.

This appendix documents a review of the 1997 report, with the principal focus being on the results of the hydraulic monitoring work. The discussions included herein are those resulting from the current review but may reflect some of the comments in the original report.

## D.2 Queen Mary's Drive Exfiltration System

### D.2.1 Methodology

Hydraulic monitoring was conducted at the upstream end of the system (Figure D.1). The inlets to the perforated pipes in maintenance hole 12 (MH 12) were plugged for this study so that any influent from the catch basins connected directly to MH 12 or to the storm sewer pipe between MH 12 and MH 14 would appear as influent flow to MH 14. A pressure transducer and weir were installed in MH 14 to measure the runoff entering the system. Flow entering MH 14 had an opportunity to exfiltrate through the perforated pipes and gravel trench between MH 14 and MH 15. Any overflow could be measured as influent to MH 15 by a pressure transducer and weir. There are no catchbasin leads entering the storm sewer between MH 14 and MH 15. Pressure transducers were also installed in monitoring wells in the gravel bed at MH 14 and MH 15.

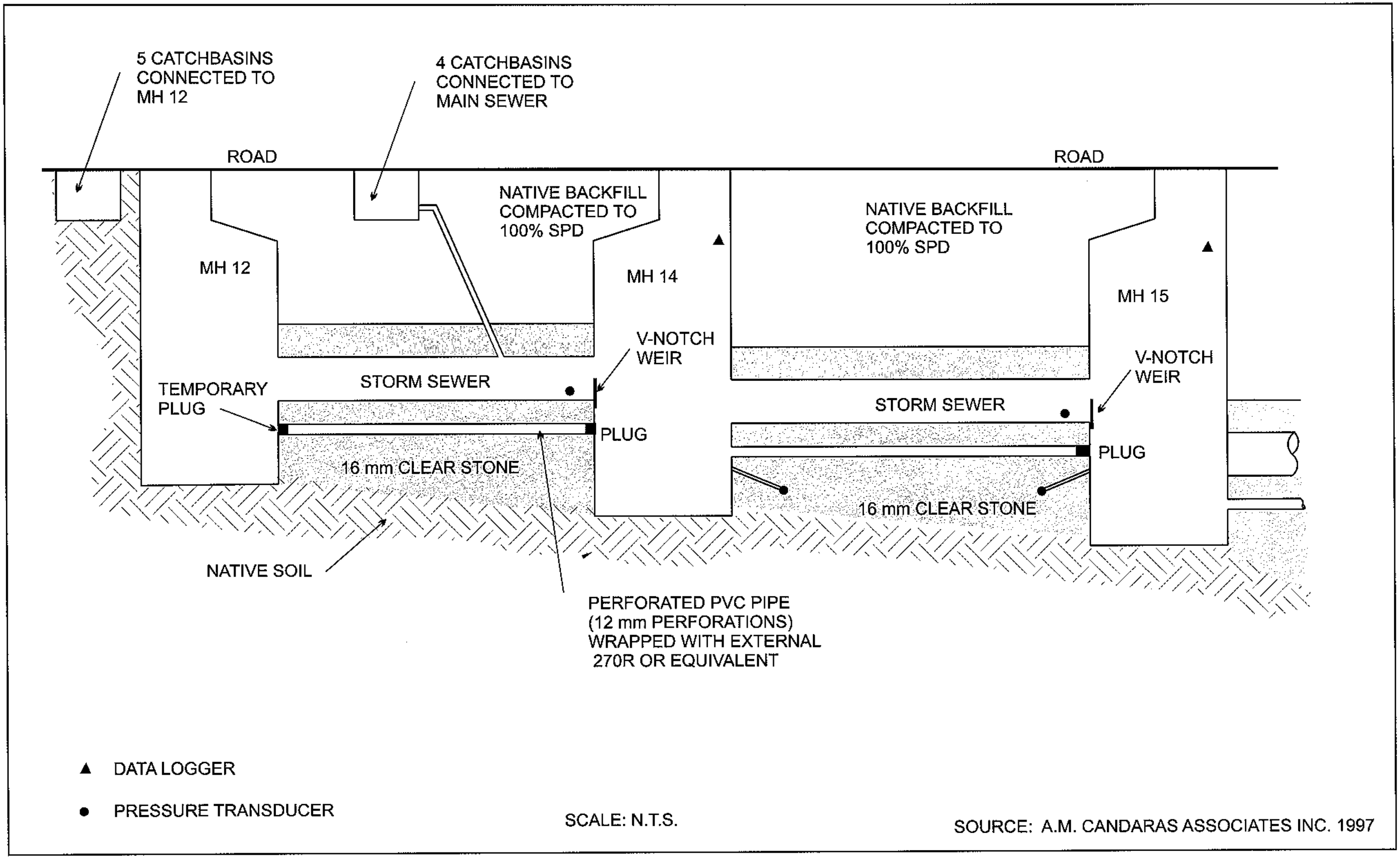


***Figure D.1:*** Queen Mary's Drive monitoring configuration 1994-1995

### D.2.2 Results

Construction of the Queen Mary's Drive facility was completed in the fall of 1994. One rainfall event of greater than 10 mm occurred after construction that year. A large event occurred in October of 1995.

The Sept. 25, 1994 event had a total rainfall of 19.1 mm over a duration of 6 hours. The peak influent flow was 52 L/s (MH 14) and the peak overflow rate was 6.5 L/s at MH 15. The peak water depths in the gravel trench were 220 mm at MH 14 and 180 mm at MH 15, both well below the 650 mm depth that would indicate saturation of the bed up to the invert of the storm sewer.

The October 5-6, 1995 event had a total rainfall of 63 mm and a duration of 18 hours. The peak inflow rate was 17.5 L/s and the peak overflow rate was 10 L/s. The peak water depths in the gravel trench were approximately 150 mm at MH 14 and 550 mm at MH 15.

### D.2.3 Discussion

Quantitative interpretation of the data must be based on assumptions regarding the active portion of the gravel bed. In this case, the researchers appear to have assumed that the active bed was that located between MH 14 and MH 15. In other words, flow does not pass around the maintenance hole structures in either the upstream or downstream directions. If valid, this assumption also implies that the bed between MH 14 and MH 15 was receiving more than twice the hydraulic load[1] that it was intended to receive because of the plugging of the inlets to the perforated pipes in MH 14.

The fact that effluent flow or overflow was observed in both cases, while the water level in the gravel bed did not indicate saturation to the sewer invert elevation, was interpreted as evidence of extraneous flow. The hypothesis would be that, since the gravel bed was not full, there would not have been any overflow from MH 14 and any flow measured at MH 15 must have come from somewhere else. The Candaras Associates report erroneously refers to flow from sealed catchbasins between MH 14 and MH 15. There are no catchbasins between MH 14 and MH 15, as was correctly shown in the original version of Figure D.1. However, residential roof drains are known to connect to the storm sewer in this area.

System dynamics should be taken into consideration in interpreting the performance of the system. Headloss occurring at the inlet to the perforated pipes, in the pipes, at the perforations and across the filter fabric covering the pipes will limit the rate of transfer of runoff into the gravel bed. If the rate of flow into the maintenance holes exceeds the rate of transfer to the gravel bed, water will back up in the maintenance holes and cause brief overflow conditions even when substantial storage capacity exists in the gravel. Also, the gravel bed is isolated from the atmosphere by the backfill and road surface and it "breathes" only through the

[1] Five catchbasins discharge to MH 12 and four discharge to the storm sewer between MH 12 and MH 14 (there is no MH 13). Detailed information on the tributary areas is not available, but the number of cachbasins indicates that more runoff would normally be discharged to the MH 12 to MH 14 leg of the infiltration system than to the MH 14 to MH 15 leg. The MH 12 to MH 14 leg is 75 m long and the MH 14 to MH 15 leg is 50 m long.

upstream ends of the perforated pipes. Hence, pressurization of the bed is also possible causing an air lock situation that would further inhibit flow.

The September1994 event was of moderate volume but high intensity. The throughput (not storage) capacity of the system was the limiting factor causing overflow. The downward gradient of the water table in the gravel bed suggests that either the exfiltration rate was good or that the water did not have enough time to equilibrate in the bed during the event, or a combination of both factors.

The October 1995 event was of large volume but moderate intensity. Overflow occurred over a period of approximately 5.5 hours with three peaks that corresponded to the influent peak flows. The water table in the gravel bed appears to have had an upward gradient in the direction of flow, allowing for the 339 mm fall in the sewer line shown in the as-built drawings between MH 14 and MH 15. The latter observation is anomalous[2] and may be related to the condition of the downstream pressure sensor, which failed to report readings less than about 300 mm.

## D.3 Braecrest Avenue Filtration System

### D.3.1 Methodology

The performance of the filtration system was evaluated using monitoring data collected between April 1994 and October 1995. Figure D.2 shows the placement of monitoring equipment in the upstream leg of the filtration system. One catchbasin drains directly to MH 1 and two discharge to the sewer system between MH 1 and MH 2. Two of these catchbasins were sealed, leaving only the south-side catchbasin draining to the sewer system in operation for the monitoring study.

Catchbasin overflow, from the upper catchbasin lead, was measured using a low head pressure transducer fitted to the storm sewer invert and a V-notch weir at the upstream end of MH 2. Filtrate exiting the underdrain pipe was measured with a second pressure transducer and weir combination installed on the floor of the maintenance hole. A deflector plate prevented flow from the main storm sewer from mixing with the filtrate. Additional pressure transducers were installed in the catchbasin and in the gravel trench.

### D.3.2 Results

The Candaras Associates report included data from four events, one of which caused catchbasin overflow to the storm sewer. Filtrate flow was negligible or absent in all events.

2 A review of the same study by Smith (1999) indicated that the actual depths of the pressure sensors in the gravel bed, with respect to the bottom of the bed or the bottom of the maintenance holes, were uncertain.

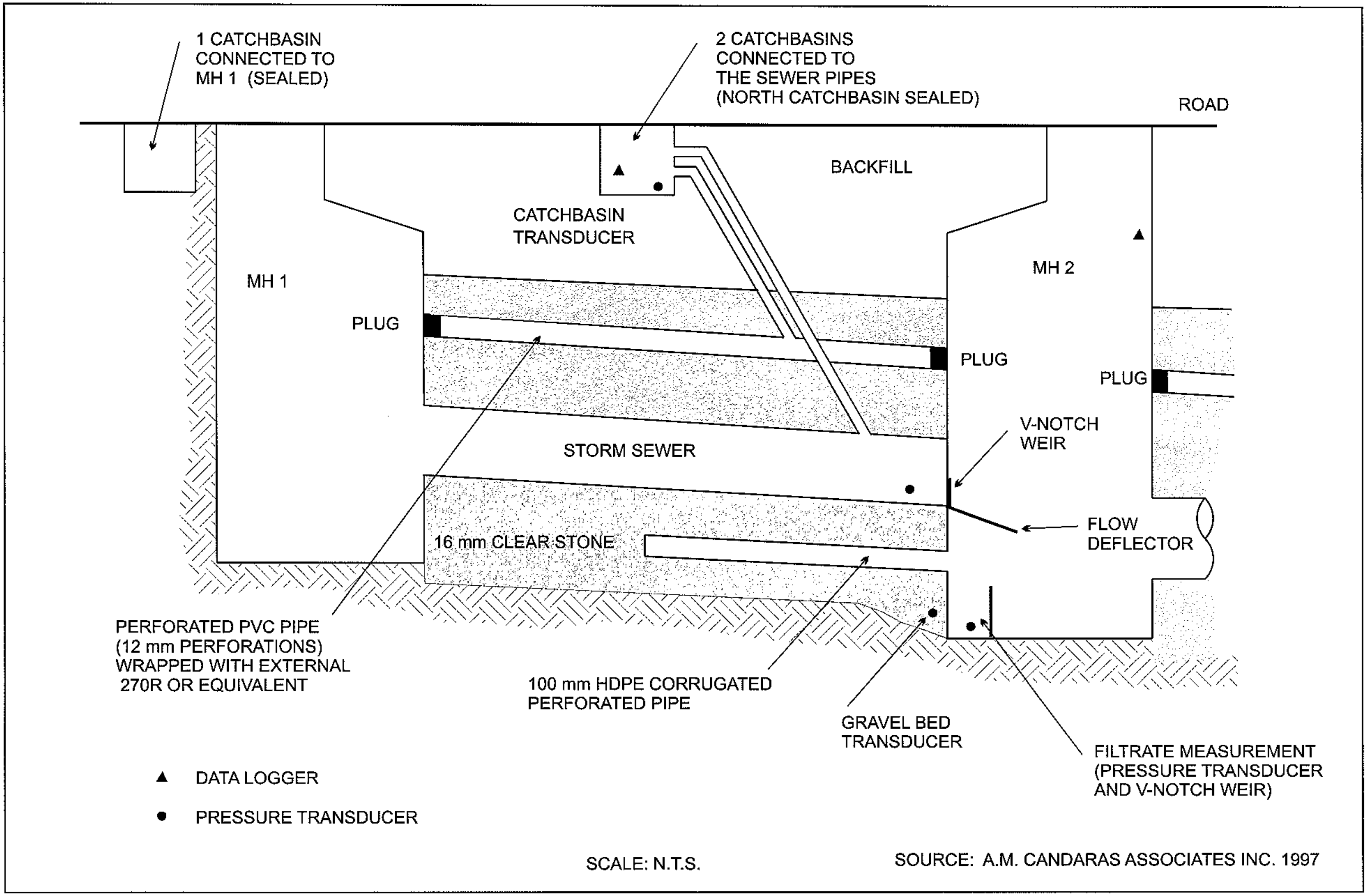


***Figure D.2:*** Braecrest Avenue monitoring configuration 1994-1995

### D.3.3 Discussion

The three events that caused no catchbasin overflow had rainfall depths varying from 11 to 63 mm. The event that did cause overflow had a total rainfall of 28 mm. Apparently based on the total rainfall and a peak rainfall of approximately 23 mm/h, the authors attributed the overflow condition to blocking of the lower catchbasin lead.

## D.4 Princess Margaret Boulevard Exfiltration System

### D.4.1 Methodology

Monitoring of the Princess Margaret exfiltration system was undertaken at the upstream end of the pipe network between maintenance holes 1 and 3 (MH 1 to MH 3). The monitoring system is illustrated in Figure D.3. Influent flow was measured at MH 2 using a pressure transducer and weir in the upstream leg of the storm sewer. Catchbasins between MH 2 and MH 3 were sealed to prevent additional inflow such that the overflow could be measured in the upstream leg of the storm sewer at MH 3. In addition, pressure transducers were located in the gravel bed at MH 2 and MH 3.

### D.4.2 Results

Four rainfall events had total depths of 10 mm or greater during the monitoring periods.

The first event (May 26, 1994) had a total rainfall of 28 mm over a period of 22.5 hr. The peak inflow was 9.7 L/s and the peak overflow was 0.3 L/s. The maximum water depth in the gravel bed at MH 3 was 65 mm but no reading was reported for MH 2.

The second event (May 31, 1994) had a total rainfall depth of 11 mm in 0.5 hr. The peak inflow was 8.1 L/s and the peak outflow was 1.5 L/s. The maximum water depth in the gravel bed at MH 3 was 5 mm but no reading was reported for MH 2.

The third event (June 24, 1994) consisted of 24 mm of rain in 24 hours. The peak inflow was 2.2 L/s and the peak outflow was 0.1 L/s. The maximum water depth in the gravel bed at MH 3 was 3 mm but no reading was reported for MH2.

The fourth event (October 5-6, 1995) had a total rainfall of 63 mm and a duration of 18 hours. The peak inflow was 10 L/s and the peak outflow was 3.3 L/s. The maximum water depth in the gravel bed at MH 3 was 0.5 m, and that at MH 2 was 0.38 m.

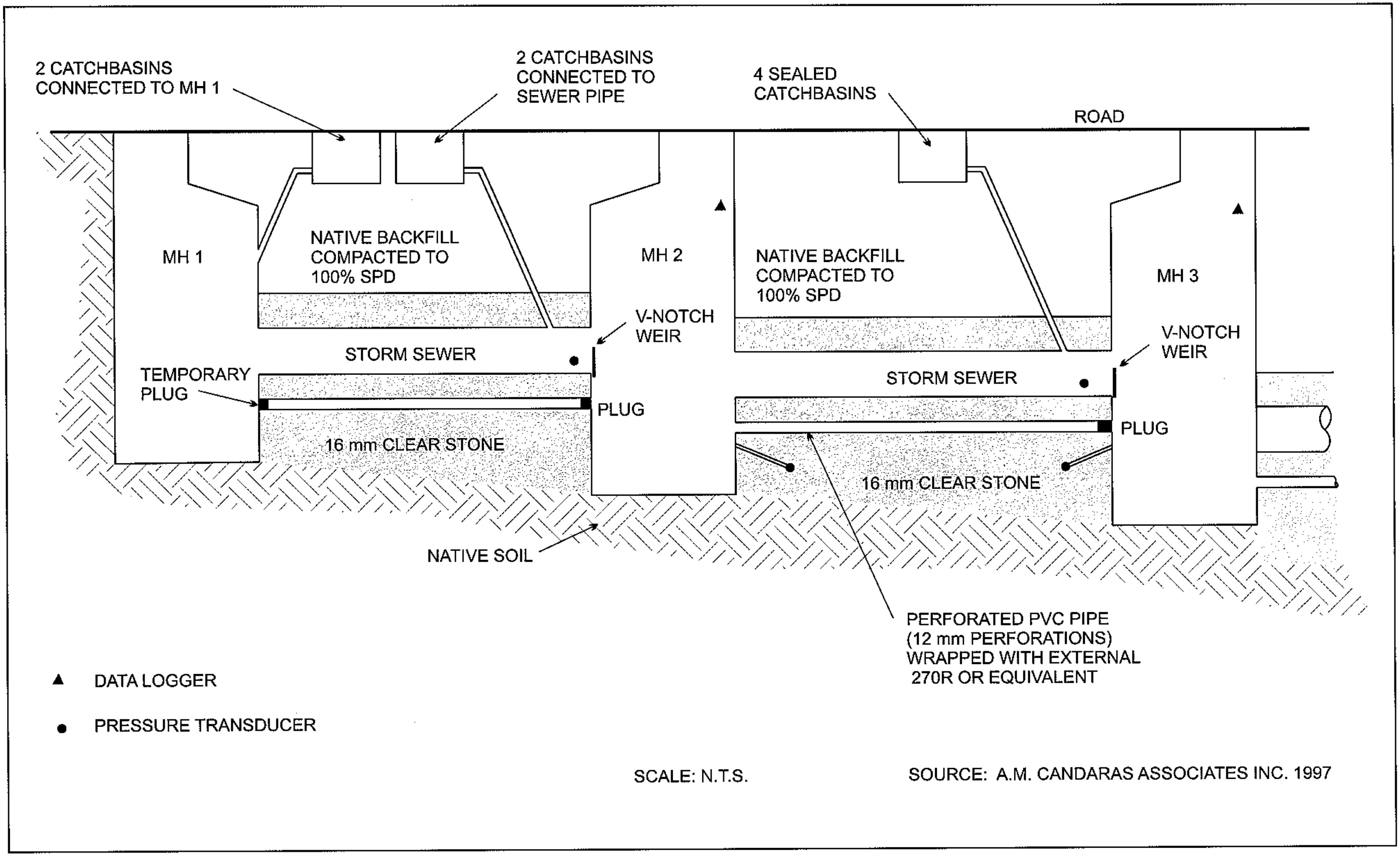


***Figure D.3:*** Princess Margaret Boulevard monitoring configuration 1994-1995

### D.4.3 Discussion

The sewer system illustrated in Figure D.3 does not agree with the original construction drawings. The original design included a conventional storm sewer (84 m length, 375 mm diameter) between MH 1 and MH 2. Two catchbasins discharge to MH 1 and two discharge to the sewer between MH 1 and MH 2, in both the original design and Figure D.3. Functionally, the effects are the same for the study since the upper end of the perforated pipes at MH 1 were reported to be plugged.

The sewer pipe falls 507 mm from MH 2 to MH 3 according to the design drawings. Consequently, appreciable storage of water in the bed would be necessary before a measurable water level is seen at MH 2. Some of the outflow measured at MH 3 was considered to be the result of leakage from the sealed catchbasins between MH 2 and MH 3. Downspout or other connections from the residential area may have contributed additional flows.

As in the case of the Queen Mary's Drive site, the depth of water in the gravel bed would be at least 650 mm at the upstream end to cause overflow, if the levels in the bed and maintenance hole were equal. The levels would not be equal under high flow conditions because of headloss between the two locations. Consequently, overflow conditions may result from throughput capacity limitations rather than storage capacity limitations. The smaller overflows observed might be attributed to leakage or extraneous flows and the larger overflows may have resulted in part from throughput capacity limitations.

The drawdown time as measured at the MH 3 pressure sensor was approximately 10 hours. Drawdown extended approximately 6 to 8 hours after the termination of inflow. The system's exfiltration capacity was thus far greater than that required to meet the bed emptying objective of 48 hours.

## D.5 Flow Testing

Hydraulic tests were conducted at the Braecrest Avenue and Princess Margaret Boulevard sites in July of 1994. Metered flows from fire hydrants were applied to the catchbasins. Hydraulic head and flow were monitored at the locations indicated in Figures D.2 and D.3.

### D.5.1 Braecrest

Hydraulic load was applied continuously in increasing steps (10, 15, 20 and 23 L/s) with each step being approximately 15 minutes in duration.

At a hydraulic load of 10 L/s, the filtrate flow gradually increased from 7.5 to 8.5 L/s. The remaining water was evidently being stored in the gravel bed or was exfiltrating, and the storage/exfiltration capacity was decreasing with time. There was no overflow to the main sewer pipe.

At 15 L/s, approximately 13 L/s were seen as filtrate and 2 L/s were apparently exfiltrating. The filtrate flow rate was increasing gradually.

When the influent flow was increased to 20 L/s, approximately 8 L/s exited the main sewer pipe as overflow and 11 L/s were measured as filtrate. The implication of these approximate average numbers is that exfiltration had decreased or ceased, but the flows were somewhat variable over this part of the test.

When the influent flow was increased to 23 L/s, the effluent flow was divided equally between the filtrate and the overflow (main pipe flow) at about 10 to 11 L/s each. No exfiltration was apparent. And, in this case, the flows were steadier than in the previous step.

This hydraulic test indicated that the effect of exfiltration and/or storage decreases with time until the total effluent flow equals the influent flow.

An interesting finding is that the maximum filtrate flow occurred with an influent flow of 15 L/s, when only the lower catchbasin lead was in use. The filtrate flow decreased when the influent flow jumped from 15 to 20 L/s and overflow began. Thus, although the hydraulic head over the lower catchbasin lead had increased, the flow through the lead had not. The hydraulic behaviour of the catchbasin - if not the entire system - is apparently quite complex.

### D.5.2 Princess Margaret

The influent flow was gradually increased and then held constant at 13.3 L/s (800 l/min.) in this test. The flow at MH 2 represented the influent flow and could be calibrated to the metered influent rate.

Flow at MH 3 did not occur until approximately 45 minutes after the test began. After increasing steadily, the flow reached a peak of 8.3 L/s when the test was terminated (110 minute duration). The remaining 5 L/s were being either stored or exfiltrated. The maximum water depth recorded in the gravel bed at MH 3 was 450 mm, and that at MH 2 was 430 mm. Since a depth of 650 mm would be required in MH 2 to cause an overflow, the water levels in the maintenance hole and the gravel bed were not in equilibrium and - as reported elsewhere - the capacity limitation was related to throughput and not to storage or exfiltration.

## D.6 Other Study Components

### D.6.1 Modelling

Rainfall-runoff modelling was undertaken for the Princess Margaret facility. The results suggest that several modelling parameters need to be reconsidered in the prediction of runoff rates and volumes. This section of the 1997 report was not reviewed in detail.

### D.6.2 Operation and Maintenance

The 1997 report documented the results of visual inspections of the exfiltration and infiltration systems, including the catchbasins, maintenance holes, perforated pipes and the structural integrity of the roads. The report also made recommendations for periodic video inspection and power flushing of the systems.

Video inspection of the systems was carried out in July 1994 and December of 1995. In December of 1995, after the major storm in October, sediment was found in the Princess Margaret facility, in the perforated pipes between MH 2 and MH 3. The depth was estimated to be approximately 25 mm at a location 20 m upstream of MH 3, with a deeper deposit expected to exist closer to the maintenance hole.

On April 17, 1996 samples of sediment were collected from the perforated pipes at MH 3 in the Princess Margaret facility. Particle size distributions and sediment quality data were compared to data from stormwater ponds and data provided in provincial guidelines. The material found in the perforated pipes consisted of 35% sand, 57% silt and 8% clay. The clay content was less than that found in the ponds, suggesting that clay may have been penetrating the fabric surrounding the pipes and entering the gravel bed. Chemical analysis of the sediment indicated that the concentrations of some constituents were great enough to require disposal in sanitary landfill.

## D.7 Conclusions and Recommendations

The following sections summarize some of the important statements included in the previous monitoring study reported by A.M. Candaras Associates in 1997.

### D.7.1 System Performance

- The exfiltration/filtration capacity of the systems exceeded the design runoff from a 15 mm rainfall event. The systems successfully percolated/infiltrated stormwater for events that exceeded the design runoff volume.
- The collected data suggested that because of the high exfiltration capacity of the system, efficiencies can be derived through an optimization of the design, which could include a reduction in the sizing of the storm sewer and a reduction in the trench cross-section used in the system.
- For catchments serviced by these systems, stormwater runoff contaminant loadings discharged directly to surface waters were virtually eliminated during the period of study. Additional monitoring is required, however, to assess the potential impact of these systems on groundwater sources.

### D.7.2 Future Study Needs

Since the systems were newly developed and untested, the report also suggested that additional study is warranted to investigate the following aspects of the exfiltration system.

- A monitoring program should be devised to assess the overall system performance for the exfiltration system on a long-term basis.
- The long-term maintenance and operation requirements should also be assessed. Additional analysis of material trapped within the perforated pipes is warranted to confirm the disposal options.
- An assessment of the potential ground water impact should be conducted.
- A detailed design brief should be developed to include an evaluation of the design parameters and to provide an optimization for the design of the exfiltration system using available performance data.
- A full cost-benefit analysis for the system should be conducted and compared to a conventional system designed with an end-of-pipe treatment facility.

## D.8 Discussion

The use of upstream sections of the sewer systems in the 1994-1995 study was necessitated by the objectives of quantifying influent and effluent flows, and of relating the flow to the characteristics of the catchment area. The negative implication of that method is that the catchment area may not have been representative of the entire system. The water quality monitoring component of the study, which failed due to equipment problems and the lack of outflow, was intended to measure the final system effluent.

The exfiltration facilities were seen to have the capability of containing and exfiltrating large volumes of runoff, but overflows occurred while the gravel beds were apparently less than fully utilized. The rate of loading was apparently the critical factor. The throughput capacity is not obvious from an examination of peak flows. Some events suggest a capacity of approximately 10 L/s although the hydraulic test attained a peak flow of 13.3 L/s before overflow was observed. Under dynamic loading conditions, water would accumulate in the maintenance holes gradually because of small discrepancies between the input rate and the throughput capacity and would eventually cause an overflow condition unless the influent flow subsided.

The monitoring program at the Braecrest Avenue filtration site did not observe any appreciable filtrate flow. The runoff was exiting the gravel bed either by exfiltrating into the local soils or by flowing downstream around the maintenance hole. The infiltration capacity of the local soil was probably greatly underestimated or an anomalous deposit of sand or pervious loam was situated near the test site.

# APPENDIX E

# Monitoring Program & Rainfall Data

# MONITORING PROGRAM & RAINFALL DATA

## E.1 Introduction

Tables E.1 to E.3 summarize the rainfall events and the monitoring program at the three Etobicoke sites for 1996, 1997 and 1998 respectively.

Rain data for 1996 were obtained from the Atmospheric Environment Service of Environment Canada. The rain gauge was located at Toronto-Pearson International Airport. The data were reported as hourly total rainfall depths in millimetres, and have been summarized in Table E.1 as daily total rainfall.

Rain data for 1997 were obtained from the City of Etobicoke. The rain gauge was located at Richview Collegiate Institute, a public secondary school located at the south-west corner of Islington Avenue and Eglington Avenue West. In the available spreadsheets the data were tabulated as hourly total rainfall depths in millimetres; they have been summarized in Table E.2 as daily total rainfall.

Rain data for 1998 were obtained from the City of Etobicoke. Data for April 1 to May 5 were obtained from a rain gauge at the Seventh Street Junior School, located south of Lakeshore Road and east of Islington Avenue. The remaining data were obtained from a rain gauge at Westway Junior School, located between Royal York Road and Islington Avenue, close to the Braecrest Avenue study site. In the available spreadsheets the data were tabulated as 5-minute total rainfall depths in millimetres; they have been summarized in Table E.3 as daily total rainfall.

***Table E.1:*** Rainfall events and data availability -- 1996 monitoring program summary

| Date | Rainfall (mm) | QM Flow | QM Qual. | PM Flow | PM Qual. | BR Flow | BR Qual. |
|---|---|---|---|---|---|---|---|
| Aug. 01 | 6.4 | - | | - | | - | |
| Aug. 02 | 1.2 | - | | - | | - | |
| Aug. 08 | 7.8 | - | | - | | - | |
| Aug. 13 | 5.8 | - | | - | | - | |
| Aug. 15 | 5.8 | • | | - | | - | |
| Aug. 20 | 1.4 | • | | - | | • | |
| Aug. 22 | 9.4 | • | | - | | • | |
| Aug. 23 | 0.8 | • | | - | | • | |
| Aug. 26 | 3.4 | • | | - | | - | |
| Aug. 27 | 6.2 | • | | - | | - | |
| Sept. 07 | 66.3 | • | | - | | • | |
| Sept. 08 | 0.6 | • | | - | | • | |
| Sept. 09 | 3.6 | • | | - | | • | |
| Sept. 11 | 6.0 | • | | - | | • | |
| Sept. 12 | 8.5 | • | | - | | • | |
| Sept. 13 | 30.8 | • | | - | | • | |
| Sept. 14 | 1.4 | • | | - | | • | |
| Sept. 15 | 0.6 | • | | - | | • | |
| Sept. 16 | 0.4 | • | | - | | • | |
| Sept. 22 | 10.2 | • | | - | | • | |
| Sept. 24 | 11.9 | • | | - | | • | |
| Sept. 26 | 3.2 | • | | - | | • | |
| Sept. 27 | 4.8 | • | | - | | • | |
| Sept. 28 | 17.4 | • | | - | | • | |
| Sept. 29 | 1.0 | • | | - | | • | |
| Oct. 02 | 0.4 | - | | - | | • | |
| Oct. 09 | 4.8 | • | | - | | • | |
| Oct. 10 | 6.4 | • | | - | | • | |
| Oct. 13 | 0.2 | • | | • | | • | |
| Oct. 16 | 7.0 | • | | • | | • | |
| Oct. 18 | 26.7 | • | | • | | • | • |
| Oct. 19 | 8.0 | • | | • | | • | |
| Oct. 20 | 1.6 | • | | • | | • | |
| Oct. 21 | 4.5 | • | • | • | | • | • |
| Oct. 23 | 4.8 | • | | • | | • | |
| Oct. 24 | 0.6 | • | | • | | • | |
| Oct. 29 | 1.0 | • | | • | | • | |
| Oct. 30 | 9.1 | • | | • | • | • | |
| Nov. 04 | 0.6 | • | | • | | • | |
| Nov. 05 | 0.6 | • | | • | | • | |
| Nov. 06 | 0.2 | • | | • | | • | |
| Nov. 07 | 14.8 | • | | • | | • | |
| Nov. 08 | 3.2 | • | | • | | • | |
| Nov. 13 | nil | • | • | • | • | • | • |
| Nov. 17 | 1.6 | | | | | | |
| Nov. 18 | 0.2 | | | | | | |
| Nov. 30 | 1.8 | | | | | | |
| Dec. 17 | - | - | • | - | • | - | • |

Notes: QM = Queen Mary's Drive
PM = Princess Margaret Boulevard
BR = Braecrest Avenue

***Table E.2:*** Rainfall events and data availability -- 1997 monitoring program summary

| Date | Rainfall (mm) | QM Flow | QM Qual. | PM Flow | PM Qual. | BR Flow | BR Qual. |
|---|---|---|---|---|---|---|---|
| Jan. 03, '97 | - | | • | - | • | | • |
| Jan. 22, 97 | - | | • | - | • | | • |
| Feb. 18, '97 | - | | • | - | • | | • |
| Feb. 21, '97 | - | | • | - | • | | • |
| Feb. 27, '97 | - | | • | - | • | | • |
| Mar. 25, '97 | - | | • | - | • | | • |
| May. 06, '97 | - | | | - | • | | |
| Jun. 09, '97 | 0.4 | | | | | | |
| Jun. 12, '97 | 8.6 | | | - | | | |
| Jun. 13, '97 | 7.0 | | | - | | | |
| Jun. 16, '97 | 12.0 | | | - | | | |
| Jun. 17, '97 | 0.2 | | | - | | | |
| Jun. 24, '97 | 13.8 | | | • | | | |
| Jul. 02, '97 | 0.2 | | | - | | | |
| Jul. 03, '97 | 2.2 | | | - | | | |
| Jul. 06, '97 | 0.2 | | | - | | | |
| Jul. 07, '97 | 2.4 | | | - | | | |
| Jul. 08, '97 | 10.2 | | | - | | | |
| Jul. 09, '97 | 0.6 | | | • | | | |
| Jul. 15, '97 | 14.8 | | | • | | | |
| Jul. 17, '97 | 2.0 | | | • | | | |
| Jul. 18, '97 | 7.2 | | | • | | | |
| Jul. 21, '97 | 4.2 | | | • | | | |
| Jul. 28, '97 | 3.6 | | | • | | | |
| Aug. 07, '97 | 1.6 | | | • | | | |
| Aug. 11, '97 | 1.0 | | | • | | | |
| Aug.12, '97 | 1.4 | | | • | | | |
| Aug. 13, '97 | 10.0 | | | • | | | |
| Aug. 15, '97 | 20.8 | | | • | | | |
| Aug. 16, '97 | 1.0 | | | • | | | |
| Aug. 20, '97 | 20.8 | | | • | | | |
| Aug. 21, '97 | 19.6 | | | • | | | |
| Aug. 24, '97 | 0.4 | | | • | | | |
| Aug. 31, '97 | 0.6 | | | • | | | |
| Sep. 6, '97 | 6.8 | | | • | | | |
| Sep. 07, '98 | nil | | | • | | | |
| Sep.10, '97 | 16.0 | | | • | | | |
| Sep.17, '97 | 1.8 | | | • | | | |
| Sep. 19, '97 | 6.0 | | | • | | | |
| Sep. 20, '97 | 2.2 | | | | | | |
| Sep. 25, '97 | 4.6 | | | • | | | |
| Sep. 29, '97 | 14.6 | | | • | | | |
| Sep. 30, '97 | 2.2 | | | | | | |
| Oct. 02, '97 | 0.4 | | • | • | | | |
| Oct. 09, '97 | 0.8 | | | | | | |
| Oct. 31, '97 | 2.0 | | | • | | | |
| Nov. 01, '97 | 23.0 | | | • | | | |
| Nov. 02, '97 | 0.8 | | | | | | |
| Nov. 03, '97 | 0.2 | | | | | | |
| Nov. 04, '97 | 0.8 | | | | | | |
| Nov. 13, '97 | 3.2 | | | • | | | |
| Nov. 15, '97 | 0.4 | | | | | | |
| Nov. 16, '97 | 1.4 | | | • | | | |
| Nov. 20, '97 | 3.2 | | | • | | | |
| Nov. 21, '97 | 1.8 | | • | • | • | | |
| Nov. 22, '97 | 1.4 | | | • | | | |
| Nov. 23, '97 | 0.4 | | | | | | |
| Nov. 24, '97 | 1.8 | | | • | | | |
| Nov. 26, '97 | 2.8 | | | • | | | |
| Dec. 04, '97 | - | | • | • | • | | |

Notes: (as in Table E.1)

***Table E.3:*** Rainfall events and data availability -- 1998 monitoring program summary

| Date | Rainfall (mm) | QM Flow | QM Qual. | PM Flow | PM Qual. | BR Flow | BR Qual. |
|---|---|---|---|---|---|---|---|
| Jan. 05, '98 | - | | • | | • | | |
| Jan. 08, '98 | - | | • | | • | | |
| Jan.09, '98 | - | | • | | • | | |
| Feb. 12, '98 | - | | • | | • | | |
| Feb. 17, '98 | - | | | | | | |
| Feb. 18, '98 | - | | • | | | | |
| Mar. 02, '98 | - | | | | • | | |
| Mar. 09, '98 | - | | • | | • | | |
| Mar. 19, '98 | - | | • | | • | | |
| Mar. 28, '98 | 5.6 | | | | | | |
| Apr. 01 | 6.1 | | • | | | | |
| Apr. 02 | 4.2 | | | | | | |
| Apr. 08 | 2.3 | | | | • | | |
| Apr. 09 | 0.1 | | | | | | |
| Apr. 14 | 1.5 | | | | | | |
| Apr. 15 | 0.1 | | | | | | |
| Apr. 16 | 12.3 | | | | | | |
| Apr. 17 | 2.2 | | | | • | | |
| Apr. 19 | 5.5 | | | | | | |
| Apr. 20 | 2.4 | | • | | | | |
| May 01 | 0.5 | | | | | | |
| May 02 | 3.0 | | | | | | |
| May 03 | 0.1 | | | | | | |
| May 04 | 0.2 | | | | | | |
| May 10 | 11.8 | | | | | | |
| May 11 | 31.0 | | • | | • | | |
| May 12 | 0.3 | | | | | | |
| May 18 | 0.1 | | | | | | |
| May 19 | 0.3 | | | | | | |
| May 25 | 4.4 | | | | | | |
| May 26 | 0.1 | | | | | | |
| May 29 | 0.3 | | | | | | |
| May 31 | 3.1 | | | | | | |
| Jun. 02 | 2.1 | | | | | | |
| Jun. 10 | 2.3 | | | | | | |
| Jun. 11 | 3.1 | | | | | | |
| Jun. 12 | 17.1 | | • | | • | | |
| Jun. 13 | 3.6 | | | | | | |
| Jun. 16 | 6.2 | | | | | | |
| Jun. 17 | 5.1 | | | | • | | |
| Jun. 18 | nil | | | | • | | |
| Jun. 20 | 3.0 | | | | | | |
| Jun. 23 | 6.3 | | | | | | |
| Jun. 24 | 0.1 | | | | | | |
| Jun. 25 | 0.4 | | | | | | |
| Jun. 26 | 9.6 | | | | | | |
| Jun. 30 | 26.8 | | partial | | • | | |
| Jul. 04, '98 | 12.3 | | | | | | |
| Jul. 06, '98 | 0.9 | | | | • | | |
| Jul. 07, '98 | 15.1 | | | | | | |
| Jul. 08, '98 | 2.1 | | partial | | • | | |
| Jul. 09, '98 | 1.9 | | | | | | |
| Jul. 16, '98 | 10.2 | | | | | | |
| Jul. 19, '98 | 1.6 | | | | | | |
| Jul. 27, '98 | 4.5 | | | | | | |
| Jul. 28, '98 | 0.1 | | | | • | | |
| Jul. 30, '98 | 0.2 | | | | | | |
| Aug. 06, '98 | 10.7 | | • | | • | | |
| Aug. 07, '98 | 11.3 | | | | | | |
| Aug. 09, '98 | 0.7 | | | | | | |
| Aug. 10, '98 | nil | | • | | • | | |
| Aug. 17, '98 | 0.1 | | | | | | |
| Aug. 18, '98 | 0.9 | | | | | | |
| Aug. 24, '98 | nil | | | | • | | |
| Sep. 02, '98 | 2.0 | | | | • | | |
| Sep. 06, '98 | 15.2 | | | | | | |
| Sep. 08, '98 | 2.8 | | | | • | | |
| Sep. 15, '98 | 3.7 | | | | • | | |
| Oct. 01, '98 | 8.1 | | | | | | |

Notes: (as in Table E.1)

# APPENDIX F

# Princess Margaret Boulevard Data

# PRINCESS MARGARET BOULEVARD DATA

## F.1 Introduction

Table F.1 provides a detailed summary of the Princess Margaret Boulevard exfiltration site monitoring program. Thirty-eight samples were collected from the Princess Margaret Boulevard site: 10 samples were identified as being taken from the main storm sewer. However, many of the locations were not specified other than by maintenance hole number. Field notes indicate that a flow sensor was initially installed in the downstream leg of the storm sewer at MH 72 and a sampling bucket was installed to capture main sewer flow entering MH 72 in October of 1996. The sensor was removed in late November but the sampling bucket was left in place. In June of 1997, a flow sensor and weir were installed in MH 73 as described in Chapter 5 and illustrated in Figure 5.1. Maintenance hole 73 is the last access point in the exfiltration system. The weir in MH 73 and the area-velocity probe upstream of the weir measured all overflow from the exfiltration system. A depth sensor and automatic sampler were located in MH 72.

## F.2 Discussion -- Princess Margaret Boulevard Monitoring Data

### F.2.1 Hydraulic data

Hyetographs and water level hydrographs are plotted on a monthly basis in Figures F.1 to F.19[1]. In 1996, data were obtained from an area-velocity probe in the sewer connecting MH 72 to MH 73. As seen in Figures F.1 and F.2, very little liquid depth was detected and no flow values were obtained. The area-velocity probe was re-installed in June of 1997, this time in conjunction with a v-notch weir installed where the storm sewer enters MH 73. Thus, water was backed up into the sewer pipe, increasing depth readings at the area-velocity probe. With the exception of a data gap in late July and early August, the level data are available until the end of October 1997.

Beginning in early July 1997 a water level probe was installed in MH 72. The probe was 365 mm below the invert of the downstream sewer pipe, such that any readings greater than that depth would indicate an overflow condition. The probe appears to have been out of service in early December, but was otherwise left in place over the winter because it was located below the frost line. It remained in use until the end of October 1998.

Level data indicate overflow conditions on June 13$^{th}$, June 30$^{th}$ and September 6$^{th}$ 1998. These three events are illustrated in Figures F.20 to F.22. Table F.2 summarizes the rainfall characteristics for these three events and for other large events during the monitoring program.

[1] In Figures F.1 to F.19, the rainfall is plotted above using the right y-axis scale and the water depth is plotted below using the left y-axis scale.

***Table F.1:*** Princess Margaret Boulevard exfiltration site -- monitoring program summary

| Date | Rain mm | MH 72 level/flow | MH 73 level/flow | Main samples | Date | Rain mm | MH 72 level/flow | MH 73 level/flow | Main samples |
|---|---|---|---|---|---|---|---|---|---|
| 10-Oct-96 | 6.4 | | | | 04-Dec-97 | n/a | | | b-g |
| 13-Oct-96 | 0.2 | ● | | | 05-Jan-98 | n/a | ● | | grab |
| 16-Oct-96 | 7.0 | ● | | | 08-Jan-98 | n/a | ● | | grab |
| 18-Oct-96 | 26.7 | ● | | | 09-Jan-98 | n/a | ● | | grab |
| 19-Oct-96 | 8.0 | ● | | | 12-Feb-98 | n/a | ● | | b-g |
| 20-Oct-96 | 1.6 | ● | | | 18-Feb-98 | n/a | ● | | |
| 21-Oct-96 | 4.5 | ● | | | 02-Mar-98 | n/a | ● | | b-c |
| 23-Oct-96 | 4.8 | ● | | | 09-Mar-98 | n/a | ● | | b-c +g |
| 24-Oct-96 | 0.6 | ● | | | 19-Mar-98 | n/a | ● | | b-g |
| 29-Oct-96 | 1.0 | ● | | | 08-Apr-98 | 2.3 | ● | | b-g |
| 30-Oct-96 | 9.1 | ● | | b | 17-Apr-98 | 2.2 | ● | | b-g |
| 04-Nov-96 | 0.6 | ● | | | 11-May-98 | 31.0 | ● | | type ? |
| 05-Nov-96 | 0.6 | ● | | | 12-Jun-98 | 17.1 | ● | | bucket |
| 06-Nov-96 | 0.2 | ● | | | 17-Jun-98 | 5.1 | ● | | bucket |
| 07-Nov-96 | 14.8 | ● | | | 18-Jun-98 | nil | ● | | b-c |
| 08-Nov-96 | 3.2 | ● | | | 30-Jun-98 | 26.8 | ● | | buc+o/f (2) |
| 13-Nov-96 | nil | ● | | b | 06-Jul-98 | 0.9 | ● | | b-g |
| 17-Nov-96 | 1.6 | | | | 07-Jul-98 | 15.1 | ● | | b-c |
| 18-Nov-96 | 0.2 | | | | 08-Jul-98 | 2.1 | ● | | b-c |
| 30-Nov-96 | 1.8 | | | | 28-Jul-98 | 0.1 | ● | | b-g |
| 17-Dec-96 | n/a | | | b | 06-Aug-98 | 10.7 | ● | | type ? |
| 03-Jan-97 | n/a | | | b | 10-Aug-98 | nil | ● | | type ? |
| 22-Jan-97 | n/a | | | b | 24-Aug-98 | nil | ● | | b-g |
| 18-Feb-97 | n/a | | | b | 02-Sep-98 | 2.0 | ● | | b-c |
| 21-Feb-97 | n/a | | | b | 08-Sep-98 | 2.8 | ● | | b-c |
| 27-Feb-97 | n/a | | | b | 15-Sep-98 | 3.7 | ● | | b-c |
| 25-Mar-97 | n/a | | | b | | | | | |
| 06-May-97 | n/a | | | grab | | | | | |
| 24-Jun-97 | 13.8 | | ● | | | | | | |
| 09-Jul-97 | 0.6 | ● | ● | | | | | | |
| 15-Jul-97 | 14.8 | ● | ● | | | | | | |
| 17-Jul-97 | 2.0 | ● | ● | | | | | | |
| 18-Jul-97 | 7.2 | ● | ● | | | | | | |
| 21-Jul-97 | 4.2 | ● | ● | | | | | | |
| 28-Jul-97 | 3.6 | ● | ● | | | | | | |
| 07-Aug-97 | 1.6 | ● | ● | | | | | | |
| 11-Aug-97 | 1.0 | ● | ● | | | | | | |
| 12-Aug-97 | 1.4 | ● | ● | | | | | | |
| 13-Aug-97 | 10.0 | ● | ● | | | | | | |
| 15-Aug-97 | 20.8 | ● | ● | | | | | | |
| 16-Aug-97 | 1.0 | ● | ● | | | | | | |
| 20-Aug-97 | 20.8 | ● | ● | | | | | | |
| 21-Aug-97 | 19.6 | ● | ● | | | | | | |
| 24-Aug-97 | 0.4 | ● | ● | | | | | | |
| 31-Aug-97 | 0.6 | ● | ● | | | | | | |
| 06-Sep-97 | 6.8 | ● | ● | | | | | | |
| 07-Sep-97 | nil | ● | ● | | | | | | |
| 10-Sep-97 | 16.0 | ● | ● | | | | | | |
| 17-Sep-97 | 1.8 | ● | ● | | | | | | |
| 19-Sep-97 | 6.0 | ● | ● | | | | | | |
| 20-Sep-97 | 2.2 | ● | ● | | | | | | |
| 25-Sep-97 | 4.6 | ● | ● | | | | | | |
| 29-Sep-97 | 14.6 | ● | ● | | | | | | |
| 30-Sep-97 | 2.2 | ● | ● | | | | | | |
| 02-Oct-97 | 0.4 | ● | ● | | | | | | |
| 09-Oct-97 | 0.8 | ● | ● | | | | | | |
| 31-Oct-97 | 2.0 | ● | ● | | | | | | |
| 01-Nov-97 | 23.0 | ● | ● | | | | | | |
| 02-Nov-97 | 0.8 | ● | ● | | | | | | |
| 03-Nov-97 | 0.2 | ● | | | | | | | |
| 04-Nov-97 | 0.8 | ● | | | | | | | |
| 13-Nov-97 | 3.2 | ● | | | | | | | |
| 15-Nov-97 | 0.4 | ● | | | | | | | |
| 16-Nov-97 | 1.4 | ● | | | | | | | |
| 20-Nov-97 | 3.2 | ● | | | | | | | |
| 21-Nov-97 | 1.8 | ● | | b-g | | | | | |
| 22-Nov-97 | 1.4 | ● | | | | | | | |
| 23-Nov-97 | 0.4 | ● | | | | | | | |
| 24-Nov-97 | 1.8 | ● | | | | | | | |
| 26-Nov-97 | 2.8 | ● | | | | | | | |

Legend: b-c = bucket composite b-g = bucket grab b = bucket (no further information)

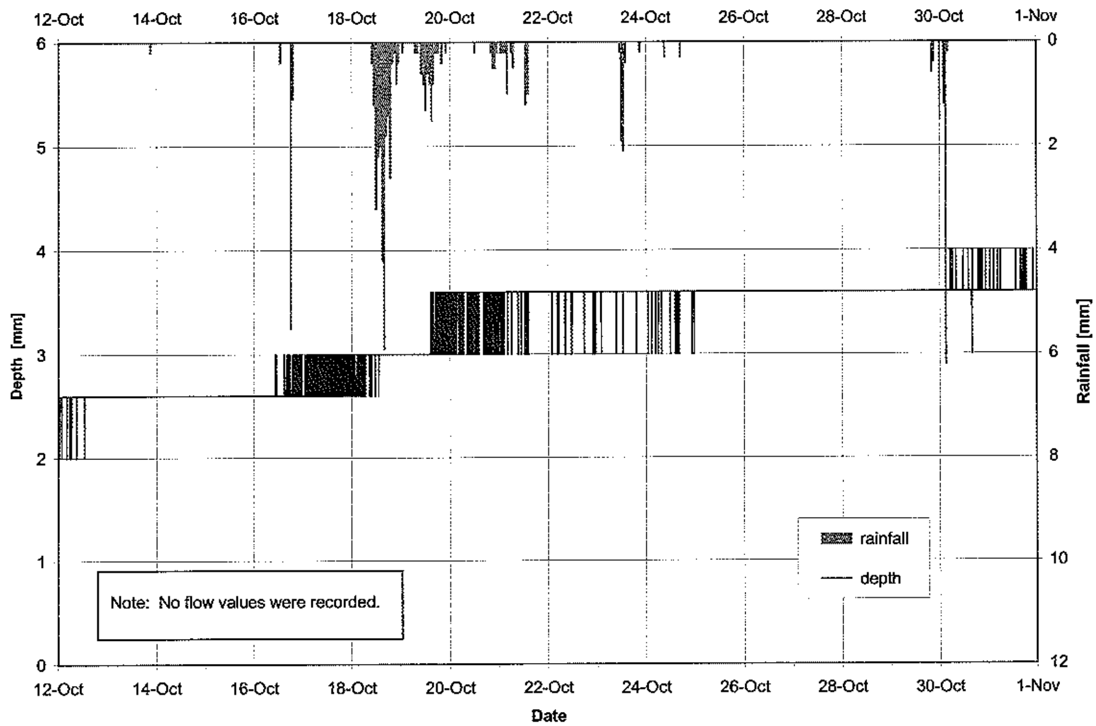


***Figure F.1:*** Water depth and rainfall -- Princess Margaret exfiltration facility, October 1996

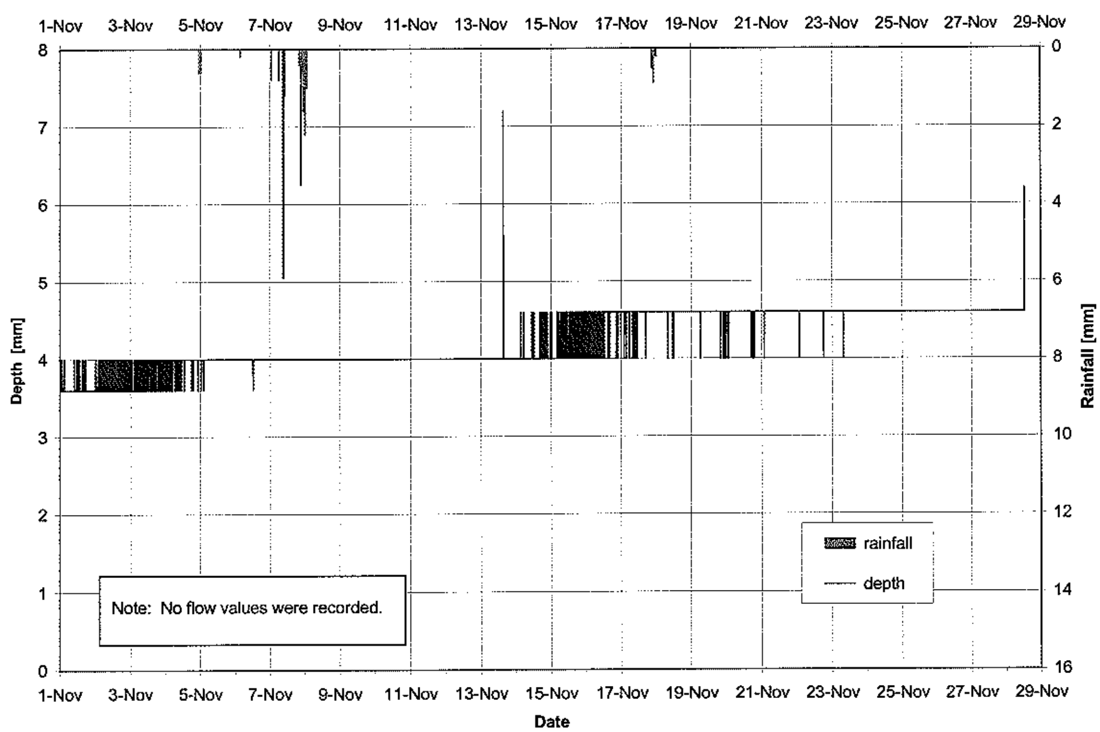


***Figure F.2:*** Water depth and rainfall -- Princess Margaret exfiltration facility, November 1996

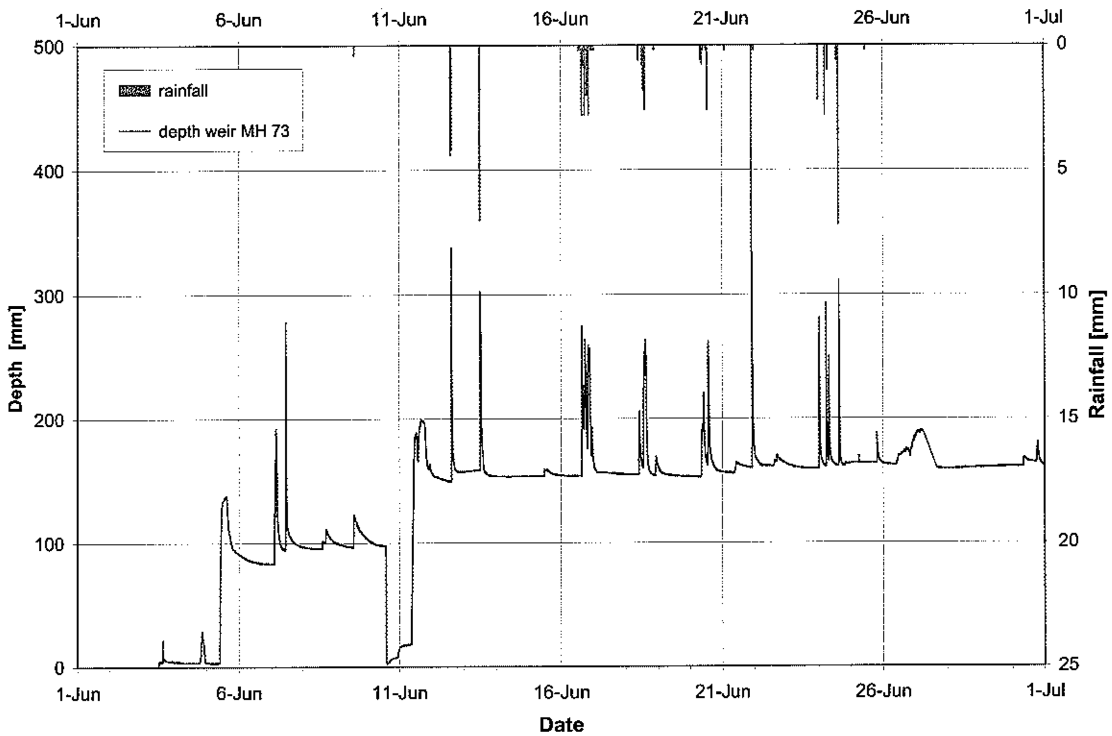


***Figure F.3:*** Water depth and rainfall -- Princess Margaret exfiltration facility, June 1997

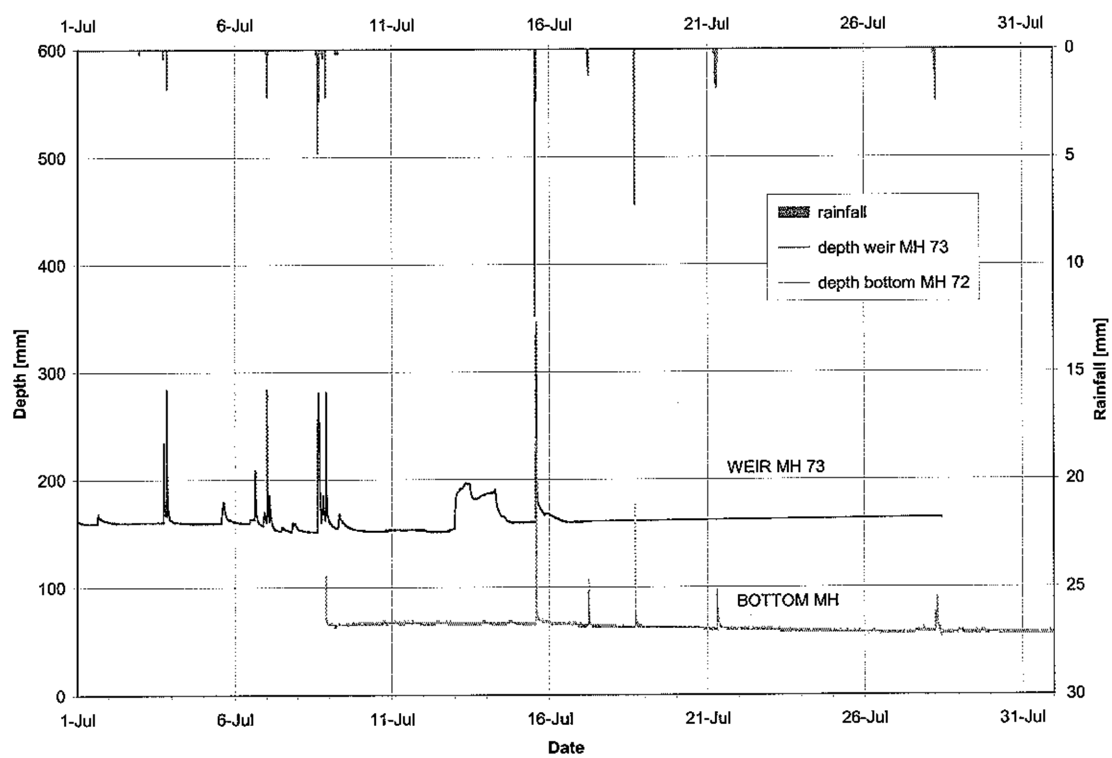


***Figure F.4:*** Water depth and rainfall -- Princess Margaret exfiltration facility, July 1997

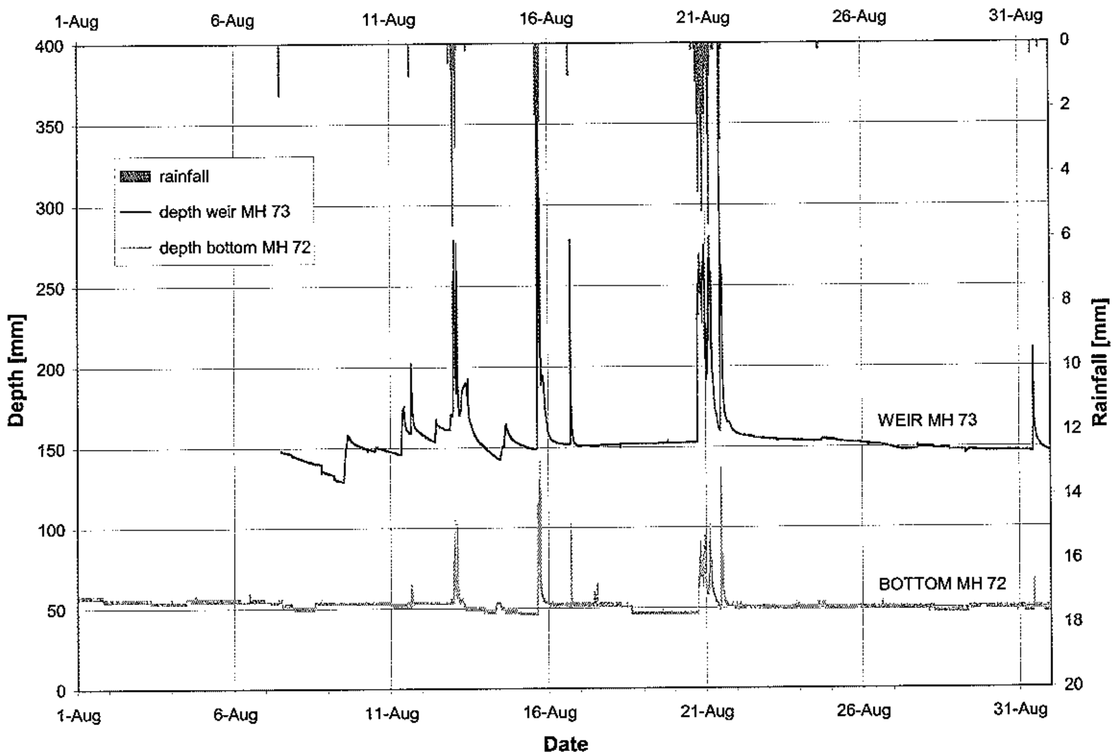


*Figure F.5:* Water depth and rainfall -- Princess Margaret exfiltration facility, August 1997

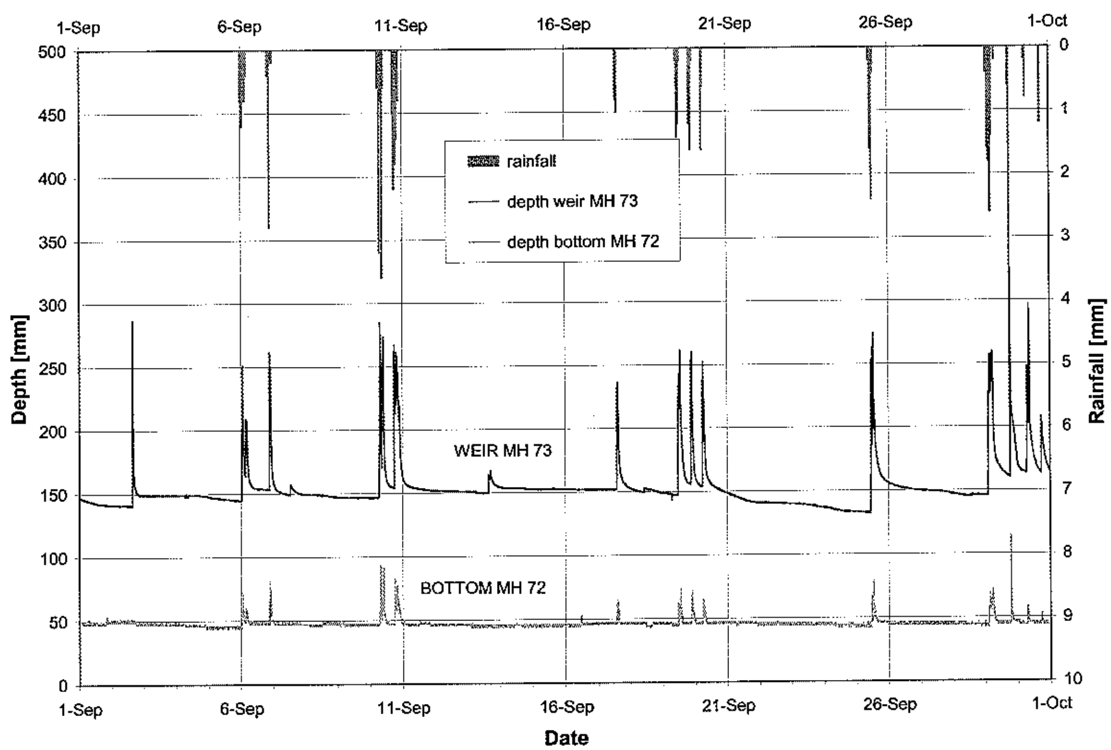


*Figure F.6:* Water depth and rainfall -- Princess Margaret exfiltration facility, September 1997

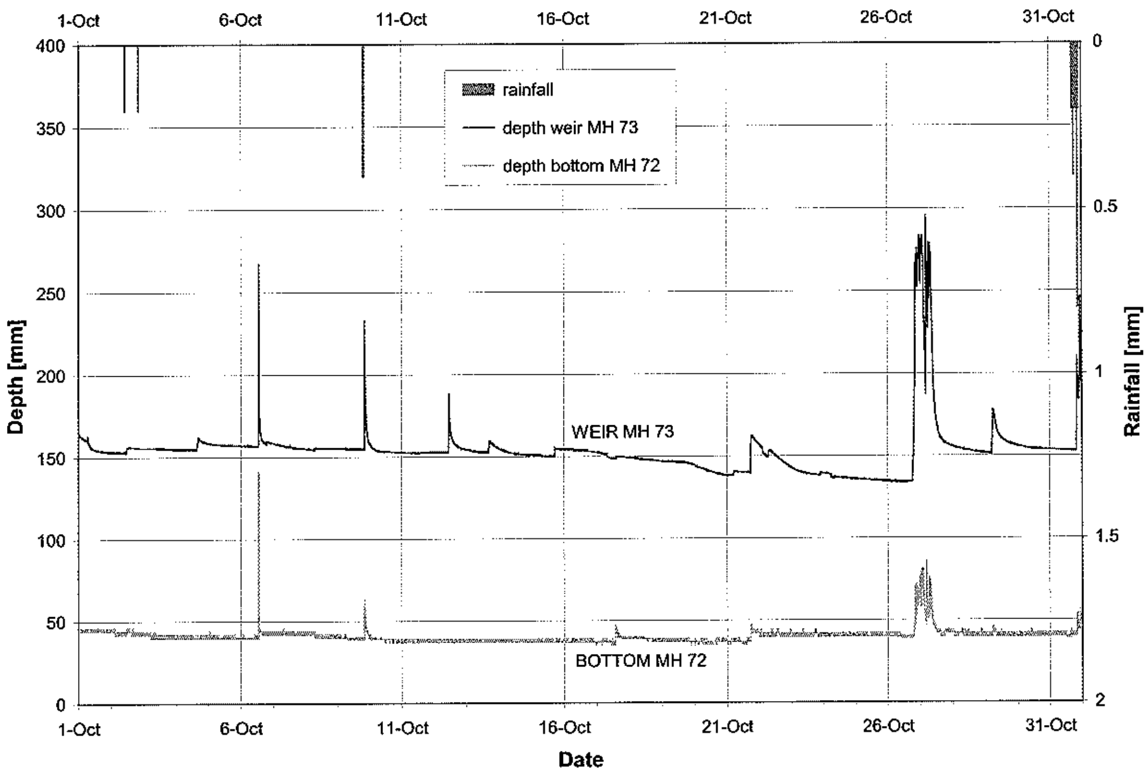


***Figure F.7:*** Water depth and rainfall -- Princess Margaret exfiltration facility, October 1997

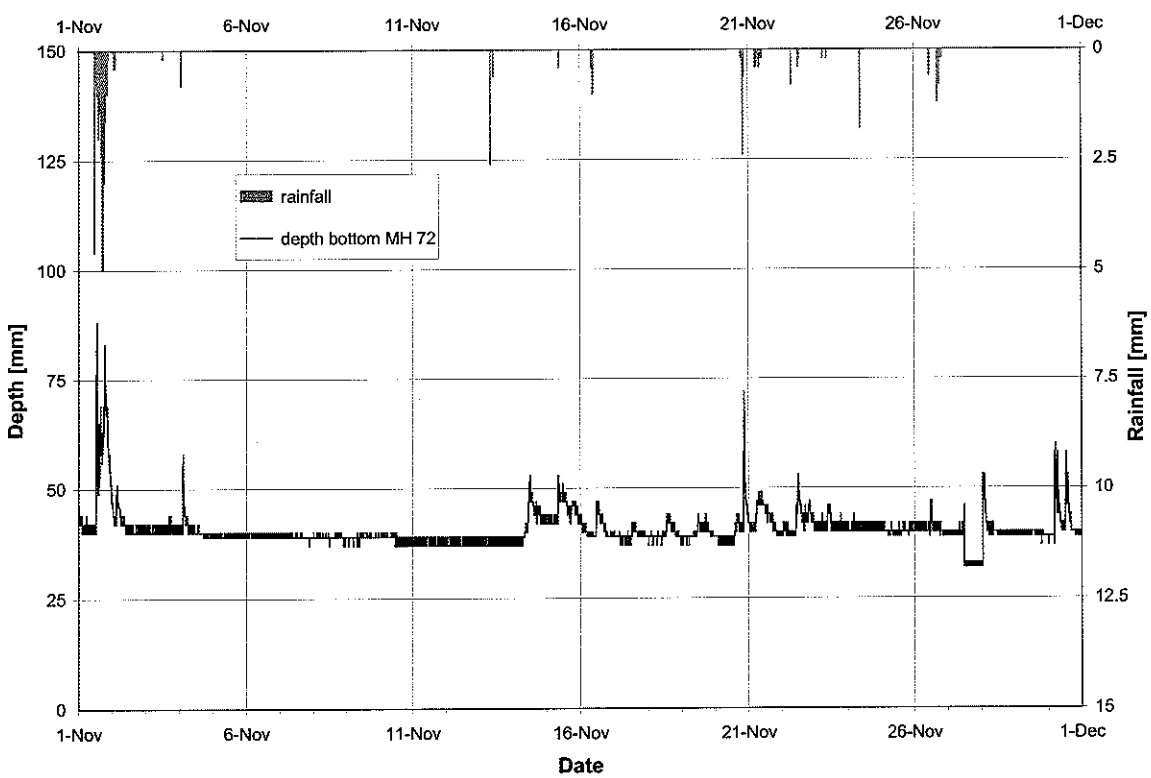


***Figure F.8:*** Water depth and rainfall -- Princess Margaret exfiltration facility, November 1997

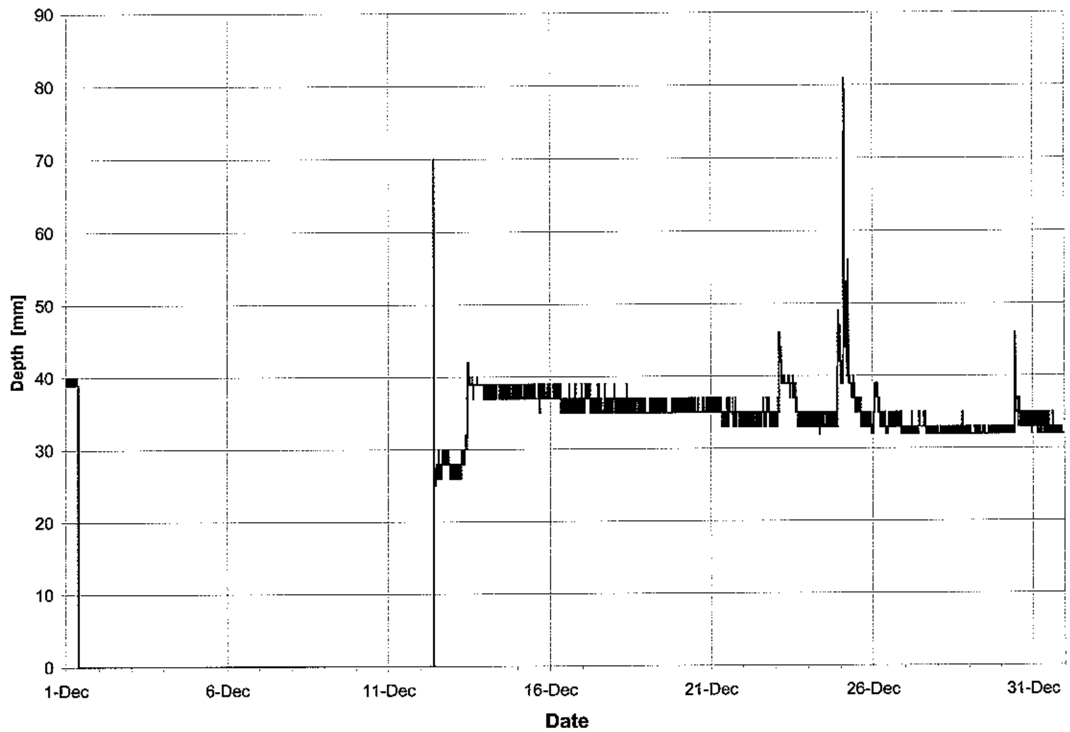


***Figure F.9:*** Water depth and rainfall -- Princess Margaret exfiltration facility, December 1997

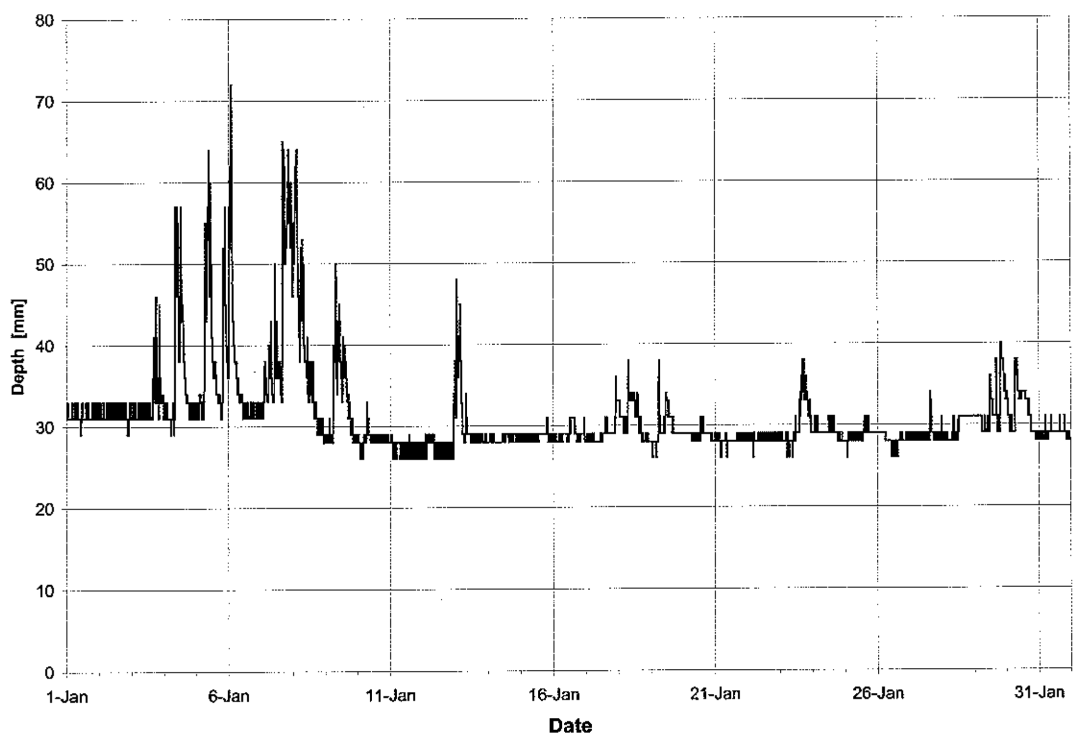


***Figure F.10:*** Water depth and rainfall -- Princess Margaret exfiltration facility, January 1998

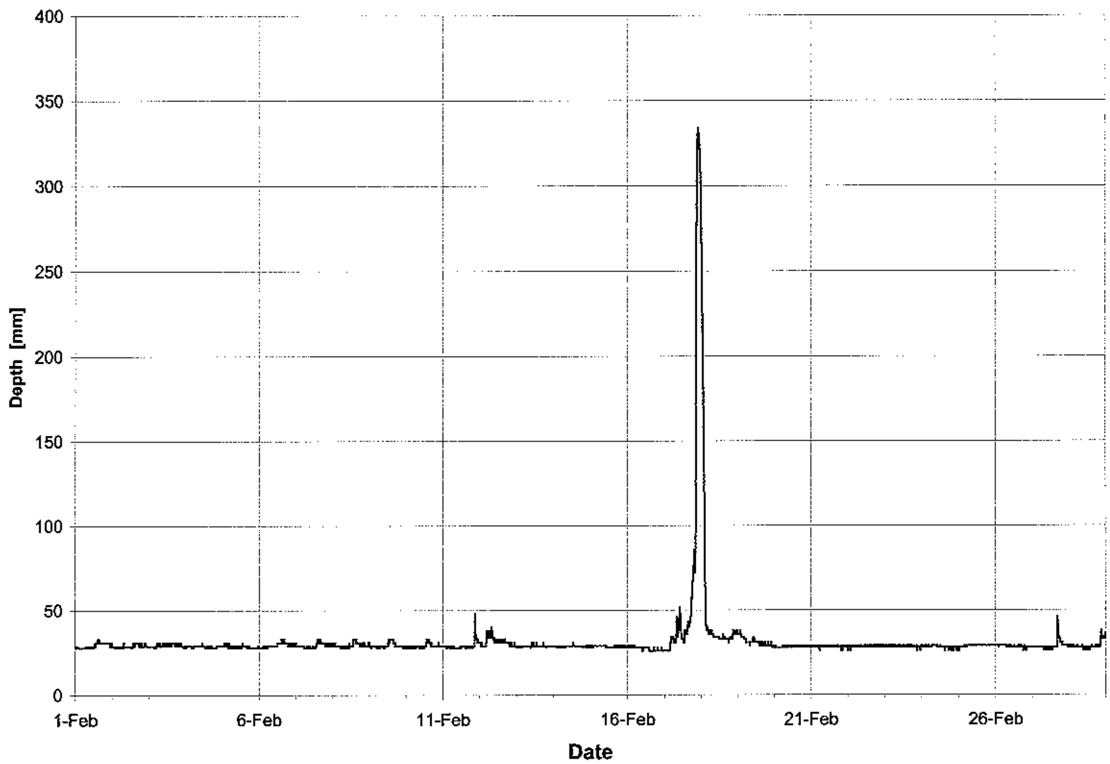


***Figure F.11:*** Water depth and rainfall -- Princess Margaret exfiltration facility, February 1998

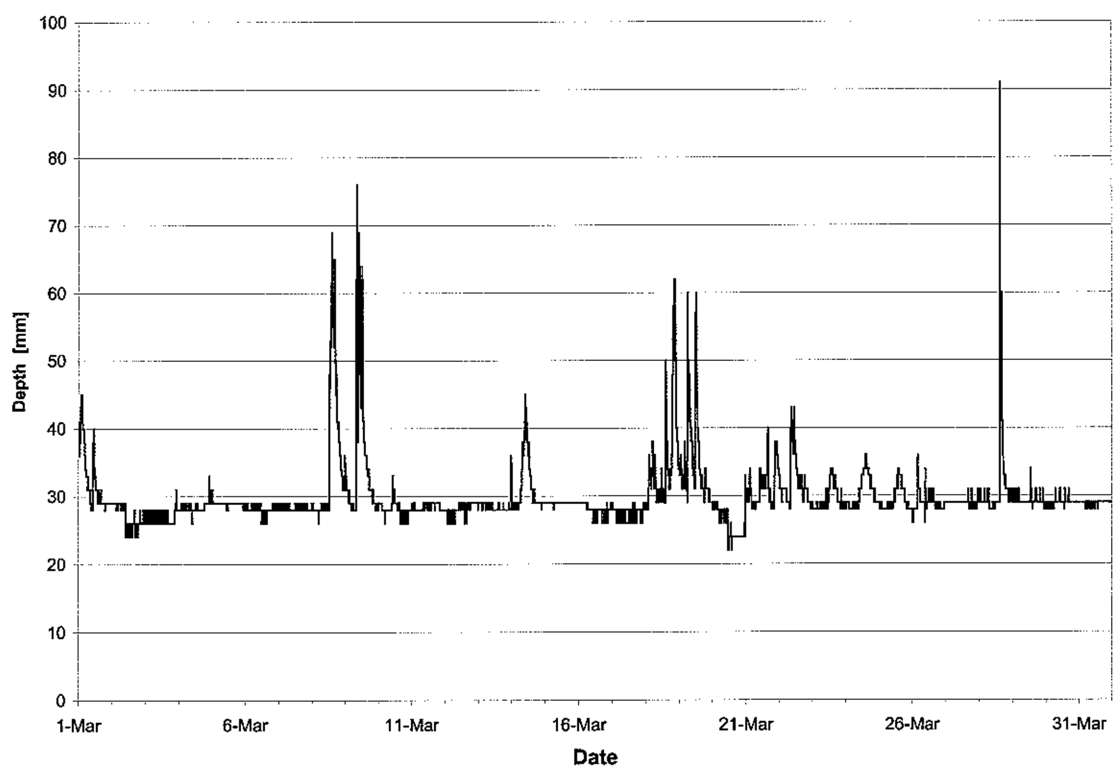


***Figure F.12:*** Water depth and rainfall -- Princess Margaret exfiltration facility, March 1998

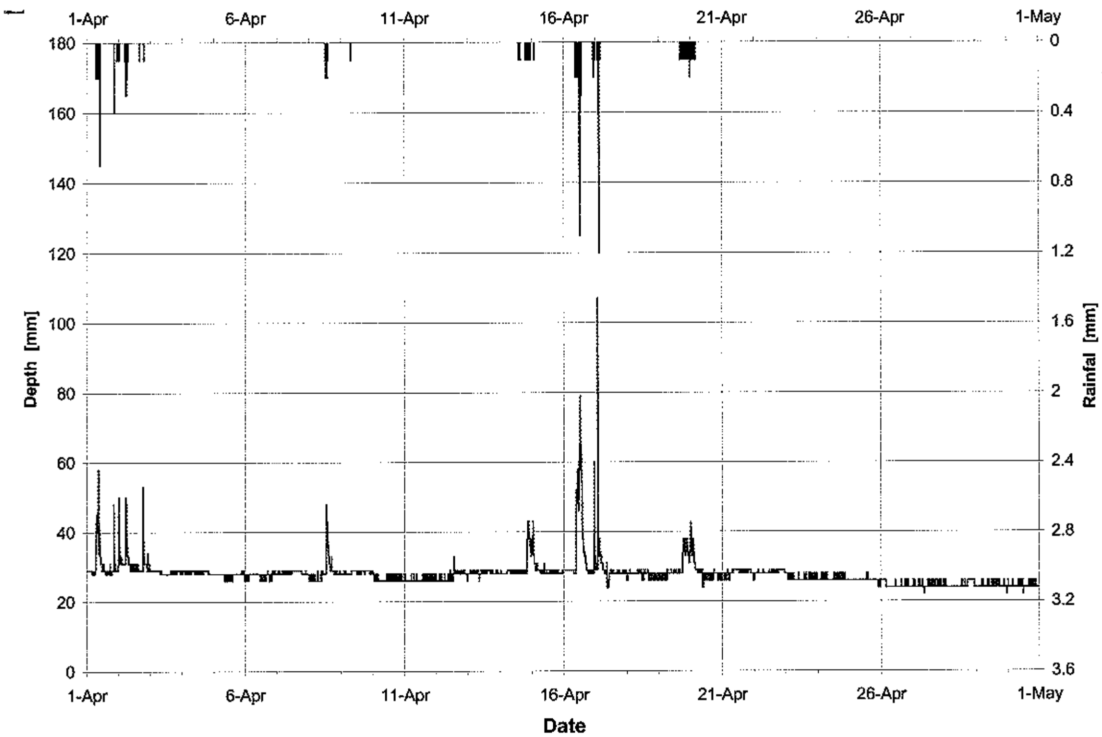


***Figure F.13:*** Water depth and rainfall -- Princess Margaret exfiltration facility, April 1998

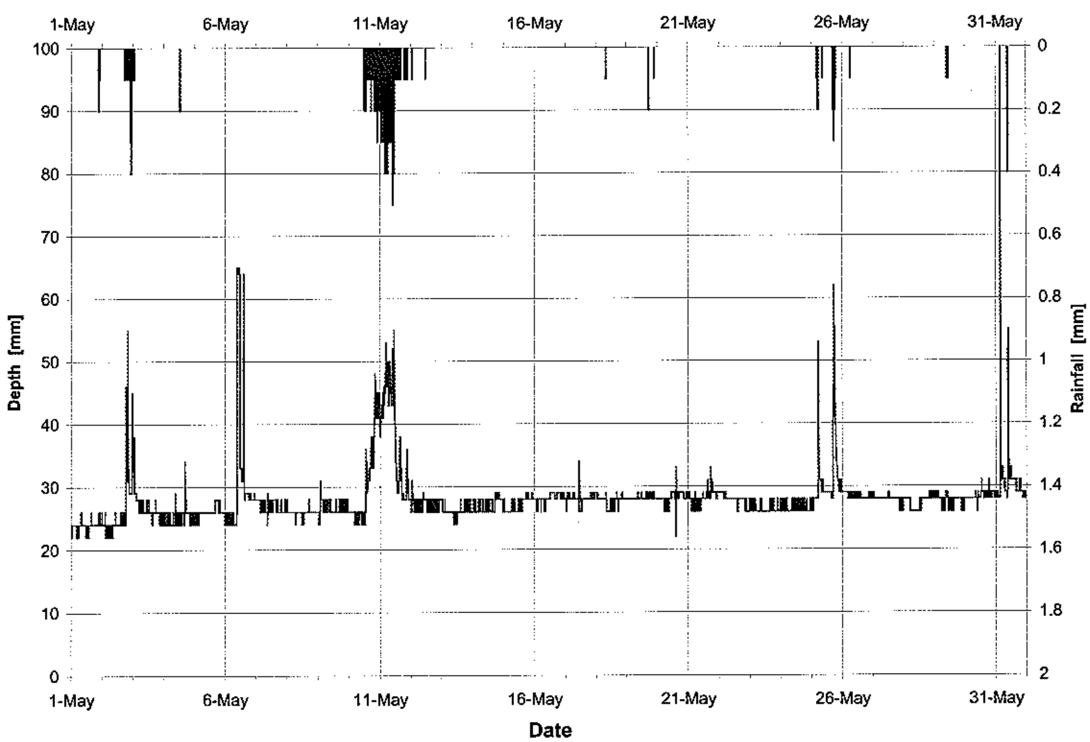


***Figure F.14:*** Water depth and rainfall -- Princess Margaret exfiltration facility, May 1998

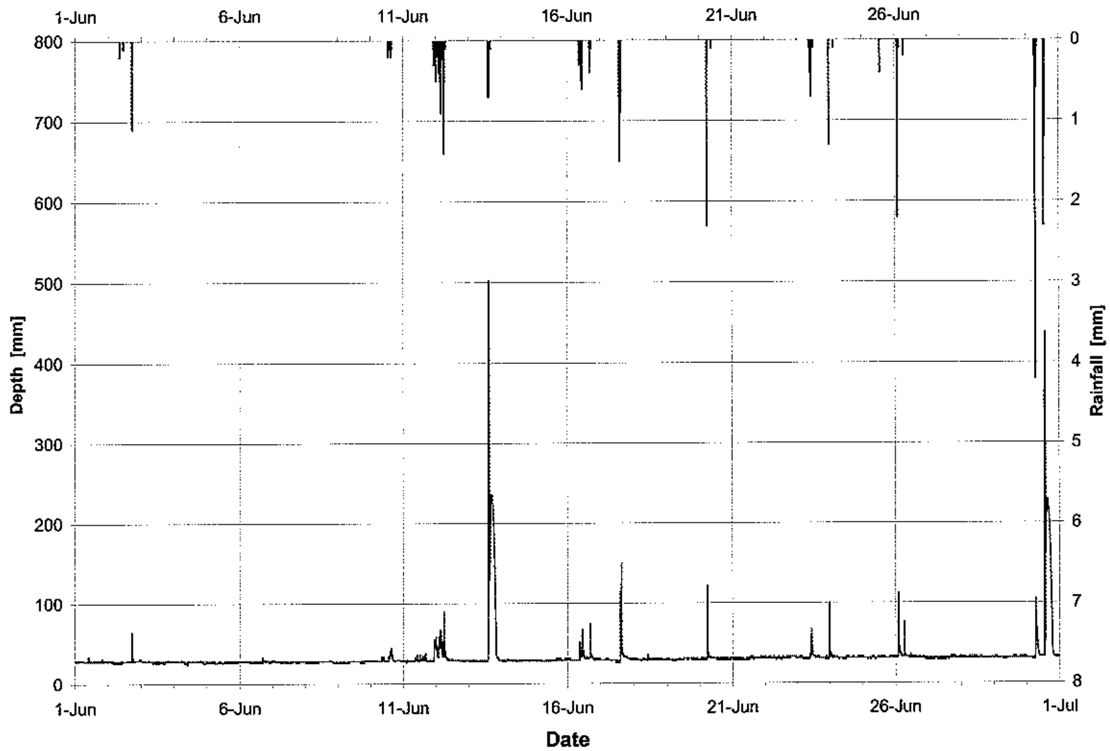


***Figure F.15:*** Water depth and rainfall -- Princess Margaret exfiltration facility, June 1998

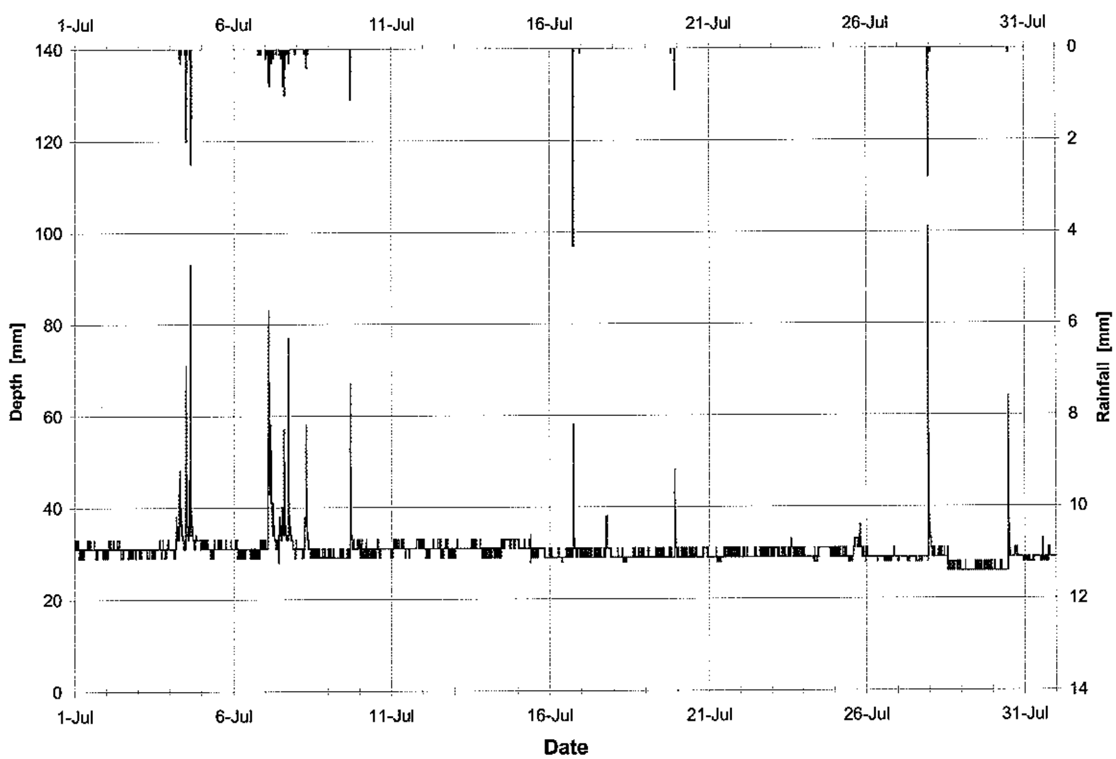


***Figure F.16:*** Water depth and rainfall -- Princess Margaret exfiltration facility, July 1998

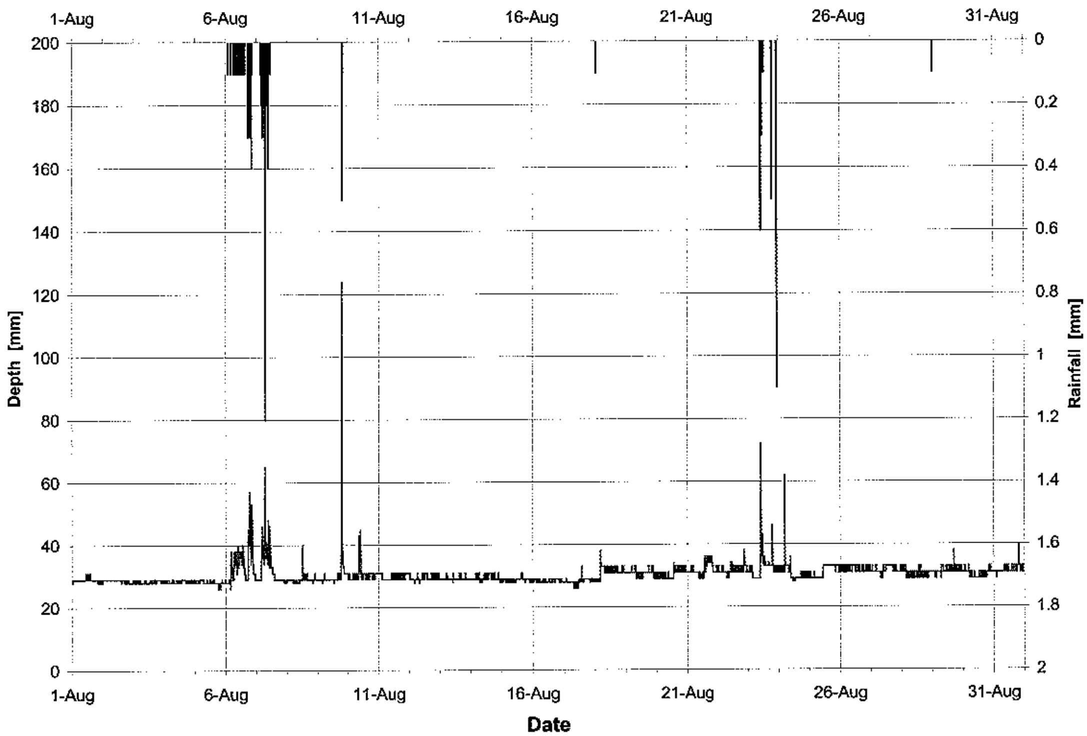


*Figure F.17:* Water depth and rainfall -- Princess Margaret exfiltration facility, August 1998

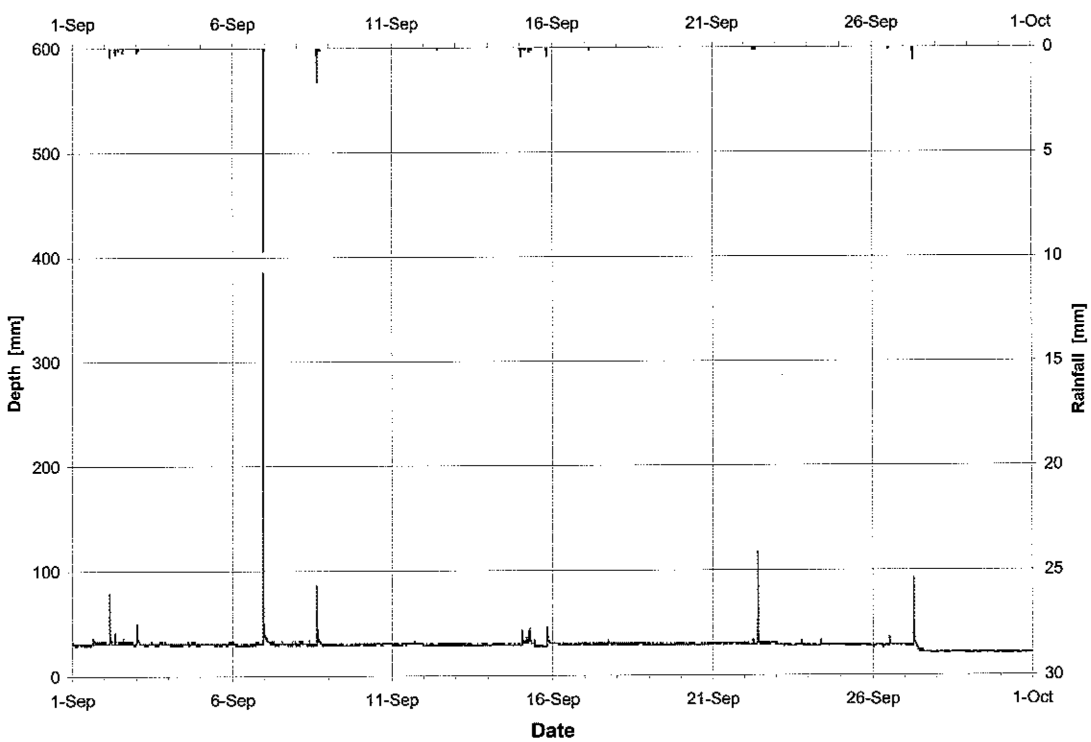


*Figure F.18:* Water depth and rainfall -- Princess Margaret exfiltration facility, September 1998

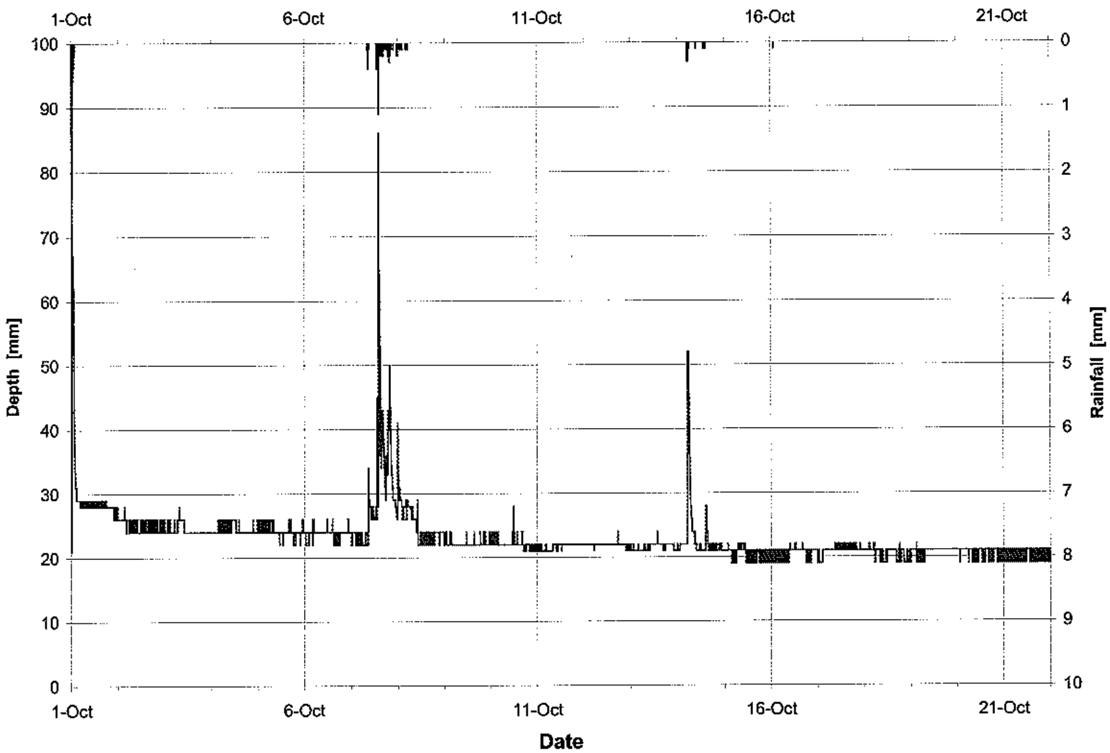


*Figure F.19:* Water depth and rainfall -- Princess Margaret exfiltration facility, October 1998

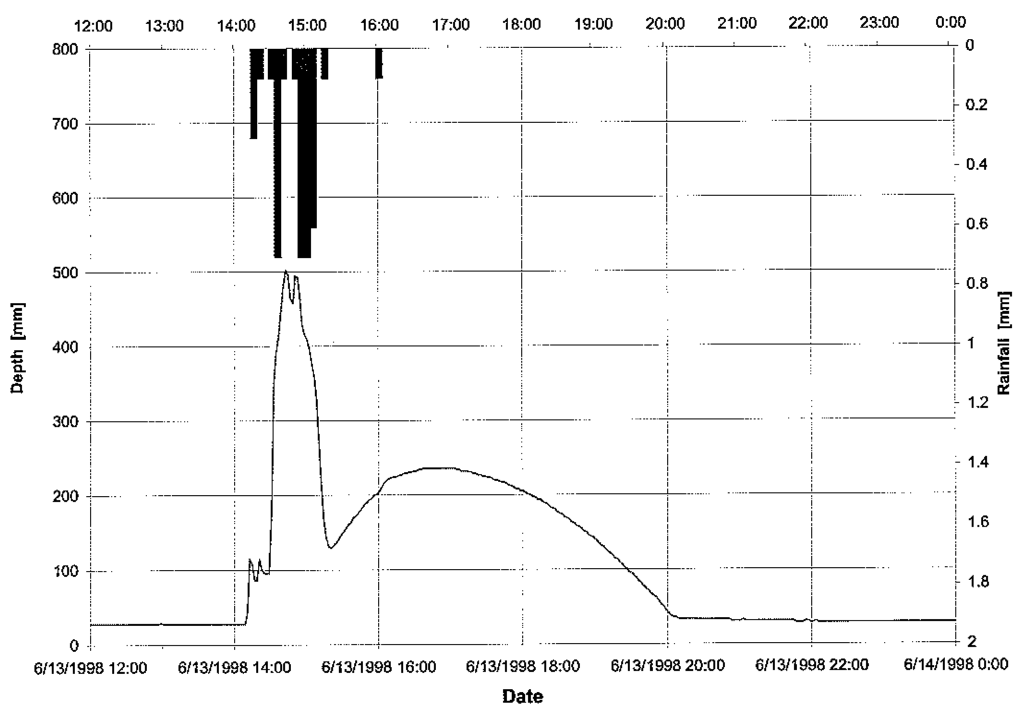


*Figure F.20:* Water depth and rainfall -- Princess Margaret exfiltration facility, June 13, 1998

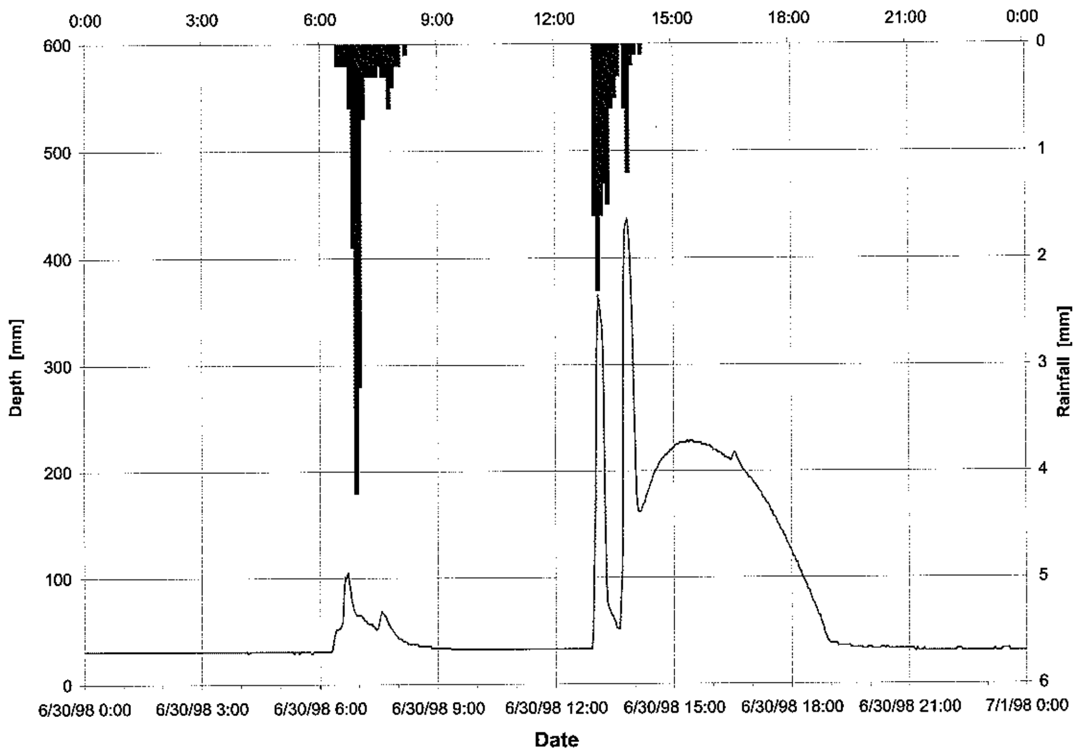


***Figure F.21:*** Water depth and rainfall -- Princess Margaret exfiltration facility, June 30, 1998

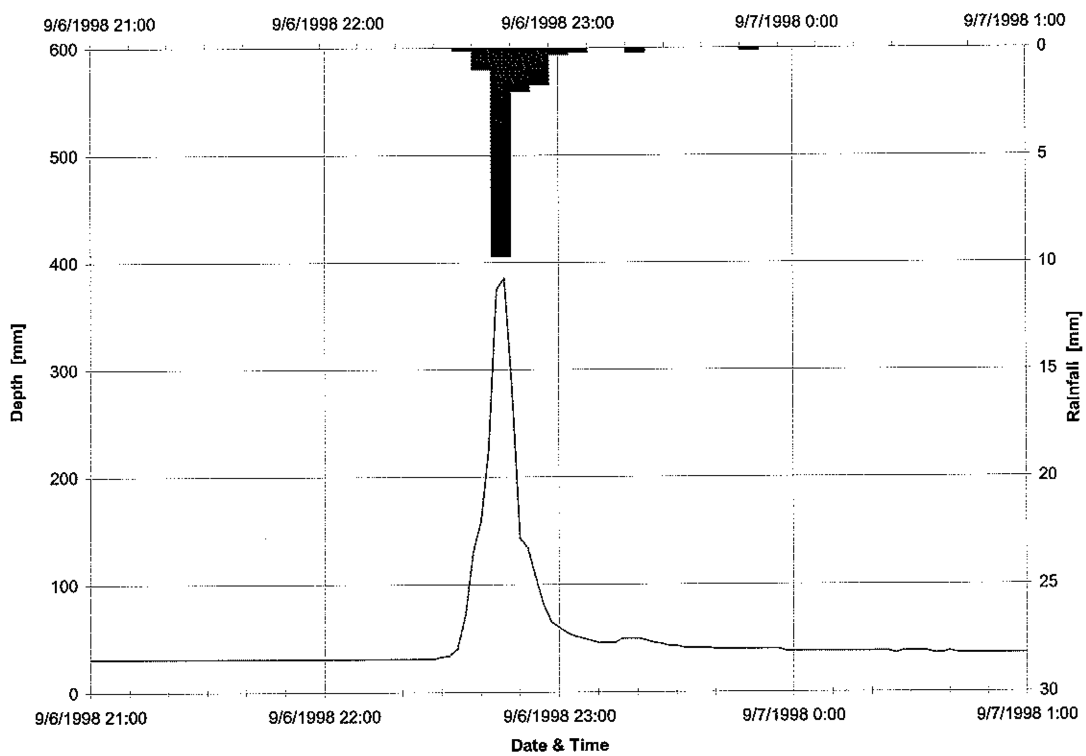


***Figure F.22:*** Water depth and rainfall -- Princess Margaret exfiltration facility, Sept. 6, 1998

***Table F.2:*** Summary of large rain events

| Date | Duration[1] (min) | Total Depth (mm) | Maximum 5-minute (mm) | Maximum hour (mm) | Overflow |
|---|---|---|---|---|---|
| Oct. 18, '96 | 840 | 26.7 | n/a | 14.0 | N |
| Nov. 7-8, '96 | 600 | 18.0 | n/a | 5.9 | N |
| Aug. 15, '97 | 240 | 20.8 | n/a | 11.0 | N |
| Aug. 20-21, '97 | 1,140 | 40.4 | n/a | 5.6 | N |
| Sep. 10, '97 | 600 | 16.0 | n/a | 3.6 | N |
| Nov. 1, '97 | 660 | 23.0 | n/a | 5.0 | N |
| May 10-11, '98 | 2,885 | 42.8 | 0.5 | 3.6 | N |
| June 11-13, '98 | 420 | 23.8 | 1.4 | 4.6 | N |
| June 13, '98 | 55 | 3.6 | 0.7 | 2.8 | Y |
| June 30, '98 | 170 | 26.8 | 4.2 | 10.7 | Y |
| Sept. 6, '98 | 45 | 15.3 | 9.7 | 14.8 | Y |

[1] Duration is based on the number of non-zero observations, and is not the elapsed time.

Overflow conditions result from some combinations of rainfall volume, duration and intensity. The overflow events of June 30th and September 6th, 1998 had volumes and intensities that caused overflows, but events with larger volumes and longer durations did not. The event of September 6th was similar to the design storm, in that the overall duration was approximately one hour and the total rainfall depth was approximately 15 mm.

Antecedent conditions may also have an effect on capacity by raising the groundwater table, saturating the soil and reducing percolation rates, and possibly leaving some water in the gravel bed. This condition may have contributed to the event on June 13, 1998. Rain occurring from late on the 11th to the morning of the 12th may have affected the event that began at 14:15 on the 13th. Alternative hypotheses may be postulated to suggest a very localized intense storm condition not reflected in the rain data, or an extraneous source of water, such as from street cleaning or water main flushing, that may have contributed to the overflow condition.

Some storms of moderate duration and volume, but high peak flow, also did not cause overflows (Oct. 18, 1996 and Aug. 15, 1997). Comparison of the 1996 and 1997 events to those that caused overflows in 1998 suggests that some capacity change may have been occurring over time. TSS concentrations of up to 895 mg/L and turbidities of up to 200 FTU, particularly in early 1998, may have been responsible for plugging of the filter fabric around the exfiltration pipes or other parts of the system.

The shapes of the hydrographs are also of interest. The hydrographs from June 13 and June 30 include a post-rainfall surge of effluent flow that does not appear in the hydrograph for September 6$^{th}$. Hydrographs from the first two events appear to consist of two superimposed hydrographs, the first resulting from overflow that moved through the main sewer pipes, and the second being caused by a storage effect. If that interpretation is correct, water held in upstream portions of the sewer system was migrating downstream in the gravel bed and re-entering the main storm sewer. Assuming that there is sufficient gradient in a system, water in an upstream portion of the gravel trench would move down-grade through the soil or around the maintenance holes to a lower section of trench. At the lowest point, the resulting water depth may be sufficient that water flows from the trench into the maintenance hole through the perforated pipes. That hypothetical flow pattern would cause a delayed and smooth outflow hydrograph in addition to the earlier and more peaked runoff hydrograph.

The earlier study of the Princess Margaret facility (Candaras Associates, 1997) had been conducted at the upstream end of the system. Water level probes in the gravel bed indicated that the stored water was draining down rapidly after the termination of the runoff. The hydrographs in Figures F.20 and F.21 suggest that some of the stored water was migrating downstream within the system rather than leaving the system to become groundwater.

The fact that the September 6$^{th}$ event had a different hydrograph shape may have resulted from the dry antecedent conditions. The previous four to five days had been dry and little rain had fallen for the past 15 days. By comparison, two events occurred in rapid succession on June 30$^{th}$ and a large volume of rainfall had occurred on June 11 to 13, several hours before the small June 13$^{th}$ event.

Although the database is limited, the results indicate a complex relationship between exfiltration (i.e., water loss by percolation into the soil) and internal flow down-slope in the gravel trench contributing to a delayed overflow, with the relationship influenced by soil moisture conditions. Based on the Princess Margaret downstream system dimensions, the gravel trench is approximately 1 metre wider than the maintenance hole (2.1 m wider than the main pipe outside diameter as seen in Figure 2.1). Hence, flow in the downstream direction is likely to occur unless special measures are taken to create a barrier to flow. Alternative approaches to design might include providing an increased storage volume at the downstream end of the system, or building short sections of exfiltration sewer on the flatter gradients with intervening sections of conventional sewer that will block the downstream migration of stored runoff.

### F.2.2 Water quality data

The water quality data are presented in Table F.3. A number of sampling techniques were used. The automatic sampler that collected a composite sample of the overflow was apparently activated only three times (June 13, June 30 and September 6, 1998). However, there were no samples reported on June 13 or September 6, 1998. Field notes indicate that the sampling bucket was completely submerged on June 30$^{th}$ and that a grab sample of the overflow was collected; the grab sample was analyzed for bacteria and the results of the two samples have been combined in Table F.3.

All other samples must have been bucket or grab samples. The available documentation distinguishes between bucket composite samples and bucket grab samples, with the difference presumably being the length of time over which the sample was collected.

Note that, without an overflow condition, the material being sampled would be the discharge of the catch basins located between MH 71 and MH 72.

The general trends were as might be expected:

- The average suspended solids concentration was greater in summer (summer/fall sampling period) than in winter (winter/spring sampling period), but the turbidity was greater in winter.
- Both the chloride concentration and the conductivity of the outflow were one order of magnitude greater in winter than in summer.
- Nutrient, bacteria and biocide concentrations were greater in summer than in winter.
- Some inorganic constituent concentrations were greater in summer, others were greater in winter.

Possible anomalies are:

- Fecal streptococcus concentrations were occasionally much greater than fecal coliform concentrations.
- One or more spills or dumping of the herbicide 2,4-D appear to have taken place beginning in August of 1998.

### F.2.3 Particle size distributions

The particle size distributions for the summer/fall period samples are illustrated in Figure F.23. The distributions are seen to have an appreciable range. Several factors may be postulated to explain the differences seen in this graph. The laser scanning method used for analysis may lose accuracy if too much or too little material is in suspension. Smaller particle sizes are generally associated with greater turbidity values. However, inspection of the results has suggested that the sampling procedure has affected the results. The larger average sizes are generally the result of composite samples that presumably caught the "first flush" of solids. Also, as discussed in Appendix E, the bucket-composite sampling method may have had a tendency to accumulate larger particles. The finer particles are generally associated with grab samples that presumably were taken some time after the event began and would have missed the "first flush".

Figure F.24 contains the particle size distributions from the winter/spring monitoring period. In this case, the smaller particle sizes appear to be associated with low TSS values. The coarsest average particle size came from a suspension with a TSS concentration of 495 mg/L.

*Table F.3*: Princess Margaret Boulevard -- water quality results

| Parameter & Units / Date & Sample Type | MDL | PWQO | 30/10/96, type?, 9.1 mm rainfall | 13/11/96, type?, no rainfall | 17/12/96, type?, winter | 03/01/97, type?, winter | 22/01/97, type?, winter | 18/02/97, type?, winter | 21/02/97, type?, winter | 27/02/97, type?, winter | 25/03/97, type?, winter | 06/05/97, grab, rainfall n/a | 21/11/97, b-g, 1.8 mm rainfall | 04/12/97, b-g, winter | 05/01/98, grab, winter | 08/01/98, grab, winter | 09/01/98, grab, winter | 12/02/98, b-g, winter | 02/03/98, b-c, winter | 09/03/98, b-c, winter |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **General Water Chemistry** | | | | | | | | | | | | | | | | | | | | |
| Suspended Solids mg/L | 2.5 | | 253.0 | 248.0 | 20.0 | 12.0 | 169.0 | 63.0 | 17.0 | 34.0 | 28.0 | 78.0 | 149.0 | 52.5 | 41.5 | 14.5 | 15.0 | 200.0 | 108.0 | 31.0 |
| Turbidity FTU | 0.01 | | 23.20 | 11.40 | 17.60 | 10.60 | 122.00 | 54.20 | 28.90 | 66.20 | 47.50 | 17.90 | 150.00 | 200.00 | 35.20 | 38.00 | 20.00 | 203.00 | 53.70 | 53.20 |
| pH | N/A | 6.5 - 8.5 | 7.27 | 8.06 | 7.80 | 7.80 | 7.48 | 7.38 | 7.71 | 7.89 | 7.33 | 7.91 | 7.57 | 7.28 | 7.51 | 7.83 | 7.56 | 7.70 | 7.81 | 7.75 |
| Alkalinity mg/l CaCO3 | 0.25 | | 56.60 | 122.00 | 34.40 | 95.80 | 58.20 | 31.00 | 41.20 | 76.00 | 46.00 | 50.40 | 72.00 | 35.20 | 29.20 | 68.80 | 31.00 | 100.00 | 69.20 | 60.20 |
| Chloride mg/L | 0.2 | | 9.2 | 18.2 | 52.8 | 6,340.0 | 3,260.0 | 4,220.0 | 124.0 | 306.0 | 190.0 | 14.8 | 586.0 | 32.0 | 63.6 | 217.0 | 59.2 | 1,320.0 | 163.0 | 128.0 |
| Conductivity µS/cm | 1 | | 167 | 357 | 290 | 18,600 | 9,530 | 12,000 | 520 | 1,190 | 772 | 214 | 2,340 | 246 | 482 | 814 | 306 | 4,080 | 667 | 626 |
| **Nutrients** | | | | | | | | | | | | | | | | | | | | |
| Total Ammonium mg/L | 0.002 | | 0.166 | 0.120 | 0.216 | 0.522 | 0.636 | 0.506 | 0.258 | 0.324 | 0.502 | 0.270 | 0.256 | 0.676 | 0.108 | 0.152 | 0.228 | 0.162 | 0.118 | 0.160 |
| Nitrite mg/L | 0.001 | | 0.010 | 0.096 | 0.013 | 0.105 | 0.171 | 0.096 | 0.040 | 0.056 | 0.045 | 0.028 | 0.275 | 0.139 | 0.041 | 0.067 | 0.044 | 0.133 | 0.052 | 0.049 |
| Nitrate + nitrite mg/L | 0.005 | | 0.155 | 0.965 | 0.535 | 0.970 | 0.845 | 0.800 | 0.800 | 0.870 | 1.040 | 1.870 | 2.920 | 1.130 | 0.410 | 0.725 | 0.355 | 1.870 | 1.140 | 0.485 |
| Total Kjeldahl Nitrogen mg/L | 0.02 | | 3.50 | 9.00 | 0.64 | 0.54 | 2.90 | 1.44 | 1.00 | 1.70 | 1.36 | 0.84 | 3.10 | 1.30 | 0.62 | 0.70 | 0.48 | 2.40 | 1.30 | 0.84 |
| Total Phosphorus mg/L | 0.002 | 0.01 - 0.03 | 0.524 | 0.624 | 0.126 | 0.080 | 0.420 | 0.204 | 0.180 | 0.530 | 0.184 | 0.110 | 0.520 | 0.150 | 0.106 | 0.136 | 0.058 | 0.540 | 0.216 | 0.184 |
| Phosphate mg/L | 0.0005 | | 0.5450 | 0.2500 | 0.0615 | 0.0730 | 0.2470 | 0.0870 | 0.1040 | 0.4000 | 0.0600 | 0.0295 | 0.1750 | 0.0230 | 0.0335 | 0.0700 | 0.0400 | 0.0625 | 0.0595 | 0.0800 |
| **Organics** | | | | | | | | | | | | | | | | | | | | |
| Carbon, Dissolved Organic mg/L | 0.1 | | 7.1 | 9.7 | 1.5 | | 3.0 | 2.0 | 3.1 | 4.0 | 3.3 | 2.8 | 3.8 | 3.4 | 1.5 | 4.0 | 2.5 | 2.9 | 3.4 | 3.5 |
| Solvent extractable mg/L | 1 | | 6.5 | 6.0 | 1.5 | 0.5 | 30.0 | 12.0 | 1.5 | 3.5 | 3.5 | 2.5 | 18.0 | 7.5 | 6.0 | 2.5 | 3.0 | 15.0 | 5.0 | 3.0 |
| **Inorganics** | | | | | | | | | | | | | | | | | | | | |
| Aluminum µg/L | 11 | 75 | 717 | 515 | 286 | 118 | 817 | 241 | 324 | 644 | 486 | 434 | 935 | 353 | 378 | 388 | 183 | 1,160 | 810 | 649 |
| Arsenic mg/L | 0.001 | 0.1 | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | 0.001 | 0.002 | <MDL | <MDL | <MDL | <MDL | <MDL | 0.001 | <MDL | 0.001 | 0.001 | <MDL |
| Barium µg/L | 0.2 | | 23.1 | 20.9 | 8.1 | 112.0 | 45.8 | 21.7 | 7.1 | 16.9 | 13.8 | 10.0 | 48.7 | 15.1 | 11.9 | 14.2 | 7.9 | 58.7 | 24.2 | 14.5 |
| Beryllium µg/L | 0.02 | | 0.07 | 0.05 | 0.01 | 0.02 | 0.05 | 0.01 | 0.02 | 0.04 | 0.03 | 0.04 | 0.06 | 0.02 | 0.02 | 0.03 | 0.01 | 0.09 | 0.06 | 0.04 |
| Cadmium µg/L | 0.6 | 0.2 | 0.8 | 1.4 | 0.1 | 0.3 | 1.2 | 0.6 | 0.1 | 0.0 | <MDL | 0.3 | 1.1 | 0.8 | 0.6 | 0.0 | <MDL | 0.7 | 1.3 | 0.2 |
| Calcium mg/L | 0.005 | | 27.700 | 49.100 | 14.700 | 165.000 | 70.600 | 54.900 | 15.800 | 37.700 | 25.800 | 31.100 | 66.200 | 20.700 | 13.700 | 35.000 | 15.900 | 136.000 | 42.900 | 21.800 |
| Carbon, Dissolved Inorganic mg/L | 0.2 | | 14.6 | 27.8 | 7.6 | 21.8 | 11.8 | 6.8 | 9.0 | 17.0 | 10.4 | 11.8 | 17.4 | 8.6 | 8.6 | 16.2 | 6.8 | 23.0 | 15.8 | 14.4 |
| Chromium µg/L | 1.4 | 8.9 as $Cr^{III}$ | 4.0 | 1.9 | 1.7 | 2.3 | 13.8 | 5.4 | 1.5 | 4.4 | 3.3 | 3.5 | 10.8 | 5.6 | 4.3 | 1.9 | 1.2 | 15.3 | 8.7 | 5.0 |
| Cobalt µg/L | 1.3 | 0.9 | 1.0 | <MDL | 0.2 | <MDL | 1.2 | 1.1 | 0.7 | 0.4 | 0.3 | 0.1 | 1.1 | 0.5 | <MDL | <MDL | <MDL | 0.7 | 1.1 | 0.8 |
| Copper µg/L | 1.6 | 5 | 39.7 | 22.2 | 7.6 | 10.5 | 58.5 | 19.9 | 10.8 | 15.0 | 12.2 | 11.4 | 40.3 | 15.6 | 16.6 | 9.8 | 9.3 | 56.8 | 36.4 | 11.8 |
| Iron µg/L | 0.8 | 300 | 1,930.0 | 1,160.0 | 461.0 | 311.0 | 1,920.0 | 462.0 | 425.0 | 1,000.0 | 699.0 | 698.0 | 2,620.0 | 786.0 | 784.0 | 418.0 | 303.0 | 2,110.0 | 1,800.0 | 533.0 |
| Lead µg/L | 10 | 25 | 17 | 12 | 9 | 1 | 81 | 12 | 9 | 12 | 14 | 6 | 50 | 20 | 14 | 9 | 9 | 82 | 24 | 10 |
| Magnesium mg/L | 0.008 | | 7.580 | 10.300 | 1.960 | 16.200 | 7.130 | 3.050 | 2.570 | 5.480 | 3.390 | 5.180 | 10.400 | 2.500 | 2.380 | 3.980 | 1.820 | 19.100 | 8.050 | 2.700 |
| Manganese µg/L | 0.2 | | 267.0 | 153.0 | 36.0 | 72.2 | 239.0 | 98.4 | 33.2 | 77.2 | 57.7 | 90.7 | 199.0 | 93.3 | 70.3 | 48.9 | 34.4 | 258.0 | 205.0 | 56.2 |
| Mercury µg/L | 0.02 | 0.2 | 0.03 | <MDL | <MDL | <MDL | 0.03 | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | 0.03 | <MDL | <MDL | 60.00 | 0.04 | 0.04 | <MDL |
| Molybdenum µg/L | 1.6 | 40 | 0.2 | 0.1 | <MDL | <MDL | <MDL | <MDL | 0.2 | <MDL | 0.1 | <MDL | 0.4 | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL |
| Nickel µg/L | 1.3 | 25 | 4.0 | 2.3 | 0.5 | 0.4 | 3.5 | 2.0 | 2.1 | 2.0 | 1.3 | 2.0 | 3.7 | 2.1 | 1.4 | 1.5 | 0.4 | 4.3 | 4.4 | 1.9 |
| Selenium mg/L | 0.001 | 0.1 | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | 0.001 | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL |
| Silicon mg/L | 0.02 | | 0.64 | 2.24 | 0.42 | 1.30 | 0.80 | 0.34 | 0.78 | 1.48 | 0.64 | 1.20 | 0.96 | 0.46 | 0.22 | 0.84 | 0.28 | 1.40 | 0.90 | 0.78 |
| Strontium µg/L | 0.1 | | 58.0 | 133.0 | 70.5 | 1,120.0 | 612.0 | 636.0 | 96.7 | 209.0 | 152.0 | 170.0 | 284.0 | 127.0 | 73.9 | 228.0 | 111.0 | 558.0 | 250.0 | 145.0 |
| Titanium µg/L | 0.5 | | 1.9 | 8.8 | 3.6 | 0.1 | 10.8 | 5.6 | 3.1 | 3.0 | 3.4 | 10.9 | 7.5 | 4.3 | 8.1 | 2.8 | 3.2 | 11.5 | 5.7 | 9.9 |
| Vanadium µg/L | 1.5 | 6 | 3.6 | 1.9 | 1.2 | 0.4 | 5.7 | 1.4 | 1.3 | 2.4 | 2.5 | 2.7 | 5.9 | 2.3 | 2.6 | 0.6 | 0.9 | 6.8 | 3.9 | 2.5 |
| Zinc µg/L | 0.6 | 30 | 160.0 | 82.9 | 59.8 | 39.1 | 320.0 | 96.4 | 40.9 | 74.2 | 66.9 | 54.0 | 252.0 | 90.2 | 96.8 | 49.6 | 45.7 | 314.0 | 241.0 | 57.1 |
| **Bacteria** | | | | | | | | | | | | | | | | | | | | |
| Escherichia coli c/100mL | N/A | 100 | | | 40 | | 20 | 10 | | 180 | 10 | | | 140 | | | | 80 | | 10 |
| Fecal streptococcus c/100mL | N/A | | | | 460 | | 880 | 100 | | 780 | 270 | | | | | | | 38,000 | | 210 |
| Pseudomonas aeruginosa c/100mL | N/A | | | | 10 | | 60 | 10 | | 12 | 10 | | | | | | | 20 | | 4 |
| **Organics** | | | | | | | | | | | | | | | | | | | | |
| 2,4-dichlorophenol, ng/L | 2000 | 4,000 | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | | <MDL | | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL |
| 2,4,6-trichlorophenol, ng/L | 20 | 18,000 | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | | <MDL | | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL |
| 2,4,5-trichlorophenol, ng/L | 100 | 18,000 | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | | <MDL | | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL |
| 2,3,4-trichlorophenol, ng/L | 100 | 18,000 | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | | <MDL | | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL |
| 2,3,4,5-tetrachlorophenol, ng/L | 20 | 1,000 | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | | <MDL | | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL |
| 2,3,4,6-tetrachlorophenol, ng/L | 20 | 1,000 | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | | <MDL | | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL |
| Pentachlorophenol, ng/L | 10 | 500 | 28 | <MDL | <MDL | 11 | <MDL | <MDL | 28 | <MDL | <MDL | | <MDL | | <MDL | 11 | <MDL | <MDL | 13 | 10 |
| Dicamba, ng/L | 50 | 200,000 | <MDL | <MDL | <MDL | <MDL | 64 | <MDL | <MDL | <MDL | <MDL | | 150 | | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL |
| Bromoxynil, ng/L | 50 | | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | | <MDL | | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL |
| 2,4-D-propionic acid, ng/L | 100 | | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | | <MDL | | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL |
| 2,4-D, ng/L | 100 | 4,000 | 340 | 110 | <MDL | 130 | <MDL | 190 | 150 | 280 | <MDL | | <MDL | | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL |
| Silvex, ng/L | 20 | | <MDL | <MDL | <MDL | <MDL | <MDL | 36 | <MDL | <MDL | <MDL | | <MDL | | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL |
| 2,4,5-T, ng/L | 50 | 18,000 | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | | <MDL | | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL |
| 2,4-DB, ng/L | 200 | | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | | <MDL | | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL |
| Picloram, ng/L | 100 | | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | | <MDL | | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL |
| Diclofop-methyl, ng/L | 100 | | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | | <MDL | | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL |

| Parameter & Units / Date & Sample Type | 09/03/98, grab, winter | 19/03/98, b-g, winter | 08/04/98, b-g, winter (2.3 mm rainfall) | 17/04/98, b-g, winter (2.2 mmrainfall) | 11/05/98, type?, 31.0 mm rainfall | 12/06/98, bucket, 17.1 mm rainfall | 17/06/98, bucket, 5.1 mm rainfall | 18/06/98, b-c, no rainfall reported | 30/06/98, bucket, 26.8 mm rainfall | 06/07/98, b-g, 0.9 mm rainfall | 08/07/98, b-c, 2.1 mm rainfall | 28/07/98, b-g, 0.1 mm rainfall | 06/08/98, type?, 10.7 mm rainfall | 10/08/98, type?, no rainfall reported | 24/08/98, b-g, no rainfall reported | 02/09/98, b-c, 2.0 mm rainfall | 08/09/98, b-c, 2.8 mm rainfall | 15/09/98, b-c, 3.7 mm rainfall | average, summer | average, winter | summer - winter |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **General Water Chemistry** | | | | | | | | | | | | | | | | | | | | | |
| Suspended Solids mg/L | 53.0 | 73.5 | 42.0 | 495.0 | 12.5 | 147.0 | 895.0 | 139.0 | 37.5 | 9.0 | 33.5 | 107.0 | 27.0 | 2.5 | 212.0 | 170.0 | 407.0 | 28.5 | 164.2 | 81.6 | 82.6 |
| Turbidity FTU | 70.60 | 56.30 | 18.40 | 139.00 | 10.40 | 42.10 | 200.00 | 54.80 | 25.40 | 5.64 | 4.54 | 16.30 | 28.70 | 1.55 | 47.10 | 23.20 | 80.20 | 14.50 | 42.05 | 68.58 | -26.53 |
| pH | 7.78 | 7.97 | 7.75 | 7.75 | 7.34 | 7.85 | 9.82 | 8.13 | 7.39 | 6.83 | 7.66 | 7.32 | 7.00 | 7.84 | 7.03 | 7.09 | 7.56 | 7.02 | 7.59 | 7.67 | -0.08 |
| Alkalinity mg/l CaCO3 | 78.40 | 87.20 | 40.20 | 153.00 | 29.60 | 81.80 | 93.20 | 179.00 | 29.60 | 44.00 | 40.40 | 54.00 | 28.20 | 300.00 | 39.40 | 39.40 | 91.00 | 22.60 | 76.29 | 63.06 | 13.23 |
| Chloride mg/L | 171.0 | 405.0 | 22.0 | 492.0 | 16.8 | 21.4 | 9.4 | 147.0 | 9.4 | 16.8 | 6.8 | 4.0 | 6.2 | 184.0 | 12.6 | 8.8 | 53.4 | 4.0 | 62.7 | 975.9 | -913.2 |
| Conductivity µS/cm | 788 | 1,580 | 217 | 1,950 | 124 | 273 | 218 | 979 | 105 | 167 | 134 | 143 | 152 | 1,260 | 168 | 163 | 491 | 138 | 422 | 3,037 | -2,615 |
| **Nutrients** | | | | | | | | | | | | | | | | | | | | | |
| Total Ammonium mg/L | 0.126 | 0.194 | 0.238 | 0.142 | 0.080 | 0.262 | 0.298 | 0.340 | 0.314 | 0.570 | 0.314 | 0.924 | 0.190 | 0.004 | 0.256 | 0.370 | 0.942 | 0.618 | 0.350 | 0.293 | 0.057 |
| Nitrite mg/L | 0.048 | 0.039 | 0.097 | 0.092 | 0.020 | 0.077 | 0.225 | 0.184 | 0.052 | 0.052 | 0.187 | 0.146 | 0.195 | 0.004 | 0.065 | 0.173 | 0.197 | 0.095 | 0.116 | 0.074 | 0.042 |
| Nitrate + nitrite mg/L | 0.610 | 0.810 | 1.150 | 1.460 | 0.265 | 1.180 | 0.820 | 3.410 | 0.585 | 0.155 | 1.290 | 0.505 | 3.240 | 4.590 | 1.010 | 0.800 | 4.060 | 2.870 | 1.705 | 0.889 | 0.816 |
| Total Kjeldahl Nitrogen mg/L | 1.04 | 1.16 | 3.30 | 0.76 | 0.74 | 1.76 | 7.00 | 4.38 | 1.16 | 2.04 | 1.04 | 2.40 | 1.76 | 0.26 | 6.10 | 1.80 | 6.10 | 1.70 | 3.04 | 1.30 | 1.73 |
| Total Phosphorus mg/L | 0.264 | 0.244 | 0.500 | 0.200 | 0.136 | 0.424 | 2.350 | 0.576 | 0.264 | 0.224 | 0.180 | 0.360 | 0.204 | 0.068 | 0.800 | 0.290 | 0.970 | 0.104 | 0.485 | 0.240 | 0.245 |
| Phosphate mg/L | 0.1100 | 0.0965 | 0.0235 | 0.0600 | 0.0505 | 0.1930 | 0.0340 | 0.2930 | 0.1300 | 0.0790 | 0.0930 | 0.2470 | 0.0760 | 0.0540 | 0.0745 | 0.0645 | 0.1500 | 0.0235 | 0.1423 | 0.0939 | 0.0484 |
| **Organics** | | | | | | | | | | | | | | | | | | | | | |
| Carbon, Dissolved Organic mg/L | 4.1 | 2.5 | 8.4 | 5.4 | 2.1 | 6.2 | 9.3 | 15.4 | 3.5 | 8.0 | 3.9 | 11.0 | 14.4 | 1.6 | 17.7 | 19.6 | 10.1 | 9.9 | 8.7 | 3.4 | 5.2 |
| Solvent extractable mg/L | 2.5 | 4.0 | 2.5 | 14.0 | 2.0 | 5.0 | 10.0 | 5.0 | 1.5 | 3.0 | 3.0 | 8.5 | 44.0 | <MDL | 24.0 | 21.0 | 22.0 | 9.0 | 11.2 | 6.5 | 4.7 |
| **Inorganics** | | | | | | | | | | | | | | | | | | | | | |
| Aluminum µg/L | 478 | 605 | 205 | 945 | 141 | 504 | 2,420 | 1,590 | 457 | 90 | 126 | 401 | 239 | 16 | 839 | 549 | 869 | 220 | 615 | 504 | 111 |
| Arsenic mg/L | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | 0.001 | 0.001 | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | 0.001 | 0.001 | <MDL | 0.001 | 0.001 | 0.000 |
| Barium µg/L | 15.6 | 21.0 | 9.1 | 36.6 | 5.0 | 14.4 | 31.3 | 40.9 | 7.5 | 8.0 | 7.1 | 24.8 | 13.9 | 43.1 | 39.4 | 29.5 | 39.5 | 12.7 | 23.3 | 25.2 | -1.9 |
| Beryllium µg/L | 0.05 | 0.04 | 0.02 | 0.09 | 0.01 | 0.04 | 0.20 | 0.12 | 0.02 | <MDL | 0.01 | 0.05 | 0.03 | 0.01 | 0.10 | 0.06 | 0.09 | 0.03 | 0.06 | 0.04 | 0.02 |
| Cadmium µg/L | 0.5 | 0.4 | 0.2 | 1.7 | <MDL | 0.0 | 0.4 | 0.5 | <MDL | <MDL | 0.3 | 0.6 | <MDL | 0.2 | 1.3 | 1.9 | 0.9 | 1.1 | 0.8 | 0.5 | 0.2 |
| Calcium mg/L | 26.400 | 50.400 | 20.900 | 105.000 | 8.060 | 38.700 | 82.700 | 97.300 | 6.940 | 12.000 | 16.700 | 37.700 | 19.200 | 113.000 | 38.600 | 45.700 | 61.400 | 20.100 | 42.900 | 48.511 | -5.611 |
| Carbon, Dissolved Inorganic mg/L | 18.6 | 19.6 | 9.2 | 36.6 | 5.5 | 18.0 | 8.0 | 42.8 | 6.4 | 12.4 | 8.8 | 12.4 | 6.8 | 72.0 | 10.0 | 14.0 | 23.6 | 5.4 | 17.7 | 14.4 | 3.2 |
| Chromium µg/L | 3.0 | 5.5 | 5.4 | 6.1 | 0.8 | 4.1 | 11.3 | 8.3 | 2.9 | 0.3 | 1.2 | 3.7 | 2.8 | 0.5 | 6.5 | 4.8 | 4.0 | 2.1 | 4.1 | 5.2 | -1.2 |
| Cobalt µg/L | 1.2 | 0.5 | 0.2 | 0.4 | <MDL | <MDL | 2.0 | 1.5 | <MDL | <MDL | <MDL | 1.0 | 0.4 | 0.7 | 1.9 | 0.7 | 1.6 | 1.1 | 1.1 | 0.7 | 0.4 |
| Copper µg/L | 12.5 | 16.2 | 19.8 | 33.6 | 3.9 | 11.3 | 27.3 | 50.9 | 4.4 | 5.4 | 6.0 | 28.7 | 16.1 | 2.2 | 36.4 | 33.5 | 26.0 | 12.5 | 21.0 | 20.7 | 0.3 |
| Iron µg/L | 393.0 | 1,120.0 | 453.0 | 1,300.0 | 211.0 | 686.0 | 1,760.0 | 2,450.0 | 375.0 | 162.0 | 131.0 | 959.0 | 437.0 | 10.2 | 1,560.0 | 1,180.0 | 1,470.0 | 364.0 | 1009.1 | 848.8 | 160.3 |
| Lead µg/L | 17 | 23 | 8 | 23 | <MDL | 1 | 23 | 38 | <MDL | <MDL | <MDL | 10 | 7 | 1 | 16 | 16 | 24 | 6 | 16 | 21 | -5 |
| Magnesium mg/L | 3.440 | 7.730 | 2.780 | 22.500 | 0.818 | 5.010 | 5.580 | 22.900 | 1.340 | 1.490 | 2.430 | 10.500 | 2.770 | 12.000 | 10.900 | 12.800 | 14.700 | 3.610 | 7.795 | 6.487 | 1.308 |
| Manganese µg/L | 62.7 | 102.0 | 84.4 | 382.0 | 27.0 | 68.5 | 130.0 | 299.0 | 29.2 | 39.5 | 27.2 | 184.0 | 73.9 | 12.4 | 390.0 | 209.0 | 252.0 | 73.5 | 139.2 | 111.7 | 27.4 |
| Mercury µg/L | | <MDL | <MDL | 0.49 | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | 0.03 | 0.04 | 0.03 | 13.44 | -13.41 |
| Molybdenum µg/L | <MDL | <MDL | 0.1 | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | 0.7 | <MDL | <MDL | <MDL | <MDL | <MDL | 0.3 | 0.1 | 0.2 |
| Nickel µg/L | 1.8 | 2.6 | 1.5 | 4.9 | 0.4 | 1.6 | 6.6 | 8.1 | 1.5 | 1.5 | 1.1 | 1.8 | 3.5 | 0.6 | 5.1 | 4.2 | 4.8 | 1.7 | 3.0 | 2.1 | 0.9 |
| Selenium mg/L | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | | | |
| Silicon mg/L | 1.06 | 1.14 | 0.54 | 1.88 | 0.28 | 2.36 | 4.54 | 3.26 | 0.46 | 0.78 | 0.72 | 0.92 | 0.68 | 4.94 | 0.68 | 1.10 | 2.10 | 0.48 | 1.57 | 0.85 | 0.73 |
| Strontium µg/L | 148.0 | 228.0 | 213.0 | 697.0 | 51.7 | 132.0 | 196.0 | 304.0 | 25.5 | 65.8 | 78.9 | 127.0 | 99.0 | 305.0 | 116.0 | 139.0 | 193.0 | 79.9 | 142.1 | 315.3 | -173.2 |
| Titanium µg/L | 4.9 | 6.9 | 2.7 | 7.3 | 1.5 | 13.1 | 66.3 | 12.3 | 6.3 | 0.1 | 0.9 | <MDL | 3.2 | <MDL | 3.4 | 1.0 | 14.7 | 2.3 | 9.6 | 5.4 | 4.3 |
| Vanadium µg/L | 1.4 | 4.1 | 3.1 | 2.8 | 0.4 | 3.1 | 9.6 | 5.0 | 1.9 | 1.6 | 1.6 | 5.1 | 6.5 | 0.8 | 8.2 | 5.0 | 5.3 | 6.1 | 4.1 | 2.5 | 1.6 |
| Zinc µg/L | 82.9 | 102.0 | 84.4 | 227.0 | 33.4 | 59.6 | 173.0 | 198.0 | 26.1 | 27.0 | 38.4 | 203.0 | 82.2 | 12.6 | 312.0 | 273.0 | 254.0 | 86.6 | 129.3 | 116.0 | 13.3 |
| **Bacteria** | | | | | | | | | | | | | | | | | | | | | |
| Escherichia coli c/100mL | 30 | 100 | | | 600 | | 4 | 2,600 | 8,900 | | 140 | | 9,200 | 720 | 100 | 300 | 320 | 80 | 2,088 | 62 | 2,026 |
| Fecal streptococcus c/100mL | 240 | 700 | | | 9,000 | | 11,000 | 34,000 | 100,000 | | 8,000 | | 58,000 | 1,490 | 1,300 | 1,140 | 33,000 | 4,700 | 23,785 | 4,627 | 19,158 |
| Pseudomonas aeruginosa c/100mL | 4 | 10 | | | 42 | | 40 | 500 | 1,700 | | 530 | | 7,400 | 400 | 1,040 | 1,140 | 900 | 3,400 | 1,554 | 16 | 1,538 |
| **Organics** | | | | | | | | | | | | | | | | | | | | | |
| 2,4-dichlorophenol, ng/L | <MDL | <MDL | <MDL | <MDL | <MDL | | <MDL | <MDL | | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | | | |
| 2,4,6-trichlorophenol, ng/L | <MDL | <MDL | <MDL | <MDL | <MDL | | <MDL | <MDL | | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | | | |
| 2,4,5-trichlorophenol, ng/L | <MDL | <MDL | <MDL | <MDL | <MDL | | <MDL | <MDL | | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | | | |
| 2,3,4-trichlorophenol, ng/L | <MDL | <MDL | <MDL | <MDL | <MDL | | <MDL | <MDL | | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | | | |
| 2,3,4,5-tetrachlorophenol, ng/L | <MDL | <MDL | <MDL | <MDL | <MDL | | <MDL | <MDL | | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | | | |
| 2,3,4,6-tetrachlorophenol, ng/L | <MDL | <MDL | <MDL | <MDL | <MDL | | <MDL | <MDL | | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | | | |
| Pentachlorophenol, ng/L | 11 | <MDL | <MDL | 12 | 11 | | <MDL | <MDL | | 12 | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | 17 | 14 | 3 |
| Dicamba, ng/L | <MDL | <MDL | <MDL | <MDL | <MDL | | <MDL | <MDL | | <MDL | <MDL | 100.0 | 310 | <MDL | 110 | <MDL | 360 | 190 | 203 | 64 | 139 |
| Bromoxynil, ng/L | <MDL | <MDL | <MDL | <MDL | <MDL | | <MDL | <MDL | | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | | | |
| 2,4-D-propionic acid, ng/L | <MDL | <MDL | <MDL | <MDL | <MDL | | <MDL | <MDL | | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | | | |
| 2,4-D, ng/L | <MDL | <MDL | <MDL | <MDL | 220 | | 240 | 110 | | <MDL | <MDL | 560 | 3,500 | <MDL | 400 | 4,000 | 26,000 | 1,700 | 3,380 | 188 | 3,193 |
| Silvex, ng/L | <MDL | <MDL | 21 | <MDL | <MDL | | <MDL | <MDL | | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | | | |
| 2,4,5-T, ng/L | <MDL | <MDL | <MDL | <MDL | <MDL | | <MDL | <MDL | | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | | | |
| 2,4-DB, ng/L | <MDL | <MDL | <MDL | <MDL | <MDL | | <MDL | <MDL | | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | | | |
| Picloram, ng/L | <MDL | <MDL | <MDL | <MDL | <MDL | | <MDL | <MDL | | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | | | |
| Diclofop-methyl, ng/L | <MDL | <MDL | <MDL | <MDL | <MDL | | <MDL | <MDL | | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | | | |

Notes: Samples from MH 72, 1996 - 1998
Statistics in the four right-most columns were obtained by spreadsheet analysis and do not include consideration of detection limits or trace quantities.
Blank cells in this table represent either insufficient sample volume to perform all tests or samples for bacterial tests were too old to be analyzed.

Figure F.25 compares the average summer/fall and winter/spring particle size distributions. The winter/spring suspensions had a smaller average size than those of the summer/fall monitoring period. This difference is often attributed to reduced flow rates associated with snowmelt. However, as discussed with respect to Figure F.23, sampling technique may explain much of the difference. Winter monitoring was based on grab samples and summer monitoring was based largely on composite samples. The use of various monitoring techniques at this site during the summer/fall period has shown that sampling method can influence the results.

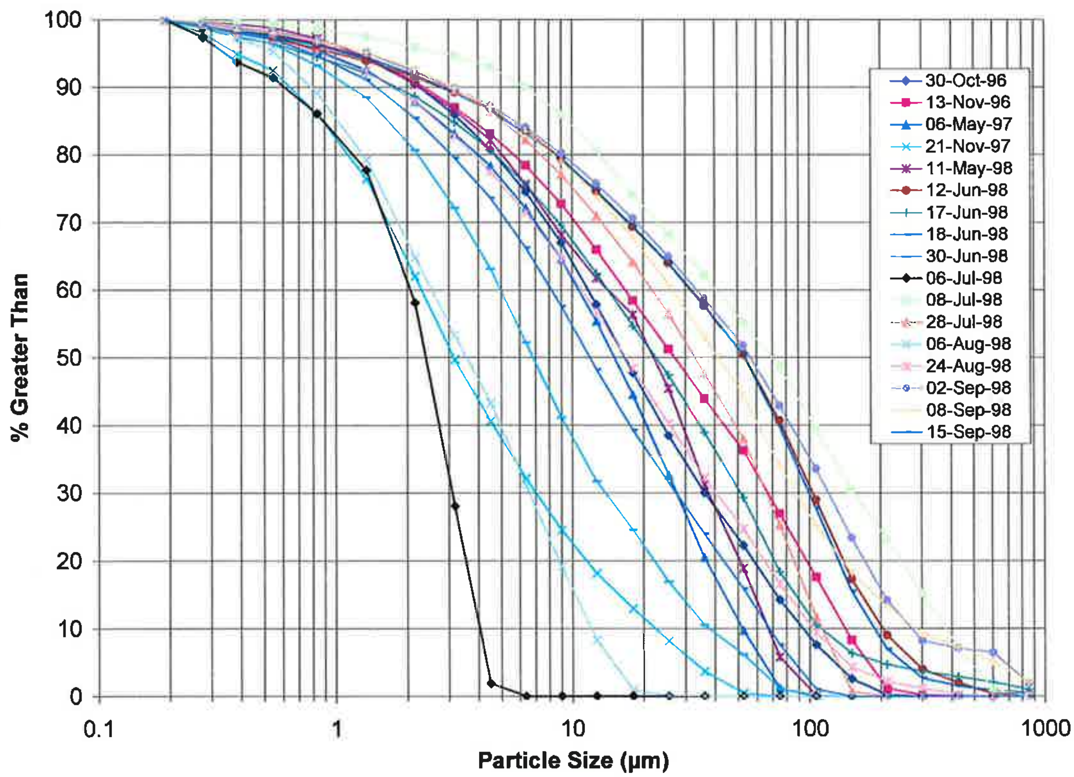


***Figure F.23:*** Particle size distributions -- Princess Margaret - summer / fall period

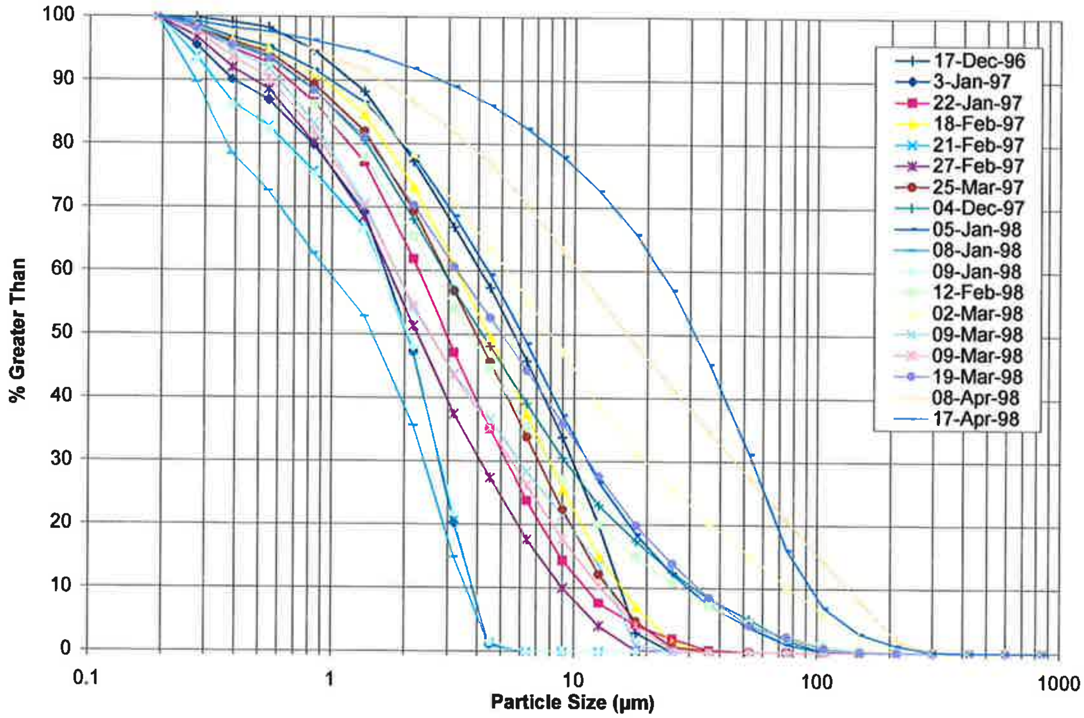


***Figure F.24:*** Particle size distributions -- Princess Margaret - winter / spring period

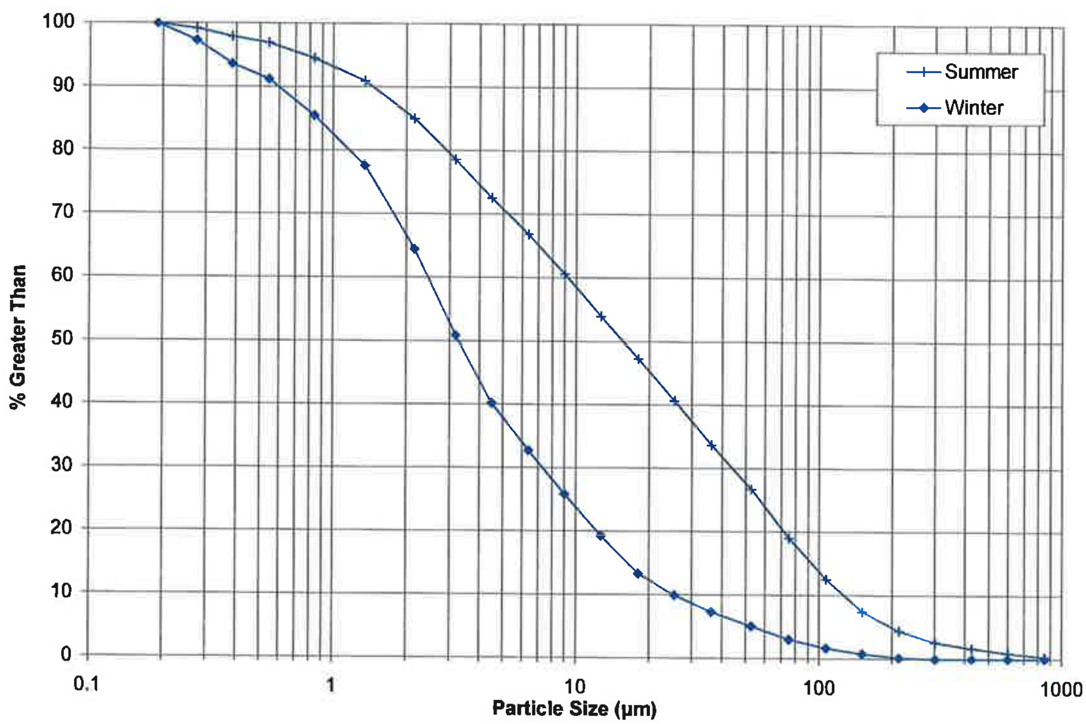


***Figure F.25:*** Average particle size distributions -- Princess Margaret exfiltration facility

# APPENDIX G

# Queen Mary's Drive Data

# QUEEN MARY'S DRIVE DATA

## G.1 Introduction

Table G.1 provides a summary of the Queen Mary's Drive exfiltration site monitoring program. A total of 35 samples were collected from the Queen Mary's Drive site: 8 samples were taken from the main storm sewer, 22 from the relief pipe, 5 from either the maintenance hole bottom or the outfall.

Tables G.2 and G.3 summarize the hydraulic data for the Queen Mary's site. Flow monitoring at this site was undertaken only in 1996.

## G.2 Discussion -- Queen Mary's Drive Monitoring Data

### G.2.1 Hydraulic data -- summer / fall period

Hyetographs and water level hydrographs are plotted on a monthly basis in Figures G.1 to G.4[1]. Hydrographs have been plotted for each event; they are kept in working files and are not included in this report except as specific examples. Water level and flow were measured in the Queen Mary's Drive main sewer pipe (exfiltration system overflow) from August 15$^{th}$ to October 11$^{th}$, 1996. Outflow from the maintenance hole was measured from October 2$^{nd}$ to November 28$^{th}$. In addition, flow in the Kingsway Crescent storm sewer was measured from September 26$^{th}$ to October 11$^{th}$.

The Queen Mary's Drive storm sewer conveys the overflow of the exfiltration system. It should produce flows of much less volume than the rainfall, and runoff coefficients much less than 0.3 on average. According to the design criteria, there should be no runoff for storms with precipitation depths less than 15 mm. The sewer is dry between rainfall events.

The Queen Mary's Drive exfiltration facility is actually a hybrid of exfiltration sewers and conventional sewers. The drainage area directly tributary to the new exfiltration sewer is approximately 3.7 ha. The total drainage area is 13.3 ha. According to available plans:

- part of Dunedin Drive (0.6 ha) drains to MH 12,
- part of Prince Edward Drive north of Queen Mary's Drive, including a portion of Kings Garden Road, (2.5 ha) drain southward to MH 16,
- part of Prince Edward Drive south of Queen Mary's Drive, including parts of The Kingsway, Grenview Blvd. N. and Strath Ave., ( 6.5 ha) drain northward to MH 16.

[1] In Figures G.1 to G.4, the rainfall is plotted above using the left y-axis scale and the water depth is plotted below using the right y-axis scale.

***Table G.1:*** Queen Mary's Drive exfiltration site -- monitoring program summary

| Date | Rain[1] mm | Main Flow | Main Samples | Kingsway Flow | Kingsway Samples | Relief Flow | Relief Samples | Outfall Flow | MH Samples |
|---|---|---|---|---|---|---|---|---|---|
| 15-Aug-96 | 5.8 | • | | | | | | | |
| 20-Aug-96 | 1.4 | • | | | | | | | |
| 22-Aug-96 | 9.4 | • | | | | | | | |
| 23-Aug-96 | 0.8 | • | | | | | | | |
| 26-Aug-96 | 3.4 | • | | | | | | | |
| 27-Aug-96 | 6.2 | • | | | | | | | |
| 07-Sep-96 | 66.3 | • | | | | | | | |
| 08-Sep-96 | 0.6 | • | | | | | | | |
| 09-Sep-96 | 3.6 | • | | | | | | | |
| 11-Sep-96 | 6.0 | • | | | | | | | |
| 12-Sep-96 | 8.5 | • | | | | | | | |
| 13-Sep-96 | 30.8 | • | | | | | | | |
| 14-Sep-96 | 1.4 | • | | | | | | | |
| 15-Sep-96 | 0.6 | • | | | | | | | |
| 16-Sep-96 | 0.4 | • | | | | | | | |
| 22-Sep-96 | 10.2 | • | | | | | | | |
| 24-Sep-96 | 11.9 | • | | | | | | | |
| 26-Sep-96 | 3.2 | • | | • | | | | | |
| 27-Sep-96 | 4.8 | • | | • | | | | | |
| 28-Sep-96 | 17.4 | • | | • | | | | | |
| 29-Sep-96 | 1.0 | • | | • | | | | | |
| 02-Oct-96 | 0.4 | • | | • | | | | • | |
| 09-Oct-96 | 4.8 | • | | • | | | | • | |
| 10-Oct-96 | 6.4 | • | | • | | | | • | |
| 13-Oct-96 | 0.2 | • | | | | | | • | |
| 16-Oct-96 | 7.0 | • | | | | | | • | |
| 18-Oct-96 | 26.7 | • | | | | | | • | |
| 19-Oct-96 | 8.0 | • | | | | | | • | |
| 20-Oct-96 | 1.6 | • | | | | | | • | |
| 21-Oct-96 | 4.5 | • | | | | | | • | • |
| 23-Oct-96 | 4.8 | • | | | | | | • | |
| 24-Oct-96 | 0.6 | • | | | | | | • | |
| 29-Oct-96 | 1.0 | • | | | | | | • | |
| 30-Oct-96 | 9.1 | • | | | | | | • | |
| 04-Nov-96 | 0.6 | • | | | | | | • | |
| 05-Nov-96 | 0.6 | • | | | | | | • | |
| 06-Nov-96 | 0.2 | • | | | | | | • | |
| 07-Nov-96 | 14.8 | • | | | | | | • | |
| 08-Nov-96 | 3.2 | • | | | | | | • | |
| 13-Nov-96 | nil | • | | | | | | • | • |
| 17-Nov-96 | 1.6 | - | | | | | | • | |
| 18-Nov-96 | 0.2 | - | | | | | | • | |
| 30-Nov-96 | 1.8 | - | | | | | | | |
| 17-Dec-96 | n/a | - | • | | | | | | |
| 03-Jan-97 | n/a | - | • | | | | | | |
| 22-Jan-97 | n/a | - | • | | | | | | • |
| 18-Feb-97 | n/a | - | • | | | | • | | • |
| 21-Feb-97 | n/a | - | • | | | | • | | • |
| 27-Feb-97 | n/a | - | • | | | | • | | |
| 25-Mar-97 | n/a | - | • | | | | • | | |
| 02-Oct-97 | 0.4 | - | | | | | | | • |
| 21-Nov-97 | 1.8 | - | | | | | • | | |
| 04-Dec-97 | n/a | - | | | | | • | | |
| 05-Jan-98 | n/a | - | | | | | • | | |
| 08-Jan-98 | n/a | - | | | | | • | | |
| 09-Jan-98 | n/a | - | | | | | • | | |
| 12-Feb-98 | n/a | - | | | | | • | | |
| 18-Feb-98 | n/a | - | | | | | • | | |
| 09-Mar-98 | n/a | - | | | | | • | | |
| 19-Mar-98 | n/a | - | | | | | • | | |
| 01-Apr-98 | 6.1 | - | | | | | • | | |
| 20-Apr-98 | 2.4 | - | | | | | • | | |
| 11-May-98 | 31.0 | - | | | | | • | | |
| 12-Jun-98 | 17.1 | - | | | | | • | | |
| 30-Jun-98 | 26.8 | - | | | | | • | | |
| 07-Jul-98 | 15.1 | - | | | | | •[2] | | |
| 08-Jul-98 | 2.1 | - | | | | | • | | |
| 06-Aug-98 | 10.7 | - | | | | | • | | |
| 10-Aug-98 | nil | - | • | | | | | | |

[1] Total daily rainfall

[2] No laboratory report sheets were found corresponding to a submission sheet for the July 7, 1998 sample.

***Table G.2:*** Queen Mary's Drive rainfall and flow summary -- August - September, 1996

| Rain[1] | | | | | Queen Mary's storm sewer | | | | | Kingsway storm sewer | | | | | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Date | Start Time | Dur. (hr) | Depth (mm) | Vol.[2] ($m^3$) | Start Time | Dur.[4] (hr) | Peak (l/s) | Vol. ($m^3$) | Coef. | Start Time | Dur.[4] (hr) | Peak (l/s) | Vol. ($m^3$) | Coef.[3] | |
| Aug. 15 | 12:00 | ≤1 | 5.8 | 771 | 14:00 | 1.25 | 241 | 152 | 0.20 | | | | | | |
| Aug. 20 | 14:00 | ≤1 | 1.4 | 186 | n/a | n/a | n/a | 0 | 0 | | | | | | |
| Aug. 22 | 18:00 | ≤2 | 9.4 | 1,250 | 19:30 | 1.08 | 15 | 12 | 0.01 | | | | | | |
| Aug. 23 | 07:00 | ≤2 | 0.8 | 106 | n/a | n/a | n/a | 0 | 0 | | | | | | |
| Aug. 26 | 13:00 | ≤3 | 3.4 | 452 | 15:05 | 1.58 | 53 | 54 | 0.12 | | | | | | |
| Aug. 27 | 05:00 | ≤3 | 6.2 | 825 | 07:15 | 3.58 | 59 | 127 | 0.15 | | | | | | |
| Sep. 07 | 03:00 | ≤22 | 66.7 | 8,871 | 12:55 | 13.0 | 84 | 1,500 | 0.17 | | | | | | |
| Sep. 09 | 12:00 | ≤10 | 3.6 | 479 | 22:10 | 0.3 | 1.6 | 1.2 | 0.003 | | | | | | |
| Sep. 11 | 19:00 | ≤15 | 14.5 | 1,928 | 22:15 | 12.9 | 75 | 115 | 0.06 | | | | | | |
| Sep. 13 | 09:00 | ≤16 | 31.2 | 4,150 | 11:25 | 12.9 | 135 | 575 | 0.14 | | | | | | |
| Sep. 14 | 15:00 | ≤2 | 1.0 | 133 | 18:00 | 0.25 | 1.2 | 1.1 | 0.01 | | | | | | |
| Sep. 15 | | | trace | n/a | 04:15 | 1.67 | 6.1 | 16 | n/a | | | | | | |
| Sep. 22 | 06:00 | ≤16 | 10.2 | 1,357 | 08:35 | 6.92 | 28 | 62 | 0.05 | | | | | | |
| Sep. 23 | | | nil | 0 | 16:20 | 0.67 | 6.1 | 8.0 | n/a | | | | | | |
| Sep. 24 | 07:00 | ≤9 | 11.9 | 1,583 | 08:45 | 9.17 | 37 | 227 | 0.14 | | | | | | |
| Sep. 25 | | | nil | 0 | 14:30 | 0.58 | 21 | 19 | n/a | | | | | | Kingsway on-line noon 26th |
| Sep. 27a | 06:00 | ≤7 | 2.6 | 346 | 10:15 | 2.92 | 2.0 | 3.7 | 0.01 | | | | 0 | 0 | |
| Sep. 27b | 22:00 | ≤12 | 19.6 | 2,607 | 01:00 | 11.0 | 47 | 215 | 0.08 | 00:10 | 9.50 | 21 | 76 | 0.10 | |
| Sep. 29 | 15:00 | ≤2 | 1.0 | 133 | n/a | n/a | n/a | 0 | 0 | | | | 0 | 0 | |
| Sep. 30 | | | nil | 0 | 08:40 | 0.67 | 18 | 17 | n/a | | | | 0 | 0 | |

Notes:
1. Rain data are from Pearson International Airport. The event total rainfall depth is tabulated.
2. Calculated rain volume pertains only to the Queen Mary's site, using a tributary area of 13.3 ha.
3. Kingsway Crescent tributary area = 3.8 ha. Note that only one of three pipes entering MH 25 was monitored for flow.
4. Runoff duration is based on inspection of hydrograph curve shape.

***Table G.3:*** Queen Mary's Drive rainfall and flow summary -- October - November, 1996

| Rain | | | | | Queen Mary's Sewer | | | | | Kingsway Sewer | | | | | Outlet Sewer (vol. without baseflow)[4] | | | | | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Date | Start Time | Dur. (hr) | Depth (mm) | Vol.[1] ($m^3$) | Start Time | Dur. (hr) | Peak (l/s) | Vol. ($m^3$) | Coef. | Start Time | Dur. (hr) | Peak (l/s) | Vol. ($m^3$) | Coef. | Start Time | Dur (hr) | Peak (l/s) | Vol ($m^3$) | Coef. | |
| Oct. 02 | 17:00 | ≤2 | 0.4 | 53.2 | 20:10 | 0.25 | 0.52 | 0.3 | 0.006 | 08:55 | 0.25 | 8.7 | 4.0 | 0.26 | 19:00 | 1.92 | 3.6 | 2.9 | 0.04 | -48 % error[5] |
| Oct. 05 | | | nil | 0 | | | | 0 | | 14:20 | 0.33 | 14.3 | 7.5 | | 15:10 | 1.25 | 13.0 | 8.2 | | 8 % error |
| Oct. 07 | | | nil | 0 | 15:20 | 0.25 | 6.4 | 2.4 | n/a | 13:20 | 0.25 | 16.3 | 9.3 | | 14:10 | 3.00 | 14.9 | 18.7 | | 37 % error |
| Oct. 09a | 10:00 | ≤2 | 2.0 | 266 | 10:10 | 3.93 | 5.2 | 20.1 | 0.08 | 09:10 | 0.42 | 6.4 | 6.9 | 0.09 | 10:00 | 1.42 | 13.4 | 22.8 | 0.07 | -22 % error |
| Oct. 09b | 16:00 | ≤14 | 9.2 | 1,224 | 23:00 | 9.58 | 2.2 | 38.8 | 0.03 | | | | | | 00:00 | 10.8 | 9.2 | 176 | 0.11 | see note 2 |
| Oct. 13 | 21:00 | ≤1 | 0.2 | 26.6 | - | - | - | - | - | - | - | - | - | - | 22:00 | 2.2 | 4.9 | 5.7 | 0.17 | see note 3 |
| Oct. 16 | 13:00 | ≤6 | 7.0 | 931 | - | - | - | - | - | - | - | - | - | - | 10:40 | 11.5 | 36.4 | 104 | 0.08 | |
| Oct. 18 | 10:00 | ≤15 | 26.9 | 3,578 | - | - | - | - | - | - | - | - | - | - | 13:40 | 12.7 | 26.5 | 469 | 0.10 | |
| Oct. 19 | 07:00 | ≤15 | 7.8 | 1,037 | - | - | - | - | - | - | - | - | - | - | 11:25 | 32.7 | 18.3 | 456 | 0.34 | |
| Oct. 20 | 12:00 | ≤26 | 6.1 | 811 | - | - | - | - | - | - | - | - | - | - | 21:40 | 32.3 | 8.0 | 205 | 0.19 | |
| Oct. 23 | 11:00 | ≤10 | 4.8 | 638 | - | - | - | - | - | - | - | - | - | - | 10:55 | 2.4 | 14.4 | 11.9 | 0.01 | |
| Oct. 27 | | | nil | 0 | - | - | - | - | - | - | - | - | - | - | 14:15 | 3.8 | 6.7 | 17.9 | | |
| Oct. 28 | | | nil | 0 | - | - | - | - | - | - | - | - | - | - | 05:20 | 1.33 | 5.4 | 4.5 | | |
| Oct. 29 | 19:00 | ≤8 | 10.1 | 1,343 | - | - | - | - | - | - | - | - | - | - | 00:45 | 23.50 | 20.1 | 335 | 0.19 | |
| Nov. 04 | 23:00 | ≤2 | 1.2 | 160 | - | - | - | - | - | - | - | - | - | - | | | | nil | | |
| Nov. 7a | 01:00 | ≤4 | 8.7 | 1,157 | - | - | - | - | - | - | - | - | - | - | 01:15 | 11.8 | 25.2 | 271 | 0.18 | |
| Nov. 7b | 20:00 | ≤6 | 9.3 | 1,237 | - | - | - | - | - | - | - | - | - | - | 22:35 | 9.6 | 12.6 | 337 | 0.21 | |
| Nov. 17 | 21:00 | ≤4 | 1.8 | 239 | - | - | - | - | - | - | - | - | - | - | | | | n/a | | see note 6 |
| Nov. 30 | 12:00 | ≤8 | 1.8 | 239 | - | - | - | - | - | - | - | - | - | - | | | | n/a | | |

Notes:
1. The total event rain volume tabulated pertains only to the Queen Mary's site, using a tributary area of 13.3 ha. The tributary area of the Kingsway Crescent sewer north and south of Queen Mary's Drive is 3.8 ha. The tributary area for the outfall is 17.1 ha.
2. The flow sensor in the Kingsway Crescent was apparently operational but did not indicate any flow for the second event on October 9th.
3. The Queen Mary's main storm sewer and the Kingsway storm sewer flow data sets terminated on October 11th.
4. The outlet storm sewer at maintenance hole 25 has a continuous flow.
5. Volumetric error was calculated using the total volumes as reported by the three sensors and reported relative to the outlet volume. Flows from the relief pipe and from the two "interceptor" sewers were not measured.
6. The outlet sensor began reporting zero values on November 23rd and was removed on November 28th.

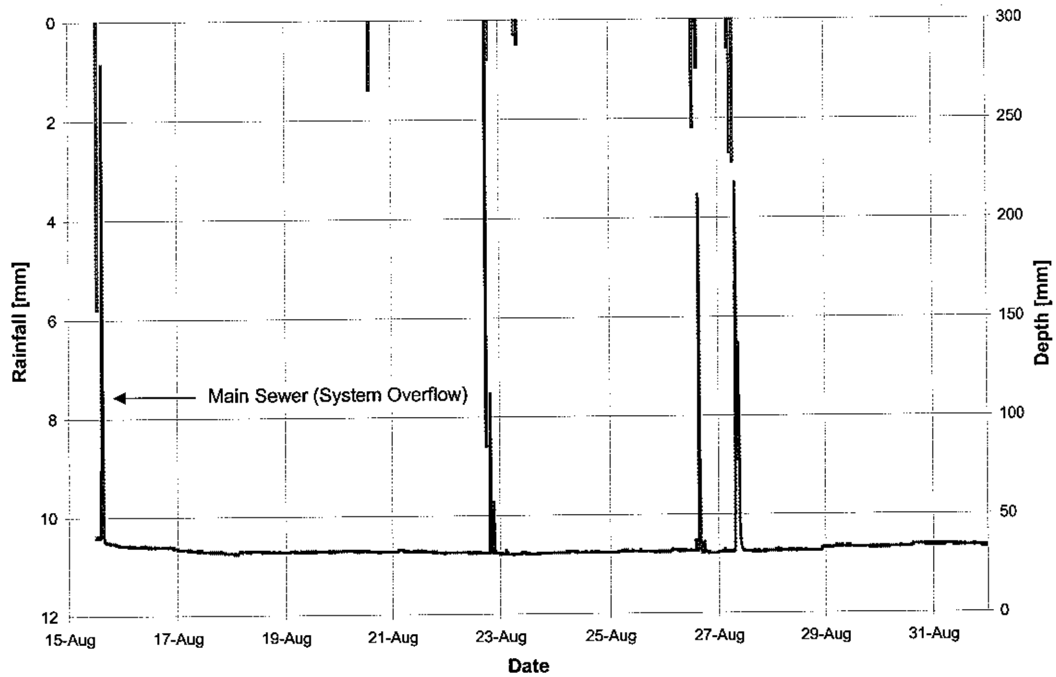


***Figure G.1:*** Water depth and rainfall -- Queen Mary's exfiltration facility, August 1996

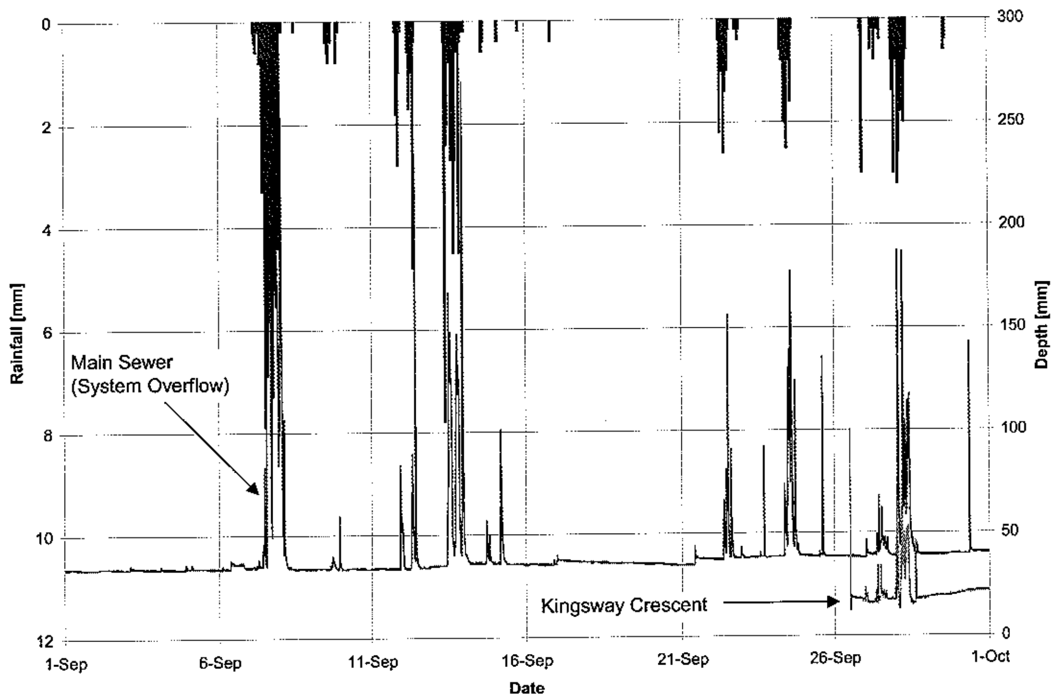


***Figure G.2:*** Water depth and rainfall -- Queen Mary's exfiltration facility, September 1996

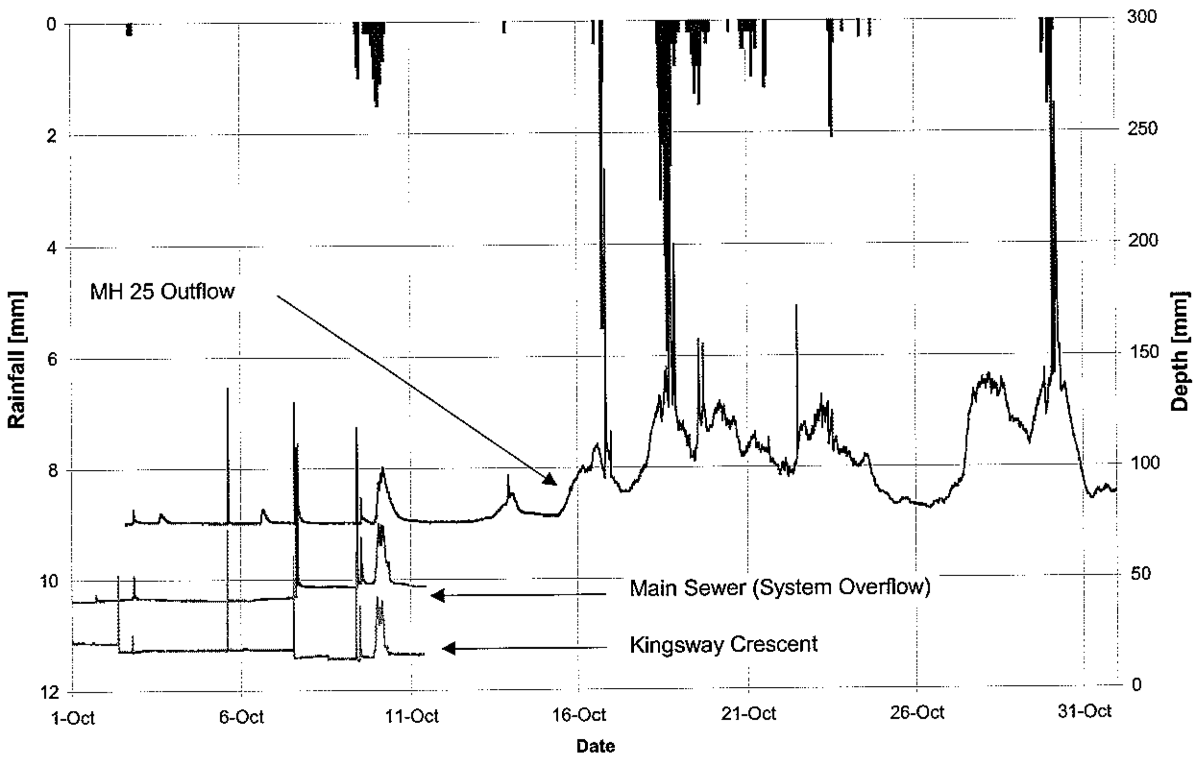


***Figure G.3:*** Water depth and rainfall -- Queen Mary's exfiltration facility, October 1996

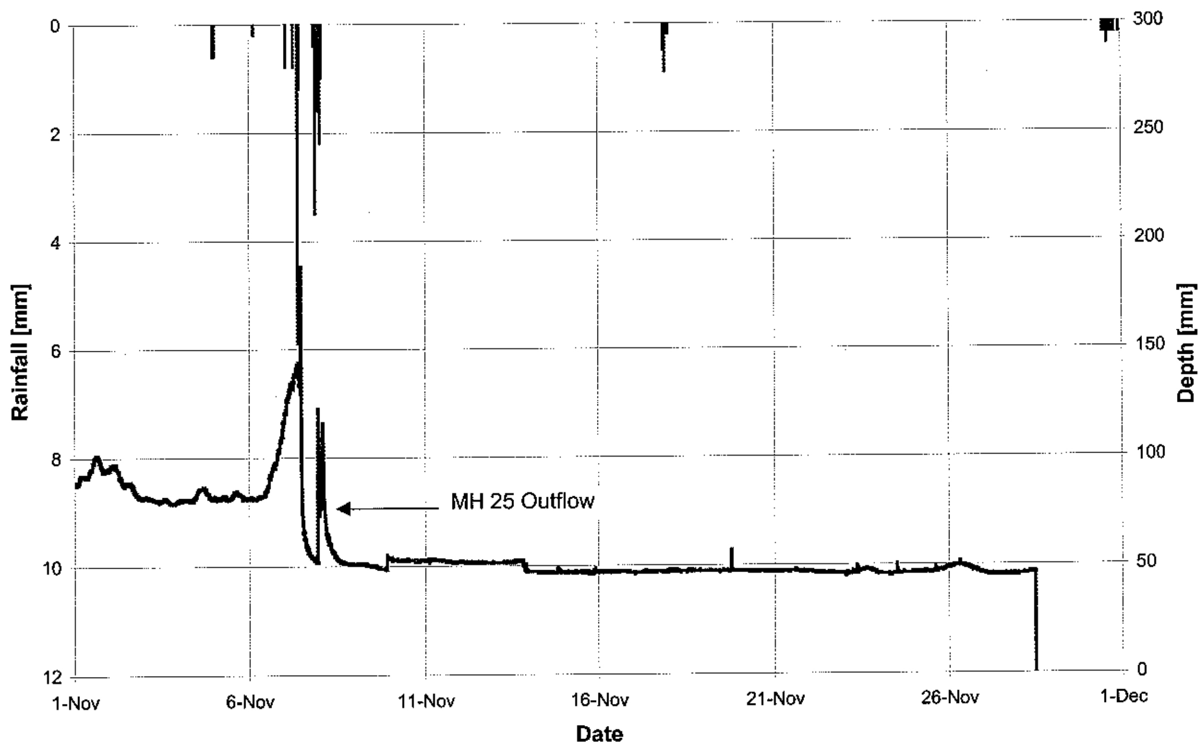


***Figure G.4:*** Water depth and rainfall -- Queen Mary's exfiltration facility, November 1996

A portion of Kingsway Crescent north of Queen Mary's Drive, including part of Kings Garden Road, drain into maintenance hole 25 (3.8 ha). Catchbasins on Kingsway Crescent south of Queen Mary's Drive also drain to maintenance hole 25; the tributary area is apparently included in the 3.8 ha. This area does not impact the exfiltration system directly but does contribute to the total outflow.

The consequence of this geometry is that the exfiltration sewer system, with its typical cross-section and storage volume, is treating flows from an area that is much larger than that tributary to the exfiltration system itself. This factor, in combination with the apparently high water table in the area, make the facility unsuitable for assessing performance on a quantitative basis.

Maintenance hole 25 is approximately 13 m deep and contains a safety platform below the elevations of the two main incoming sewers (Figure G.5). Both main sewers have drop structures. The 975 mm diameter outlet sewer discharges to the creek and Humber River. In addition, three pipes enter the maintenance hole near the bottom. The smallest of these pipes (100 mm diameter) was apparently installed for groundwater relief. The remaining two pipes are 200 mm in diameter and are assumed to be catchbasin leads and/or short sections of perforated exfiltration pipe. The original plans included a "north interceptor" on Kingsway Crescent consisting of a 525 mm main pipe and a single 200 mm exfiltration pipe, and a "south interceptor" consisting of only a 200 mm perforated pipe connected to catchbasins, both discharging to the deleted MH 21. The as-built drawings indicate that a modification of these plans was implemented, but draining to MH 25 which was more centrally located on Kingsway Crescent. Observations of the system include occasional dry-weather flow in the main Kingsway Crescent storm sewer, dry-weather flow in the relief pipe and dry-weather flow around the 200 mm north interceptor pipe (i.e., through the joint between the MH 25 wall and the pipe).

The outlet storm sewer conveys the flows of the Queen Mary's Drive and Kingsway Crescent storm sewers plus groundwater that enters the maintenance hole through the relief pipe and cracks. The outlet sewer has a constant dry-weather flow that ranges from approximately 1 to 4 litres per second depending on the general weather and groundwater conditions. As tabulated, the peak flows include the baseflow quantity but the event volumes exclude baseflow in an attempt to achieve a volumetric balance with the two inlet sewer flows. The flow data from the outlet sewer are somewhat erratic, including apparently random zero entries. Also, zero values may have been substituted for flows above the sensor's calibration range. Consequently, obtaining clean, baseline-corrected flow vectors and event volumes from this sensor station is difficult.

The flow sensor/logger clocks had apparently not been synchronized, and/or the clocks were set to current local time (with daylight savings) while the Environment Canada rain data were reported using standard time. Some of the hyetographs appear to be offset in time.

Some, but presumably not all, of the spurious data may have resulted from the spatial separation of the rain gauge and the site.

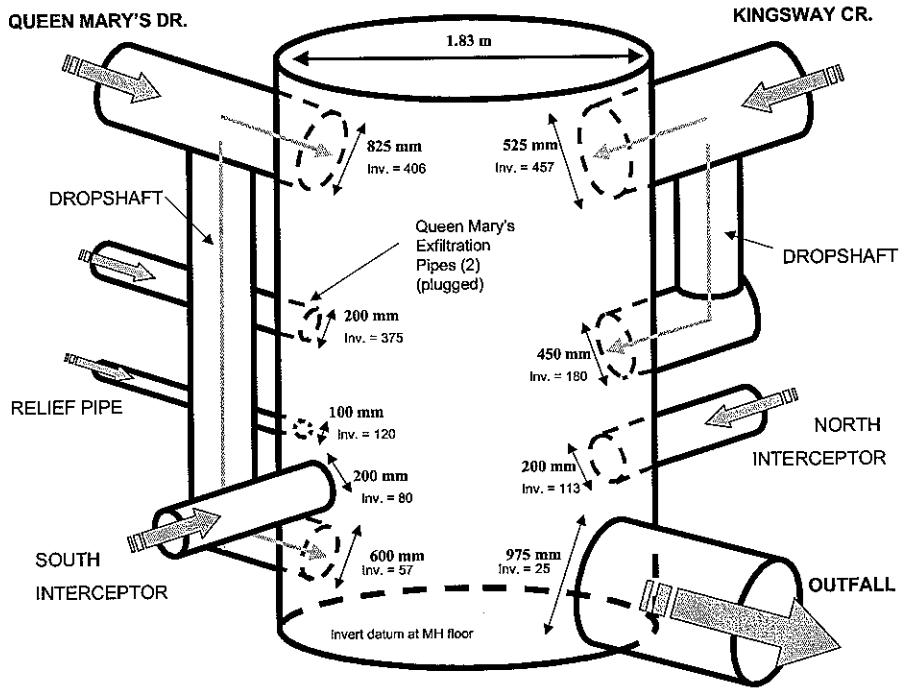


***Figure G.5:*** Schematic diagram of maintenance hole 25

Continuous infiltration of groundwater into MH 25 indicates a groundwater table at least approximately 12 m below the surface. Whether the table is high enough to affect the performance of the exfiltration system is not evident in the monitoring results.

The results show that the Queen Mary's Drive exfiltration system has overflows during events with substantially less than 15 mm of rainfall. However, the calculated runoff coefficients were substantially less than would be expected for a conventional sewer system. These conditions are considered to be in accordance with the mixed exfiltration and conventional design of the overall system. The outfall data show similar performance, since the Kingsway Crescent sewer system is also a mix of exfiltration and conventional designs.

As would be expected, the runoff coefficient values are influenced by the magnitude of the rainfall events and antecedent conditions. Available data suggest that the Queen Mary's Drive sewer will overflow at rainfall depths of 1.4 mm or greater when the system is dry, but may overflow with lesser amounts of rain if insufficient time is available for exfiltration between events.

The maximum runoff coefficient value (0.34 for the outfall sewer) resulted from 7.8 mm rainfall that occurred shortly after a major storm event (26.9 mm). A value of that magnitude might be expected for a conventional sewer system, suggesting that the previous storm had saturated the gravel trench and local soils. The observation also tends to corroborate the overall data set.

### G.2.2 Water quality data

The water quality data for this site are summarized in Tables G.4 and G.5.

As previously noted, several sources contribute to the maintenance hole bottom samples. The Queen Mary's Drive main sewer (exfiltration system overflow) enters the maintenance hole. A conventional[2] storm sewer on Kingsway Crescent also enters the maintenance hole, as do two short lengths of exfiltration pipe and one small-diameter pipe apparently installed for groundwater relief. Groundwater enters the maintenance hole through cracks.

The "main sewer" contains the overflow from the exfiltration system. Seven winter samples and one summer sample were analyzed. On the basis of winter/spring samples, the effluent of the main sewer was generally cleaner than the mixed stormwater in the maintenance hole bottom (Table G.4). Exceptions were phosphorus, oil and grease (solvent extractables) and two of the bacterial constituents. The maintenance hole bottom sample represents conventional stormwater, diluted by groundwater seepage, and mixed with the main sewer overflow. The volumetric proportions are unknown[3], but the fact that the exfiltration system overflow was cleaner suggests that much of the first flush of pollutants is being discharged to the gravel bedding material and that the later overflow has less impact on the environment.

Twenty samples were collected from the relief pipe, 12 from the winter/spring period and 8 from the summer/fall period (Table G.5). Two of the summer/fall samples were analyzed only for bacteria. The concentrations of 24 constituents were greater in winter/spring, and the concentrations of 13 constituents were greater in summer/fall. Mechanisms may be open to speculation. For example, most nutrient concentrations were greater in winter than summer. The value of these data may be for comparison to other urban groundwater data and comparison to data from later (proposed) monitoring of this site to determine if conditions have changed.

### G.2.3 Particle size distributions

Particle size distributions were measured for all but one of the samples included in Table G.4, and for six of the groundwater samples included in Table G.5. Data for some samples were all below detection level because the TSS concentrations were insufficient for the PSD test method.

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[2] The "north interceptor" apparently replaced approximately 27 m of existing sewer with an exfiltration system.
[3] Flow data included the two main inlets and the outlet of MH 25 for only three events.

The particle size distributions from the Queen Mary's Drive main sewer are plotted in Figure G.6. The distributions were consistent from sample to sample in the winter/spring period, with average sizes of approximately 4.0 to 6.5 μm.

The maintenance hole bottom samples (Figure G.7) include the summer/fall and winter/spring periods. The October 21, 1996 distribution appears to be anomalous, possibly because TSS concentration was only 18 mg/L. Otherwise, the distributions demonstrate the type of seasonal difference experienced elsewhere.

Figure G.8 demonstrates that the particle size distributions in samples from the relief pipe were variable. All samples were from the winter/spring sampling period.

The average PSD curves for the three sampling locations are compared in Figure G.9. The average particle size of the suspended material in the maintenance hole bottom was 6 to 7 μm. The average size in the relief pipe samples was approximately 3 μm, and the average size in the exfiltration system effluent was approximately 5 μm.

*Table G.4:* Queen Mary's Drive -- water quality results

| Parameter & Units \ Date & Sample Type | RMDL | PWQO | Exfiltration System -- Main Sewer Effluent | | | | | | | | | Maintenance Hole 25 Bottom Samples | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 17/12/96 | 03/01/97 | 22/01/97 | 18/02/97 | 21/02/97 | 27/02/97 | 25/03/97 | average, main pipe, winter/spring | 10/08/98 Summer | 21/10/96, 4.5 mm rainfall | 13/11/96, "outfall", no precipitation | 22/01/97, rainfall n/a, winter | 18/02/97, rainfall n/a, winter | 21/02/97, rainfall n/a, winter | 02/10/97, 0.4 mm rainfall | average, winter/spring | average, summer/fall |
| **General Water Chemistry** | | | | | | | | | | | | | | | | | | | |
| Solids, suspended, mg/L | 2.5 | | 34.0 | 51.0 | 241.0 | 357.0 | 80.0 | 38.0 | 70.0 | 124.4 | 7.0 | 18.0 | 84.0 | 227.0 | 309.0 | 52.0 | 122.0 | 196.0 | 74.7 |
| Turbidity, FTU | 0.01 | | 25.90 | 46.10 | 144.00 | 395.00 | 56.90 | 21.40 | 62.70 | 107.43 | 5.20 | 11.80 | 25.30 | 187.00 | 299.00 | 37.90 | 60.00 | 174.63 | 32.37 |
| pH | n/a | 6.5 - 8.5 | 7.73 | 7.43 | 7.53 | 7.65 | 7.49 | 7.77 | 7.22 | 7.55 | 7.84 | 7.66 | 7.45 | 7.82 | 7.73 | 7.84 | 7.94 | 7.80 | 7.68 |
| Alkalinity, mg $CaCO_3$/L | 0.25 | | 29.20 | 43.20 | 69.00 | 61.80 | 52.00 | 49.20 | 38.60 | 49.00 | 81.60 | 158.00 | 114.00 | 150.00 | 141.00 | 67.20 | 332.00 | 119.40 | 201.33 |
| Chloride, mg/L | 0.2 | | 23.2 | 1,140.0 | 2,470.0 | 3,540.0 | 130.0 | 35.2 | 74.8 | 1,059.0 | 24.2 | 86.8 | 57.2 | 2,050.0 | 2,600.0 | 151.0 | 176.0 | 1,600.3 | 106.7 |
| Conductivity, µS/cm | 1.0 | | 167.0 | 3,790.0 | 7,440.0 | 9,800.0 | 532.0 | 258.0 | 382.0 | 3,195.6 | 309.0 | 619.0 | 452.0 | 6,470.0 | 7,750.0 | 645.0 | 1,250.0 | 4,955.0 | 773.7 |
| **Nutrients** | | | | | | | | | | | | | | | | | | | |
| Nitrogen; ammonia + ammonium, mg/L | 0.002 | | 0.144 | 0.784 | 7.580 | 1.270 | 0.788 | 0.696 | 0.994 | 1.751 | 0.346 | 0.104 | <MDL | 4.920 | 2.850 | 0.718 | 0.002 | 2.829 | 0.053 |
| Nitrogen; nitrite, mg/L | 0.001 | | 0.024 | 0.130 | 0.230 | 0.255 | 0.055 | 0.030 | 0.056 | 0.111 | 0.058 | 0.094 | 0.024 | 0.139 | 0.169 | 0.042 | 0.003 | 0.117 | 0.040 |
| Nitrogen; nirate + nitrite, mg/L | 0.005 | | 0.490 | 0.950 | 1.550 | 1.290 | 0.700 | 0.735 | 1.450 | 1.024 | 0.380 | 3.010 | 0.030 | 2.880 | 2.880 | 1.120 | 4.980 | 2.293 | 2.673 |
| Nitrogen; total Kjeldahl, mg/L | 0.02 | | n/a | 1.04 | 9.20 | 4.90 | 4.70 | 2.20 | 2.80 | 4.14 | 0.82 | 1.60 | 3.24 | 9.90 | 9.50 | 2.16 | 1.30 | 7.19 | 2.05 |
| Phosphorus; total, mg/L | 0.002 | 0.01 - 0.03 | n/a | 0.320 | 0.780 | 0.540 | 0.940 | 0.490 | 0.370 | 0.573 | 0.094 | 0.330 | 1.380 | 0.480 | 0.490 | 0.344 | 0.356 | 0.438 | 0.689 |
| Phosphorus; phosphate, mg/L | 0.0005 | | 0.0455 | 0.1400 | 0.4080 | 0.1700 | 0.2600 | 0.3400 | 0.1300 | 0.2134 | 0.0450 | 0.1850 | 0.9800 | 0.2220 | 0.0475 | 0.2200 | 0.0525 | 0.1632 | 0.4058 |
| **Organics** | | | | | | | | | | | | | | | | | | | |
| Carbon; dissolved organic, mg/L | 0.1 | | n/a | 2.0 | 22.1 | 4.0 | 4.3 | 5.2 | 5.8 | 7.2 | 2.8 | 7.1 | 30.0 | 23.1 | 5.0 | 3.9 | 1.9 | 10.7 | 13.0 |
| Solvent extractable, mg/L | 1.0 | | 3.0 | 7.0 | 42.0 | 26.0 | 9.5 | 4.0 | 12.0 | 14.8 | <MDL | <MDL | 4.0 | 23.0 | 11.0 | 6.0 | 3.5 | 13.3 | 3.8 |
| **Inorganics** | | | | | | | | | | | | | | | | | | | |
| Aluminum, µg/L | 11 | 75 | 377 | 293 | 765 | 813 | 433 | 293 | 407 | 483 | 136 | 281 | 280 | 632 | 622 | 319 | 391 | 524 | 317 |
| Arsenic, mg/L | 0.0005 | 0.1 | <MDL | <MDL | 0.002 | 0.001 | 0.002 | 0.002 | 0.002 | 0.002 | <MDL | <MDL | <MDL | <MDL | 0.001 | 0.002 | <MDL | 0.002 | <MDL |
| Barium, µg/L | 0.2 | | 9.1 | 15.3 | 48.9 | 55.6 | 13.8 | 9.2 | 10.8 | 23.2 | 19.3 | 29.1 | 26.0 | 69.9 | 66.5 | 14.2 | 61.0 | 50.2 | 38.7 |
| Beryllium, µg/L | 0.02 | | 0.02 | 0.01 | 0.07 | 0.07 | 0.03 | 0.01 | 0.02 | 0.03 | 0.01 | 0.03 | 0.03 | 0.06 | 0.06 | 0.02 | 0.05 | 0.05 | 0.04 |
| Cadmium, µg/L | 0.6 | 0.2 | 0.4 | 0.5 | 0.6 | 1.3 | 0.6 | 0.0 | 0.0 | 0.5 | 0.1 | 0.3 | 0.7 | 0.4 | 0.9 | 0.3 | 0.8 | 0.5 | 0.6 |
| Calcium, mg/L | 0.005 | | 14.100 | 29.500 | 118.000 | 134.000 | 27.800 | 21.200 | 20.100 | 52.100 | 34.200 | 74.800 | 50.800 | 136.000 | 149.000 | 32.300 | 164.000 | 105.767 | 96.533 |
| Carbon; dissolved inorganic, mg/L | 0.2 | | n/a | 9.6 | 13.6 | 13.0 | 12.2 | 10.8 | 8.6 | 11.3 | 18.8 | 38.4 | 27.6 | 32.6 | 31.4 | 15.6 | 77.6 | 26.5 | 47.9 |
| Chromium, µg/L | 1.4 | 8.9 as $Cr^{III}$ | 3.7 | 4.4 | 11.0 | 14.6 | 7.5 | 3.6 | 4.6 | 7.1 | 0.5 | 0.5 | 0.9 | 8.0 | 10.0 | 4.2 | 1.2 | 7.4 | 0.9 |
| Cobalt, µg/L | 1.3 | 0.9 | <MDL | 0.2 | 1.6 | 2.1 | 1.4 | 0.6 | 0.6 | 1.1 | <MDL | 0.6 | 1.9 | 1.3 | 1.7 | 0.9 | <MDL | 1.3 | 1.2 |
| Copper, µg/L | 1.6 | 5 | 9.1 | 13.7 | 44.3 | 45.9 | 20.9 | 10.5 | 16.6 | 23.0 | 2.9 | 14.6 | 25.2 | 36.8 | 37.5 | 16.7 | 15.2 | 30.3 | 18.3 |
| Iron, µg/L | 0.8 | 300 | 619.0 | 721.0 | 1550.0 | 1360.0 | 902.0 | 447.0 | 767.0 | 909.4 | 323.0 | 315.0 | 716.0 | 1350.0 | 1040.0 | 599.0 | 260.0 | 996.3 | 430.3 |
| Lead, µg/L | 10 | 25 | 13 | 23 | 66 | 69 | 41 | 8 | 25 | 35 | 0 | 6 | 13 | 37 | 51 | 19 | 15 | 36 | 12 |
| Magnesium, mg/L | 0.008 | | 1.830 | 3.260 | 15.300 | 54.300 | 5.390 | 3.560 | 4.080 | 12.531 | 7.750 | 7.780 | 6.850 | 24.400 | 27.400 | 4.760 | 18.900 | 18.853 | 11.177 |
| Manganese, µg/L | 0.2 | | 37.1 | 85.9 | 306.0 | 359.0 | 108.0 | 50.7 | 78.5 | 146.5 | 33.4 | 88.6 | 543.0 | 228.0 | 289.0 | 73.2 | 193.0 | 196.7 | 274.9 |
| Mercury, µg/L | 0.02 | 0.2 | <MDL | <MDL | 0.04 | 0.03 | 0.02 | 0.02 | 0.02 | 0.03 | <MDL | <MDL | <MDL | 0.03 | 0.03 | <MDL | 0.04 | 0.03 | 0.04 |
| Molybdenum, µg/L | 1.6 | 40 | <MDL | <MDL | 0.0 | <MDL | 0.3 | <MDL | 0.2 | 0.2 | 0.4 | <MDL | 0.1 | <MDL | 0.2 | 0.4 | <MDL | 0.3 | 0.1 |
| Nickel, µg/L | 1.3 | 25 | 1.2 | 1.3 | 3.8 | 4.1 | 1.5 | 1.1 | 2.1 | 2.2 | 0.7 | 0.9 | 4.0 | 3.6 | 2.9 | 1.5 | 1.4 | 2.7 | 2.1 |
| Selenium, mg/L | 0.0005 | 0.1 | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL |
| Silicon, reactive silicate, mg/L | 0.02 | | n/a | 0.44 | 0.44 | 0.44 | 0.52 | 0.60 | 0.32 | 0.46 | 0.72 | 2.64 | 1.84 | 1.82 | 1.80 | 0.72 | 5.30 | 1.45 | 3.26 |
| Strontium, µg/L | 0.1 | | 59.0 | 204.0 | 920.0 | 702.0 | 127.0 | 89.9 | 103.0 | 315.0 | 166.0 | 193.0 | 136.0 | 644.0 | 618.0 | 130.0 | 360.0 | 464.0 | 229.7 |
| Titanium, µg/L | 0.5 | | 6.4 | 4.2 | 2.6 | 4.5 | 5.9 | 4.8 | 5.3 | 4.8 | <MDL | 5.5 | 2.4 | 2.3 | 1.1 | 4.6 | <MDL | 2.7 | 3.9 |
| Vanadium, µg/L | 1.5 | 6 | 0.7 | 1.6 | 3.3 | 2.9 | 2.2 | 1.4 | 2.0 | 2.0 | 1.1 | 0.9 | 2.1 | 2.8 | 2.6 | 2.0 | 0.6 | 2.5 | 1.2 |
| Zinc, µg/L | 0.6 | 30 | 67.1 | 65.0 | 209.0 | 230.0 | 110.0 | 43.7 | 74.0 | 114.1 | 33.2 | 206.0 | 556.0 | 142.0 | 174.0 | 73.7 | 74.0 | 129.9 | 278.7 |
| **Bacteria** | | | | | | | | | | | | | | | | | | | |
| Escherichia coli, c/100mL | N/A | 100 | 3,500 | | 1,300 | 340 | | 1,700 | 11,100 | 3,588 | 940 | 3,400 | | 760 | 2,300 | | | 1,530 | 3400 |
| Fecal streptococcus, c/100mL | N/A | | 10,100 | | 2,900 | 1,400 | | 7,400 | 25,000 | 9,360 | 4,700 | 780 | | 3,200 | 6,600 | | | 4,900 | 780 |
| Pseudomonas aeruginosa, c/100mL | N/A | | 10 | | 20 | 20 | | 4 | 10 | 13 | 32 | 4 | | 20 | 20 | | | 20 | 4 |
| **Toxic Organics** | | | | | | | | | | | | | | | | | | | |
| 2,4-dichlorophenol, ng/L | 2000 | 4,000 | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | | |
| 2,4,6-trichlorophenol, ng/L | 20 | 18,000 | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | | |
| 2,4,5-trichlorophenol, ng/L | 100 | 18,000 | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | | |
| 2,3,4-trichlorophenol, ng/L | 100 | 18,000 | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | | |
| 2,3,4,5-tetrachlorophenol, ng/L | 20 | 1,000 | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | | |
| 2,3,4,6-tetrachlorophenol, ng/L | 20 | 1,000 | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | | <MDL | 73 | <MDL | <MDL | <MDL | <MDL | <MDL | | |
| Pentachlorophenol, ng/L | 10 | 500 | <MDL | <MDL | <MDL | 25 | 95 | 78 | 53 | 63 | <MDL | 400 | 390 | <MDL | 19 | 110 | <MDL | 65 | 395 |
| Dicamba, ng/L | 50 | 200,000 | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | | |
| Bromoxynil, ng/L | 50 | | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | | |
| 2,4-D-propionic acid, ng/L | 100 | | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | | |
| 2,4-D, ng/L | 100 | 4,000 | <MDL | <MDL | <MDL | 140 | 170 | 190 | <MDL | 167 | <MDL | <MDL | 340 | <MDL | 230 | 210 | <MDL | 220 | 340 |
| Silvex, ng/L | 20 | | <MDL | <MDL | <MDL | 42 | <MDL | <MDL | <MDL | 42 | <MDL | 48 | <MDL | <MDL | <MDL | <MDL | <MDL | | |
| 2,4,5-T, ng/L | 50 | 18,000 | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | | |
| 2,4-DB, ng/L | 200 | | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | | |
| Picloram, ng/L | 100 | | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | | |
| Diclofop-methyl, ng/L | 100 | | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | <MDL | | |

Notes:
1. Samples taken from the main sewer during the winter / spring period of 1996-1997 were presumably all grab samples. Rain data are not available for this period.
2. Samples taken from the bottom of MH25 were presumably composite samples in summer/fall and grab samples in winter/spring.
3. Averages reported here are simple averages, without consideration of log-normal distributions, etcetera.

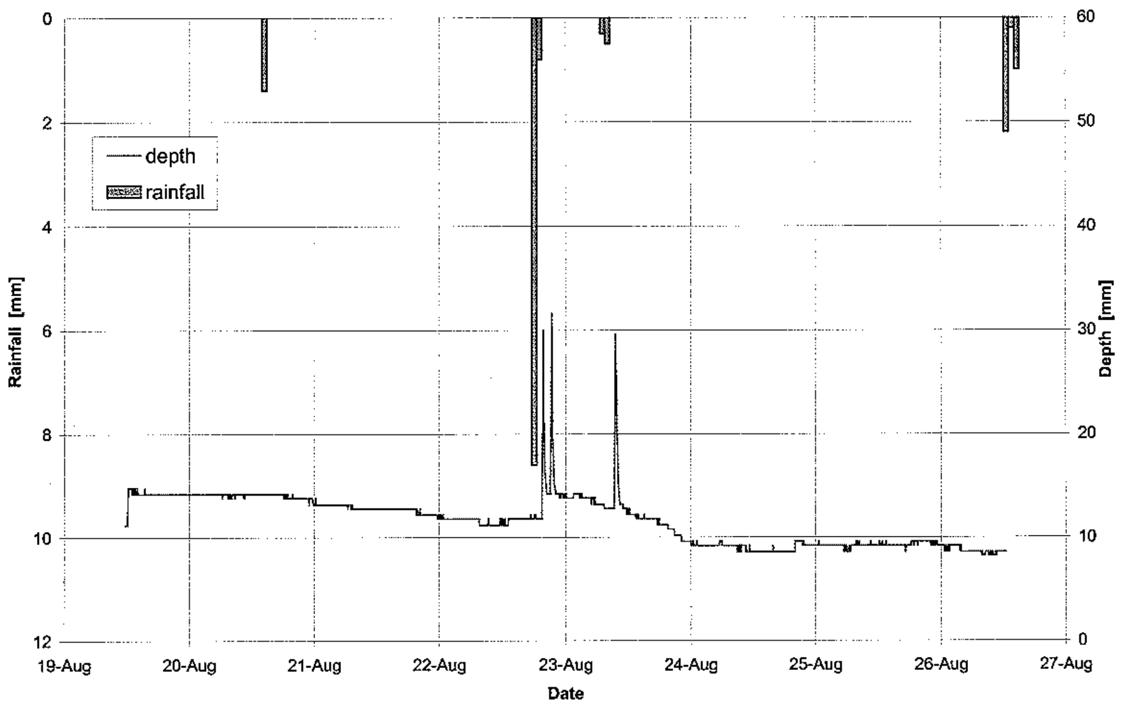


***Figure H.1:*** Water depth and rainfall -- Braecrest filtration facility, August 1996

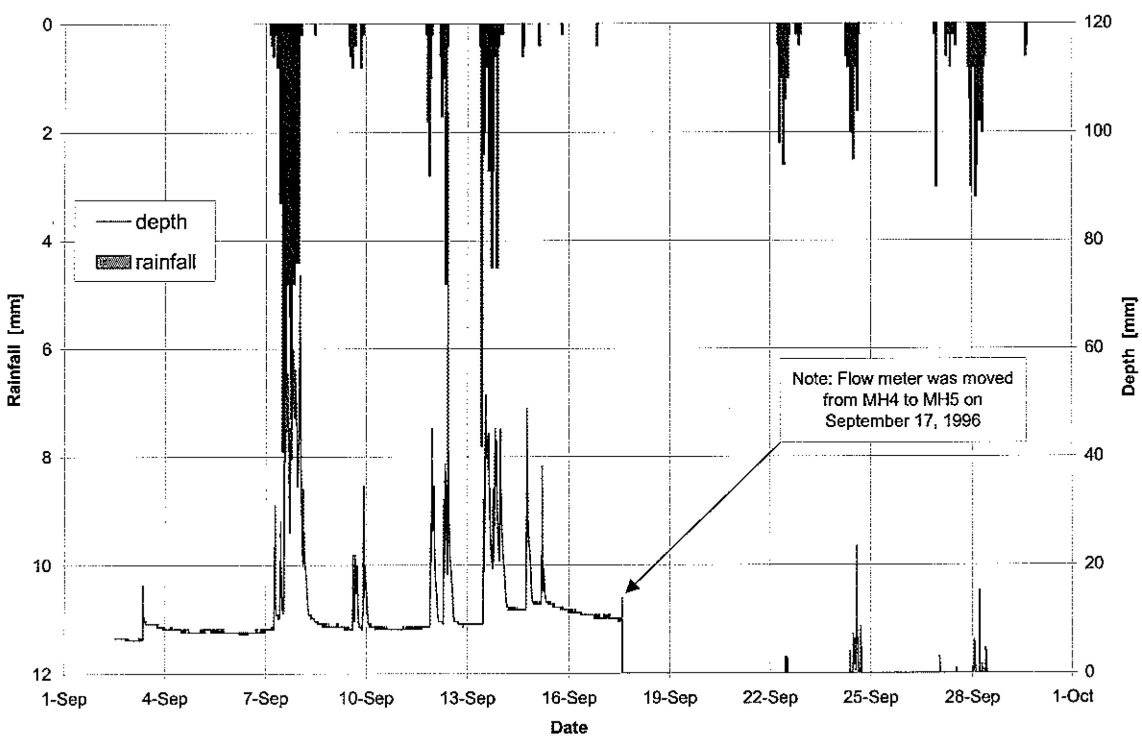


***Figure H.2:*** Water depth and rainfall -- Braecrest filtration facility, September 1996

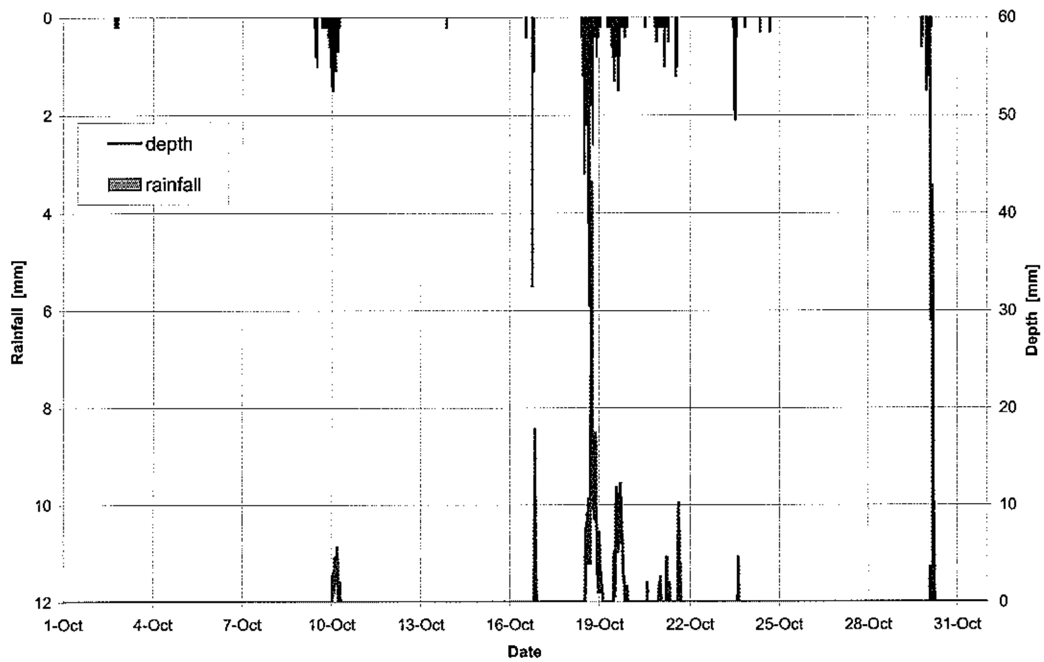


***Figure H.3:*** Water depth and rainfall -- Braecrest filtration facility, October 1996

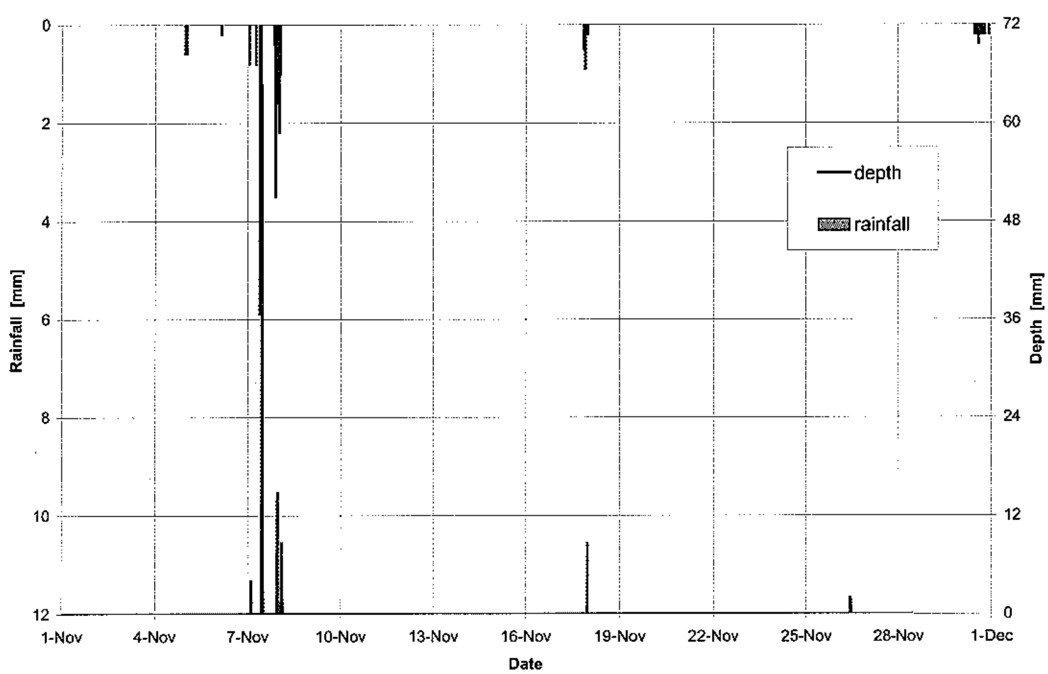


***Figure H.4:*** Water depth and rainfall -- Braecrest filtration facility, November 1996

An area-velocity meter can not measure flows at depths less than about 5 cm. Inspection of Figures H.1 to H.4 shows that water depths in the sewer rarely spiked above 2 cm (20 mm). Consequently, there were very few non-zero flow observations, and there are few data points from which a depth-to-flow correlation could be developed.

### H.2.2 Water quality data -- summer / fall period

Initial sampling was undertaken with an automated sampler located in the downstream maintenance hole. The samples represented the total discharge from the system, including the filtrate, the unfiltered discharges of two catchbasins (one draining to upstream MH 1 and one draining to downstream MH 5) and any unfiltered overflow that may have occurred. These samples also represent the summer/fall monitoring period.

Based on rainfall at the airport, 7 km to the west of the site, the first event was large (26.7 mm daily rain), the second event was of moderate size (4.5 mm daily rain) and no precipitation occurred on the third day of sampling, or for four days prior to the third day of sampling. Since a sample was obtained from a catchbasin lead on the third day, a highly localized rainfall event must be assumed.

Table H.2 averages the constituent concentrations from the three "outlet" composite samples and computes percent removal using the single "inlet" sample. Because the database is small, these results should not be taken as a definitive statement of the capability of the system, but they may indicate some significant trends. Specific comments follow:

- The single inlet TSS concentration appears to be quite large, resulting in a large percent removal value. The removal of mass (93%) was considerably greater than the removal of turbidity. The inlet may have contained large particles that contributed to suspended mass but did little to contribute to turbidity. However, the catchbasin would have been expected to remove such large suspended particles.
- The chloride concentration was increased but the conductivity was reduced through the filtration system. These results are inconsistent. Theoretically, an increase in both chloride and conductivity may have resulted from salt applied to the road in winter being trapped in the filter bed and subsequently leached out by summer runoff.
- There nitrogen removal values are inconsistent, but the phosphorus removal values appear to be reasonable.
- The removal of organic material - oil and grease and dissolved organic carbon - was good.
- The removal of inorganic material was inconsistent with some constituents having apparently good removal efficiencies and others poor removal efficiencies. In addition to the limited database, natural variability and concentrations close to the analytical detection limits may have influenced these results.

- There were appreciable bacterial concentrations in the outlet flow. No inlet data are available.
- Most of the biocide (pesticide and preservative) concentrations were less than their respective detection limits.
- Comparison of the outlet constituent concentrations from the first event to the second event indicates the effect of flow rate or the size of the event. Faster flows may carry more suspended material into the system and through the filter bed. Larger volumes may dilute some of the soluble constituents in the influent, but also have the potential to leach more material out of the filter bed by wetting a greater portion of the filter gravel. TSS and turbidity in the outlet increased with event size. Most nutrient concentrations decreased. Chloride and conductivity increased, presumably because of the increased potential for leaching. Inorganic constituent concentrations increased or decreased, presumably depending on whether the materials were predominantly soluble or suspended.

### H.2.3 Water quality data -- winter / spring period

Table H.2 also lists and averages the results of the seven winter/spring samples. These samples were obtained from the main sewer discharging into MH 5. Thus, they excluded the filtrate entering MH 5 as well as the untreated runoff entering MH 5 from one catchbasin and are not directly comparable to the summer/fall samples. No precipitation data are available for this time period and no influent samples were taken. Specific comments follow:

- Relative to the summer/fall samples, the chloride concentration increased by two orders of magnitude, and conductivity increased by one order of magnitude.
- The concentrations of many of the other constituents also increased relative to the summer period. Several mechanisms may be responsible for increased concentrations: low flow volumes in winter would reduce the dilution of some constituents such as nutrients from animal wastes, and removal mechanisms would be inhibited because of slower reaction rates and increased water viscosity at colder temperatures. Water temperature data were not available.

### H.2.4 Particle size distributions

Particle size data are available for all samples (Figure H.5). The three outlet samples from the summer/fall period have similar particle size distributions with an average size from approximately 5 to 10 μm. The inlet distribution measured on November 13th had an average size of approximately 20 μm. The particle sizes in the winter sample were noticeably finer, with an average size between approximately 1.5 and 3.5 μm. This difference between the summer and winter conditions is consistent with the decrease in the average outlet TSS concentration and the increase in the average outlet turbidity between summer and winter.

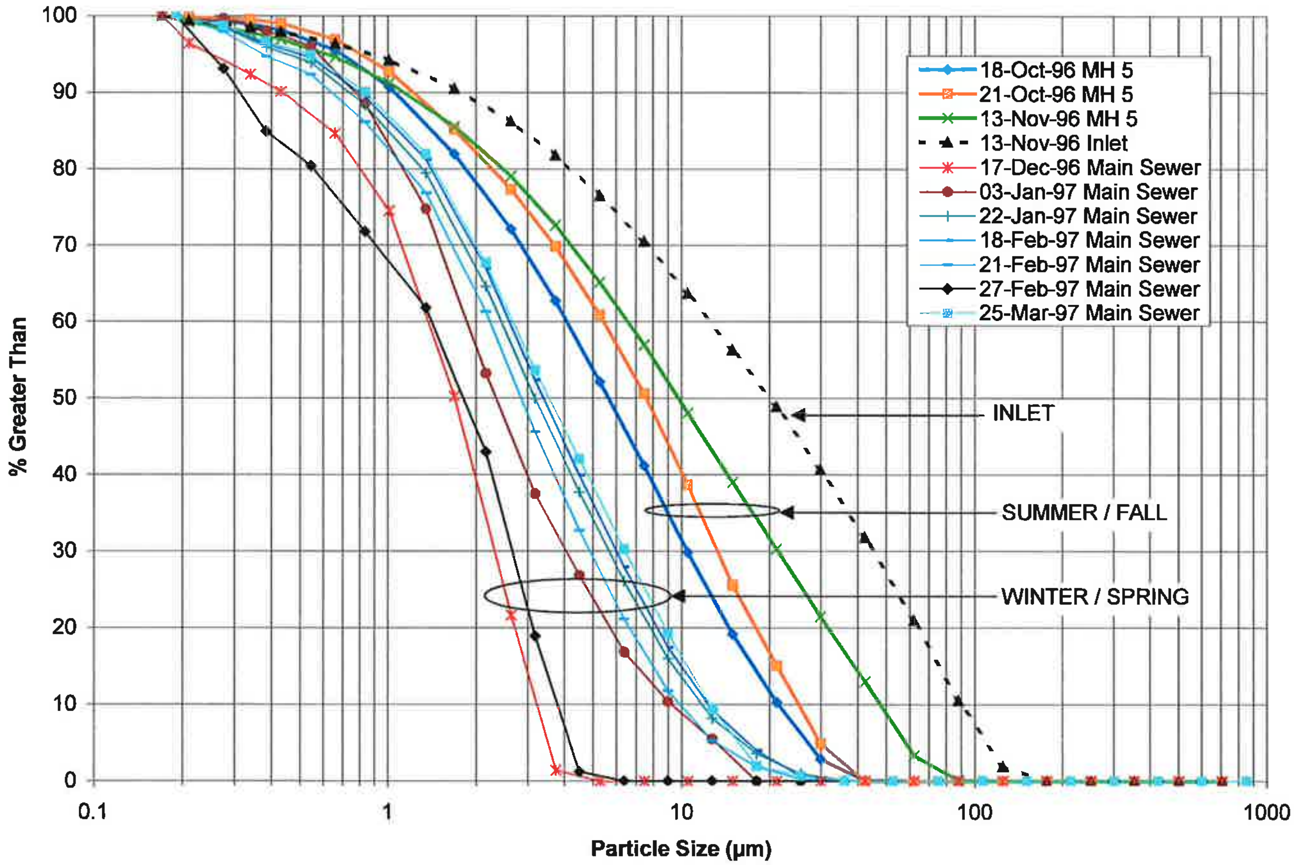


***Figure H.5:*** Particle size distributions -- Braecrest Avenue filtration facility