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

SWAMP

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Ministry of the Environment
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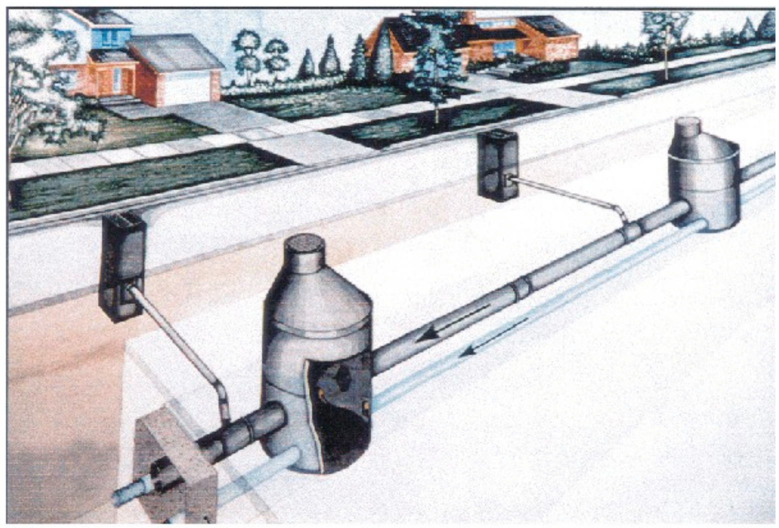

Conservation
TORONTO AND REGION

TORONTO

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

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NOTICE

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.

PUBLICATION INFORMATION

Documents in this series are available from 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.

The following individuals provided technical advice and guidance:

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- Weng Liang — Ontario Ministry of the Environment (formerly with SWAMP)
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- Pat Chessie — City of Toronto
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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.

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[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.

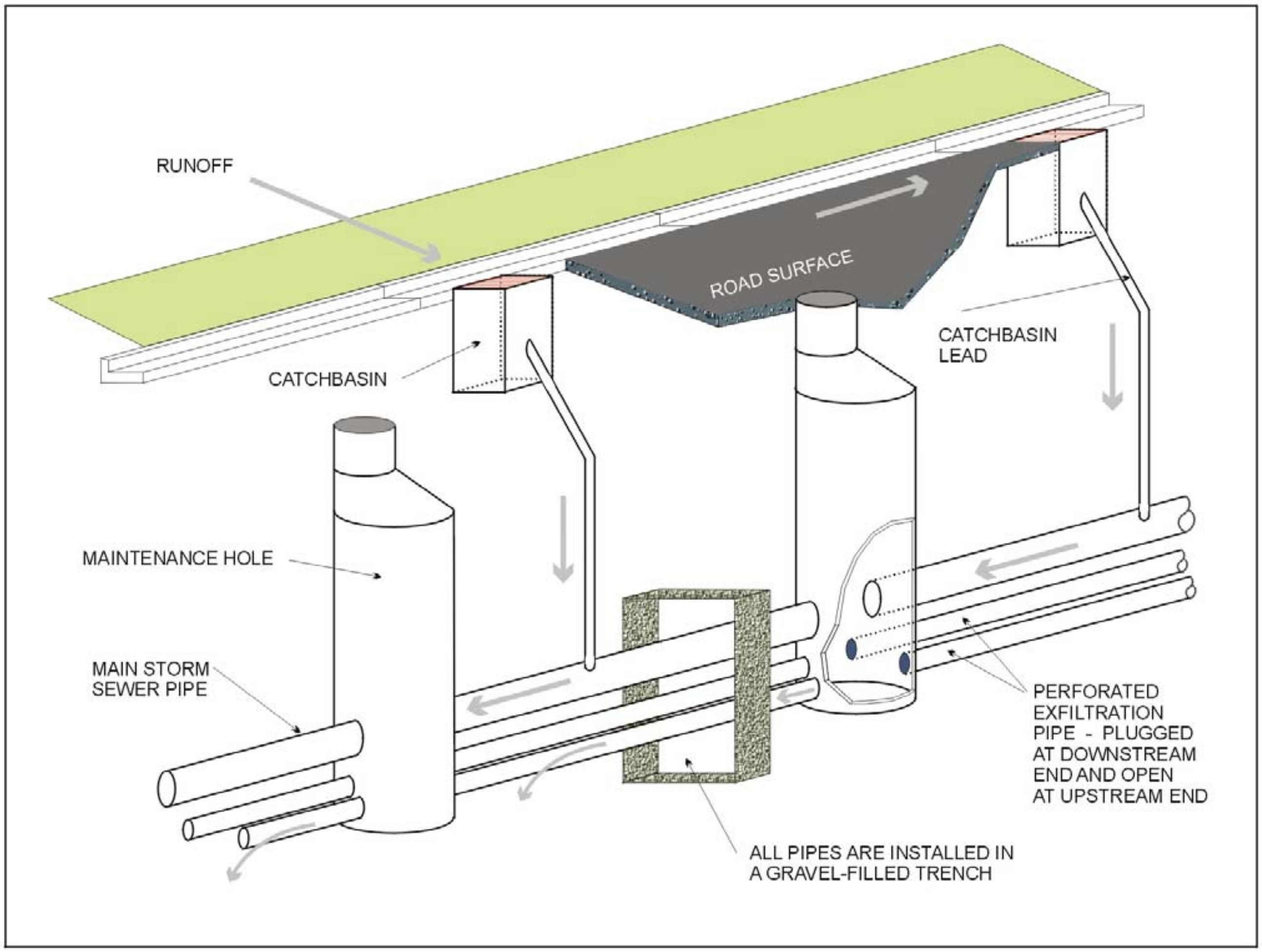

Figure 1: Etobicoke exfiltration system schematic

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.

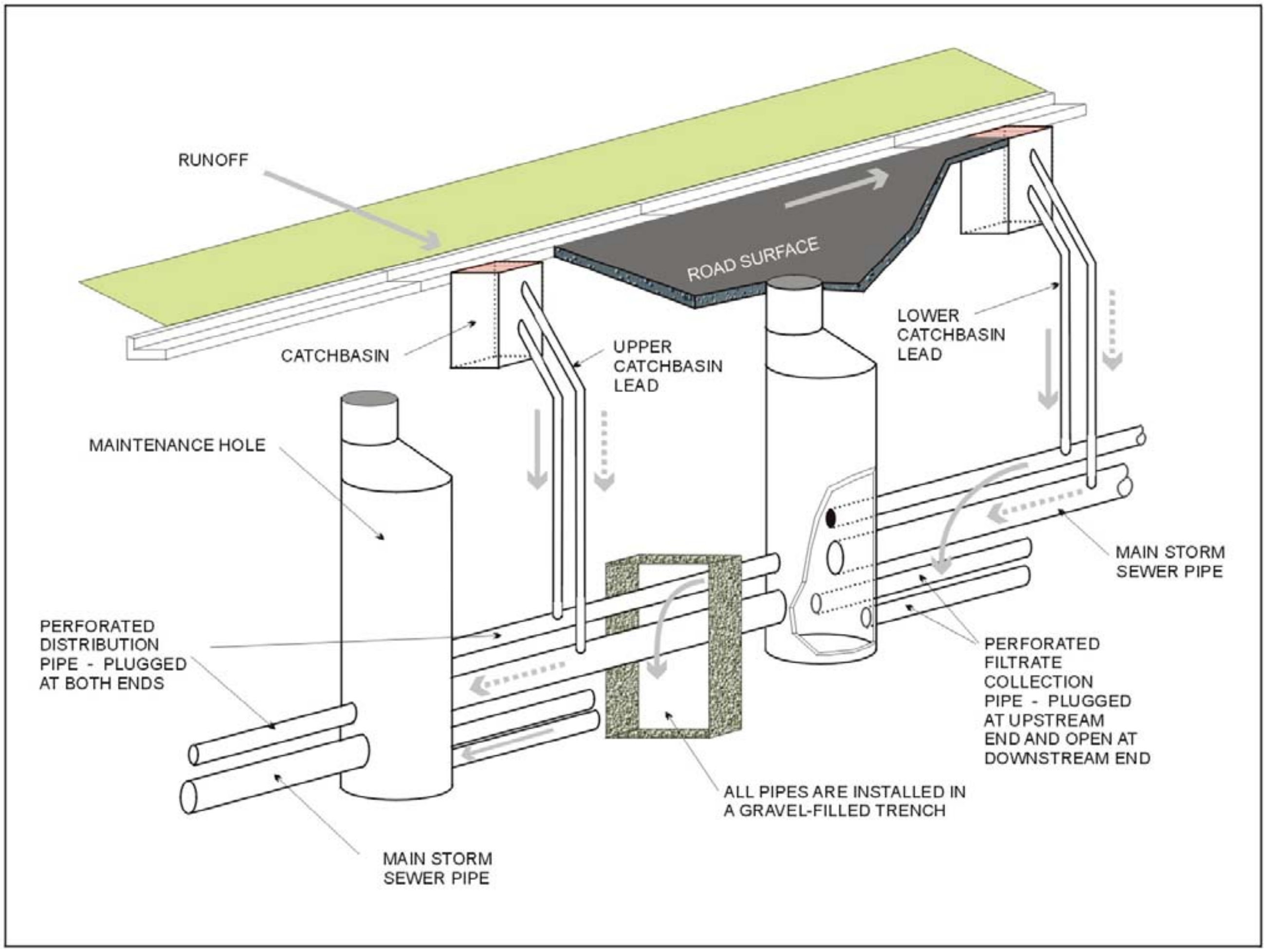

Figure 2: Etobicoke filtration system schematic

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.

TABLE OF CONTENTS

List of Figures

List of Tables