

Design Construction and Performance of Exfiltration Trenches

Alan A. Smith¹ and Tai D. Bui²

Abstract

An exfiltration trench splits an inflow hydrograph into two components. The outflow hydrograph is attenuated by the storage in the voids of the clear stone fill and the balance of the inflow is transmitted to the ground water through the pervious base and walls of the trench. Such a facility can provide an innovative approach to stormwater management with several advantages over conventional end-of-pipe solutions

Details of the trench design are described, some points concerning construction procedure are reviewed and recommendations for post-construction monitoring are presented. Experimental procedures for testing the facility are also described.

Basic Concepts

In its simplest form, an exfiltration trench comprises a trench filled with single sized gravel inserted in a storm sewer. The inflow fills the voids in the gravel and when the level exceeds the invert of the outflow conduit a portion of the inflow hydrograph is transmitted downstream. The storage in the voids causes attenuation of the peak flow and, assuming the soil surrounding the trench has finite hydraulic conductivity, will exfiltrate to the surrounding soil to recharge the groundwater as shown in Figure 1.

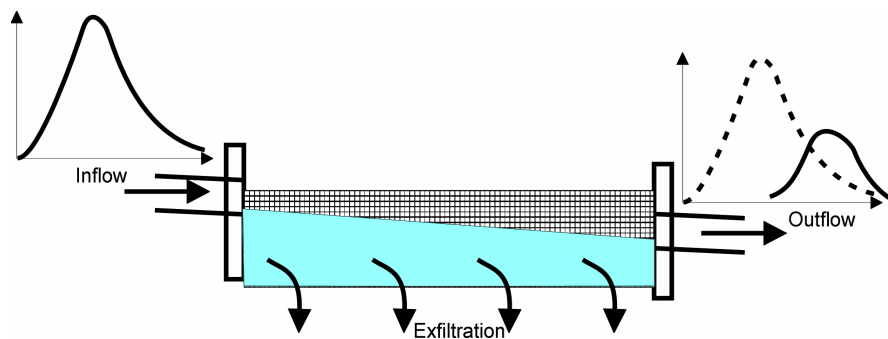


Fig. 1 – A simple exfiltration trench

¹ President, Alan A. Smith Inc., 17 Lynndale Drive, Dundas, Ontario, Canada L9H3L4; Director, Weslake Inc. Tel: 905-628-4682; info@alanasmith.com .

² Vice-President, Weslake Inc., #10 120 Lancing Dr., Hamilton, Ontario, Canada, L8W3A1. Tel: 905-574-2300; bui@weslake.com.

Clearly for this to happen the groundwater table in the vicinity of the trench must be below the trench invert at, or subsequent to, the time of the storm runoff

The Etobicoke Trench

Based on a suggestion by J. Tran, the City of Toronto, Ontario constructed a small number of trenches in an established residential area (in Etobicoke) with the more detailed geometry shown in Figure 2.

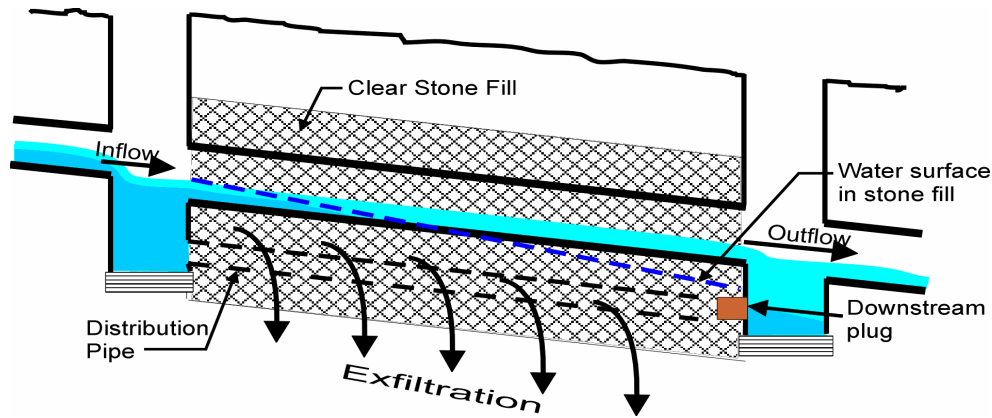


Fig. 2 – The Etobicoke exfiltration trench

The trench contains 3 pipes comprising two perforated pipes located below a conventional storm drain. The perforated pipes extend between the two manholes but are plugged at the downstream end with removable, mechanical plugs.

These plugs force inflow from the upstream manhole to be distributed along the length of the trench until the upstream water level exceeds the upstream invert level of the storm drain. Sediments tend to accumulate in the downstream end of the perforated pipes and the downstream plugs can be temporarily removed to allow accumulated sediment to be removed by raking or flushing.

Analysis and Design

Analysis of the facility is based on the continuity equation, including outflow, the rate of exfiltration and the rate of change of storage within the trench. Thus

$$\text{Inflow} = \text{Outflow} + \text{Exfiltration} + \text{Rate of change of Storage}$$

or

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

where I = inflow rate, Q = outflow rate, X = rate of exfiltration, V = volume stored in the voids of the clear stone fill and subscripts 1 and 2 define values at times t and $(t+\Delta t)$ respectively. This can be expanded as follows.

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

or

$$I_1 + I_2 = f(V_2, Q_2, X_2) - f(V_1, Q_1, X_1) + 2Q_1 + 2X_1$$

If the simplifying assumption is made that the water surface in the voids of the trench is horizontal then both the volume V and the exfiltration rate X can be expressed as a function of the outflow Q . Thus V_2 and X_2 can be found for any Q_2 and a solution for the unknown outflow Q_2 at time $(t+\Delta t)$ can be obtained from

$$f(Q_2) = f(Q_1) - 2Q_1 - 2X_1 + I_1 + I_2$$

This is similar to the method commonly used for reservoir routing and is the method currently available in version 1 of the MIDUSS 98 program. More details are available in the MIDUSS 98 User Manual. Other options available in the Trench command are as follows.

- Multiple pipes –perforated or conventional – can be described in terms of elevation, gradient, slope and length.
- Trench width can be constant or tapered with respect to height
- Outflow control devices comprising weirs, orifices or pipes can be defined.
- The trench base can be included or excluded from the exfiltration surface.

Post-Construction Field Tests

Following construction of a small number of trench facilities in 1993, a series of tests were carried out (A.M.Candaras, 1997) between May1994 and October 1995 to monitor the performance of the trenches. Some of the tests used actual rainstorm events as the source of inflow but due to the lack of severe storms during the test period a few tests were arranged using inflow from fire hydrants.

For each event both inflow and outflow were measured and piezometric water level was recorded at the upstream and downstream ends of the trench from tappings into the voids of the clear stone fill. The intent was (a) to provide information on the volume and rate of exfiltration, and (b) to obtain data on which a computer modeling and design procedure might be tested and calibrated. Figure 3 shows observations for a 63 mm storm, based on data made available by Metro Toronto Works Department.

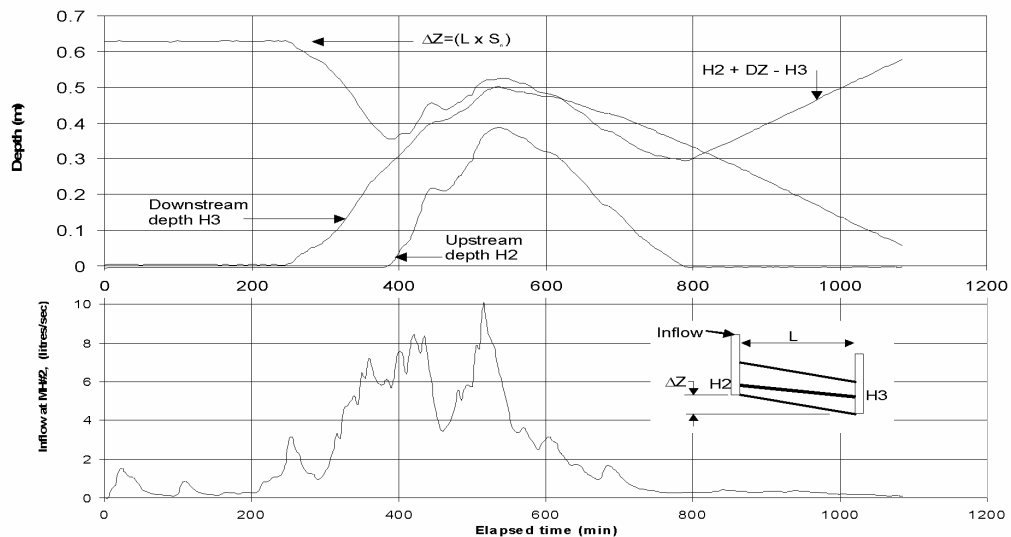


Figure 3 – Observations at Princess Margaret Blvd for storm of October 5 1995.
(Trench length $L = 98.5$ m, $S = 0.65\%$, $\Delta Z = 0.64$ m, $W = 2.86$ m. H2 and H3 are depths at manholes MH2 and MH3 respectively)

Funding for the study was provided by Environment Canada through the Great Lakes 2000 Cleanup Fund and was administered by the City of Etobicoke, now part of Metro Toronto.

A number of important observations can be made from the above information.

- (1) The lower part of Figure 3 shows no outflow hydrograph because the report states that there was “No overflow at MH2”. Thus the total inflow volume of 63 mm or 130 c.m. was absorbed into the surrounding soil.
- (2) After time $t = 800$ min the inflow is extremely small. Further, the drawdown curve of the downstream head $H3$ is almost linear. A simple calculation suggests that the hydraulic conductivity is approximately 30 mm/h –orders of magnitude greater than suggested by conventional field tests and in geotechnical texts.
- (3) The curve $H2 + \Delta Z - H3$ is the amount by which the upstream water level is above the downstream level and is initially equal to the drop ΔZ until the lower end of the trench begins to fill. It can be seen that as the inflow rate increases the gradient of the free surface increases. During the time when the upstream depth is finite the maximum difference in elevation is approximately 0.52 m – slightly less than the drop in trench invert of $\Delta Z = 0.64$ m. Some allowance for this surface gradient is necessary for both design and simulation.
- (4) From time $t=800$ min the area of the sidewalls amounts to less than 10% of the total area available for exfiltration. It seems clear therefore that the trench base is a very important component of the exfiltration process and should not be ignored as is sometimes suggested in the literature. Recall that these observations were made after the facility had been in service for 3 years.

The above discussion focuses on a single storm and a single trench but similar observations can be made for another trench and for another 4 tests.

The Brantford N.W.I.A. Development

The North-West Industrial Area is a proposed development in the City of Brantford, Ontario located adjacent to the Grand River. The soil is coarse gravel with a water table elevation which varies from 10 to 15 m below ground level.

A wetland adjacent to the proposed development constitutes a “Perched Prairie Fen” fed by groundwater seepage. The Fen contains a number of species that have been identified by the Natural Heritage Centre of the Ontario Ministry of Natural Resources as nationally and/or provincially rare.

Groundwater seepage is responsible for maintaining the wetlands and traditional development would seriously affect the quantity of groundwater seepage into the wetland and thus threaten the existence of the habitat. Weslake Inc. therefore proposed the extensive use of exfiltration trenches for stormwater management as having both environmental and economic benefits

Storm Water Management Design

The drainage system was designed to handle design storms of 2, 5 and 100-year return periods with rainfall depths of 35.9, 44.9 and 72.5 mm respectively. In addition, the exfiltration facilities were designed to absorb the total runoff from a 15 mm storm.

Phase 1 of the development has an area of 102.5 ha with a proposed percentage imperviousness of 75%. Total conduit length is 4,700m of which 1,300 m comprises open channels to facilitate the transition with adjacent areas and future works.

The 3,400 m of storm drain and exfiltration trenches will be located within the road allowance of proposed service roads and highways but exfiltration trenches will not be located in areas of anticipated heavy traffic.

The analysis required 4 steps described in the following scenarios. Each step involves an additional design feature and the process was simplified by the capability of the MIDUSS 98 program to run in 'Automatic' mode using as input the output file from the previous scenario. The four scenarios are described as follows.

(a) Worst case scenario design

A design was carried out using the 2-year storm assuming no stormwater management and no exfiltration trenches. Pipes were sized to flow 2/3 to 3/4 full. This design will carry the runoff from a 2-year storm event under a worst case scenario in which the use of exfiltration trenches may be found to be infeasible. However, if the exfiltration trenches were to be abandoned it is certain that the reduced groundwater flow would result in the loss of the unique perched fen and associated habitat.

This design provides an initial estimate of the pipe diameters and grades to be used in subsequent steps of the design process. The exfiltration trenches can then be added to this design in the next step.

(b) Exfiltration Trench Design

The so-called 'recharge' storm was used in a second analysis to determine the dimensions of the exfiltration trenches that would exfiltrate as much as possible of the runoff resulting from a storm event of 15 mm total depth. The storm sewer pipes incorporated in the trenches were taken from the 2-year design in Step (a).

A small fraction of the runoff could not be absorbed into the ground water in this way because of the decision not to locate exfiltration trenches within the road allowance of heavily trafficked routes near the downstream end of the drainage network. The output from this design scenario can now be used to test its performance under a more severe 5-year storm event.

(c) Ultimate Design

A third design session uses the 5-year storm under the following assumptions.

- Individual lots are provided with on-site controls that reduce the peak runoff from each lot by 25%. Lot owners or occupiers will be required or encouraged to provide on-site storage which will achieve a 50% reduction in runoff peak but only 25% is assumed to be achieved in order to provide a safety factor. On-site storage will be provided in the form of rooftop storage and/or parking lot storage.
- Trench dimensions are as determined for the 15 mm storm design in Step (b)
- Initial pipe diameters and grades are assumed to be as determined in Step (a) (the 2-year storm with no stormwater management). In the event that a pipe was found to be surcharged some increase in diameter can be made at this stage to allow free surface flow with a depth of approximately 2/3 to 3/4 of the diameter.

The output file from this scenario can now be used to estimate the flows on the major system in the event of a 100-year storm.

(d) Major System Design

This design uses the 100-year storm event and assumes that pipe diameters and gradients are as determined in Step (c) and that exfiltration trench dimensions are as determined in Step (b).

For each case where pipe surcharge occurs, the flow hydrograph is split into the major and minor components using the DIVERSION design command of MIDUSS 98. For this purpose no allowance was made for the small increase in pipe carrying capacity which is usually associated with the steeper hydraulic grade of surcharged flow. The major system hydrographs can then be used to check the capacity and depth of flow in the road cross-sections.

Table 1 – Typical parameter values for trench design

Voids ratio		40%
Hydraulic conductivity		300 mm/h
Trench invert gradient		0.3%
Perforated pipes	Number	2
	Diameter	200 mm
	Gradient	0.3%
	IL above trench IL	0.5 m
Trench width top & bottom		3.0 m
Trench height (approximately).		2.5 m
Storm IL above trench IL		1.0 m

Design Assumptions

Table 1 summarizes the values used for the design of the exfiltration trenches for a typical cross section. In general, the section comprises the regular storm sewer within a rectangular trench with two perforated pipes located below and to either side of the storm sewer. Figure 4 shows the cross-section layout being defined in the MIDUSS 98 window.

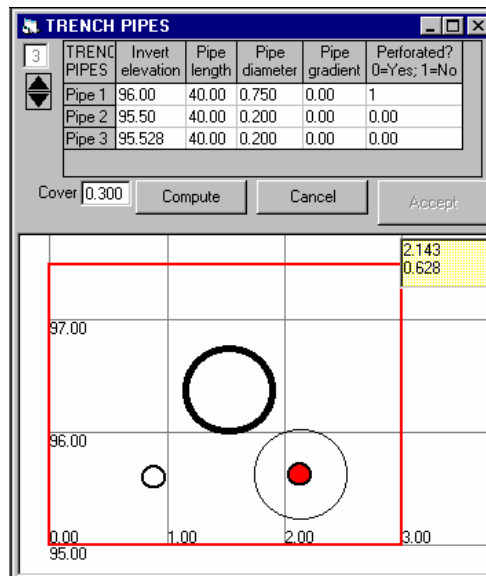


Figure 4 – Typical cross-section as shown in MIDUSS 98 window

Determination of Hydraulic Conductivity

One of the most critical parameters required for the design is the hydraulic conductivity of the native soil surrounding the clear stone fill in the trench. In a previous section it was noted that the observed draw-down rate in one of the Etobicoke trenches implied a much higher value than was suggested in textbook values for the soil type. The problem is compounded by widely different values that are suggested in the literature. As an example, Table 2 shows values in mm/hour for various soil types taken from two references on the subject, namely the German ATV Standards and the U.K. CIRIA report on infiltration systems.

Table 2 – Suggested values for Hydraulic Conductivity K (mm/hour)

Soil Description	German ATV Standards		CIRIA Report #156	
	Min.	Max.	Min.	Max.
Coarse gravel	36,000	100,000		
Fine/medium gravel	3,600	18,000	10	1000
Sandy gravel	1000	10,000		
Coarse sand	1000	6,000		
Medium sand	200	1000	0.1	100
Fine sand	36	360		
Loamy sand			0.01	1
Silty sand, sandy silt	1	100		
Sandy loam			0.005	0.05
Silt	0.03	20	0.0005	0.05
Clayey silt	0.001	3.6		
Silty clay, clay	0.0001	0.01	0.00005	0.005

The quoted values from both sources cover a wide range. In addition, values from the two sources differ by 2 and even 3 orders of magnitude. The CIRIA manual cautions that "...the high ranges reported illustrate the importance of factors such as soil packing, soil structure..." and states that an on-site percolation test is necessary".

However, geotechnical field tests to estimate hydraulic conductivity may involve different procedures and may give rise to widely varying results from a given soil type. At Brantford, a series of "slug" tests gave results suggesting that a design value of 300 mm/hour was appropriate. Care was taken to estimate conductivity from an elevation in the soil profile similar to that intended for the proposed trench.

What is needed is a series of measurements using standard geotechnical testing procedures in the vicinity of a trench for which observed drawdown rates allow an estimate to be made of the effective hydraulic conductivity. This will form part of the post-construction monitoring of the Brantford site but clearly is applicable only to that specific type of material.

Surface profile error

The algorithm used for the design assumes that the water surface in the clear stone voids of the trench is horizontal. However, for the special case of the Etobicoke trench it was observed that during periods when dQ/dt at the inlet has high positive values there is a significant difference between the upstream and downstream piezometric head values.

The surface water profile along the trench requires analysis of unsteady, spatially varied, gradually varied flow through granular media. This is further complicated by the distribution of the inflow to the trench, which in turn is a function of the difference between the surface profile and the elevation of the perforated pipe. It was therefore decided to examine the potential error that may result from using the simple algorithm in design mode.

When the outflow control is located at the downstream end of the trench the existence of any wedge storage will provide more storage than is computed by the algorithm which assumes a horizontal surface – see Figure 5.

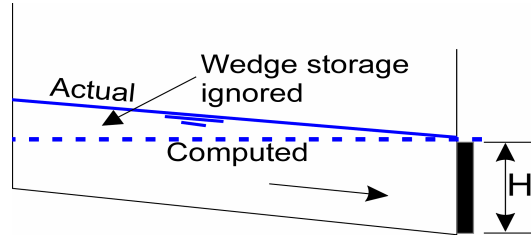


Figure 5 – Approximate profile with downstream control

For design purposes this is a conservative error and will result in a slight over-sizing of the trench or over-estimate of the peak outflow.

If the outflow control is located at the upstream end of the trench, the existence of a gradient in the surface profile will cause the actual storage to be less than the calculated volume as shown in Figure 6(a). If ignored, this would result in slight under-design or under-estimate of the peak outflow

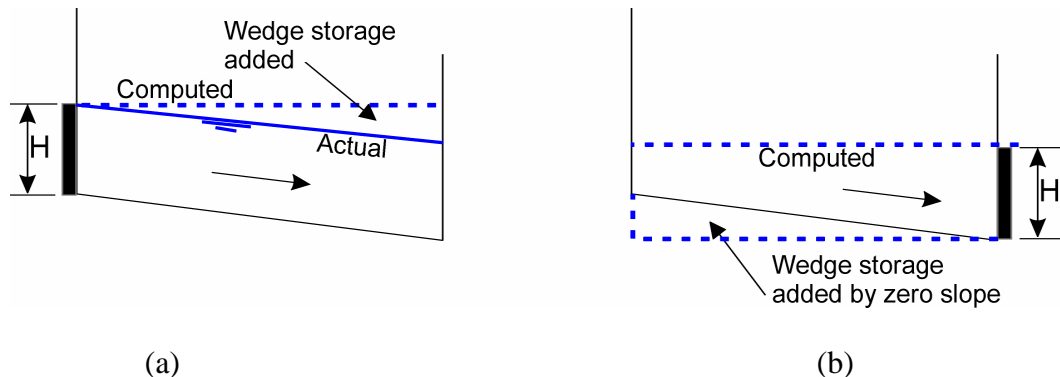


Figure 6 – Approximation used to represent an upstream control

A convenient approximation with the current design algorithm is to ignore the actual gradient of the trench bottom and assume the same control to exist at the downstream end. This causes the computed volume to be a fair approximation of what would exist if the surface profile has a gradient similar to the trench grade. The approach is illustrated in Figure 6(b).

For interest, the two approaches were evaluated for the 2-year storm event. Averaging over 26 separate trenches, it was found that using the approximation of Figure 6(b) caused the peak outflow to be reduced as expected but only by an average of about 1.6%. The storage was found to be increased by 6.2% and the exfiltrated volume was also increased but by only 3.6%.

It seems likely therefore that the errors introduced by neglect of the surface profile gradient can be partially compensated by the suggested approximation (Fig, 6(b)) but that these errors are relatively small and almost certainly smaller than the uncertainty in estimating other parameters such as the hydraulic conductivity.

Field or laboratory data is required to provide a basis for the development of a more satisfactory algorithm that can more correctly describe the surface profile in the granular media for different design configurations.

Design of the Perforated Pipes

In the project described, the perforated pipes were defined with a standard diameter of 200 mm with a gradient of 0.3%. Some grade appears to help in the accumulation of sediment at the downstream end of the pipe. Perforations are located in rings of four 16 mm (3/4") holes on the 45 degree points and spaced along the length of the pipe.

Although this design is probably satisfactory for medium sized trenches and storm sewers, it is necessary to check the capacity of this system to deliver and distribute the maximum rate of exfiltration that is expected to occur.

For the Brantford project the maximum available hydraulic grade line (HGL) is 0.3% plus a maximum possible surcharge of 0.5 m over the length of the trench. The surcharge is possible because the invert of the storm sewer is at least 0.5 m above the invert of the perforated pipes at the upstream manhole. Although the flow in the perforated pipes is spatially varied a useful check can be made by assuming uniform flow at the upstream end. For the longest trench length of 90 m the available HGL is $0.3\% + 0.5/90$ or about 0.85% and the capacity of two 200 mm pipes is approximately 0.06 c.m/s. Scanning the MIDUSS 98 output files shows that for the 2-year storm the maximum exfiltration rate is well below this limit.

Calculation of the spacing of the perforations can be estimated assuming an orifice coefficient of 0.63 and an average head of 0.5 m, which is the minimum spacing between the storm sewer and the perforated pipes. For the Brantford project a generous factor of safety of at least 2 will be used to decide the spacing to be used.

Results

For the purpose of this paper the detailed results are of no interest and only a few general observations will be made here.

As mentioned above, the project uses 3397 m of storm drain. Of this, 1919 m or 56% of the length was incorporated into exfiltration trench in order to absorb as much as possible of the 15 mm storm.

As explained in the previous section, the pipes were sized to carry a 2-year storm with y/D ratios in the range 2/3 to 3/4. With the addition of trenches and some on-site detention controls, this design was found to be adequate for the 5-year storm – about a 25% increase in depth of rainfall. For interest, the drainage system was re-designed for the 5-year storm but without the benefit of the exfiltration trenches. This produced a design which, in terms of the pipe costs alone was approximately 10% more expensive.

Thus it may be assumed that the inclusion of exfiltration trenches will in general allow some economy in pipe costs. However, the amount of cost reduction depends on two factors:

- The fraction of the design storm which the trenches are designed to absorb, and
- The size and imperviousness of the drainage area per outlet and thus the size of the maximum diameter pipes.

Thus in the example cited, trenches were designed to absorb about 33% of the 5-year storm rainfall with a maximum pipe diameter of 1500 mm. A cost saving of about 10% in the cost of pipes was achieved. Due to the highly nonlinear cost per unit length of large pipes a design that required a larger maximum diameter might achieve a greater saving in pipe costs by using trenches.

In terms of environmental benefit the use of exfiltration trenches is of great value in returning runoff to the groundwater. This advantage is not limited to small, frequent storm events. Table 3 below shows the distribution of the runoff between outflow, recharge and pervious infiltration for four design storm events of different magnitude.

Table 3 – Water budget for different storm events

Fraction of precipitation	15mm Storm	2-year Storm	5-year Storm	100-year Storm
Rainfall depth	15.00 mm (100%)	35.9 mm (100%)	44.9 mm (100%)	72.5 mm (100%)
Precipitation as volume	15,375 c.m	36,898 c.m	46,023 c.m	74,516 c.m
Pervious infiltration as depth & percentage	7.72 mm (51.4%)	12.54 mm (34.9%)	14.74 mm (32.8%)	18.17 mm (25.1%)
Outflow as depth and percentage	2.01 mm (13.4%)	12.94 mm (36.0%)	17.47 mm (38.9%)	39.37 mm (54.3%)
Recharge as depth, volume and percentage	5.27 mm 5412 c.m (35.2%)	10.42 mm 10,737 c.m (29.1%)	12.69 mm 13,024 c.m (28.3%)	14.96 mm 15,375 c.m (20.6%)

Referring to the bottom row of Table 3, the highest percentage of recharge is achieved with the smallest (15 mm) storm. However, as the storm depth increases, the fraction returned to groundwater is reduced but the actual volumes are substantial.

To reduce the possibility of ground water contamination from accidental road spills, it was decided that exfiltration trenches should not be located within the road allowance of the major roads. Since these road locations are located near the downstream limits of the drainage area, situations arise in which it is not possible to absorb the total runoff.

The 100-year storm analysis was intended to find the major system flows that cannot be captured by the minor system. Even although the precipitation is over 60% greater than that for the 5-year storm, it was found that the volumes of runoff rejected by the minor system were relatively small. This is because the trenches absorb and exfiltrate a large fraction of the extra runoff. This demonstrates the fact that the trenches greatly enhance the capacity of the minor drainage system in addition to maintaining a very large fraction of recharge to the groundwater flow.

Groundwater Quality

Although the wetland system is a “rich” fen and has been exposed to a history of agricultural and related fertilizations, excessive changes in the nutrient content of the groundwater could result in changes in species composition over time. Specifically,

changes in hardness or the calcareous component of the groundwater could also affect the fen species. Maintenance of groundwater flow through the soil profile, rather than direct discharge of surface water to the wetland, should maintain this parameter.

The more significant potential for impacts to groundwater quality relates to road runoff (e.g. oils, phenols and certain metals), overuse of lawn herbicides, or contaminant dumping and spills. Use of lawn herbicides is generally easier to control in an industrial setting than with residential land use. Concerns with individual homeowners dumping contaminants down storm drains or in driveways is also avoided. However, the potential for spills is heightened due to the industrial land use. To overcome this problem, Oil and Grit Separators (OGS) and special manhole chambers will be installed at critical locations within the subdivision. All of these will be within the road allowance to facilitate inspection and maintenance.

Construction and Post-Construction Aspects

In order that exfiltration trenches function as designed it is very important to protect the trench media from clogging with fine materials during construction. Proper design and conscientious implementation of a program to prevent erosion and ensure sediment control is therefore absolutely essential and should be continued until the site is stable. The Brantford project will use a modified form of the Etobicoke trench and additional protection will be provided by initially installing mechanical plugs at the upstream end as well as the downstream ends of the perforated pipes. This will ensure that any fines washed into the drainage system will be washed out of the system or trapped in manholes that will be cleaned out prior to acceptance by the City.

Once commissioned, the upstream plugs will be removed but will be stored in the manhole for possible emergency use in the event of a serious spill event.

Post-construction monitoring will include the following.

- Measurement and sampling of groundwater 4 times per year using permanent well-points installed during the geotechnical investigation. Quality measurements will be compared with baseline measurements made prior to construction.
- The perforated pipes will be inspected annually by removing the downstream plugs and either scraping or flushing any accumulated sediment. Disposal of these sediments will depend on the results of analysis for toxic components.
- It is intended to fit a vertical plastic piezometer in the manholes at the upstream and downstream ends of certain trenches to measure the water level in the clear stone fill. At intervals of a year or more it is intended to carry out a draw-down test by flooding the trench to the point of discharge from hydrants and then observing and recording the rate of draw-down. This will provide data on any long-term reduction in the infiltration capacity of the surrounding native material.

During development of the lots, lot grading will be carefully checked at site-plan approval stage and during construction to ensure that areas intended for materials handling and stockpiling are properly drained. Certain types of industrial activities involving hazardous materials will not be permitted.

Conclusions

Exfiltration trenches offer a potentially useful and environmentally friendly solution for stormwater management in appropriate conditions. Important conditions are the absence of a high water table and a soil type with adequate hydraulic conductivity.

Experience suggests that appropriate field tests are essential in determining the available conductivity. Observations indicate that the effective conductivity may be considerably greater than values reported in the literature. A method of accumulating the results of post-construction experience would help to reduce uncertainty associated with selecting a reasonable value for hydraulic conductivity for different soils.

A simple design algorithm such as that available in version 1 of the MIDUSS 98 program can be used for both preliminary and detailed design although some auxiliary calculation may be necessary. The assumption of a horizontal water surface profile requires refinement but experimental observations to provide a basis for the development and validation of an improved algorithm are not easily available. As a result, use of the simple approach described here should include conservative assumptions concerning design parameters.

Experience with the original Etobicoke trenches has been extremely encouraging and it may be possible to carry out further field tests to extend this body of data. It is intended to carry out some post-construction testing at the Brantford site in an effort to improve the design procedure.

Use of trenches can make a significant difference in the amount of runoff that can be captured by the minor system. Substantial runoff volumes are held in storage in the trenches to be exfiltrated to groundwater after the peak of a severe storm has passed. This reduces the amount of runoff that has to be carried by the major system.

Use of exfiltration trenches can usually result in some reduction in the pipe sizes required. However, for moderately sized drainage systems the saving may be only of the order of 10% of the pipe cost.

References

A.M. Candaras Assoc. Inc. "Post-construction evaluation of stormwater exfiltration and filtration systems." Project No. 9321 for City of Etobicoke, October 1997 (A. M. Candaras Assoc. Inc., 8400 Jane St., Suite 203, Concord, Ontario, L4K 4L8)

CIRIA Construction Industry Research and Information Association. "Infiltration Drainage – Manual of good practice". Report 156 by Roger Bettess, Ph.D. 1996.

German Association for Water Pollution Control. German ATV Standards, Wastewater – Waste. Standard ATV – A 138E, "Construction and Dimensioning of Facilities for Decentralized Percolation of Non-Harmful Polluted Surface Water". January 1990

MIDUSS 98 User Manual (320 pp). Download available at <http://www.miduss.com> .