

## Chapter 10

# Stormwater Pollution Control at a Major Highway Interchange

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A main concern of the Ontario Ministry of Transportation (MTO) has been for the control of the quantity of stormwater runoff in the design of drainage systems for highways. This trend is now being revised to include the control of the quality of the stormwater runoff. This policy is presently being applied in the design of sections of Highway 407.

Highway 407 will ultimately be a ten lane freeway extending from the western edge of Mississauga, Ontario, at Highway 403, and continuing easterly to Highway 35/115, east of Oshawa, Ontario. Sections of Highway 407 have partially been constructed with the installation of bridge structures and road base grading. Construction is proceeding from the west to the east. The proposed Highway will be in excess of 100 km (60 miles) in length. This study focused on one of the major proposed Highway 407 interchanges located at the crossing of Highway 404 in Markham, Ontario. This interchange will be a four level interchange which will increase the area percent imperviousness to 44%.

The study drainage area is approximately 380 ha (940 ac). The receiving channel for the stormwater runoff is located to the south of the interchange and is a small, unnamed tributary which flows to the west to German Mills Creek which, in turn, joins the Don River system and discharges to Lake Ontario. A tunnel will be constructed to convey the flow from the interchange to the creek.

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The area surrounding the interchange is fully developed or developing. A utility corridor (Ontario Hydro) runs south and parallel to the proposed Highway 407 in the study area.

The objective of the study was to develop a strategy for both quantity and quality control for the interchange. Quantity control includes providing protection against flooding for the 1:100 year storm. Quality control implies providing treatment for a relatively frequent storm. The goal of quality control for stormwater runoff for the interchange is to meet the guidelines provided by the publication *Interim Stormwater Quality Control Guidelines for New Development*, issued jointly by the Ontario Ministry of the Environment (MOE) and the Ontario Ministry of Natural Resources (MNR) in May of 1991.

The provision of a formalized quality control scheme in a principal interchange such as the 404/407 interchange represents a concerted effort by the Ontario Ministry of Transportation to incorporate the new Guidelines into their work.

A number of agencies were consulted during the course of the study including:

- Ontario Ministry of Transportation (MTO)
- Ontario Ministry of Environment (MOE)
- Ontario Ministry of Natural Resources (MNR)
- Metropolitan Toronto and Region Conservation Authority (MTRCA)
- Town of Markham
- Regional Municipality of York
- Ontario Ministry of Municipal Affairs (MMA)
- Ontario Hydro

As a result of these contacts, a number of objectives were developed for the quality control scheme for the interchange. The objectives include:

- Provision of quality control for suspended solids and associated pollutants for runoff from a 25 mm (1 inch) rainfall event.
- Protection of regional groundwater quality.
- Maximization of the use of overland flow networks, natural channels, infiltration trenches and basins, and wetlands.

In addition, a number of constraints affecting the provision of quality control measures were identified for the study area. Constraints included:

- Limited land area available in the vicinity of the interchange.
- The proposed Highway 407 pavement is to be a minimum of 1.0 m (3 feet) above the high water level observed from the 1:100 year storm.

- High groundwater table at the northern section of the interchange.
- Operation of treatment facility under variable weather conditions.

## 10.1 Methodology

In order to provide quality control for runoff from a 25 mm daily rainfall event, a number of alternatives were considered. These included:

- porous pavement
- infiltration trenches
- infiltration basins
- confined filtration basins
- grassed swales
- detention tanks
- pipe/tunnel storage
- centralized detention facility
- source control
- redirection of flow to alternate watershed

Preliminary screening of these quality control alternatives was carried out to identify the most feasible alternatives for further assessment. The preliminary screening was based on quality control, engineering, environmental and acceptability issues to selected agencies. Table 10.1 provides the preliminary assessment and identifies which alternatives are acceptable to all agencies with regards to the runoff quality. Based on the remaining three criteria, quality control, engineering and environmental, the most feasible alternatives to be carried out for further detailed analysis are source control, centralized detention facility and confined filtration facility.

The confined filtration facility (CFF) was developed during the course of the study as a result of the concerns for groundwater quality expressed by the MOE. Confined filtration facilities are self-contained sand filters, with a collection system at their base to convey the treated discharge to the surface receiving water. The treated discharge is not released to the aquifer. Figure 10.1 provides a schematic of a confined filtration facility. As shown in Figure 10.1, the facility was designed to capture a volume equivalent to runoff from a 25 mm rainfall event, with volumes in excess of this overflowing to the storm collection system. The filtration collection system (weeping tile) at the base of the facility also discharges to the storm collection system. Although there is little information on facilities of this type operating in Canada, it is estimated that replacement of the top 15 cm (6 in.), which will become clogged, will be required every 5 to 10 years. Trapping of materials along the grass lined ditches before they reach the CFFs will extend the maintenance period.

Maintaining highways free of debris for safety requirements is achieved,

**Table 10.1  
EFFECTIVENESS OF PRELIMINARY ALTERNATIVES WITH RESPECT TO SELECTED CRITERIA  
FOR THE 404/407 STUDY SITE**

Alternative	Quality Control <sup>1</sup>				Engineering						Environmental <sup>2</sup>			Acceptability to Agencies <sup>3</sup>					
	Suspended solids	Oil & grease	Floatables	Temperature	Cost <sup>4</sup>						Feasibility	Safety	Baseflow augmentation	Protection of Groundwater Quality	Aesthetics	M T O	M O E	M N R	M T R C A
					Capital			O&M											
					L	M	H	L	M	H									
<i>porous pavement</i>	•	•		•			•		•			•		•		•	•	•	
<i>infiltration trenches</i>	•	•	•	•		•		•			•	•		•		5	•	•	
<i>infiltration basins</i>	•	•	•	•				•			•			•		5	•	•	
<i>confined filtration basins</i>	•	•	•	•		•		•			•	•		•		•	•	•	
<i>grassed swales</i>	•			•	•			•			•	•		•		•	•	•	
<i>detention tanks</i>	•	•	•	•			•		•			•		•		•	•	•	
<i>pipe/tunnel storage</i>	•	•	•	•		•		•			•			•		•	•	•	
<i>centralized detention facility</i>	•	•	•			•		•			•	•		•		•	•	•	
<i>source controls</i>					•			•			•		•	•		•	•	•	
<i>redirect to alternate watershed</i>						•					•			•		•			

Notes:

1. The only parameter requiring quality control was suspended solids.
2. These environmental criteria represented those considered most significant for this project.
3. The acceptability of each alternative was specific to this study and currently available information.
4. L: Low cost; M: Medium cost; H: High cost.
5. Infiltration was not acceptable to M.O.E. at the time of publication of this report.

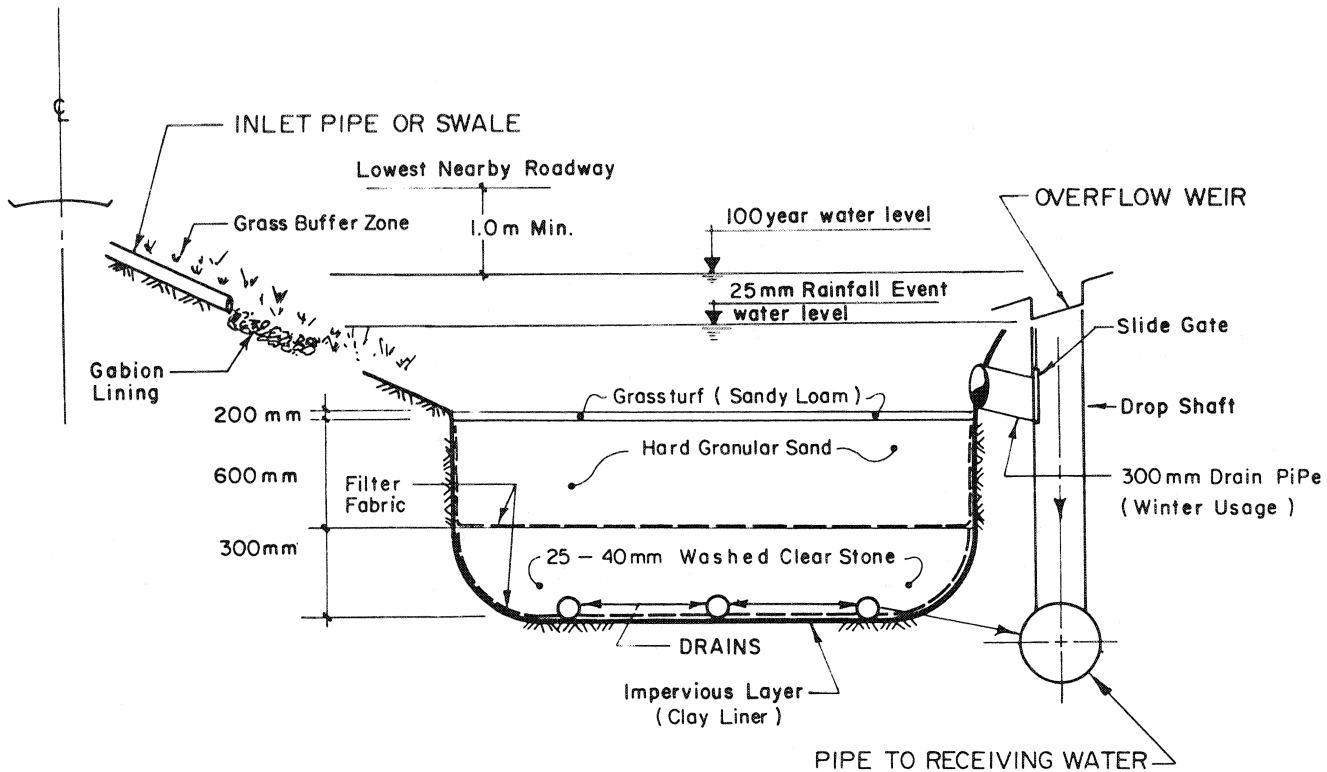


Figure 10.1  
Confined filtration basin.

in part, by source control. However source control alone is not sufficient to provide the necessary level of quality control for protection of receiving waters. The remaining two alternatives, centralized detention facility (CDF) and confined filtration facility (CFF) were assessed with regard to concerns expressed by the MOE, MNR, MTRCA and MTO. The concerns are discussed further below.

The requirements of the MOE include promoting groundwater recharge with treated runoff and control of suspended solids in surface discharges. Since dissolved salts, likely to be found in highway runoff, are difficult to remove, the MOE also stipulated that discharges contaminated with dissolved salts may not contribute to a regional aquifer, but may contribute to a local near-surface aquifer which, in turn, provides baseflow to local streams. A detailed hydrogeological study would be required to determine the extent of the aquifer. In addition, the MOE guideline for control of suspended solids in runoff discharging to an open stream is 25 mg/L.

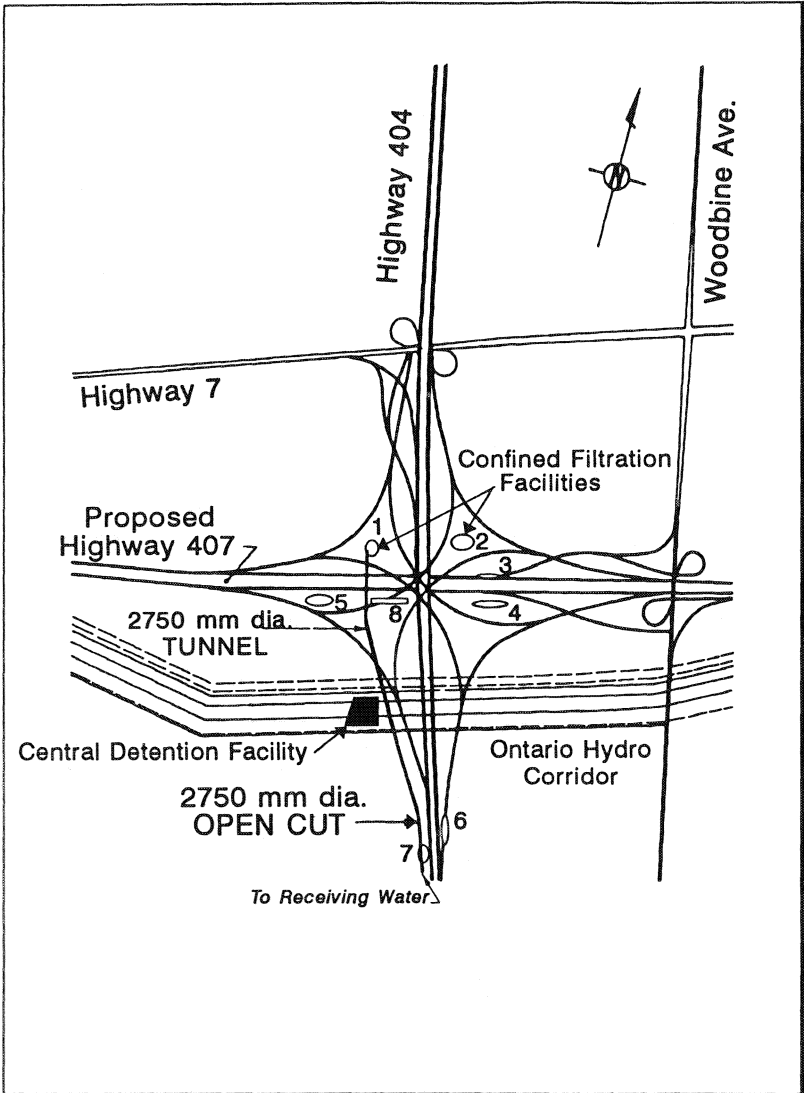
The MNR requirements are to provide treatment of the storm runoff such that suspended solids to a maximum particle size of 40 microns are removed prior to discharging to the receiving stream, and to promote aquifer recharge such that base flows to streams are not interrupted. In addition, the temperature of the runoff water is not to be increased (such as would occur with ponded water) to protect the local fisheries.

The MTRCA's major concern is to control runoff from frequent events such as the 25 mm rainfall event from new developments to the pre-development level to minimize stream bank erosion. In addition, flow increases due to developments are to have no detrimental flooding impacts downstream.

The MTO requirements are to provide drainage for the interchange such that no flooding is experienced from the 1:100 year return storm. In addition, open water for the management of quantity and quality is to be minimized to reduce possible safety liabilities.

The CFFs and CDF were located within the interchange configuration as indicated on Figure 10.2. The facilities were located with the following constraints taken into consideration:

- groundwater elevation
- soil type
- receiving stream elevation
- consideration of existing features (e.g. an existing 2.4 m diameter sanitary sewer)
- pavements elevation
- embankment slope requirements
- available land area
- location of Highway high mast lighting poles



**Figure 10.2**  
**Location of quality control alternatives proposed 404/407 Interchange.**

## 10.2 Runoff Pollutant Source

Suspended solids are one of the primary pollutants associated with highway runoff. The sources of the particulate matter include pavement wear, vehicular traffic, atmospheric deposition, road maintenance and traffic safety. Associated with the sediments are numerous pollutants, the most significant being heavy metals. Table 10.2 lists these pollutants along with their sources (from EPA, 1991).

Other common highway pollutants include the non-particulate pollutants sodium, calcium and chloride (from de-icing salts), sulphates (from roadbeds and de-icing salts), nitrogen and phosphorous compounds (from atmospheric deposition and roadside fertilizer application), and petroleum products (from spills of motor lubricants, antifreeze and hydraulic fluids and asphalt surface leachate). These pollutants are generally more difficult to remove from the runoff. The removal of de-icing salts are more feasibly achieved with source controls such as application reduction or alternative de-icing materials more compatible with the environment.

The CFFs and CDF provide treatment of the storm runoff through the process of filtration and sedimentation. The approximate effectiveness of these mechanisms in removing pollutants within the runoff is summarized in Table 10.3.

**Table 10.2**  
**SUMMARY OF POLLUTANTS IN HIGHWAY RUNOFF AND THEIR SOURCES**  
**(USEPA, 1991)**

Pollutant	Source
<i>lead</i>	exhaust of vehicles using leaded gasoline, and tire wear
<i>zinc</i>	tire wear, motor oil additives, and grease
<i>iron</i>	auto body rust, steel highway structures, moving engine parts
<i>copper</i>	metal plating, bearing and bushing wear, moving engine parts, brake lining wear, fungicides and insecticides
<i>cadmium</i>	tire wear, insecticide application
<i>chromium</i>	metal plating, moving engine parts, brake lining wear
<i>nickel</i>	diesel fuel and gasoline exhaust, lubricating oil, metal plating, bushing wear, brake lining wear, asphalt paving
<i>manganese</i>	moving engine parts

<b>Pollutant</b>	<b>Filtration</b>	<b>Sedimentation</b>
<i>Suspended Solids (T.S.S.)</i>	85%	70%
<i>Lead (Pb)</i>	80%	75%
<i>Zinc (Zn)</i>		50%
<i>Nitrogen (T.N.)</i>	50%	25%
<i>Phosphorous (T.P.)</i>	55%	20%

\*Source: Removals estimated from Schueller, T.R., "Controlling Urban Runoff: A Practical Manual for Planning and Designing Urban BMPs", Metropolitan Washington Council of Governments.

## 10.3 Stormwater Modelling

Modelling of the Highway 404/407 Interchange Drainage System was carried out to assess the hydraulic and quality/treatment requirements. For the hydraulic requirements, the single event INTERHYMO model was applied to simulate runoff hydrographs from the proposed interchange and apply the hydrographs for the sizing of the drainage scheme to carry the 1:100 year storm event and also for the preliminary sizing of the CFFs and CDF to intercept runoff from a 25 mm rainfall and overflow the portion of the 1:100 year event exceeding the first 25 mm of rainfall. To assess the hydraulic impacts from the proposed interchange runoff on the existing downstream channel the HEC-2 model was applied.

Details of the hydraulic modelling are not printed here; instead the focus is directed at quality considerations.

The quality and treatment assessment of the interchange runoff was carried out with the application of QUALHYMO (Rowney and MacRae, 1991). The simulation was carried out for the period from May 1 to October 31 for an average precipitation year. For the development of runoff hydrographs, the catchment physical characteristics applied in QUALHYMO were similar to those applied in the single event model INTERHYMO. These parameters included drainage areas, extent of imperviousness, depression storage and channel details. The overland characteristics applied in INTERHYMO were applied to determine times to peak for QUALHYMO. In addition the model accounts for the soil moisture condition with recharge through infiltration and depletion through sub-surface flow, evapotranspiration and deep groundwater losses.

The runoff quality analysis was carried out with the assumption that pollutants tend to build up during dry periods and are subsequently entrained in runoff as 'washoff' during wet periods.

The build-up of sediment was based on the power linear method which has the following form:

$$PBUILD_i = PBUILD_{2-1} + PK1(T_c^{pk2}); PBUILD < PMAX$$

where:

- $T_c$  = build-up time (days)
- PBUILD = pollutant build-up on the catchment surface (mass/m<sup>2</sup>)
- PMAX = maximum allowable value of PBUILD (mass/m<sup>2</sup>)
- PK1 = rate constant (mass/m<sup>2</sup>/day)
- PK2 = rate constant (dimensionless)

It was anticipated that the sediment build-up at the highway interchange would be higher than that experienced for a residential area. This was confirmed by work carried out by Soderland and Lehtinen (1972), who extensively sampled and analysed stormwater runoff from various urban areas. They estimated the suspended solids loading from a cloverleaf junction area (vehicle density of 65,000/day) to be twice the loading from a suburban area with 32% open space and almost seven times the loading from an area consisting of terrace housing with 36% open space. For this simulation it was determined that three times the loadings from a residential area was appropriate.

The exponential method was used for sediment washoff to adequately represent the first flush effect:

$$WRATE = AREA [PBUILD (PCO) Q^{PEX}]$$

where:

- WRATE = constituent washoff rate (mass/m<sup>2</sup>)
- AREA = area (m<sup>2</sup>)
- PBUILD = available pollutant mass on the watershed surface (mass/m<sup>2</sup>)
- PCO = rate constant (per m<sup>2</sup>)
- Q = runoff (m<sup>3</sup>/s)
- PEX = rate constant (dimensionless)

In order to model the movement of both flows and sediments through the CFFs, an additional model was developed, termed the CFF (Confined Filtration Facility) model (Dagg-Foster and Hulley, 1992). The model utilizes as input the runoff flow and corresponding sediment concentrations in the runoff generated by QUALHYMO. Other inputs required are number and characteristics of available overflow structures, time step, maximum allowable inflow,

fractional removal rate of sediments in a filter-type facility, surface area of facility, bottom elevation, starting water elevation, hydraulic conductivity, depth of the filter medium, evaporation rate, and sediment settling velocities.

The CFF model represents the storage volume above the turf layer as pond inflow (see Figure 10.1). A third order Runge-Kutta solution technique was applied, rather than the conventional storage-indication approach. This alternative approach permitted simulation of pond drainage through a soil medium with a time variable hydraulic conductivity. An important feature of the alternative to pond routing is that the outflow from the pond is through the pervious bottom, rather than through a conventional outflow structure. The outflow rate is governed by the hydraulic conductivity, depth of the limiting filter layer and hydraulic gradient. The model allows for the simulation of outflow through an arbitrary overflow structure, for periods when the depth of water in the pond exceeds the specified overflow weir height. The model also allows for water loss through evaporation. Two sediment removal processes are simulated: removal by discrete settling in the pond, and removal in the filter portion of the facility. The removal rates are based on removal rates of sediments in infiltration basins and trenches reported by Schueler (1987).

Output from the model includes a time series of outflow to the underdrains, overflow rate, facility bypass rate, and concentration of sediments in the discharge. The model was also developed to yield storage volume utilization information.

## 10.4 Results

Peak flows were calculated for the 25 mm rainfall event, the 1:100 year storm, and Hurricane Hazel (a 1954 major storm recorded in Ontario having 11.2 inches of rainfall in 48 hours), using the INTERHYMO model. The peak 1:100 year flow under the future conditions with filtration facilities was calculated to be 219.2 m<sup>3</sup>/s (1,030 cfs), slightly less than the peak flows experienced under existing conditions of 31.9 m<sup>3</sup>/s (1,130 cfs). Attenuation of the 1:100 year peak flow as a result of the storage provided by the CFFs was computed.

INTERHYMO was used for preliminary sizing of the CDF for the 25 mm rainfall event. A total volume of 9000 m<sup>3</sup> was deemed necessary.

Final sizing of the confined filtration facilities was accomplished by applying QUALHYMO with continuous simulation, using an average summer of precipitation (May to October), in conjunction with the CFF model. Winter conditions were not modelled since the filtration facilities would not operate under frozen conditions. In addition, the MOE and MNR recognize that the spring freshette is a natural phenomena with its associated sediment load and therefore is not required to be controlled with respect to quality.

The QUALHYMO/CFF models were used to estimate effluent sediment concentrations, and develop storage utilization curves and overflow

frequency curves for the CFFs. The storage utilization curve provides the frequency of detention volume utilization. The overflow frequency curve provides the number of overflows that would be experienced on average for various design facility storage depths.

The following example illustrates the final CFF sizing procedure. Figure 10.3 is a storage utilization curve for Facility 3. Figure 10.4 is an overflow frequency curve for Facility 3. The storage utilization plot shows that the Facility's water depth is less than the maximum available depth approximately 96% of the time. In addition, the plot shows that the pond is dry 30% of the time.

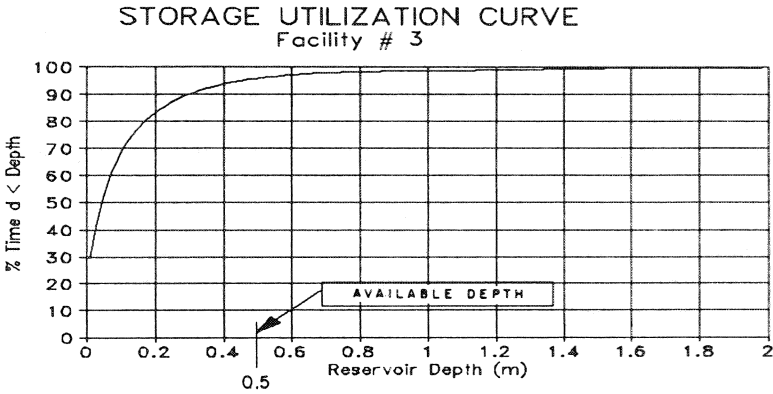


Figure 10.3

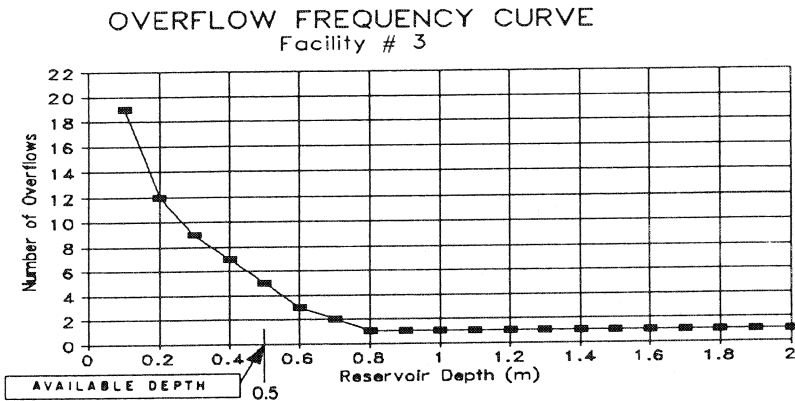


Figure 10.4

The overflow frequency plot shows that at the maximum available depth of 0.5 m (20 in.), there are five overflows during the simulation period. Examination of the input rainfall record revealed that two of these overflows occurred on days when less than 25 mm of rainfall was measured. Therefore, the size of the facility was insufficient to capture the objective runoff from a 25 mm rainfall event. Accordingly, the facility's preliminary volume estimate was increased. A similar approach was used for each of the facilities.

The results of the QUALHYMO/CFF model simulations illustrated that, for all the facilities, the estimated discharge concentration of suspended sediment remained below the 25 mg/L MOE objective for the entire simulation period. The maximum discharge concentration estimated was 22 mg/L, for facilities 7 and 8. Thus it is anticipated that the MOE guideline will be met with the implementation of the proposed filtration facilities. In addition, the MNR guideline of removal of particles 40 microns and larger is also expected to be met.

Although the quality analysis was directed at suspended solid concentration and removal efficiencies, other quality considerations were indirectly addressed. Many of the pollutants identified in Table 10.2 are associated with suspended material. Therefore control of suspended solids will result in a reduction in variety of pollutants.

## 10.5 Costing

Preliminary design cost calculations were undertaken based on engineering experience, in-house documents and available information. The total capital cost to provide both quality and quantity control of runoff from the interchange was \$12.2 million for the confined filtration facilities, and \$15.0 million for the central detention facility. Thus, the confined filtration facilities alternative costs were approximately 20% lower.

An additional cost calculation was undertaken to estimate the premium associated with the provision of quality control for an intersection drainage. The total cost to provide quality control for the interchange using the CFFs was estimated to be \$12.2 million. The cost to provide quantity control only was estimated to be \$10.6 million.

## 10.6 Recommended Drainage Scheme

The recommended stormwater management scheme consists of a series of confined filtration basins to provide quality control along with a 2700 mm diameter stormwater pipe in both tunnel and open cut to convey the peak flow from a 1:100 year rainfall event.

This scheme has the following advantages:

- 1) The scheme meets the objectives for both quantity and quality control. In particular, the scheme provides quality control in the form of removal of suspended solids and associated pollutants for the runoff from a 25 mm rainfall event. In addition, the confined filtration facilities will not contribute to warming of the runoff, since the runoff is directed to and conveyed through underground systems. It is expected that floatables and oil & grease will be removed to some extent along the grass lined ditches which convey the runoff to the confined filtration facilities. Floatables and oil & grease not removed by the conveyance system will be trapped in the near surface media of the CFFs.
- 2) The CFF scheme is less costly than the CDF scheme, with a total estimated cost of \$12.2 million. Approximately \$1.6 million of the total cost may be attributed to quality control.
- 3) The scheme provides protection of groundwater quality, as the runoff is not discharged to groundwater.

## References

Hulley, M. and G. Dagg-Foster (1992), Confined Filtration Facility (CCF) Model, developed at Gore & Storrie Limited.

Gore & Storrie Limited, Quantity and Quality Control for the 404/407 Interchange Drainage, prepared for the Ontario Ministry of Transportation, April 1992.

Ontario Ministry of the Environment, Ontario Ministry of Natural Resources, Interim Stormwater Quality Control Guidelines for New Development, May 1991.

Rowney, A.C. and MacRae, C.R., QUALHYMO User Manual - Release 2.1, Royal Military College of Canada, Kingston, Ontario, 1991a.

Rowney, A.C. and MacRae, C.R., QUALHYMO Technical Reference Manual - Release 2.1, Royal Military College of Canada, Kingston, Ontario 1991b.

Schueler, T.R., Controlling Urban Runoff: A Practical Manual for Planning and Designing Urban Best Management Practices, prepared for Washington Metropolitan Water Resources Planning Board, 1987.

Soderland, G., and Lehtinen, H., Comparison of Discharges from Urban Stormwater Runoff, Mixed Storm Overflow and Treated Sewage, *Advances in Water Pollution Research*, 1972.

U.S. Army Corps of Engineers, HEC-2 Water Surface Profiles Users Manual, Davis, California, 1982.

United States Environmental Protection Agency, Proposed Guidance Specifying Management Measures for Sources of Non Point Pollution in coastal Waters, May, 1991.

Wisner, P.E., Sabourin, J.F. and Alperin, L., INTERHYMO/OTTHYMO 89: An International Hydrologic Model for Stormwater Management and Flood Control., INTERHYMO Centre, Ottawa, Ontario, 1989.

