Chapter 12

HSP-F Simulation of a Constructed Wetland Stormwater Best Management Practice for Urban Highway Runoff

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This chapter describes the use of the HSP-F program methodology to model and design best management practices (BMPs) for a proposed freeway interchange in Hamilton, Ontario within the Red Hill Creek watershed. BMP screening and agency liaison have led to the selection of a constructed wetland, along with associated companion BMPs, as the preferred solution for addressing fisheries and water quality criteria for this freeway interchange.

Urban highway runoff typically contains suspended sediments, heavy metals, nutrients, oil and grease, bacteria and other pollutants. Artificial wetlands, constructed for stormwater treatment, provide efficient particulate pollutant removal, and the capability for both nutrient uptake and soluble pollutant removal. The wetlands' removal capabilities are directly linked to the biological interactions with aquatic vegetation in

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the wetlands. Constructed wetlands can be designed to promote the flow of storm runoff through densely planted beds of aquatic plants.

A key factor in the establishment and subsequent preservation of the vegetation and species diversity is the hydraulic regime in the wetland. This chapter focuses on the use of HSP-F, in continuous simulation mode, to assess the fluctuations in water levels within the proposed wetland. It is shown how the information developed through this analysis is used to design the wetland bathymetry and aquatic planting species distribution.

12.1 Background Information

12.1.1 General

In July 1989 a preliminary drainage concept was advanced for the proposed crossing of the Red Hill Creek and the freeway interchange (Philips Planning and Engineering, 1989). A proposed drainage system for the Dartnall Road interchange was recommended, consisting of approximately 210 m of concrete box culvert, 190 m of concrete-lined trapezoidal channel, and 425 m of gabion-lined trapezoidal channel. In addition to the channel realignment and conveyance improvement works, a *dry* detention facility was proposed to be constructed, in combination with the earthen highway embankment, for control of storm flows from a future industrial development area.

At the time, this approach to flood and erosion control satisfied the requirements of the lead agencies, namely Regional Municipality of Hamilton-Wentworth, Hamilton Region Conservation Authority, Ministry of Natural Resources, and Ministry of Transportation Ontario, in accordance with their respective mandates.

12.1.2 Fisheries Habitat and Water Quality

Current fisheries habitat policies and guidelines of the Department of Fisheries and Oceans, administered by the Ministry of Natural Resources, require *no net loss* of fisheries habitat resulting from the implementation of projects of this type (DFO/MNR, 1991).

In addition to the potential degradation of fisheries habitat which would be expected to result from the 1989 proposal, the quality of runoff stormwater quality is also of concern, from a similar perspective. The July 1989 report predated the 1991 Ministry of Natural Resources/Ministry of

the Environment Interim Stormwater Quality guidelines (MNR/MOE, 1991), hence did not address the issue of stormwater quality. Clearly the works recommended in July 1989 did not satisfy either objective, hence an alternative design has been developed.

The Ministry of Transportation Ontario Draft Guidelines for Stormwater Quality Management (MTO, 1993) recommend that a stormwater quality management plan should incorporate best management practices (BMPs) that may include surface storage, infiltration, vegetation, and special purpose measures. The plan is required to account for runoff from highway right-of-ways in their ultimate configuration, intercepted overland tributary sheet runoff that is discharged to right-of-ways, and intercepted channelized tributary runoff that cannot be passed through or diverted without mixing with highway stormwater drainage.

These guidelines, along with those of the MOEE/MNR and DFO, have been used in the preparation of the stormwater management plan for the interchange.

The updated stormwater management plan for the Dartnall Road Interchange has been proposed to be integrated with the rechannelization of the Red Hill Creek to form an overall solution to mitigate potential impacts on water quality and fisheries habitat.

12.1.3 Urban Highway Runoff

Urban nonpoint source (NPS) pollutants include sediment, trace metals, toxicants, hydrocarbons, nitrogen and phosphorus that originate from atmospheric deposition, metal corrosion, material from worn brake linings and tires, organic matter, litter, and debris. These materials accumulate rapidly on impervious surfaces and are easily washed off by rain and other means into streams and water bodies (Linker, 1992).

Mechanisms that tend to remove pollutants from highways include hydrologic and vehicular scrubbing, maintenance, and natural and traffic-generated winds. It has been shown that pollutants and suspended solids generally exhibit a linear relationship to the cumulative number of vehicles during storms (Horner and Mar, 1983).

Highway location and design should ensure protection of receiving water biota by providing adequate dilution of contamination in runoff or treatment by means of drainage through vegetation, especially when lanes carrying more than 10000 vehicles per day are involved (Horner and Mar, 1983).

12.2 Best Management Practices

12.2.1 Criteria

The governing criteria for the stormwater management plan associated with the Red Hill Creek - Dartnall Road Interchange, a warm-water fisheries creek (Portt, C. and Associates, 1991), is that the runoff from all impervious surfaces resulting from a 13 mm short duration rainfall event must be retained for no less than 24 hours (MOE/MNR, 1991).

In addition, the overall stormwater management plan, including the main branch realignment and the stormwater quality and quantity controls, are required to demonstrate *no net loss*, and a net gain where feasible, of fisheries and associated habitat.

12.2.2 BMP Screening

An approximate drainage area of 14 hectares is required to be addressed by the stormwater quality management plan for the Red Hill Creek - Dartnall Road Interchange. This drainage area limits the selection of BMP's to either a pond or an infiltration basin, since other BMP's such as infiltration trenches, porous pavement, water quality inlets, grassed swales and vegetated filter strips are more suited to serve areas of less than 5 hectares (Schueler, 1987).

A geotechnical investigation of the Dartnall Road Interchange (Peto MacCallum, 1991), indicated that the overburden consists of clay/silt till, ranging in depths from 0.6 m to 1.7 m near the grade separation structure. Clayey-silt till has poor infiltration potential; this characteristic, coupled with the close proximity of bedrock, precludes the use of infiltration basins at the site as a BMP.

Of the three remaining BMPs suggested in the literature (vegetative control, retention basins and wetlands) (M.M. Dillon, 1992), vegetative controls are an obvious choice since grassed swales are proposed for collecting the highway runoff. In addition to using the residual infiltration potential and related pollution removal benefits offered by the swales, a retention pond or a constructed wetland would be considered feasible for runoff water quality management.

It has hence been recommended to evaluate the potential of constructed wetlands as the selected companion-BMP to grassed swales. The primary rationale for selecting a wetland system over retention ponds

as the BMP, is the ability to create compensatory fish and wildlife habitat. The loss of habitat, through creek re-alignment and overall shortening due to the proposed interchange configuration, is a key concern of DFO and MNR. Another concern is the proximity of bedrock in the proposed facility areas. The proximity of bedrock may prohibit or hinder construction of a retention system, due to the greater depths associated with these types of facilities. Both wetlands and retention ponds typically provide efficient pollutant removal rates. Aesthetically, wetlands would be preferred over retention ponds since ponds are often deemed to require man-made barriers (fences and roadside concrete barriers) for safety reasons.

The effect of the recommended BMP strategy on the temperature of the receiving waters was also taken into consideration. Fisheries are sensitive to thermal impacts such as the warming of water caused by retention of water in shallow areas. As the temperature of water increases, the concentration of dissolved oxygen in the water decreases, thus decreasing the potential of the water for both the support of aquatic species and for water quality treatment. The maximum water temperature observed at the proposed interchange during the period of August 19 - September 30, 1991, was 28.5 °C (Portt, C. and Associates, 1991). In order to mitigate the potential harmful effects of increased water temperatures, two potential design features that may be incorporated in the design of the stormwater wetlands include the use of bottom-draw outlet control, and the planting of vegetation on the shoreline that provides shading.

12.3 Constructed Wetlands

The use of constructed wetlands for stormwater quality control has been practised for a number of years. Recently, an increased emphasis on water quality criteria has led to the evolution of more complex designs for constructed wetlands. When properly designed, stormwater wetlands have many advantages as an urban best management practice, including reliable pollutant removal, longevity, adaptability to many development sites, and excellent wildlife habitat potential (Schueler, 1992).

A conventional constructed stormwater wetland is defined as a shallow pool that creates growing conditions suitable for the growth of marsh plants. Stormwater wetlands are designed to maximize pollutant removal through wetland uptake, retention and settling. These constructed systems are typically not located within delineated natural wetlands, since

the release of uncontrolled stormwater into natural wetlands eventually transforms the natural wetland into a stormwater wetland. This generally results in a disruption and/or loss of natural wetland species diversity and functional values (Schueler, 1992).

The design of a stormwater wetland must consider a number of objectives. The wetlands should be designed to effectively treat the polluted urban highway stormwater. A means of pretreating the stormwater runoff before it reaches the wetland area should be provided. The design should reduce water velocity and hence promote settling of coarse sediments. As much of the trash and debris should be prevented from entering the wetlands as possible.

By creating a diversity of depth zones within the wetland, the design should meet the unique growing requirements of emergent wetland plants. Additional design of the microtopography of the wetlands should promote a diverse and dense wetland plant community, augment pollutant removal by reducing hydraulic short-circuiting, create better and safer wildlife habitat including privacy, nesting areas and islands.

Due to the location of the proposed wetlands within a freeway interchange, the design should be as attractive as possible. The free passage of wildlife and humans along the Red Hill Creek corridor should also be maintained.

In order to evaluate the effectiveness of the recommended BMP and to develop appropriate design details for meeting the aforementioned objectives, the hydrology of the system needed to be accurately simulated.

12.4 Analysis

12.4.1 General - HSP-F Model

The base analysis technique used in this design is the Hydrological Simulation Program - Fortran (HSP-F) model of Red Hill Creek that was developed for the Mountain E-W and N-S Transportation Corridor Drainage Study (Philips Planning and Engineering Limited, 1989).

The HSP-F program is a set of modules that can simulate hydrologic and associated water quality processes for pervious and impervious land surfaces in the soil profile, and in streams and lakes. Developed in the late 1970's by Hydrocomp Inc., for the U.S. Environmental Protection Agency, HSP-F evolved from the Stanford watershed model. HSP-F is considered to be a continuous simulation model (of course, all continuous

models can also be used to evaluate the response of a watershed model to specific historical or design storm events).

HSP-F requires precipitation and evaporation time series input for runoff modeling. In addition, air temperature, dewpoint temperature, wind movement, and solar radiation time series are required for snowmelt modeling. Meteorologic data from 1962 to 1990 was compiled for use in the Red Hill Creek application as shown in Table 12.1.

Table 12.1
Meteorologic data.

STATION	METEOROLOGIC DATA	MEASUREMENT FREQUENCY
RBG	Rainfall	hourly
RBG	Extreme Event Rainfall	15 minutes
RBG	Pan Evaporation	daily
RBG	Air Temperature	daily
RBG	Precipitation (including snowfall)	daily
RBG	Wind Movement	hourly
PEA	Dew Point Temperature	hourly
ELO	Solar Radiation	hourly

RBG - Royal Botanical Gardens

PEA - Pearson International Airport

ELO - Elora

The original HSP-F input datafile has, as part of this analysis, been modified by re-discretizing in detail the portion of the proposed E-W Expressway that drains to Red Hill Creek at the proposed Dartnall Road Interchange. Twenty subcatchments were delineated to model the Dartnall Road Interchange. The hydrologic parameterization of these subcatchments was carried out in the same manner as described in detail in the July 1989 report. Parameters such as percent imperviousness, average overland flow length, ground slope, Manning's n, detention storage volumes and infiltration rates were estimated based on air photos, land use and topographic maps. Soil maps of Wentworth County were used to determine the types of soil present in the area, in order to establish infiltration parameters. Where applicable, parameters from the original parent subcatchments were used for consistency.

The Dartnall Road Interchange is proposed to be constructed such that all stormwater runoff that originates on impervious surfaces, which is expected to have the highest concentrations of pollutants such as lead or zinc, is collected by the minor system of swales and culverts. In addition to this, any runoff from pervious surfaces, or from external areas, that becomes mixed with the *polluted* runoff from the impervious areas, is proposed to be collected by the minor system. It is recommended that all efforts should be made to maximize the potential for diversion of external runoff in order to prevent any unnecessary mixing of *pervious* and *impervious area* runoff. The runoff to be treated is proposed to be directed to one of three constructed wetlands located within the interchange - immediately prior to discharging to the Red Hill Creek.

12.4.2 Continuous Simulation

Continuous simulation is a means of assessing overall drainage system performance by evaluating the effectiveness of proposed management techniques using long-term records of actual rainfall distributions. The return periods for peak flow and runoff volume may be assigned on the basis of the simulated record rather than assuming rainfall and runoff frequency to be identical as is the case with conventional design storm methodology (Huber et al, 1981).

The primary advantage of continuous simulation over single-event simulation is the reliability of the results. Continuous simulation overcomes the unpredictability of the frequency of design storm events, which are based on assumed antecedent and intensity-duration-frequency relationships. Similarly, the interactions between the meteorology and the hydrology of the area may be simulated with the use of historical time series of data, thus removing the inaccuracy associated with using averaged, constant values and empirical equations. If extreme event analysis is required, it is better to select events from the historical length of record which accurately simulates the local precipitation conditions.

12.4.3 HSP-F Simulation of a Stormwater Wetland

The HSP-F model simulation of the stormwater wetland was used as a design and analysis tool for satisfying the key design objectives. HSP-F was used to demonstrate that the proposed stormwater wetland configuration is capable of containing the required treatment volume. The model also demonstrated that the water supply to the wetland is greater

than the expected loss rate, in order that minimum water elevations can be maintained.

The model was also used to assess the potential fluctuations in water levels within the proposed wetland; the information developed through this analysis has been used to design the wetland bathymetry and aquatic planting species distribution. Schueler (1992) recommends field inspection to determine and/or delineate the inundated zones of the wetland. With the use of HSP-F, this information can be determined in advance of construction, and presumably better results will follow when the stormwater wetland is designed with this prior knowledge.

The assessment of water level fluctuations in the proposed stormwater wetland assisted in the design for the establishment of a diverse wetland plant community, and in the pondscaping which reflected a variety of soil moisture conditions within the wetland.

12.5 Results and Discussion

An analysis of the wetlands was carried out using the HSP-F analysis tool, for a continuous record of rainfall from 1962 to 1990. The modeling has shown that each proposed wetland, after an initial filling period, would be expected to retain water for the entire year. The bathymetry of the proposed wetland system was established, based on the analysis of the modeled water levels which are dependent on the infiltration and evapo-transpiration rates, such that the proposed reed beds would never be exposed between storm events.

An analysis of the anticipated water levels in the proposed wetland system has shown that the wetlands would overflow a proposed control weir, set at 0.5 m above the permanent water level, on average, once per month (see Figure 12.1). The average annual total duration of all overflows is computed to be 5.6 hours, 7.8 hours, and 11.7 hours from Wetlands 1, 2, and 3 respectively. Table 12.2 summarizes the analysis of water levels in each wetland.

The bathymetry and shoreline of the wetlands is proposed to consist of three basic areas (see Figure 12.2 and Table 12.3):

1. the permanently flooded zone (which includes the inlet zone and two wetland bottom zones: the macrophyte zone, and open water zone),
2. the intermittently flooded shoreline area, and
3. the infrequently flooded shoreline area.

Figure 12.1
Stormwater wetland sections.

Along the shoreline of the permanently flooded zone, the vegetation must be chosen such that it will tolerate periodic inundation. The shoreline is proposed to be irregular in order to lengthen it and hence maximize the potential for habitat. An island or islands may be incorporated into the wetland design, provided that the water quality volume is not decreased below minimum standards for the contributing drainage area (see Figure 12.2).

12.6 Conclusions

The use of the HSP-F model in continuous simulation mode has been shown to be useful as a design and analysis tool for satisfying design objectives of the proposed stormwater wetland system.

Table 12.2
Analysis of water levels above the normal pool elevation.

Water Depth Relative To Normal Pool (m)	DURATION (days) 1962-1990 Average					
	Wetland #1		Wetland #2		Wetland #3	
	Hours	Days	Hours	Days	Hours	Days
0.00	8766.0	365.3	8766.0	365.3	8766.0	365.3
0.05	625.8	26.1	780.7	32.5	855.1	35.6
0.10	411.5	17.1	509.34	21.2	590.5	24.6
0.15	230.6	9.6	265.7	11.1	365.5	15.2
0.20	158.1	6.6	173.6	7.2	255.9	10.7
0.25	108.4	4.5	112.5	4.7	175.9	7.3
0.30	76.5	3.2	80.7	3.4	127.8	5.3
0.35	50.4	2.1	53.0	2.2	88.3	3.7
0.40	29.8	1.2	35.5	1.5	58.9	2.5
0.45	14.9	0.6	21.7	0.9	33.4	1.4
0.50	5.6	0.2	7.8	0.3	11.7	0.5

HSP-F has been used to demonstrate that the proposed storm-water wetland configuration is capable of storing the required treatment volume. The model analysis also demonstrates that the water supply to the wetland is greater than the expected loss rate, in order that minimum water elevations can be maintained.

With the use of HSP-F, knowledge of potential fluctuations in water levels within the proposed wetland can be used to design the wetland bathymetry and aquatic planting species distribution, as well as the pondscaping, which should reflect a variety of soil moisture conditions within the wetland.

While not yet completed for the Dartnall Road Interchange project, HSP-F can also be used to assess the potential for water quality enhancement offered by the stormwater wetland. The use of the continuous simulation approach allows for the estimation of both sediment and pollutant loading and theoretical removal.

Table 12.3
Stormwater wetland microtopography.

	DESIGN INFORMATION/OBJECTIVES		
	DEPTH (m)	PLANTINGS	COMMENTS
PERMANENTLY FLOODED ZONE			
Inlet Zone	0.5	grasses	-inflow velocities reduced and a forebay provided for settling -a gabion line which serves as a level spreader, and separates the inlet zone from the macrophyte zone
Macrophyte Zone	0.1	persistent emergents such as duck potato, softstem bulrushes, pickerelweed, irises and sedges	-enhances nutrient uptake from stormwater -reduces velocity and promotes settling -stabilizes bottom sediments
Open Water Zone	up to 1.5 deep	pond and water lilies	- deep to encourage flocculation and disinfection of microbial matter by direct sunlight - provides temperature moderation, habitat and refuge for fish in drought periods
INTERMITTENTLY FLOODED ZONE			
	variable up to 0.5	must tolerate periodic inundation e.g. sedges, switchgrass, rice cutgrass, chokecherry, buttonbush, black willow, river birch	- maximum depth 0.5 m plus the weir head developed at the outlet spillway - maximum duration of flooding in this zone is 48 hours, based on the water quality volume draw down requirements
INFREQUENTLY FLOODED ZONE			
	greater than 0.5	woody plants, which provide cover, shading and aesthetic benefits, however cannot tolerate great lengths of submergence	-provide habitat and food for wildlife -stabilize wetland side slopes

Figure 12.2
Plan of stormwater wetlands.

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