Chapter 11

The Use of HSP-F in Subwatershed Planning

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Subwatershed planning, incorporating multi-disciplinary input from the engineering, geotechnical, hydrogeologic, and environmental sectors, is greatly facilitated by continuous simulation techniques. This paper describes the use of the HSP-F hydrologic model applied to an urbanizing watershed in Burlington, Ontario. The *conventional* continuous analysis approach has been shown not to be a cost-effective means of evaluating stormwater management techniques (Best Management Practices) in subwatershed planning. Various alternative approaches have been examined to simplify this analysis, while maintaining the overall integrity of the continuous simulation philosophy. As a simplification of continuous simulation, the concept of *continuous analysis* has been advanced by technical agencies and the consulting community. Continuous analysis is a procedure whereby hydrographs, produced through long-term continuous simulation, are numerically processed using simple computational techniques (i.e. *black box*), external to any standard hydrologic model. Typically this procedure facilitates the functional assessment of alternate stormwater management techniques appropriate for the watershed system under analysis. The advantages and disadvantages of each approach are documented, along with an indication of computational effort.

In addition to the foregoing, this paper outlines:

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- 1) A method of transposing to a neighbouring watershed.
- 2) The use of the HSP-F duration analysis in assessing the effect of future development on the erosion regime.
- 3) An anomaly resulting from the application of frequency analysis when comparing existing and future annual maximum flows.

11.1 Introduction

Subwatershed planning, addressing the engineering, geotechnical, hydrogeologic and environmental issues associated with the development potential of a watershed, is becoming a common process in most mid- to large-sized municipalities. Hydrologic and hydraulic models, in most cases, serve as the tools to facilitate the evaluation of watershed management alternatives. The selection of a hydrologic model for any study is influenced by many factors, including the required level of detail, available mapping, geologic information, as well as the economic resources for the study.

The level of detail required at a local level for subwatershed planning is typically at a higher resolution than for watershed studies. The conventional design storm approach is considered limiting in addressing the full range of watershed factors. The continuous simulation methodology, which uses actual historical stream flow and meteorologic data, is considered to provide more reliable results. This approach is consistent with current agency philosophy, (see Ministry of the Environment "Stormwater Quality Best Management Practices" 1991). The Ontario Ministry of the Environment recommends that the continuous simulation methodology be applied through a simplified process termed continuous analysis, whereby continuous historical hydrographs are used to evaluate the performance of proposed watershed management alternatives (see pp 83, Ministry of the Environment "Stormwater Quality Best Management Practices", 1991).

This paper presents an application of the Hydrological Simulation Program - Fortran (HSP-F) (ref. U.S. EPA Users Manual for Hydrological Simulation Program - Fortran, 1980) continuous simulation model to a Subwatershed Master Planning study. The Sheldon Creek Watershed Master Plan, initiated by both the City of Burlington and Town of Oakville, because the watershed traverses Municipality boundaries, is to serve as the basis for agency and administrative approval of future drainage system works. The Subwatershed Plan is to ensure that hydrologic, geotechnical, hydrogeologic, and environmental issues are addressed in a co-ordinated and efficient manner.

The Sheldon Creek discharges into Lake Ontario in the Town of Oakville, with significant headwater area in the City of Burlington. A small tributary of the Bronte Creek was also included within the study area; its headwaters are within the City of Burlington discharging into the Bronte Creek in the Town of Oakville. Currently, most of the drainage area (17.6 sq.km) is

under agricultural land usage, with the existing development predominantly in the lower 20% of the watershed. Municipal planning documentation, ranging from Official Plans to Secondary Plans, has designated most of the remaining, undeveloped lands within the study area for development.

11.2 The Model

11.2.1 General

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, however it can also be used in discrete mode 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 modelling. In addition, air temperature, dewpoint temperature, wind movement, and solar radiation time series are required for snowmelt modelling. Meteorologic data from 1962 to 1990 was compiled for use in the Sheldon Creek application (see Table 11.1).

In order to model the study area, the watershed was discretized into a number of smaller subcatchments and reaches as follows:

- 1) Main Sheldon Creek-23 subareas, 18 reaches,
- 2) East Sheldon Creek-8 subareas, 6 reaches, and
- 3) Bronte Creek Tributary-9 subareas, 4 reaches.

11.2.2 Calibration

The Sheldon Creek model was calibrated to a portion of a nearby watershed, previously modelled using HSP-F, using historical streamflow time-series. This *pseudo-calibration* approach was adopted since the Sheldon Creek watershed is ungauged. A portion of the Upper Red Hill Creek watershed model (City of Hamilton) was slightly modified in terms of land use and geologic properties to more closely conform to the hydrologic characteristics of the Sheldon Creek watershed. The "modified" Red Hill Creek watershed model parameters were used to calibrate the Sheldon Creek watershed model. Figures 11.1 and 11.2 present scatter plots of the log runoff volume and log peak flows for the 12 calibrations/verification events respectively. The shapes of the simulated and calibration curves show an *excessively* high fit due to both hydrographs being generated by the same model algorithm, rather than an actual

Table 11.1
Meteorologic Data

STATION*	METEOROLOGIC DATA	MEASUREMENT FREQUENCY
RBG	Rainfall	hourly (15 minute for extreme events)
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

recorded event. Consequently, the most important comparison variables are runoff volume and peak flow.

11.2.3 Frequency Analysis

Once calibrated and executed for the full 29 years of meteorologic input, annual maxima peak flows at each site were abstracted from the time-series for existing and post- development conditions which were input to the consolidated frequency analysis package Version 2 (1989) CFA (see "User's Manual for Version 1", Environment Canada, July 1985). The Ontario Ministry of Natural Resources "Technical Guidelines for Floodplain Mapping", May 1986 suggests the use of Three-Parameter Log Normal Distribution or the Log Pearson Type-Three Distribution. Use of these distributions in this application led to an anomaly: although annual maximums were greater in the post-development case for every year and every node, pre-development return period peak flows were determined, using these two distributions, to be greater than post-development for the 50 and 100 year frequencies (see Figure 11.3). Clearly, the estimated curves for both the existing and post-development case fit the data well. However, the two curves cross between the 20 and 50 year return periods, thus giving rise to the anomaly.

Based on discussion with the authors of CFA1, it was decided to apply

Figure 11.1
Log (simulated volumes) vs log (calibration volumes)

Figure 11.2
Log (simulated peak flows) vs log (calibration peak flows)

the Wakeby distribution to the time-series of annual maxima. The Wakeby distribution is a five-parameter distribution which fits both ends of the data, high and low frequencies, with parameters that are more sensitive to either one end or the other. Figure 11.4 shows the same site with the Wakeby distribution applied; the result is a consistent increase in return period flows for the post-development case.

11.2.4 Erosion Analysis

As part of the Sheldon Creek study, an assessment of the potential impact of post-development land use on erosion was undertaken. The “duration-analysis” procedure using HSP-F was used to define the temporal duration of various discharge levels for existing and post-development conditions. The duration analysis approach defines the time during which erosion, or erosive flow, is expected to occur. Maximum permissible velocities for each reach were translated into discharges using the HEC-2 backwater model. With this type of analysis, the impact of post-development land use on erosion is measured, in a relative sense, by the change in duration of exposure to erosive flow levels.

11.3 Continuous Simulation vs Continuous Analysis

The continuous analysis technique outlined in the Ontario Ministry of the Environment, Best Management Practices Manual recommends that the performance of watershed management options be evaluated using continuous simulation output (i.e. long term flow time-series) at the location of a proposed facility using a customized *black-box* approach. Such a technique, since it is external to the continuous model, would be practical for assessing local management alternatives. However when assessing watershed management alternatives which potentially affect downstream systems, an efficient means of incorporating these impacts is required.

In the Sheldon Creek study, applying the continuous analysis approach meant executing the continuous model for 29 years of data, extracting the 29 year hydrograph at the location of the watershed management alternative, processing this hydrograph through customized “black box” software (i.e. to assess detention, infiltration, extended detention, etc.), and finally inputting the processed hydrograph back into the HSP-F model to determine downstream effects.

Clearly, this technique is not practical for watershed management alternative evaluation on a global scale. It would be more appropriate for evaluation of BMP's that have just local implications. Watershed management alternative assessment techniques are described with their associated processing times (reflecting the Sheldon Creek study) and data management issues as follows:

Figure 11.3
Post and pre-development frequency distributions
(Three Parameter Log Normal Distributions)

Figure 11.4
Post and pre-development frequency distributions
(Wakeby Distribution)

*Other Methods of Watershed Management Alternative Assessment**Method 1: Conventional Continuous Simulation*

Run HSP-F for each alternative using HSP-F process statements to model alternatives. This approach has the drawback of excessive computer time; 2.5 days per alternative; as well, 2.5 days would be required for each iteration when sizing a facility.

Method 2: Continuous Analysis

Use customized external continuous analysis software to process nodal hydrographs for each watershed management alternative. Processed hydrographs are then re-entered back into the HSP-F datasets so that downstream effects may be determined. This approach also requires excessive computer time: about 0.5 days for continuous analysis plus 2.5 days per alternative where downstream effects are examined. This technique has an advantage over Method 1, since sizing of facilities can be done, for the most part, external to the full HSP-F dataset model. This technique would also require the handling of large quantities of data since 29 year hydrographs would be required to be input to and output from the model. Each 29 year hydrograph would require approximately 3 megabytes of compressed disk space.

Method 3: "Scaled" Design Storm

Scale design storms so that frequency events correspond as closely as possible to that determined by the continuous simulation/frequency analysis. Computer run-time for each alternative would be less than 0.5 hours. However, this approach would not provide results based on actual meteorologic data and antecedent conditions. Significant potential for discrepancies would exist when the recommended Watershed Management Plan is analyzed for the full 29 years of actual observed data.

Method 4: "Lumped" HSP-F Model

Create a lumped model that would have only a small number of subcatchments for the entire watershed. HSP-F run-time would be about one day per alternative. Once again drawbacks include compromised system performance and poor correlation with the detailed analysis.

Method 5: Historical Rainfall Analysis

Use "full" HSP-F datasets which apply a "one to two year" dataset which

comprises the most "significant" historical events of the total simulation period. Storms are selected which correspond to particular event frequencies in order to determine the watershed management alternative response to these events. A scaling factor may be necessary if no historical storm is available for the required design response. As part of this technique, it is necessary that the full rainfall time-series be screened in order to determine the most "significant" events in terms of runoff volumes and peak flows. This approach would have run-times similar to the scaled design storm technique of Method 3, however evaluation of watershed management options is based on actual historical events. This approach also facilitates duration analysis since a range of higher frequency events would provide an indication of watershed response to erosive flow events, using only a fraction of the processing time.

Table 11.2 presents a comparison of these five methods in terms of run-time and disk storage requirements. Based on time and space requirements indicated in Table 11.2, as well as the integrity of results associated with each methodology, Method 5 has been deemed to be the most practical approach.

Table 11.2
Processing Time and Space Requirements for Each Analysis Technique

Analysis Technique	Estimated Time Per Alternative*	Estimated Space per Alternative	Comment
Conventional Continuous Simulation	60 hours	6.0 megabytes for input and summary output files.	Similar additional requirements for sizing iterations
Continuous Analysis	70 hours	6.0 megabytes for input and summary output files. 1.5 megabytes for one 29 year hydrograph with 15 minute time step.	Sizing iterations may be performed external to the model.
"Scaled" Design Storm	< 0.5 hours	100 kilobytes	Significant level of uncertainty.
"Lumped" HSP-F Model	20-30 hours	2-4 megabytes	Reduced level of detail.
Historical Rainfall Analysis	0.5 hours	100 kilobytes	Some uncertainty

*Processing time based on an IBM 386 compatible computer with math co-processor.

Once the “final” watershed management alternatives are selected, the system is ultimately evaluated by running the recommended solution through the continuous simulation model for the full 29 years of rainfall with corresponding frequency analysis, then comparing the results to those predicted by historical rainfall analysis for verification.

11.3.1 Preferred Methodology

As outlined in the foregoing, creating a “one to two year” dataset, comprising the most significant historical events, requires extensive rainfall screening. In the Sheldon Creek application, the rainfall database was screened using 2, 3, 6, and 12 hour windows to determine the most severe events (i.e. highest volume; see Table 11.3).

Table 11.3
Number of Storms Exceeding a Specified Depth
for the 29 year Analysis Period

Storm Depth (mm)	Storm Duration (hours)			
	2	3	6	12
40	2	6	13	25
50	1	2	7	11
60	0	2	2	6

Screening long term rainfall time-series provides the engineer with an indication of the events that shape the frequency distribution. From this, the modeller will determine which events have the greatest impact in determining the distribution parameters. As a result, these events can be used when evaluating watershed management alternatives. Rainfall screening performed as part of this study revealed that the August 30, 1981 event resulted in a runoff response that was significantly greater than any other event. Consequently, it is likely that the fit of the frequency distribution would be sensitive to this event in the low frequency ranges (i.e. 50 to 100 year return periods).

Although it is unlikely that any historical event will correspond directly to a design frequency, storms that are close to the design frequency can be “scaled” to approximate the desired event. As an example, it was determined that scaling the August 30, 1981 event by a factor of 1.11 (or increasing rainfall ordinates by 11%) would result in model response which closely approximated

the 100 year return period peak flows, throughout almost the entire watershed, (see Table 11.4). As additional verification, two other low frequency events were also scaled to approximate the 100 year return period, since the August 30, 1981 event may not have been the most significant in terms of runoff volume.

Table 11.4
Model Response of Historical Storms Scaled to the 100 year Return Period Level

Site Node No.	Continuous Simulation/ Frequency Analysis 100 year Return Period Peak Flow (cms)	Historical Storms "Scaled" to the 100 year Return Period Level (cms)		
		Storm 1	Storm 2	Storm 3
208.1	12.3	14.1	12.3	13.1
207.1	17.8	21.7	18.4	19.0
206.1	20.1	21.1	20.4	17.4
205.1	19.8	21.7	20.2	18.3
204.1	1.4	1.3	1.4	1.3
203.2	21.2	23.0	21.6	19.4
203.1	23.5	25.8	23.8	22.1
202.1	26.5	27.6	26.7	26.9
201.1	28.5	27.9	28.6	28.9

* Storm 1: September 11, 1978 (52mm in 6 hours, scaling factor=1.55)

* Storm 2: August 30, 1981 (63mm in 3 hours, scaling factor=1.11)

* Storm 3: August 25, 1982 (93mm in 10 hours, scaling factor=1.42)

11.4 Results

During the course of the study, it was determined that detention storage would be required at Node No. 207.1 approximately one km upstream of Node No. 206.1, in order to control the 100 year peak flow at Node No. 206.1 to 14.0 cms due to a deficient culvert at this location. The volume of storage was estimated using the scaled August 30, 1981 storm to meet this criterion. The model, with detention storage at Node 207.1, was then run in continuous simulation mode, and a frequency analysis performed on the resulting 29 year hydrograph.

Table 11.5 presents the results of the foregoing analyses. The scaled historical storm response of the detention storage model compares well with the

results of the same model run in continuous mode with corresponding frequency analysis. Most importantly, the constraint node, Node No. 206.1, does not exceed the 14.0 cms capacity of the associated culvert. In fact, the Historical Rainfall Method resulted in a slightly conservative design.

Table 11.5
Comparison of Historical Rainfall Analysis Approach
to Full Continuous Simulation

Location	Site Node No.	100 year Return Period Peak Flow (cms)	
		"Scaled" Historical Storm	Frequency Analysis of 29 year Hydrograph
1 km upstream of detention facility	208.1	12.3	12.3
Detention facility outlet	207.1	12.0	12.2
1 km downstream of detention facility (location of flow constraint)	206.1	14.0	13.5

* Note: The detention facility was sized to overcontrol at Node 207.1 in order to decrease the 100 year return period peak flow at Node 206.1 to 14.0 cms.

11.5 Conclusions

Based on the foregoing findings, the following conclusions are made:

- 1) Continuous Analysis is only considered practical for localized stormwater management alternative assessment.
- 2) Frequency analysis using the Three Parameter Log Normal Distribution and the Log Pearson Type - Three Distribution in this application led to an anomaly which resulted in post-development 50 and 100 year frequency peak flows greater than those for pre-development. Frequency analysis using the Wakeby Distribution resulted in an excellent fit with consistent increases in pre-development to post-development frequency peak flows.
- 3) Rainfall screening provides the engineer with valuable insight into which events shape the frequency distribution.

- 4) The Historical Rainfall Analysis Method can reduce processing time by up to two orders of magnitude when compared to continuous simulation and continuous analysis methods.
- 5) The Historical Rainfall Analysis Method performs satisfactorily in terms of alternative Best Management Practices assessment, compared to full continuous simulation.

11.6 Discussion

The municipalities of the Town of Oakville and the City of Burlington have installed streamflow gauges at two locations, in order to collect continuous streamflow time-series for the purpose of future model calibration/refinement.

In addition, as part of the Sheldon Creek Master Watershed Study, representative water quality samples were collected (seasonally), and analyzed at various locations throughout the watershed system. This seasonal program of water quality sampling has been recommended to continue, in order to serve as a baseline for future water quality modelling, and monitoring.

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