Chapter 23

A COMPARISON OF DUAL DRAINAGE MODELING TECHNIQUES

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In 1993 the City of Edmonton initiated a project to update existing SWMM2 RUNOFF and EXTRAN models of the 30th Avenue storm sewer system for the purpose of evaluating cost-effective solution strategies for upgrading the system. Part of the requirements for attaining this goal included simulating the major system operation to compute surface flooding locations, depths and frequencies.

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The 30th Avenue storm basin encompasses a total area of some 5,400 ha in south Edmonton. The vast majority of the basin's major system does not follow a dendritic drainage pattern. Rather, surface runoff collects in localized street depressions before entering the storm sewer system. During intense rainfalls, localized ponding can cause temporary nuisance and flooding.

Three alternative methods were proposed to simulate both major and minor system storm drainage: modified SWMM modeling to simulate ponding at major system depressions; modeling with OTTHYMO 89; and modeling with PC OTTSWMM. Each model generates runoff data suitable for minor system routing with EXTRAN.

Monitored rainfall and flow data was available for model calibration. Rainfall-runoff models were compared on performance against measured data and suitability for City requirements.

A test catchment was proposed to determine which of the three methods was most appropriate for overall basin modeling. The 280 ha Knottwood Community in south west Mill Woods was selected because it represented a manageable size, contained over 50 major system depressions, comprised a representative mixed land use, was flow monitored and located close to a rain gage (Figure 23.1)

23.1 General Model Setup and Assumptions

The Knottwood test catchment was modeled at a scale compatible with the 30th Avenue basin. Therefore, for discretization, subcatchment sizes varied from 3 to 37 ha in size. Subcatchment boundaries were defined to divide areas contributing major system runoff to depressed areas. Some 58 depressions were identified from orthophoto plans and field inspection and classified as either principal or secondary sags by the size of the contributing area. Sags that have experienced a history of past flooding were classified as principal. Sags which would overflow at a depth of less than 0.5 m and spill to a lower sag were considered secondary. In this way, 21 principal sags and contributing subcatchments were defined in Knottwood.

Parameters were given equivalent values in all three models wherever possible (eg. subcatchment area, rainfall hyetograph input, catch basin capture relationships). This ensures that all models were compared on an equal basis. Subcatchment boundaries were identical for each of the three models. All models provided the same number of input hydrographs at the same EXTRAN node locations.

- streets are graded at 0.5% towards the sag;
- road cross-fall grades are 2.0%;
- curbs are 150 mm high;
- boulevard cross-slopes are in the range of 1.5% to 2.0%;
- storage volumes were calculated up to a maximum depth of 0.5 m.

All catch basin types, locations and sag locations were field verified. By combining stage-storage estimates with catch basin stage-discharge data, storage-discharge relations were obtained for all principal sags. Each of the three models simulated inflows at sags differently, but was based on the same storage-discharge relations.

23.1.1 SWMM4.2 RUNOFF Model Setup

The SWMM RUNOFF model was designed to generate runoff from rainfall, route it through overland channels or local sewers and transfer it into the storm sewer system at inlets which are assumed to capture 100% of incoming flows. Although SWMM4.2 RUNOFF does not provide major system links between subcatchments, a non-dendritic major system dominated by depressions can be modeled. The following approach was adopted for the Knottwood area.

Runoff was generated from each subcatchment twice: once for major flows and once for minor flows. Subcatchment areas were divided according to the percentage of runoff which would be captured at catch basins and transferred directly to the sewer system and that which would be directed to major system depressions. From the capture efficiencies of catch basins in Knottwood, it was estimated that 25% of the runoff would be captured by catch basins and 75% would carry over to principal sag locations. The 25% - 75% split was confirmed by the OTTSWMM and OTTHYMO modeling results using actual inlet efficiency capture curves under various approach flow conditions.

Sags were modeled as oversized triangular channels with orifice controls in the RUNOFF block. By providing storage with a controlled release rate, the effect of routing through sag catch basins was simulated. Channels and orifices were sized to simulate the storage-discharge relationship at the principal sags. The validity of this approach was tested at two sag locations. An inflow hydrograph was routed through the oversized channel with orifice and also by the storage-indication method in OTTHYMO. This comparison indicated the two methods produced almost identical inflows at sags.

23.1.2 PC OTTSWMM Model Setup

PC OTTSWMM was originally developed to simulate the dual drainage process which SWMM RUNOFF was incapable of modeling. The major system in OTTSWMM is linked in a manner similar to the minor system in EXTRAN. Major system flow can be routed down one street segment and into the next catchment. Gutter flow is intercepted to the minor system according to the number and efficiency of the catch basins. A sag routine allows for ponding of surface flows at depressions where drainage to the minor system takes place at a constant inflow rate. OTTSWMM interfaces with EXTRAN3 for minor system routing.

Subcatchment runoff in OTTSWMM is generated in the same way as in SWMM RUNOFF. For lumped basin simulation, a typical road cross-section was selected to route major system flows in each subcatchment. To characterize sags, input parameters consisted of the volumes of storage available at ponding depths of 0.5 m and catch basin inlet rates at curb-full depth (150 mm).

23.1.3 OTTHYMO 89 Model Setup

OTTHYMO 89 is different from the other two models in that the runoff algorithms use unit hydrographs. Based on the HYMO command structure, a basin can be modeled by building up a series of commands to generate event runoff, separate and add flows, route hydrographs and store them in a format usable for EXTRAN.

This structure provides OTTHYMO with great flexibility and versatility. Although designed as a lumped watershed model, hydrographs in OTTHYMO were split into major and minor system flows based on catch basin efficiency curves using DIVERT HYD. Once separated, the major system hydrograph was routed through the sag inlet using the storage-discharge relationship specific to that sag. The major and minor system flows were summed at the appropriate EXTRAN nodes.

Unlike the other models, OTTHYMO does not produce an EXTRAN interface file. OTTHYMO hydrographs must be reformatted as user input hydrographs to run in EXTRAN. This intermediate step of setting up a formatted input file makes the process slightly more time consuming.

Table 23.1 compares the methods and commands used by each model to accomplish major/minor system simulation. Figure 23.2 illustrates the parallel processes schematically.

Table 23.1
Model components.

Function	SWMM 4.2*	PC OTTSWMM	OTTHYMO 89
Generate Runoff	RUNOFF Module	RUNOFF Module	CALIB STANDHYD Command
Infiltration	Horton Equation	Horton Equation	Horton Equation
Overland Routing	Manning's Equation	Manning's Equation	Conceptual Unit Hydrograph Method
Major/Minor Flow Separation	Apportioning subcatchment area to major/minor contributions.	User-Input Catch Basin Capture Curve	DIVERT HYD command with user-input catch basin capture curve.
Major System Routing	Use G1 cards to specify a trapezoidal channel.	User Defined Road Cross-Section	Not used (could use ROUTE CHANNEL Command).
Minor System Routing	With EXTRAN 4	With EXTRAN 3	With EXTRAN 4
Sag Treatment	Simulated by oversized channel with orifice control in G1 and G2 cards.	Built-in sag routine requires maximum storage volume and constant outflow rate.	Use ROUTE RESERVOIR command with storage-discharge coordinates derived from actual storage-discharge relationship at particular sag location.

* The TRANSPORT module was not used.

23.1.4 EXTRAN Model Setup

EXTRAN performed sewer routing for all three models. The trunk sewer model consisted only of 900 mm diameter sewers and larger. A schematic of the EXTRAN minor system is given in Figure 23.3. The flow monitor was located in Maintenance Hatch 82241.

SWMM4.2 (and OTTHYMO with manual interfacing) are compatible with EXTRAN4 while OTTSWMM interfaces with EXTRAN3. EXTRAN3 uses imperial units and requires conversion of the output to

Figure 23.2 Model structure schematics.

metric units for comparison. Otherwise EXTRAN3 produces results identical to EXTRAN4 for all intents of this comparison.

23.2 Measured Calibration Events and Historic Rainfalls

Flow monitoring at the outlet of the Knottwood catchment (Figure 23.1) was commenced in 1992. In that year, the available period of record was restricted to August and half of September. Events generating the four highest peak flows occurred on August 19, 21, 27 and September 4 - 7, 1992 and were selected for model calibration (Table 23.2). A rain gage is located near the Knottwood catchment at the Mill Woods Reservoir (Figure 23.1).

Because the four calibration events were not large enough to produce surface flooding, historic storms were also run to determine how well the models computed surface flooding. These historic events occurred July 10-11, 1978 and July 5-6, 1988 and are also summarized in Table 23.2. The 1978 storm was estimated to have a 1:100 year return period during the peak two hour duration.

Table 23.2
Summary of calibration rainfall events.

Event No.	Date	Duration (hrs)	Volume (mm)	Peak Intensity (mm/hr)	Approx. Return Period (yrs)
1	Aug. 19, 1992	9.83	6.4	10.8	2-5
2	Aug. 21, 1992	10.67	7.2	4.8	2-5
3	Aug. 27, 1992	2.67	4.4	3.6	<2
4	Sep. 4-7, 1992	55	16.6	2.4	<2
5	Jul. 10-11, 1978	20	133.6	105.6	100
6	Jul. 5-6, 1988	34	102.6	38.4	20

23.3 Model Calibration

Each of the three models was calibrated to the measured flow hydrographs of the four selected 1992 storm events.

Initial SWMM RUNOFF runs indicated that simulated runoff volumes were generally lower than monitored volumes, but that peak flow rates were slightly higher. However, for multiple peak events, the early peak flows were usually underestimated. The calibration effort consisted of adjusting subcatchment width, gutter lengths, and depression storage to improve early peak flows. Additionally, Horton infiltration parameters were reduced and imperviousness increased to improve both volume and initial peak flows. These modifications significantly improved the overall volume and appearance of the simulated hydrographs compared with measured data. The calibrated parameters are listed in Table 23.3. The calibration results for the four 1992 rainfall events are summarized in Table 23.4 and illustrated in Figure 23.4.

Historic 1978 and 1988 storms were also run to determine how well SWMM RUNOFF could compute surface ponding occurrences and depths. Approximate depths of ponding were determined for principal depressions by relating the maximum storage volume modeled at a sag to the actual depth-storage relationship used to dimension the oversized triangular channel.

The Knottwood community was under development in 1978 and surface flooding may not have occurred or been reported for this reason. The lack of surface ponding records for these events makes it difficult to determine whether any model is an accurate calculator of historic flood depths. SWMM RUNOFF computed ponding up to 0.5 m for the 1978 storm with an average depth of 0.26 m at 21 sag locations. The magnitude of flooding seems reasonable for the severity of that storm. The modeled 1988 storm produced few significant flooding locations with an average depth of 0.08 m and a maximum depth of 0.26 m.

Generally, the same initial parameter values used in SWMM RUNOFF were used as input for OTTHYMO. As with SWMM, initial runs indicated that peak flows were generally lower than observed peaks and simulated volumes were both higher and lower than observed runoff volumes. Also, early peaks on multiple peak events were underestimated both in terms of rate and volume. Calibration involved adjusting Horton infiltration parameters, depression storage, pervious and impervious length parameters, and the pervious slope to reduce the response time and increase peak flow rates. The result was a slight improvement in runoff volume and peak flows. Further modifications involved increasing the percentage of total and directly connected imperviousness which made a greater improvement to hydrograph volumes, peaks and shape. The

Table 23.3
Calibrated model parameters.

Parameter	SWMM 4.2 RUNOFF	OTTHYMO 89	PC OTTSWMM
Total Imperviousness Ratio	0.25 - 0.55	0.30 - 0.60	0.30 - 0.60
Directly-Connected Imperviousness Ratio	N/A	0.30 - 0.55	N/A
Horton Initial Infiltration Rate (mm/hr.)	20.0	50.0	50.0
Horton Final Infiltration Rate (mm/hr.)	1.5	2.5	2.5
Decay Constant (1/sec.)	0.001	0.001	0.001
Pervious Depression Storage (mm)	1.5	1.5	3.8
Impervious Depression Storage (mm)	0.5	0.5	0.8
Impervious Runoff Manning's n	0.015	0.018	0.018
Pervious Runoff Manning's n	0.250	0.250	0.250
Subcatchment Width (m)	140 - 1,650	N/A	240 - 2,200
Pervious Length (m)	N/A	90 - 260	N/A
Impervious Length (m)	130 - 430	200 - 670	240 - 2,200
Pervious Slope (%)	1.5	2.0	1.5
Impervious Slope (%)	0.2 - 1.2	0.2 - 1.2	0.5

N/A = Not Applicable

calibrated parameters are listed in Table 23.3. The calibration results are summarized in Table 23.4 and illustrated in Figure 23.5.

The 1978 and 1988 historic storm events were also run. Widespread street flooding above 0.5 m in depth was computed by the model for the 1978 event. The 1988 storm produced lower flooding depths as expected with an average of 0.18 m per location. Thus, OTTHYMO computed higher depths than SWMM for both storms.

Table 23.4 Calibration results.

Model	Event No.	Date	Rainfall Vol. (mm)	Runoff Volume (m ³)			Peak Flow (m ³ /s)		
				Simulated	Observed	% Difference	Simulated	Observed	% Difference
SWMM 4.2 RUNOFF	1	Aug. 19/92	7.2	7,730	7,052	9.6	1.38	0.91	42.9
	2	Aug. 21/92	7.2	8,334	7,886	5.7	1.25	1.19	5.0
	3	Aug. 27/92	4.4	5,000	5,471	-8.6	1.00	1.16	-14.1
	4	Sept. 4-7/92	16.6	19,600	21,698	-9.7	0.55	0.93	-40.9
OTTHYMO 89	1	Aug. 19/92	7.2	9,650	7,052	36.8	1.25	0.91	37.4
	2	Aug. 21/92	7.2	9,475	7,886	20.2	1.12	1.19	-5.9
	3	Aug. 27/92	4.4	5,533	5,471	1.1	0.92	1.16	-20.7
	4	Sept. 4-7/92	16.6	21,196	21,698	-2.3	0.61	0.93	-34.4
PC OTTSWMM	1	Aug. 19/92	7.2	7,383	5,402*	36.7	0.96	0.91	5.5
	2	Aug. 21/92	7.2	8,473	7,397*	14.5	0.97	1.19	-18.5
	3	Aug. 27/92	4.4	7,046	5,399*	30.5	0.94	1.16	-19.0
	4	Sept. 4-7/92	16.6	7,487	8,700*	-13.9	0.65	0.93	-30.1

* Observed volumes for OTTSWMM are lower than SWMM RUNOFF and OTTHYMO because a truncated storm was used since OTTSWMM has a maximum simulation length of 50 computational time steps.

Figure 23.4 Calibration runs for SWMM RUNOFF.

Figure 23.5 Calibration runs for OTTHYMO.

Initial OTTSWMM parameter values were similar to those used for SWMM RUNOFF with the addition of catch basin rating curves, sag input and street cross-sections. The simulated storm durations were shortened to a maximum of 500 minutes since OTTSWMM only allows 50 computational time steps per run. Initial runs produced low peak flows and high runoff volumes. Calibration involved adjustment to subcatchment width, Horton infiltration rates, depression storage and imperviousness in an effort to generate less runoff volume and produce better peaks. The subcatchment width and infiltration parameters were more sensitive than the same parameters in SWMM RUNOFF. Consequently, it was difficult to simultaneously match runoff volumes and peak flows for the four calibration events. Calibrated parameters are listed in Table 23.3. Calibration results are summarized in Table 23.4 and illustrated in Figure 23.6.

The 1978 and 1988 historical storms were also modeled with OTTSWMM. The 1978 event generated sag storage volumes above the 100 m³ maximum allowable in OTTSWMM at all 21 locations, thereby producing no definable results. The 1988 event produced an average flooding depth of 0.10 m at five locations; the other 16 nodes did not experience any ponding.

23.4 Comparison of Results

From a visual comparison of timing and hydrographs shapes (Figures 23.4 to 23.6), all models performed well. The best simulated volumes were achieved by SWMM4.2 RUNOFF (Table 23.4). In terms of peak flow performance, OTTHYMO and SWMM RUNOFF were similar. OTTSWMM runoff volumes and peak flows were not as good as the SWMM RUNOFF or OTTHYMO results. OTTSWMM volumes were high while peak flows were generally too low. It was difficult to match both volumes and peak flows for some events because the width and imperviousness parameters altered both peak flows and overall runoff volumes.

There were no reported surface flooding occurrences for the 1978 and 1988 historical storms. Consequently, direct calibration of depths could not be conducted. For the monitored 1992 events, no surface ponding was observed, which agrees with model results. OTTHYMO computed 1978 flooding depths over 0.5 m at 14 of 21 locations. It is more likely that ponding depths are closer to an average depth of 0.26 m

Figure 23.6 Calibration runs for OTTSWMM.

computed by SWMM RUNOFF. OTTSWMM depths were too high to be definable for the 1978 storm. For the smaller 1988 storm, both SWMM RUNOFF and OTTSWMM ponding depths seem realistic.

23.5 Suitability of Models

Other factors were considered in the process of selecting a model for the 30th Avenue basin. These factors include ease of application, model limitations, availability and effort of input data preparation, and suitability of output for the intended uses. A listing of the limitations of each model is summarized in Table 23.5.

Simulating sags as oversized triangular channels with orifice controls in SWMM4.2 RUNOFF requires more data preparation time and effort than the other two approaches require.

PC OTTSWMM has several drawbacks related to internal array capacities. Limits of 150 subcatchments and 10 major system sag types were not constraints for the Knottwood test catchment, but would severely limit analysis of the 5,400 ha 30th Avenue basin. The restriction of 50 computational time steps made modeling of longer historic events difficult. PC OTTSWMM interfaces with EXTRAN 3 which operates in imperial units. Consequently, EXTRAN input files must be in imperial units and a reconversion of output data to metric units is required as post processing. The handling of mixed unit data files made the entire procedure more time consuming and increased the potential for errors. These limitations were being addressed by the model developer.

OTTHYMO, by virtue of a completely different model structure, is not subject to the same array size limitations as the other two models, but does not interface directly with EXTRAN. OTTHYMO hydrographs were entered as user input hydrographs in EXTRAN. This process, repeated for each calibration run, was time consuming. In addition, EXTRAN limits the number of user-input hydrographs to 65 for a single run. This implies multiple EXTRAN runs would be required for a large watershed such as the 30th Avenue basin.

23.6 Conclusions

In summary, all three models, when calibrated with monitored rainfall/runoff data performed adequately as major/minor system simulators and were able to model street ponding in sag locations.

Table 23.5 Model limitations.

	SWMM 4.2 (RUNOFF)	PC OTTSWMM 1988 version	OTTHYMO 89
No. of Computational Time Steps	Unlimited	50**	400
No. of Subcatchments	100* (new versions higher) XP version limited by RAM available on PC (i.e. 1,000 subcatchments possible).	150* (Therefore multiple runs required.)	Unlimited (uses and recycles hydrograph ID No.'s).
No. of Catch Basin Types	Not Applicable	10 User-input capture curves	Unlimited (rating curves used).
Major System Bypass Flow	Not Available	Yes	Yes (use DIVERT HYD).
Major System Routing	Only within catchment where runoff generated.	Yes	Yes (using CHANNEL ROUTE) but not utilized in this study.
No. of Major System Sections	150 Pipes/Channels (new versions higher)	10	Unlimited (CHANNEL ROUTE) but not utilized in this study.
No. of Major System Sag Types	150 oversized channels to simulate sags (uses 3 channels per subcatchment). XP version will be restricted by size of RAM of PC (i.e. many more available).	10* (Therefore multiple runs required.)	Unlimited (defined by a storage-discharge curve for ROUTE RESERVOIR command).
Capacity to Predict Surface Ponding Depth	Indirectly.	Yes, provided total storage volume at sag is less than 100 m ³ . (The storage volume is dimensioned as L instead of m ³ .)	Yes
Interface with EXTRAN	SWMM 4.2 interfaces with EXTRAN 4, SWMM-XP with EXTRAN-XP.	Interfaces with EXTRAN 3* (output in imperial units).	Does not interface with EXTRAN. Creates hydrograph files that can be manipulated and entered into K3 cards in EXTRAN input deck.

NOTE: PC OTTSWMM is being updated. Most of the limitations will be overcome in the new version; however, it will not be available until the fall of 1993 at the earliest. **/* Represents a major limitation.

The SWMM4.2 RUNOFF model can be used to effectively model major system flow and ponding in sag-dominated catchments such as the 30th Avenue basin where overland flow between catchments is not a significant process. SWMM RUNOFF was the most convenient model to run and calibration results were generally the best.

OTTHYMO 89 provided good calibration results. It proved to be a very flexible model, capable of performing all of the major/minor flow simulation required for this study. The lack of a direct EXTRAN interface was the main drawback.

PC OTTSWMM is, conceptually, the most suitable model for this particular assignment. However, limitations with the number of elements, simulation time, the deficiency of sag depth output and the constraint of using an imperial version of EXTRAN made it inconvenient for this particular study.

Editor's note: This study did not use expanded SWMM arrays (which are user-controlled), or the TRANSPORT module of SWMM, which provides more sewer inlet options. Only SWMM, of the models tested here, can run in continuous mode.

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