Chapter 12

Hydraulic and Pollutant Modelling of CSOs Using SWMM's EXTRAN Block

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This chapter presents a unique application of the EXTRAN block of EPA's Storm Water Management Model (SWMM) and the development of a pollutant post-processing program. The program, in conjunction with the SWMM RUNOFF block, produced the time-variable pollutant concentrations required for a combined sewer overflow (CSO) abatement study of Newtown Creek, a tributary of New York City's East River. The approach provided a means to overcome the lack of a pollutant transport routine in the EXTRAN block. Also discussed is the simulation of an in-line storage weir using

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EXTRAN and the application of a CSO storage abatement model used to simulate off-line CSO storage facilities.

12.1 Newtown Creek Water Quality Facility Planning Project

Newtown Creek forms a natural boundary between the boroughs of Brooklyn and Queens. It is approximately three miles long and 150 to 850 ft wide. Twenty CSOs and twelve storm sewers discharge to the creek and together service a 7020-acre drainage area (Figure 12.1). Sampling of the creek has shown low and sometimes nonexistent dissolved oxygen (DO) concentrations, particularly in the upstream reaches where large CSOs are located (URS, 1991).

To determine to what extent CSOs are responsible for the degraded water quality and to recommend abatement actions, the New York City Department of Environmental Protection (NYCDEP) initiated the Newtown Creek Water Quality Facility Planning Project (URS, 1993). Part of the project involved a stormwater management modelling task to provide accurate hydraulic modelling of the complex, aging combined sewer system and the pollutant loadings needed for receiving water quality modelling.

12.2 Stormwater Management Modelling and the Pollutant Post-Processor

Because of tide gates and other conditions known to create backwater effects in the combined sewer system, a hydraulic model capable of simulating these effects was needed. The EXTRAN block of SWMM was developed specifically for such systems and was the model of choice. However, EXTRAN, which does not have water quality capabilities, could not provide the pollutant transport modelling required for the study. To overcome this limitation, a pollutant post-processor was developed. Used together, EXTRAN and the pollutant post-processor, along with the SWMM RUNOFF block, could provide the complex hydraulic and pollutant modelling required.

12.2.1 The Pollutant Post-Processor

The post-processor is a computer program that is implemented after running RUNOFF and EXTRAN. The program searches RUNOFF output for total suspended solid (TSS) stormwater concentrations at a particular timestep, flow-weights the concentration if there is more than one subcatchment in the CSO drainage area, and assigns the flow-weighted average concentration to the stormwater portion of the overflow generated with EXTRAN. A flowchart of

Figure 12.1
Newton Creek CSOs and storm sewers.

the process is shown in Figure 12.2.

The RUNOFF-generated stormwater TSS concentrations are calculated in RUNOFF using the buildup/washoff equations (see SWMM users manual [Huber and Dickinson, 1988] for a detailed description of these equations). The accumulation of deposited solids in combined sewers and their scour resulting from higher wet-weather flows are mechanisms which, although not modeled in EXTRAN, can be accounted for by the buildup/washoff equations (LMS, 1992a). Biochemical oxygen demand (BOD) and total coliform concentrations are then calculated using empirical relationships based on the TSS concentrations. The empirical relationships were developed using field data as described in Section 12.3. The equations are:

$$TSS = \frac{(100 \text{ mg/l}) * DWF + TSS_{sw} * SWF}{DWF + SWF} \quad (12.1)$$

$$BOD_5 = \frac{(65 \text{ mg/l}) * DWF + (5 \text{ mg/l}) * SWF}{DWF + SWF} + (C_p) TSS \quad (12.2)$$

$$\text{total coliform} = \frac{(1 \times 10^6) * DWF + (1 \times 10^4) * SWF}{DWF + SWF} + TSS^{3.3} \quad (12.3)$$

where:

DWF = dry-weather (i.e., sanitary) flow (cfs)

SWF = stormwater flow (cfs)

BOD₅ = five-day biochemical oxygen demand (mg/l)

TSS_{sw} = stormwater TSS concentration calculated in RUNOFF (mg/l)

C_p = coefficient (0.25 to 0.35)

There are several assumptions and limitations to this approach. The method assumes that the transport of pollutants in the sewer system is instantaneous. This is a valid assumption if travel times within the sewer system are short compared with the time resolution needed for receiving water quality modelling and the time resolution of field data. Receiving water quality is dependent on processes such as BOD exertion and sediment oxygen demand (SOD), which respond to CSO loadings on the order of hours to days. Measured field data were

Figure 12.2
Pollutant post-processor flowchart.

collected between 0.25- and 1-hr intervals. This resolution is also reduced due to the inherent sampling variability of the field analyses.

Travel times are dependent on the distance a particle of water has to travel within the sewer system and the velocity of flow. Velocities are higher during wet weather than during dry periods, and can rise to several feet per second. The higher the velocity, the shorter the travel time and more valid the instantaneous transport assumption. Travel times for the systems within the Newtown Creek system were usually within the minute to hour range. As discussed below, the hypothetical shift forward in time expected for the pollutant concentrations due to the instantaneous transport assumption is not discernible in the comparisons between calculated and measured concentrations. This indicates that sewer travel times were shorter than the time resolution of the data and model output.

12.3 Calibration and Verification

RUNOFF, EXTRAN, and the pollutant post-processor submodel were calibrated and verified with field data collected in the fall of 1990. Approximately 600 CSO samples were collected and flow was measured during a variety of rainfall events at eleven of the twenty CSOs, two internal overflows, and three storm sewers (LMS, 1992b). Field sampling data, which covered 97% of the total drainage area to the creek, were used to calibrate and verify the landside models. EXTRAN was considered calibrated if flows from between three to five simulated storm events were within $\pm 20\%$ of measured. Post-processor pollutant concentrations were considered calibrated if the range and average were sufficiently reproduced on temporal graphs. Total coliform calibration and verification were particularly difficult due to the high variability in sample concentrations. Total coliform model concentrations were accepted if model-predicted concentrations fell near the geometric average concentration.

Table 12.1
Measured vs calculated CSO discharge volumes
Survey No.1 (15 September 1990)

CSO Outfall	Measured Discharge Volume, MG	Calculated Discharge Volume, MG	Calculated/ Measured
NC-B1	4.14	3.48	0.84
NC-ST	2.35	2.69	1.14
NC-Q1	0.33	0.39	1.18
NC-Q2	0.11	0.12	1.09

Flow calibration of four CSOs is shown in Figure 12.3 for a storm that occurred on 15 September 1990. The total measured and model-calculated discharge volumes for these overflows are listed in Table 12.1. Pollutant calibrations for two CSOs are shown in Figures 12.4 and 12.5. As can be seen, the range and magnitude for all three pollutants are represented. Note the first-flush concentrations evident in Figure 12.4 for CSO NC-B1 (first-flush concentrations are of interest when modelling storage abatement facilities because these concentrations account for the majority of the pollutant load and are a primary target for abatement). The comparisons of model and observed discharges and pollutant concentrations are presented in full in the Newtown Creek Subtask 5.3 Landside Modelling Report (LMS, 1993a).

12.4 CSO Projections and Abatement Modelling

The calibrated model and pollutant post-processor were used to generate CSO discharges for June through September 1990. This four-month summer period was chosen as a design period based on the following rationale:

1. SOD sampling of the creek indicated that the SOD response to loadings was of the order of several weeks and that a design period of four months would include the representative range of SOD conditions encountered during sampling, and
2. a summer period should be chosen as water temperatures are at their highest and DO levels are consequently lowest.

The selection process involved an analysis of 43 years of rainfall data from LaGuardia Airport in New York City which is adjacent to the project area. Six characteristics were calculated for each year: precipitation per storm event, storm duration, average hourly intensity, average hourly peak intensity, dry period between storms, and number of storms in summer months. Averages and standard deviations were calculated and compared. Several years fell within a standard deviation of the average for each of the characteristics; the summer of 1990 was chosen as the representative year. This rainfall period was used for generating baseline conditions (i.e., assuming the combined sewer system operates under current conditions) and for projecting discharges from off-line and in-line storage scenarios as well as other abatement options (e.g., alteration of regulator settings, such as sluice gate openings, to increase flow to the Newtown Creek Water Pollution Control Plant). A similar approach to selecting a rainfall design period may be appropriate to identify the annual rainfall period proposed for CSO abatement selection in EPA's Draft CSO Control Policy (EPA, 1992).

Lawler, Matusky & Skelly Engineers' (LMS) Storage Pumping Model

Figure 12.3
CSO flow calibration.

Figure 12.4
Pollutant calibration of CSO NC-B1.

NC-Q2

CSO Survey 2 (22 September 1990)

Figure 12.5
Pollutant calibration of CSO NC-Q2.

(SPM) was used to simulate the operation of off-line storage facilities. This model takes EXTRAN and the pollutant post-processor-generated flows and pollutant loadings and routes them through hypothetical storage facilities (Apicella et al., 1987). If desired, a facility can be modeled in a settling mode that simulates a tank that, once filled with discharge, can be used as a settling tank to remove solids from additional overflow. Solids settling is computed as a function of the overflow rate and a solids settling coefficient, which is based on settling column data collected as part of the field surveys. An example of results of an application of the SPM to Newtown Creek CSO NC-B1 is illustrated in Figure 12.6. The figure shows the removal efficiencies of volume, TSS, and BOD for several off-line storage tank capacities based on continuous simulation of the 1990 summer period. The receiving water quality modelling indicated the level of CSO reduction required for a selected water quality improvement, and these graphs provided the information necessary to size off-line facilities (LMS, 1993b).

In-line storage was evaluated using EXTRAN. A large, flat conduit located in the drainage area of one of the largest CSOs (NC-ST) was identified as a possible location for in-line storage. Because NYCDEP wanted to have abatement facilities as operations and maintenance free as possible, a fixed weir-type device was suggested. The device, illustrated in Figure 12.7, would contain an orifice that would allow dry-weather flow to pass the weir unhindered. During wet weather, flows and water surface elevations would increase, submerge the orifice(s), and store flow behind the weir. If flows should increase to the point of overtopping the weir, the long weir length would minimize the discharge head and keep flooding potential to a minimum. As there are no moving parts, operations and maintenance would be kept to a minimum.

To model in-line storage, a weir element was used in EXTRAN and an orifice was simulated by placing connecting conduits at the facility location. Weir lengths and orifice areas were varied to assess various options. The model was run under various rainfall conditions to evaluate flooding potential and discharge reduction. Simulations of the 1990 summer period showed that discharge could be reduced by as much as 25%. Table 12.2 lists three in-line

Table 12.2
In-line storage scenarios

Scenario No.	Weir Length, ft	Orifice Dimensions, ft	Height of Weir Crest above Sewer Invert, ft
1	120	2.0 W x 1.0 H	12
2	120	2.5 W x 1.5 H	12
3	120	2.5 W x 1.5 H	13

Removal Efficiencies for CSO Storage at
Outfall NC-B1

Figure 12.6
Storage pumping model removal efficiency curves.

Figure 12.7
In-line storage fixed weir.

Figure 12.8
Discharge vs in-line storage.

storage scenarios modeled; Figure 12.8 shows the volume reduction for these scenarios for the 1990 summer period.

12.5 Conclusions

Pollutant modelling was successfully accomplished using the SWMM EXTRAN and RUNOFF blocks in conjunction with the pollutant post-processor. EXTRAN provided the necessary hydraulic modelling capabilities; RUNOFF and the post-processor provided the pollutant modelling capabilities. SWMM and the post-processor were calibrated with field data for various rainfall and tidal conditions. Flow and pollutant concentrations were modeled from June through September 1990 for water quality modelling projections.

Storage of CSO was also modeled, using the SPM, which simulates settling of suspended solids. The SPM provided the flow and pollutant data necessary for assessment of CSO abatement alternatives. In-line storage was also modeled, using EXTRAN, and provided the basis for assessing this abatement option.

Variables

- C_p : Pollutant coefficient used in BOD₅ equation [nondimensional units]
DWF: Dry weather flow [cfs]
SWF: Stormwater flow [cfs]
 TSS_{sw} : Stormwater total suspended solids concentration calculated in the RUNOFF block [mg/l]

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