Chapter 11

Is There a Limit to Model Size and Complexity? Practical Experiences for CSO Modeling for Narragansett Bay

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The Narragansett Bay Commission (NBC) manages a complex sewerage system that includes 65 combined sewer overflows (CSO). A model of the system was developed to determine in-system flows and CSO characteristics for use in conceptual design of CSO controls. The modeling

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approach successfully integrated six different SWMM models into a single system-wide model. The single system-wide model eliminated approximations for boundary conditions and reflected the many hydraulic inter-dependencies within the system. The model is stable and produces accurate numerical results. The estimated overflow volume is about 680,000 m³ (180 million gallons) during a 2-year design storm event.

The model is currently being used to estimate the effectiveness and size of control alternatives. The alternatives include near surface storage facilities at strategic locations in the system and a deep tunnel scheme with drop shafts at major overflow locations.

11.1 Introduction

In the summer of 1992 the NBC contracted with CH2M HILL to integrate the modeling work of several consultants as well as the University of Rhode Island. The purpose of the model integration was to provide a consistent model approach, to correct obvious omissions or errors, and to develop a tool to allow system-wide evaluation of control alternatives. The integration of six different area models, particularly the EXTRAN models, was the modeler's primary challenge (CH2M Hill, 1993). The level of effort and the modeling approach taken by the project team was a balance between the model and modelers' ability and the level of detail required to screen and assess the various control alternatives. As the NBC moves towards making decisions on the size and locations for control facilities, the more imperative it is to ensure adequate modeling of the system and the proposed facilities.

11.2 Model Integration

The modeler's primary challenge was combining six SWMM models developed over a period of about ten years for individual service areas of the NBC sewerage system. This included both RUNOFF and EXTRAN models of the areas. Although the six area models reflected obvious geographic areas of the system the extent of the area models was limited, in part, by SWMM code and computer constraints. Even though the areas are representative, they do have common boundaries the conditions at which had to be assumed or approximated through repetitive trials for a given storm event.

Recent expansions of SWMM code (CH2M Hill, 1993) and enhanced desktop computer power has enabled the integration of the NBC system into a single model. By modifying the EXTRAN program code and combining the six service area models into a single system-wide model, a more accurate representation of the hydraulic interconnections within the collection system was obtained.

The system model has attempted to eliminate many of the "fixes" used in the area models to improve stability and model results and to apply a consistent modeling approach to both runoff and hydraulic transport. However, as major re-calibration and verification tasks were not undertaken, no significant revisions to RUNOFF data were made. Nevertheless hydraulic grade lines and hydrographs at key locations were checked and adjustments made when warranted.

The current model consists of a RUNOFF model comprising 84 drainage basins and an EXTRAN model comprising 710 conduits and 727 nodes. The system also includes two siphon structures, a hydrobrake structure, and a major pump station. The model also receives dry-weather flow contributions from separated areas. There are 65 CSOs regulated by control structures generally consisting of a weir and underflow orifice. The model tracks inter- and intra-basin flow transfers.

11.3 Modeling Observations

The construction of the area models over a ten-year span produced working models that gave reasonable results for the tasks at hand. The "philosophical" difference was evident in the modelers approach to resolving problems with both RUNOFF calibration and EXTRAN calibration and instability. The underlying system data and the hydraulic complexity of the system complicated the integration of the system. For example, the area models included pipe diameters ranging in size from 76 mm to over 3050 mm (3 inches to over 10 feet) and pipe lengths from 3 m (10 feet) to over 850 m (2800 feet). Several techniques for replacing weirs or other unstable components were also evident, including equivalent pipes; a common enough model solution. RUNOFF calibrations included width and percent impervious adjustments, but not necessarily consistent between the area models. It was the team's objective to eliminate many of the model approximations and substitutions and to reconstruct a model that reflected the physical system. This included direct representation of diversion structures through use of weirs and orifices.

Computed flooding at inlets and at several internal nodes was a problem generally resolved in the area models by artificially raising the ground surface at nodes. This resolved some stability problems and kept water in the system. EXTRAN has the often artificial assumption of removing this flooded water from the system. Raising ground surfaces resolved the lost-water problem but caused higher hydraulic grades than would be expected. This also did not truly reflect the importance of flooding in the system or reflect whether flooding should be a concern. Figure 11.1 shows one method for investigating the potential for flooding and stability problems: a comparison of peak flow rate at the modeled inlets in RUNOFF and the hydraulic capacity of the receiving conduit as calculated by EXTRAN. A high ratio of inlet flow to conduit capacity may indicate a high potential for inlet flooding whereas a low ratio (high conduit capacity to inlet flow) may indicate an underestimation of runoff potential.

Resolution of flooding instability and identification of real-world flood-prone areas was initially attempted by adding a surface drainage system to the model. This surface system captured and accounted for the flow. This resulted in mixed and inconsistent results. Fortunately improvements to SWMM and more effective use of storage nodes allowed elimination of this artificial surface collection system.

Currently the model estimates the flow and hydraulic conditions throughout the system within a one percent continuity error. Limited flooding is now computed to occur at inlets and there are no flow or head instabilities at weirs or conduits (except at four weirs; replaced by equivalent pipes). Use of the dynamic solution technique of XP-SWMM (XP Software, 1993) or additional model enhancements in SWMM 4.3 (Huber, 1994) may allow restoration of the true weir representation.

11.4 Is There a Limit to Model Complexity?

Large system models are possible because modelers are more willing to assume the risks inherent in simulating large and complex systems. In part, this willingness is due to the increased power and the relative low cost of computing with desktop computers. Also the improvements and fixes to the SWMM code have removed many of the obstacles for simulating large systems. The open architecture of the SWMM code has resulted in many versions of SWMM with various internal "fixes" and program expansions or adaptations. For example, in the NBC system, a

Figure 11.1 Comparison of peak flow rates at inlets with receiving conduit capacity.

pump station option was added (CH2M Hill, 1993) to SWMM with control of the pump station based on conditions at a remote node rather than a node to which it pumps. This type of pump station is used to model pump-out of storage facilities at times when capacity is available at treatment plant or other downstream hydraulic controls, such as at a siphon.

The limitations for modeling larger systems, in the authors' view, lie with the ability of the modeler to review and assimilate the many pieces of data that make up the model. The modeler should be able to find within SWMM output that one piece of information or clue that for example aids in finding the cause of a model instability. This is nothing new to SWMM modeling, only made more difficult with large complex models. It is much more difficult, with large models, to avoid the "trap" of accepting the results (without skepticism) and enjoying the relief felt after obtaining a stable model result, particularly after many trials and aborted runs.

Reviewing pages of data input to find data entry error is not easy for large models. For the NBC system a typical input file consists of over 40 pages, output from the runs often exceeds the capabilities of common screen editors. Figure 11.2 represents the six components of the NBC system as initially imported into a management system with a quasi-geographical reference and suggests the level of confusion that can exist in large scale models.. Figure 11.3 shows a highlighted area of part of Figure 11.2 and the level of confusion is less. This visualization allows for greater clarity and understanding of the possible interactions within the system.

The analysis of output data in typical SWMM modeling is often restricted to acceptance of low continuity errors, lack of un-documented flooding, review of averages over the simulation, maximum conduit flow rate to design flow rate, and maximum head conditions. The hydraulics at flow controls such as weirs and orifices are often the major sources of errors or modeling adjustments made to make the model work. Reliance upon average or peak summaries may not be adequate, as illustrated in Figure 11.4. Figure 11.4 shows computed head at upstream and downstream nodes and the flow hydrograph at an overflow conduit. The conduit flow seems reasonable, as indicated by the peak flow rate and periodic overflow pattern, but model instabilities occurred in the rising and falling limbs of the hydrograph. Instabilities such as those shown in Figure 11.4 are not necessarily fatal or lead to unreasonable results; they are shown here to illustrate the care needed in interpreting results solely from SWMM output summaries. Instabilities in the NBC model were generally

Figure 11.2 Narragansett Bay Model: complexity shown by system-wide schematic.

Figure 11.3 Narragansett Bay Model: Area 067 sub-system schematic.

Figure 11.4 Example output showing model instabilities.

resolved through careful attention to job control parameters, the use of storage nodes, and, on occasion, replacement of control structures by equivalent pipe.

The changes made by EXTRAN for Courant conditions (Huber and Dickinson, 1991), that is, the equivalent pipe replacements for short pipes, can often have a material impact on system storage. For large models with many small and short pipes this additional storage can often rival major control components such as a storage tank. The modeler should always be aware of the magnitude of the storage added and replace or modify model configuration or job control if added storage is large in relation to total system storage.

Relying on the review of model output only can often overlook important model situations or lead to mis-understanding the hydraulics of the system. For example, the system shown in Figure 11.5 is part of the CSO control alternative using storage tanks. The review of model output would not have shown any unusual flows except for an indication that the water balance in conduits leading to the storage tank (at node 5312) implied flow reversal. This is shown in Figure 11.6 for several of the conduits leading to the storage tank area. The reversals occur at certain flow and head conditions that are not represented by the peak or average flow and head results reported in the typical SWMM output file.

The review of individual pipe flows is often not practical given the graphical limitations of SWMM. New methods and SWMM enhancements such as XP-SWMM (XP Software, 1993), Model Turbo View (10 Brooks Software, 1992), LYNX (CH2M Hill, 1994a), PCSWMM4 (this book) and FMS-AC (CH2M Hill, 1994b) all provide valuable aids in managing SWMM input and output. These new tools and utilities help to offset the exponential increase in effort with model size as discussed above.

11.5 Conclusion

The improvements to SWMM and computer technology has allowed modelers to study larger systems, thereby performing system-wide analysis of complex and inter-related systems. The limitations of SWMM are not always apparent and not necessarily discernible from common and familiar SWMM output files. In large system models the modeler should be cognizant of the many possible interactions between system components and be able to track these interactions to ensure model reasonableness.

Figure 11.5 Schematic of part of Area 2: Narragansett Bay System Model.

Figure 11.6 Flow reversals in Area 2: Narragansett Bay System Model.

As models get more complex and larger it is more evident that database management and visual representation techniques will be applied. This will include systems that build input data sets; screen editors will no longer be adequate. Database systems can provide preliminary data checks and can automate data retrieval or processing. Automated and visual review of results will be performed through interrogative or query programs that complement SWMM and read specific portions of SWMM output or saved scratch or interface files. Management of data, running of SWMM and output processing will be performed under an integrated information management system that includes mapping, system maintenance databases, and model management.

Large and small models are no better than the data put into them; the modeling is no better than the modeler. Ultimately the question in any model development and in the determination of size and complexity should be: what is the intended model use and can this use be achieved without modeling every maintenance hatch and pipe in the system? The NBC has applied this question throughout their CSO control strategy and has selected an appropriate level of model size and complexity that fits their requirements.

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