Water Quality Modeling to Support the Rouge River Restoration

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Abstract

The Rouge River National Wet Weather Demonstration Program (Rouge Project) has taken on the challenge of implementing river restoration efforts in a highly urbanized watershed. The 467-square mile Rouge River Watershed is located in southeastern Michigan, and encompasses 48 communities, including the City of Detroit. A significant number of stormwater and combined sewer overflow (CSO) controls are being installed within the watershed to address Rouge River pollution reduction objectives.

A suite of hydrologic, sewer system and riverine water quality models have been used to address technical questions that have been asked in Rouge River Watershed planning. This paper presents application of four of the models used by the Rouge Project: 1) *TRTSTORM*, 2) *Watershed Management Model (WMM*), 3) *Stormwater Management Model (SWMM)*, and 4) *Water Quality Analysis Simulation Program (WASP)*. The TRTSTORM model predicts annual overflow statistics for various CSO control facilities. A simple pollutant loadings model, the WMM evaluates and communicates the relative impacts of various stormwater controls. SWMM is aiding the development of subwatershed management plans by predicting relative changes in wet weather river response for alternative controls. Finally, the WASP event model predicts the highly transient dissolved oxygen drops caused by CSO discharges, thus the benefits for various levels of CSO control.

The Rouge Project models have been and continue to be an important decision-making aid for the project. In addition, the modeling approach used by the Rouge Project, as well as several specific modeling tools, are transferrable to other urban watershed management projects.

Introduction

The Rouge Project is using four modeling tools to support river restoration efforts in the highly urbanized Rouge River Watershed. The U.S. Environmental Protection Agency (USEPA) sponsored the Rouge Project, in 1992, to demonstrate effective solutions to wet weather water quality problems in urban areas. Under the leadership of the Wayne County Department of Environment, CSO controls and stormwater best management practices (BMPs) are being implemented within a watershed approach which stresses an inclusive process of all stakeholders.

This paper presents an overview of how water quality models are being used to answer technical questions which arise in the Rouge Watershed planning process. Application of four specific models is discussed including each model's role and sample results which illustrate how the model could be applied in other watersheds. Several lessons learned in the Rouge Project modeling effort are also presented.

The Rouge Watershed

The Rouge Watershed encompasses 467 square miles in Michigan's greater Detroit metropolitan area and is home to 1.5 million residents. The Rouge River has been identified as one of the most polluted rivers in the Great Lakes basin. The Lower, Middle, Upper and Main Rouge River branches total 127 miles in length, and comprise one of the state's most publicly accessible rivers.

Multiple pollution sources have led to the gradual degradation of water quality and habitat in portions of the Rouge River and resulted in use impairments. The primary problems include CSOs, nonpoint stormwater runoff, illicit connections, failing septic tanks, stream bank erosion and increased flow variability. The combined effect of these pollutants has led to depressed DO levels, whole-body contact prohibitions, damaged aquatic habitat, fish consumption advisories and poor aesthetics.

One-third of the CSOs in the watershed are being controlled via 11 demonstration CSO basins, several of which became operational in 1997. Performance of the demonstration facilities will be used to determine the appropriate level of control for the remaining CSOs. The watershed has been divided into 11 subwatersheds where advisory groups are forming to address all other pollution sources in a holistic fashion. Numerous stormwater BMPs, recreation and habitat projects have already begun and more are planned.

Modeling Approach

The modeling effort consists of a three-tiered approach. Tier 1 consists of several small area models used to simulate flows, pollutant loads and concentrations from specific pilot projects or localized areas of study such as wetlands, swales, wet detention ponds and individual CSO basins. Tier 2 consists of a simple pollutant loading model and a detailed sewer system model that both simulate pollutant generation by subarea for the entire watershed. Tier 3 is the river models which simulate instream flows and concentrations in the four main river branches, based on the inputs from the Tier 2 detailed sewer system models. Following are four examples of these models in use.

CSO Facility Performance

While the 11 demonstration CSO facilities were in the design stages, the TRTSTORM model was developed to provide some early predictions as to how these basins would perform (Kluitenberg et al., 1994). The model was used to address the following questions:

- How will the proposed CSO facilities, designed to several different sizing criteria, perform relative to presumptive criteria in the USEPA CSO Policy (USEPA, 1994)?
- What annual pollutant load reductions are expected from the proposed facilities?

The TRTSTORM model is a simple hydrologic mass balance model which tracks CSO facility filling, treatment, overflow, dewatering and decanting based on long-term hourly precipitation records. It is a modified version of the U.S. Army Corps of Engineers "Storage, Treatment, Overflow, Runoff Model" (Hydrologic Engineering Center, 1976). The model generates annual performance statistics for flows to the treatment plant (via interceptor), treated and untreated overflows.

The model was used to show that all CSO facilities designed to the demonstration sizing criteria should meet the 85% capture and four overflow per year presumptive criteria in the USEPA CSO policy. The model used assumed treatment efficiencies to determine expected annual load reductions for a number of pollutants at each facility. Figure 1 shows a summary of the predicted annual reduction in biochemical oxygen demand (BOD) entering the receiving water for: one site-limited facility; five basins sized to provide 20-minute detention of a 1-year, 1-hour storm (demonstration size); and two basins sized to capture a 1-year, 1-hour storm (Michigan Department of Environmental Quality (MDEQ) size). The results make it clear that for either of the two sizing criterion, annual load reduction is strongly governed by capture and is fairly insensitive to basin treatment efficiencies.

Pollutant Loading Analysis

The Watershed Management Model (WMM) is being used to estimate annual pollutant loading. In each subwatershed, WMM is being used to address the following questions and to communicate technical findings to stakeholders in an easy-to-understand fashion.

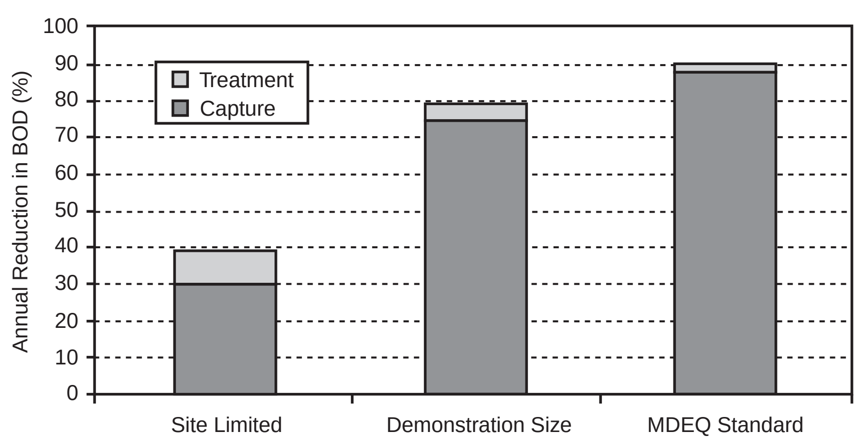

Figure 1. Annual percent reduction in BOD for various basin sizing criteria.

- What are the relative contributions of different pollutant sources in the subwatershed?
- What pollutant load reductions can be expected with various stormwater BMPs and CSO controls?
- How will expected land use changes impact pollutant loads at the bottom of the subwatershed?

The Rouge Project recently completed development of WMM for Windows (Rouge Program Office, 1997) which is being provided to each community for its own use in subwatershed planning efforts. WMM calculates pollutants loads for each source of flow (baseflow, stormwater runoff, CSOs and point sources) in each watershed subarea using annual flow volumes and event mean concentrations (EMCs) assigned to that specific source. The model projects annual pollutant loads by subarea. Various combinations of stormwater BMPs and CSO controls can be selected in specific geographic areas to determine the overall resulting pollutant reductions for a particular management plan.

WMM was used early in the project as a prioritization tool to develop pie charts showing the major pollutant sources in each subwatershed. It was recently used as an analysis and communication tool in three detailed subwatershed management studies. Figure 2 is a sample of WMM results for BOD in the Middle 3 subwatershed, where it was used to show the cumulative effect of two-phase CSO control and two different stormwater management plans.

Watershed Hydrology/River Hydraulics

The Rouge Project has developed a continuous, growing-season model of the entire watershed and the major river branches using the USEPA Stormwater Management Model (SWMM) (Huber et al., 1992). The model is used as the hydraulic driver for the riverine water quality model. It has also been used to assess river hydraulic impacts for issues which arise in the subwatershed planning efforts. Questions it has addressed include:

- How will expected land use changes impact instream hydraulics (flow rates, volumes, depths and velocities)?
- How will proposed CSO control facilities impact instream hydraulics?
- What combination of stormwater BMPs and CSO controls will reduce instream peak flow rates to workable levels for suitable fish habitat?

The SWMM RUNOFF block is used to model the hydrology of all storm sewered areas and areas with natural drainage. An existing SWMM RUNOFF/TRANSPORT model, the Greater Detroit Regional Sewer System Model (Camp Dresser & McKee, Inc., June, 1994), is used to model all CSOs entering the river. Inflow hydrographs from both these models comprise all inputs to the one-dimensional river model, which is simulated with the SWMM TRANSPORT block. A continuous simulation with the full model was calibrated to 6 months of 15-minute data collected with a network of rain and stream flow gages. We assume that these data coincide with a 40- or 50-year analysis.

As part of the Upper 2 Subwatershed Management Study, the model was used to evaluate several scenarios including the cumulative impact of future land use projections, complete CSO control, placement of regional extended dry detention ponds throughout the subwatershed. A fourth scenario involved placement of such ponds at only a few select locations in the subwatershed instead of everywhere. The average increase in peak flow rates for a range of typical storms is shown in Figure 3 for one sample location. The results clearly show that the existing high

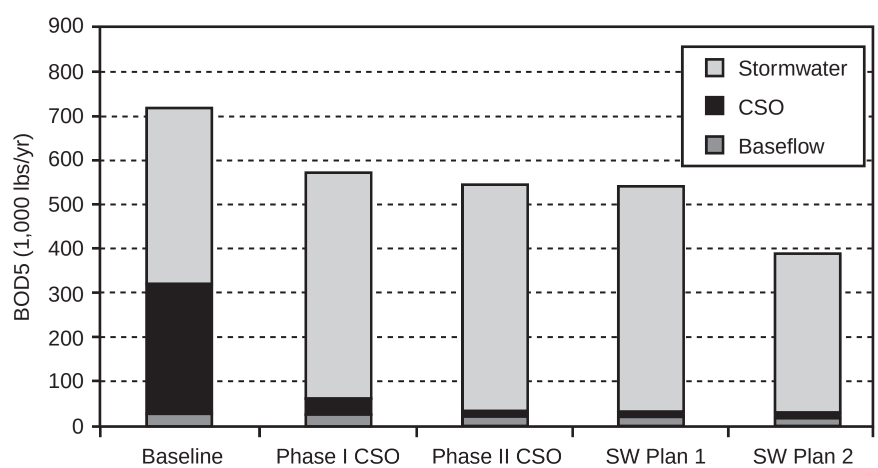

Figure 2. Middle 3 subwatershed WMM model results - average annual BOD load.

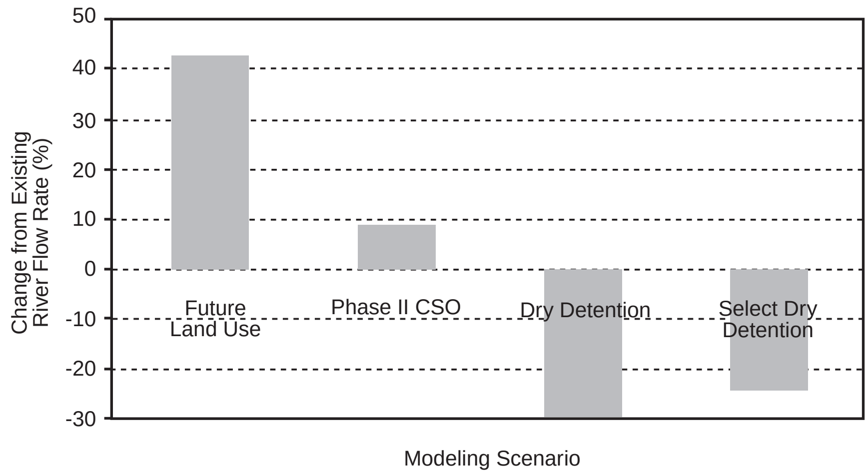

Figure 3. Model river flow rate compared to existing conditions - Upper 2 subwatershed - Bell Branch at Beech Daly.

flow rates and velocities and the resultant bank erosion problems will worsen, but that both types of regional detention could be used to accommodate future land use changes and reduce peak stream flows and velocities below existing conditions.

Instream Water Quality

Building on the SWMM quantity model, a riverine water quality model of the Lower, Middle, Upper and Main Rouge River branches was developed using the Water Quality Analysis Simulation Program (WASP) EUTRO model (Ambrose et al., 1993). While the model was originally developed and calibrated as a continuous model of eight pollutants, it has evolved to its current, primary role as an event model to simulate the CBOD-DO interaction which results from CSOs, including the sudden transitory DO drops which have been observed in the Rouge River. The model is currently being used to address the following questions:

- Will various CSO control alternatives eliminate the transitory DO drops caused by high CBOD in CSO discharges?
- What wet weather DO impairment will remain after all CSO controls are in place?
- How much will dry weather DO improve after controls eliminate most of the sediment oxygen demand (SOD) contributed by CSOs?

The water quality model developed is shown schematically in Figure 4. Stormwater inputs are simulated with the SWMM RUNOFF build-up/washoff algorithms. CSO inputs are assigned concentrations based on the time from when overflow begins, based on typical "pollutograph" shapes from monitoring data. The Rouge Project also developed a new model code linking the SWMM TRANSPORT river hydraulic output to the WASP model. Portions of the model have been calibrated to several heavily monitored wet weather events.

The model was utilized to evaluate two alternative CSO basin sizes in Oakland County on the main branch of the Rouge. For one of the calibrated wet weather events, the instream DO improvement was determined by modeling the impact of complete CSO control with three CSO basins sized to the demonstration criterion. The simulation was also repeated assuming the basins were enlarged to the MDEQ standard sizing criterion. The simulated instream DO shown in Figure 5 illustrates that the demonstration size basins improve the DO sag enough that it no longer falls below the 5 mg/l standard for this event. It also shows the marginal improvement which would have been achieved if the MDEQ basin sizing criterion were used, approximately doubling the size of each of the facilities.

The model of the entire main branch of the Rouge was also used to simulate dry weather DO, which is primarily driven by SOD and reaeration. For the first phase of CSO control and also for complete control, model SOD was reduced to approach that of in-situ SOD measurements made in river reaches which were not CSO impacted. The results in Figure 6 show that CSO controls will provide a significant benefit to dry weather DO, but that some DO impairment will remain in selected river reaches which are somewhat impounded.

Instream performance monitoring began in 1997. The monitoring is intended to show whether effluent from the demonstration facilities will cause any remaining water quality impairment. The water quality event models will be used in the future as part of the analysis of the monitoring results.

Model Findings

Many findings have arisen out of the Rouge Project, several of which the models helped bring to light. Model findings are given below.

- The impairments caused by wet weather pollution are certainly not limited to wet weather periods. In the Rouge this is especially true for the CSO contributions to SOD and the resultant dry weather DO impairment.

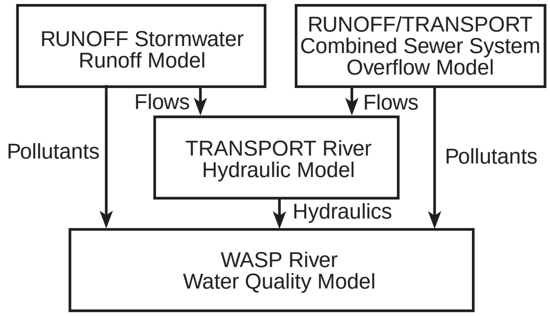

Figure 4. Rouge Tier 3 model schematic.

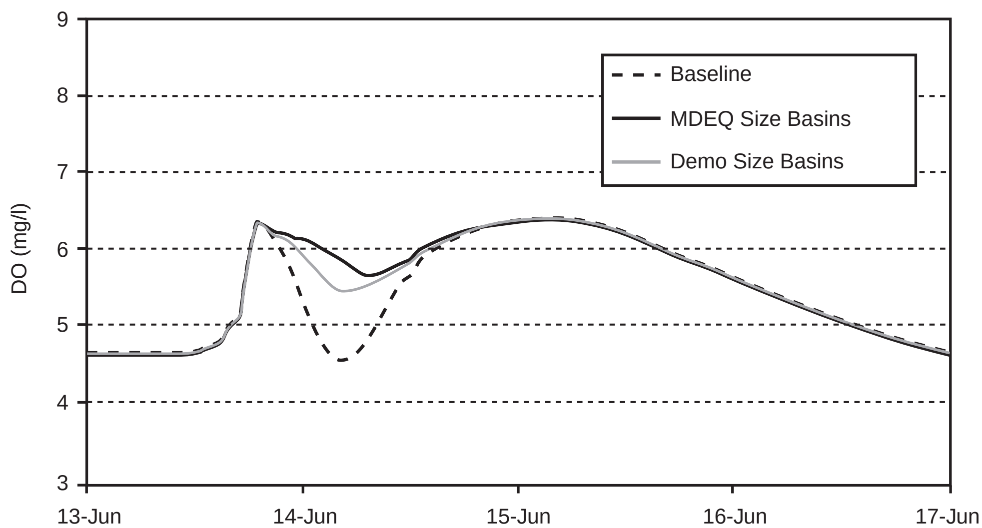

Figure 5. Modeled DO for CSO control alternatives - Main Rouge at 8 Mile Rd.

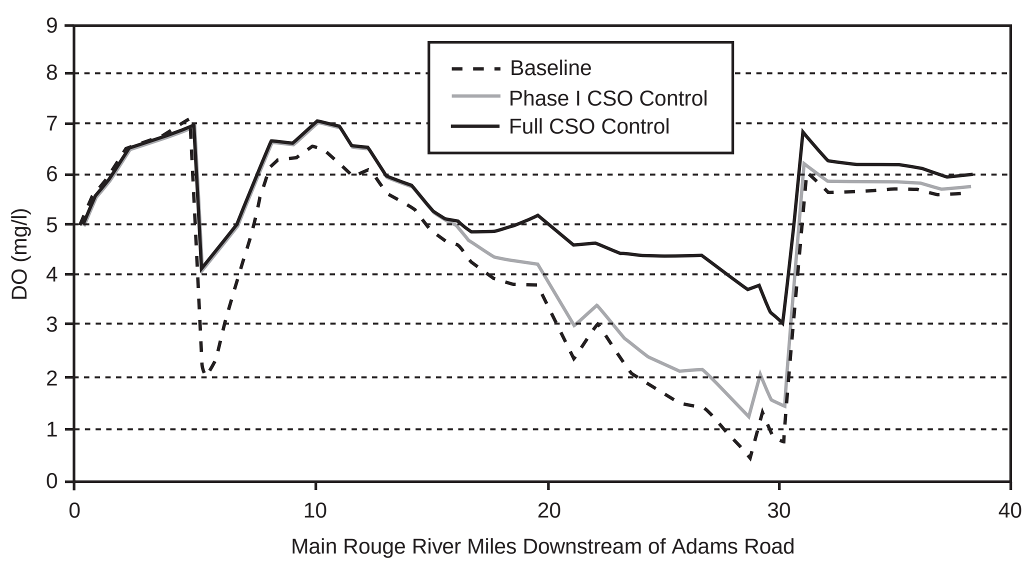

Figure 6. Dry weather model instream DO for June 13, 1994 - Main Rouge from Adams to Greenfield.

- In a predominantly urban watershed, increased stream flow due to urbanization damages aquatic habitat and causes bank erosion, log jams, sedimentation and increased instream solids concentrations.
- Some dry and wet weather DO impairment is expected to remain in the Rouge Watershed after all CSO are controlled, simply due to nonpoint stormwater runoff. Stormwater and CSO must be addressed together in a holistic approach.
- It is expected that the Rouge Watershed CSO basins sized to demonstration criteria will be adequate to eliminate any resultant water quality impairments.
- Rouge Watershed standard practices for on-site detention of stormwater do little to mitigate the development-induced flow increases for small storms, with attendant increased velocities and streambank erosion.

Lessons Learned

Over the course of the Rouge Project modeling effort a number of lessons have been learned about the modeling. Several of the key lessons are:

- If possible, model selection and development should not be performed until the specific questions to be addressed by the model are well formulated.
- A simple loadings model such as WMM can be a good technical resource, but it may be even more important as a tool for communicating technical findings.
- Urban rivers dominated by stormwater runoff present a unique modeling challenge as the difficulty of monitoring nonpoint sources means there are not well-defined inputs for the model.
- Models should not be used to try to answer every question. Many questions can still be answered via analysis of monitoring data.

Conclusions

The Rouge project is successfully using a suite of four water quality modeling tools to address technical questions raised in watershed management planning. The Rouge Project models, modeling approach and findings are a resource that is transferable to other urban watersheds.

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