A Study of the Impacts and Control of Wet Weather Sources of Pollution on Large Rivers

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The Ohio River Sanitation Commission (ORSANCO) has undertaken a study of the sources of wet weather pollution in large rivers. The study is to be completed within two years with work in the first year concentrating on defining wet weather sources of pollution while work in the second year will concentrate on evaluating effective wet weather controls. The project includes both extensive modeling and monitoring of water quality. At this point (March 1996), year one is nearing completion.

As part of this study, a complete XP-SWMM model of the drainage system within the Greater Cincinnati area was developed. This model included interceptor sewers, trunk sewers, all combined sewer overflows (CSOs), significant sanitary sewer overflows (SSOs), treatment plants, and receiving streams and rivers. Both flow and water quality data were modeled for the entire system. The model was calibrated using existing stream tributary flow and concentration data, and interceptor flow and concentration data.

The purpose of the modeling is to generate pollutographs from direct sources to the Ohio River (a significant number of CSOs and three wastewater treatment plants) and tributary streams. Tributary streams within the study area receive CSO and SSO discharges during wet weather. The results of the model are to be interfaced with a WASP model of the Ohio River, currently being developed by another member of the study team.

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The model was used to generate pollutographs for fecal coliform and suspended solids for a total of four wet weather events during the fall of 1995. These four events were selected due to the availability of event mean concentration data from water quality monitoring. Statistical analyses on collected data were completed to define event mean concentrations for CSO discharges.

Model results were compared against data collected during an extensive water quality monitoring program. Water quality was monitored in tributary streams. A comparison of modeled results with measured results indicated good agreement between predicted concentrations of fecal coliform and measured concentrations.

In the next year, the developed model will be utilized to evaluate alternatives for controlling wet weather sources of pollution into the Ohio River

15.1 Introduction

A detailed study of the wet weather sources of pollution has been undertaken for the Ohio River within the states of Ohio and Kentucky by ORSANCO. The overall study consists of water quality modeling of the Ohio River and its tributaries, continuous flow monitoring at CSO and stream locations, and event water quality monitoring using grab samples at CSO locations, stream and river locations. Figure 15.1 presents the overall framework of the study and shows the interaction between the modeling and monitoring phases of the study. This chapter details the modeling approach for the direct discharges into the Ohio River from the Greater Cincinnati Area.

Figure 15.1 Model framework.

15.2 Description of the Study Area

The Greater Cincinnati Area is located within Hamilton County and encompasses all or a portion of 50 municipalities. The study area consists of three large drainage areas: Muddy Creek drainage area; Mill Creek drainage area; and Little Miami River drainage area. Each of these drainage areas is serviced by its own collection system and wastewater treatment plant which discharge directly to the Ohio River. Terrain within the study area is generally rolling with elevations ranging from 955 feet (291 m) in the northern portions of the study area to 455 feet (138 m) at the Ohio River. Table 15.1, 15.2 and 15.3 presents the general characteristics of the Little Miami River, Mill Creek and Muddy Creek drainage areas, respectively.

Table 15.1 Little Miami River drainage area characteristics.

Characteristic	Description
Major Water Courses	<ul style="list-style-type: none"> • Duck Creek: Drainage area is 27.5 square miles. Of the 18 sub-watersheds contributing to Duck Creek, 14 drain to combined sewers which transport flow to the Little Miami Wastewater Treatment Plant. • Lower Little Miami River: Drainage area of 51.9 square miles. • Upper Little Miami River: Drainage area of 1591 square miles.
Land Use	<ul style="list-style-type: none"> • Duck Creek: Residential or commercial land uses occupy 71% of the drainage area. • Lower Little Miami River: 53% of the drainage area is developed. About 18% of the area is considered undevelopable due to slope and floodplain restrictions. • Upper Little Miami River: Mostly rural and agricultural land uses.
Sewers	<ul style="list-style-type: none"> • Duck Creek: Approximately 82% of the drainage area is sewerred. About 60% of the sewerred area served by combined sewers while remaining 40% of area is served by separate sewers. • Lower Little Miami River: About 34% of the drainage area is sewerred with less than 1 % of the sewerred area served by combined sewers.
Pump Stations	<ul style="list-style-type: none"> • There are a total of 27 wastewater pumping stations in the Little Miami Creek drainage area. Most of the pumping stations are in the East Little Miami drainage area in areas not served by gravity sewers.
SSOs	<ul style="list-style-type: none"> • There are 19 SSOs which discharge directly to adjacent storm sewers or receiving streams.
CSOs	<ul style="list-style-type: none"> • Of the 56 CSOs in the Little Miami drainage area, 10 are mechanical regulators, 33 are drop gates, and 13 are diversion dams. A total of 11 CSOs overflow as a result of high stage in the Ohio River.

Table 15.2 Mill Creek drainage area characteristics.

Characteristic	Description
Major Water Courses	<ul style="list-style-type: none"> • South Mill Creek: The drainage area is 63 square miles or about 38% of the total drainage area. • West Branch Mill Creek: The drainage area is 41 square miles or about 25% of the total drainage area. • East Branch Mill Creek: The drainage area is 62 square miles or about 37% of the total drainage area.
Land Use	<ul style="list-style-type: none"> • South Mill Creek: About 85% of the drainage area is urban land use (residential, commercial or industrial). Only 15% is open space or undevelopable lands. • West Branch Mill Creek: As of 1990, almost 83% of the drainage area was urban land use. • East Branch Mill Creek: About 70% of the drainage area is urban land use.
Sewers	<ul style="list-style-type: none"> • South Mill Creek: About 75% of the drainage area is served by a combined sewer system. The remaining areas are served by separate sanitary sewers or is unsewered. • West Branch Mill Creek: Only 7% of the drainage area is served by combined sewers. Most of the centre and northern portion of the drainage basin is unsewered. • East Branch Mill Creek: This drainage area is primarily served by a separate sanitary sewer system.
CSOs	<ul style="list-style-type: none"> • Of the 158 regulating structures in the Mill Creek Drainage Area, 47 are mechanical regulators, 57 are drop gates and 54 are diversion dams.

Table 15.3 Muddy Creek drainage area characteristics.

Characteristic	Description
Major Water Courses	<ul style="list-style-type: none"> • Muddy Creek : The drainage area is 17 square miles. • Rapid Run Creek: The drainage area is 7 square miles. • River Road: A narrow band of land along each side of River Road provides an additional 6 square miles of drainage area.
Land Use	<ul style="list-style-type: none"> • About 70% of drainage area is urban land use (residential, commercial of industrial).
Sewers	<ul style="list-style-type: none"> • About 41% of the drainage area is serviced by a combined sewer system.
CSOs	<ul style="list-style-type: none"> • There are 20 CSO in the drainage area. The CSOs are either diversion dams or drop gate structures.

Overall, a total of 227 CSO locations has been identified within the Greater Cincinnati Area, with a total of 20 CSOs located within the Muddy Creek drainage area, a total of 151 CSOs located within the Mill Creek drainage area,

and a total of 56 CSOs located within the Little Miami River drainage area. In addition, a number of SSO locations have been identified. The most significant of the SSO locations are within the Muddy Creek drainage area. Figure 15.2 presents an overall plan of the study area, including the locations of all CSOs.

15.3 Model Development

Computer models were developed to provide predictive tools for the estimation of wet weather pollutant loadings. The models were used to generate estimates of pollutant loadings at specific locations as a function of, among other things, rainfall.

As part of an earlier Facilities Planning Study undertaken for the Greater Cincinnati Area (BBS, 1995), XP-SWMM models of the existing collection systems in the three drainage areas were constructed. These models included all areas tributary to the wastewater treatment plants, all CSO locations, a number of significant SSO locations, all major pumping stations, and all interceptor pipes. These models were calibrated using flow data obtained from six permanent flow monitoring stations located in interceptors and trunk sewers. Rainfall and flow data from January to June 1993 were used to calibrate and verify the models. The calibration process produced reasonable agreement between computed and actual flows (BBS, 1994).

A detailed hydraulic capacity analysis was performed to determine the hydraulic capacity of specific elements, such as individual CSOs, under dynamic flow conditions. The results of this analysis were applied to construct a continuous XP-SWMM model. Using a typical rainfall year, average CSO loadings were estimated. Table 15.4 presents the computed average annual CSO volumes for the three drainage areas and the Ohio River.

The current study involved the extension of the existing models to include the following:

- addition of four watercourses (Muddy Creek, Rapid Run Creek, Mill Creek and the Little Miami River) tributary to the Ohio River complete with boundary locations for Mill Creek and the Little Miami River;
- addition of three wastewater treatment plants (WWTPs) including the Muddy Creek WWTP, the Mill Creek WWTP, and the Little Miami WWTP; and
- water quality modeling explicitly to estimate pollutant loadings into the Ohio River from tributary watercourses and from direct sources such as CSOs and wastewater treatment plants.

Figure X.2 Study area.

Table 15.4 Average annual CSO loadings.

Source		Average Annual CSO Volume (MG)
Tributary Sources	Little Miami River Drainage Area (including Duck Creek, Little Duck Creek, Clough Creek, and the Little Miami River)	1008
	Mill Creek Drainage Area	3084
	Muddy Creek Drainage Area (including Muddy Creek and Rapid Run Creek)	586
Direct Sources	Ohio River (Muddy Creek Drainage Area)	661
	Ohio River (Little Miami River Drainage Area)	338
	Ohio River (Mill Creek Drainage Area)	1050

Tributary watercourses were modeled using cross sectional data obtained from the U.S. Geological Survey (USGS). Boundary locations were demarcated within the Mill Creek and Little Miami River Drainage Areas. Continuous flow monitoring data was also obtained from permanent USGS stations. For Mill Creek, the upper boundary was selected at Carthage, while the upper boundary for the Little Miami River was placed at Millford. These sites were selected because of the availability of both flow and water quality data.

The models were also extended to include the three wastewater treatment plants within the Greater Cincinnati Area which discharge directly into the Ohio River. Table 15.5 presents a summary of the treatment plant capacities.

Table 15.5 Summary of WWTP treatment capacities.

Location	Capacity (MGD)				
	Raw Sewage Pumping Capacity	Hydraulic Limitations	Primary Treatment Capacity	Secondary Treatment Capacity	Disinfection Treatment Capacity
Muddy Creek WWTP	22	N/A	22	15	30
Mill Creek WWTP	520	N/A	420	240	455
Little Miami WWTP	260	55	118	100	100

Water quality was modeled explicitly using the build-up and washoff routines in XP-SWMM. Event mean concentrations were used to generate pollutographs for direct and indirect sources of pollutants to the Ohio River. Only suspended solids and fecal coliform were modeled explicitly with pollutographs for BOD5, ammonia-nitrogen (NH₃-N), organic nitrogen, nitrate nitrogen (NO₃-N), total phosphorous, copper, lead, and zinc derived as a constant fraction of suspended solids. The event mean concentrations used for suspended solids and fecal coliform are summarized in Table 15.6. These event mean concentrations were developed from statistical analyses of the results of a number of sampling programs, including the extensive monitoring program undertaken as part of this study. This monitoring program will continue in the next year and it is hoped that data collected during the two-year study will allow a relationship to be developed between land use and event mean concentrations.

Table 15.6 Event mean concentrations.

Source	Suspended Solids (mg/L)	Fecal Coliform (#/100mL)
CSO/SSO	155	1,000,000
Stormwater	93	53,000
WWTP Effluent	12	10
Little Miami River Boundary	149	3400
Mill Creek Boundary	114	7430

The updated model was used to generate pollutographs for direct and indirect sources of pollution into the Ohio River. Figure 15.3 presents a schematic of the updated XP-SWMM model.

15.4 Model Calibration

Data for model calibration and verification was obtained from a number of sources including the following:

- Permanent flow monitors operated by the USGS, located in Mill Creek and the Little Miami River. In particular, flow data at the upper boundaries of Mill Creek and the Little Miami River were used to calibrate a RUNOFF node.
- Data from the extensive water quality sampling program undertaken as part of the overall project was used to calibrate both direct

Figure 15.3 Conceptual XP-SWMM model setup.

and indirect pollutant sources. Pollutant concentrations from both CSO locations and tributary watercourses were calibrated and verified using the data collected during the water quality sampling program.

The water quality sampling program consisted of dry and wet weather sampling in the Ohio River and its tributaries, CSO sampling, and Ohio River biomonitoring. During four selected wet weather events, the monitoring program provided a complete dataset of pollutant concentrations from a number of CSOs, the Ohio River at a number of stations, and the tributary watercourses at a number of stations. Monitoring in the Ohio River consisted of samples taken at the left and right banks as well as at the centre of the river.

The XP-SWMM models were calibrated and verified to achieve good agreement between measured and modeled flows and concentrations. Figures 15.4 and 15.5 present the model calibrations of upstream boundary conditions for Wet Weather Event No. 3 of Mill Creek and the Little Miami River, respectively. Figures 15.6 and 15.7 present the model calibrations of fecal coliform concentrations for Wet Weather Event No. 3 in Mill Creek and the Little Miami River, respectively.

The XP-SWMM model output for the four selected wet weather events was used in the calibration of the Ohio River WASP model.

Figure 15.4 Calibration of upstream boundary flows, Mill Creek - wet weather event No. 3.

Figure 15.5 Calibration of upstream boundary flows, Little Miami River - wet weather event No. 3.

Figure 15.6 Calibration of fecal coliform concentration, Mill Creek at the Ohio River - wet weather event No. 3.

Figure 15.7 Calibration of fecal coliform concentration, Little Miami River at the Ohio River - wet weather event No. 3.

15.5 Model Results

As part of year one of the ORSANCO study, model results were generated for a total of four wet weather events. Model results consisted of total fecal coliform and suspended solids loadings entering the Ohio River from several sources within the study area, including tributary watercourses, wastewater treatment plants, CSOs and stormwater. Table 15.7 presents a summary of the model results.

Table 15.7 Computed suspended solids and fecal coliform loadings to the Ohio River.

Event	Percentage of Total Suspended Solids Load				Percentage of Total Fecal Coliform Load			
	CSO	WWT P	Trib. Water-courses	Storm -water	CSO	WWTP	Trib. Water-courses	Storm-water
Event #1	0.5	13	87	0.5	15	10	73	2
Event #2	0	13	87	0	1	0.2	98	0.8
Event #3	5	14	79	2	24	5	70	1
Event #4	4	10	85	1	33	3	63	1

Examination of Table 15.7 shows that tributary watercourses are computed to be the major sources of both suspended solids and fecal coliforms to the Ohio River from the study area on an event basis contributing 79% to 87% of computed suspended solids loads and 63% to 98% of computed fecal coliform loads. On an event basis, wastewater treatment plants contributed 10% to 13% of computed total suspended solids loads and 0.2% to 10% of computed fecal coliform loads. CSOs contributed 0% to 5% of computed suspended solids loads and 1% to 33% of computed fecal coliform loads on an event basis. Based on these results, stormwater is computed to be an insignificant contributor of both suspended solids and fecal coliforms to the Ohio River.

15.6 Future Program

The second year of the ORSANCO study will concentrate on enhancing modeling tools. An extensive monitoring program will be implemented in order to refine input model parameters such as event mean concentrations. Other

model improvements will include the addition of sanitary sewer overflows (SSOs), regulator dry weather bypassing due to high stages in the Ohio River, improved tributary watercourse cross-sectional information to improve the routing of flows, improved boundary conditions, and improved treatment plant hydraulics and treatment efficiencies. In addition, continuous modeling will be undertaken to study the typical, wet and dry annual loadings to the Ohio River from the study area. As in the first year, model results generated will be interfaced with a calibrated WASP model of the Ohio River.

Continuous modeling will also be used to study a number of control alternatives including the removal of all CSOs, the removal of all SSOs, and the removal of all regulator dry weather bypassing. It is hoped that the effects of pollutants entering the river from different sources will be better understood from the results of the model and that this understanding will lead to the development of a control strategy from improving water quality within the Ohio River.

As in the first year, an extensive monitoring program is planned to provide additional data for model calibration and verification purposes.

References

- BBS, 1994, Corporation Study Team, Combined Sewer Overflow Strategy Development and Facilities Planning, Technical Memorandum No. 2, Model Development, Prepared for the Metropolitan Sewer District of Greater Cincinnati, p8-16, October 5, 1994.
- BBS, 1995, Corporation Study Team, Combined Sewer Overflow Strategy Development and Facilities Planning, Phase III - CSO Implementation Plan, Prepared for the Metropolitan Sewer District of Greater Cincinnati, March, 1996.