FINAL REPORT

A STUDY OF IMPACTS AND CONTROL OF WET WEATHER SOURCES OF POLLUTION ON LARGE RIVERS

Ohio River Valley Water Sanitation Commission
September, 2002

EXECUTIVE SUMMARY

This is a final report of a study conducted by the Ohio River Valley Water Sanitation Commission (ORSANCO) titled, "A STUDY OF IMPACTS AND CONTROL OF WET WEATHER SOURCES OF POLLUTION ON LARGE RIVERS." The purpose of the study was to develop and implement a transferable methodology for the evaluation of combined sewer overflows (CSOs) and other wet weather impacts on the water quality of a large river, and to evaluate resulting benefits from certain abatement scenarios. This study specifically focused on the Cincinnati, Ohio – Northern Kentucky urban area of the Ohio River. The study methodology was successfully transferred to a similar project in the Louisville, Kentucky-New Albany, Indiana area of the Ohio River.

This study was funded by the United States Environmental Protection Agency (U.S. EPA), Metropolitan Sewer District of Cincinnati, Sanitation District No. 1 of Northern Kentucky, City of Cincinnati Water Works, and ORSANCO. Certain components of the project were completed by Limno-Tech, Inc., Tetra Tech, Inc., Woolpert LLP, XCG Consultants Ltd., and Camp Dresser and McKee (under the U.S. EPA's Rouge River Project). Special assistance was provided by the Ohio Environmental Protection Agency and U.S. EPA's Andrew W. Breidenbach Environmental Research Center.

Bacteria levels have been identified as a major cause of impairment to Ohio River water quality and its beneficial uses. An inventory compiled by the U.S. EPA showed a total of 9,471 individual combined sewer overflow (CSO) outlets nationally, of which approximately 1,400 are located along the Ohio River (15 percent of the national total). The Ohio River is used extensively for recreation and is a source of drinking water for nearly three million people. To date, very little has been done to study the causes, sources and effects of abatement efforts on the water quality of large rivers, thus evidencing the need for this study.

Specific objectives of the study included: 1) Determination of the extent and severity of wet weather water quality impacts on the Ohio River; 2) Identification of the causes (pollutants) and sources of impairment; 3) Classification of the relative importance of the identified sources; 4) Evaluation of the resulting improvements in Ohio River water quality from various CSO abatement scenarios. Major project components included: multiple wet and dry weather water quality surveys; land-side modeling to estimate pollutant loadings from CSOs and other important sources; setup and execution of a river model to determine the extent and severity of wet weather water quality impacts and evaluate resulting improvements to water quality from various CSO abatement scenarios; and special studies including evaluation of biological monitoring techniques and an investigation of cryptosporidium and giardia. In addition, project data was compiled on CD in a GIS-based storage and analytical tool, and select modeling results are viewable in a special animator available with the report on CD.

The study area lies within the Markland pool of the Ohio River bordering Ohio and Kentucky. There are approximately 350 CSO outlets, 5 municipal wastewater treatment plants, three water intakes, and 40+ direct discharges within the study area. Major tributaries include the Little Miami River, Mill Creek and Great Miami River on the north bank, and the Licking River on the south bank. The Ohio River itself has an average width of 1,600 ft, average depth of 30 ft, harmonic mean flow of 45,300 cfs (cubic feet per second), and low flow of 10,600 cfs within the pool. With the exception of the Mill Creek, all other named tributaries have drainage areas greater than 1000 sq. miles. The Mill Creek, while not a major tributary in terms of drainage area, has been named one of the worst urban-impacted streams in the nation.

Three dry weather and four wet weather water quality surveys were conducted in 1995. These studies served to help set up the water quality models and determine the pollutants of concern. Another five-day wet weather water quality survey was conducted in 1999. Results of this study were unusable, as the river model could not be calibrated to good agreement with survey data. It was believed this was because the rain event selected for the survey was unusually large and intense, with an unusually long, dry period preceding the storm (antecedent dry period). Another five-day wet weather survey was conducted in May 2000. The river water quality model was calibrated to this event and verified against 1995 surveys. Detailed descriptions of field survey design are included in the report.

XP-SWMM models were developed for the Cincinnati and Northern Kentucky CSO systems to estimate pollutant loads from CSOs based on rainfall data. The models generally calculate discharge flow volumes. Event mean pollutant concentrations are applied to the model-generated flow volumes to calculate pollutant load. In addition, non-CSO tributary loads were estimated for tributary catchments upstream of the CSO systems. This was generally done using measured daily stream flows and applying an event mean pollutant concentration to calculate a pollutant load. These loads were used as input to the river water quality model.

RMA-2V is the hydrodynamic model used to simulate river flow, and WASP5 model is used as the river water quality component to estimate pollutant transport and fate. The river models were set up, calibrated and verified with field survey data and were peer reviewed. The models were executed for a "typical year" in terms of rainfall, which was determined to be 1971. The models simulate fecal coliform only, as this was determined to be the single wet weather pollutant of concern. The models were re-run using uniform CSO fecal coliform load reductions of 25 percent, 50 percent, 75 percent, and 100 percent to determine improvements in Ohio River water quality based on such reduction scenarios.

Special studies included an evaluation of biological monitoring techniques as a tool for identifying wet weather water quality impacts, and an investigation of *Cryptosporidium* and *Giardia* impacts.

All relevant survey data is included on CD in a GIS-based data storage and analytical package. Selected typical year modeling results are also included on CD in an animation viewer package.

Figure 1 on the following page shows the study area.

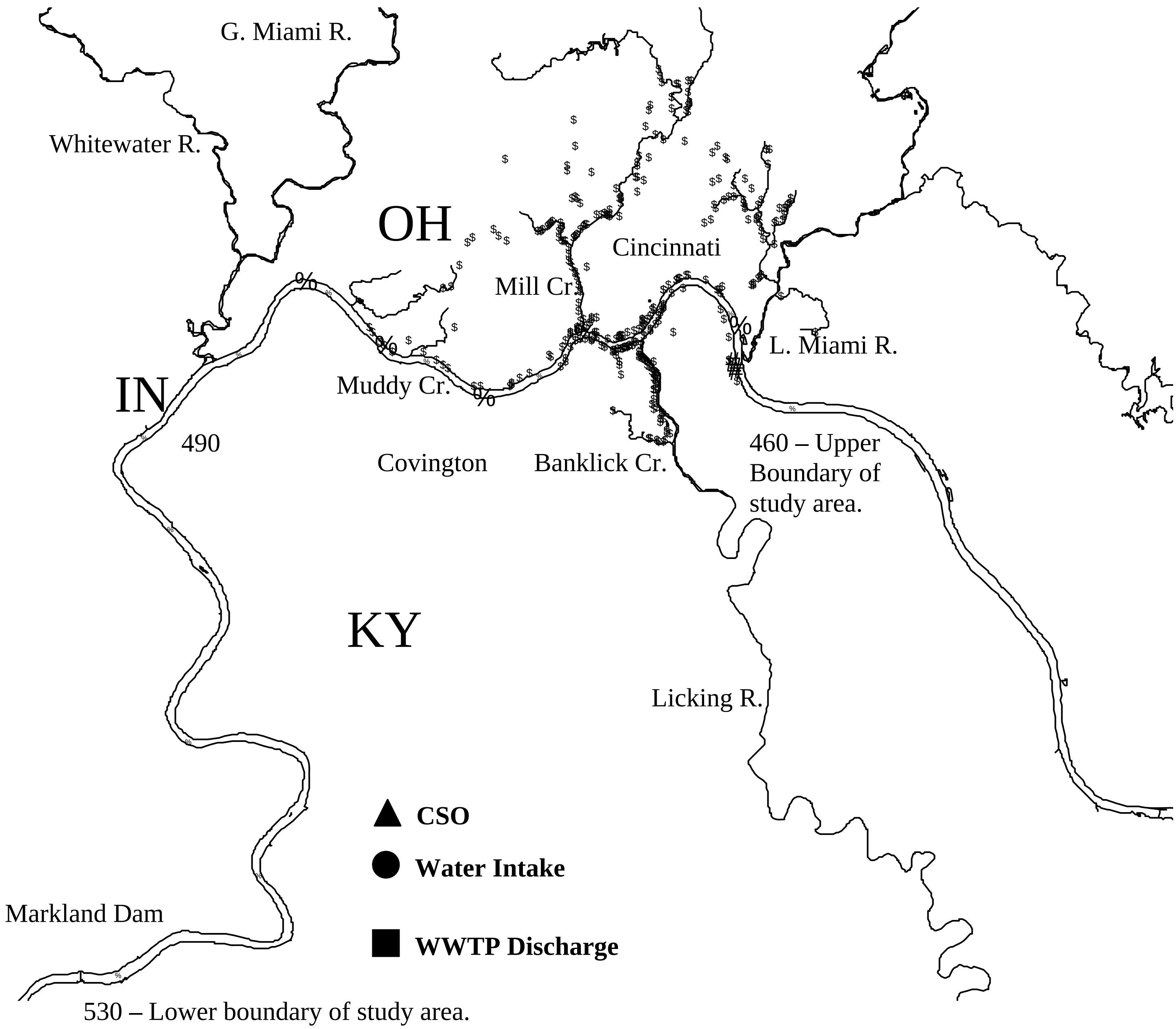


Figure 1. Study Area

Major conclusions from the study include:

• The project framework is being successfully transferred to a similar project in the greater Louisville, Kentucky area.

• Bacteria (fecal coliform indicator) were determined to be the pollutants of concern regarding adverse wet weather water quality impacts for the Cincinnati study area. This conclusion may not apply to other large river urban areas.

• Ohio River bacteria levels exceed criteria for the protection of human health from contact recreation, at times even during dry weather. Ohio River bacteria levels exceed criteria for the protection of human health for drinking water at times during wet weather.

• Based on modeling results (subject to error) from the typical year 1971, CSOs collectively contribute approximately 75 percent of the total fecal coliform load. Tributaries within the study area upstream of the CSO catchment areas account for almost all of the remaining bacteria load (24 percent).

• The following is a summary of relative source load contributions based on model results for the typical year:

Mill Creek Loads	22 %
Direct CSO Loads (Ohio side)	22 %
Licking River Loads	19 %
Little Miami River Loads	15 %
Great Miami River Loads	12 %
Direct CSO Loads (Kentucky side)	8 %
Upstream Ohio River Loads	1 %
All WWTP Loads combined	<1 %

• Based on model results (subject to error) for the typical year, the Ohio River exceeds the contact recreation criterion about 15 percent of the time along its center channel. Worst-case locations occur along the shores immediately downstream of the major tributaries.

• Based on modeling results (subject to error), the greatest benefit to river water quality improvement occur for an “average storm” defined as 0.54 inches rain total and maximum rainfall intensity of 0.14 inches per hour. For heavy storms, 100 percent reductions in CSO load contributions are necessary to affect significant river water quality improvements.

• Based on modeling results (subject to error), even with 100 percent control of CSO loads, the contact recreation criterion is exceeded approximately 5 percent of the time along the center channel of the Ohio River and 15 percent of the time along the banks, particularly below tributary confluences.

- *Giardia* is detected frequently in the Ohio River while *Cryptosporidium* is detected somewhat less frequently. There does not appear to be a correlation between the occurrence of *Cryptosporidium* nor *Giardia* and rainfall. *Giardia* levels in the Mill Creek WWTP effluent were lower than in the influent, while no *Cryptosporidium* were observed.

- A number of important lessons were learned during this project and are detailed in Chapter 6. Many involved laboratory QA/QC oversight since large numbers of bacteria samples (one hundred or more) tend to be difficult for laboratories to handle. Another important lesson learned was that delays caused by uncooperative weather must be anticipated and accounted for in project budgets and schedules.

TABLE OF CONTENTS

A STUDY OF IMPACTS AND CONTROL OF WET WEATHER SOURCES OF POLLUTION ON LARGE RIVERS

FIGURES

TABLES

1.0 INTRODUCTION

This is a final report of a study conducted by the Ohio River Valley Water Sanitation Commission (ORSANCO) titled, “A STUDY OF IMPACTS AND CONTROL OF WET WEATHER SOURCES OF POLLUTION ON LARGE RIVERS.” This study focuses on wet weather water quality issues of the Ohio River in the Greater Cincinnati area. The study was funded as a national demonstration study by the United States Environmental Protection Agency (U.S. EPA) under Federal Assistance Agreement # CX824105-01-2, with local contributors including the Metropolitan Sewer District of Greater Cincinnati, Northern Kentucky Sanitation District No. 1, and the City of Cincinnati Water Works. Project management and design and implementation of water quality monitoring surveys were provided by ORSANCO. Major modeling components were contracted to Limno-Tech, Inc. (LTI), Ann Arbor, MI, Woolpert LLP, Covington, KY, and XCG Consultants Ltd., Kingston, Ontario, Canada. Contact the Ohio River Valley Water Sanitation Commission, 5735 Kellogg Ave., Cincinnati, OH 45228 for additional information.

1.1 BACKGROUND

Combined sewer overflows (CSOs) are seen as a problem in the Ohio River Basin due to their preponderance within the basin states. A national inventory compiled by the U.S. EPA showed a total of 9,471 individual CSOs nation wide in 772 communities. Approximately two-thirds of the national total is located within the boundaries of ORSANCO’s member states. Over 1,400 CSOs are located in the cities and towns along the Ohio River. This represents approximately ten percent of the CSOs in the United States. Because the Ohio River serves as a boundary between states for most of its length, many of the CSOs (approximately two thirds) are located in interstate urban areas. Those areas also encompass more than one U.S. EPA Region. For example, Wheeling, West Virginia (Region III) has 220 CSOs while directly across the river, the Eastern Ohio Regional Wastewater Authority (Region V) has 45. Cincinnati, Ohio (Region V) has 240 CSOs while the communities across the river in Northern Kentucky (Region IV) have 104.

While other large rivers besides the Ohio receive discharges from CSOs, most of the studies of water quality impacts of CSOs in the United States were conducted on marine waters and lakes. Little is known, therefore, about the specific impacts of CSOs on the water quality of large rivers. It is likely that due to certain distinguishing characteristics of large rivers (i.e., large volume of water, moderate to swift velocity), the impacts of intermittent discharges such as CSOs are considerably different than those impacts found in the estuarine and lake environments. Likewise, little is known about the expected improvements in the water quality of large rivers due to abatement of CSOs.

ORSANCO has worked with state agencies, municipal sewer districts, U.S. EPA, U.S. Army Corps of Engineers (COE), and U.S. Geological Survey (USGS) to develop a basic strategy for monitoring CSO impacts on the Ohio River. That strategy assumes that an initial objective is to identify monitoring approaches that work. To do so, the strategy assigns areas of responsibility and calls for the sharing of information on a regular basis. Dischargers are called on to monitor

CSOs and the receiving waters most likely to show the greatest impacts (e.g., smaller tributaries receiving large volumes of overflows). As the interstate entity with responsibility for the entire river, ORSANCO is given responsibility to monitor the impacts of interstate CSO "clusters" on the Ohio River. The states and U.S. EPA are called on to provide information on CSO impacts from other areas and to provide their expertise in the cooperative assessment of monitoring results.

ORSANCO's approach to its responsibilities under the strategy has been to compile information on CSOs including locations, sizes and quantities discharged (where available). This will allow the identification of areas along the river most likely to show impacts from CSOs. It is anticipated that, as information from dischargers' monitoring efforts becomes available, a better understanding of the content of CSOs and the impacts on smaller streams will emerge. This should result in a better idea of what impacts are likely to occur on the Ohio, and thereby help determine monitoring needs.

A drawback to ORSANCO's approach is that its resources restrict the scope of its monitoring efforts. Operating on its own, it would take ORSANCO ten or more years to carry out the studies needed, even on a bare bones basis, to define the impacts of all interstate CSO areas on the Ohio. Given the current schedule for CSO abatement, both the cities and the regulatory agencies want answers on a shorter-term basis. In recognition of this fact, U.S. EPA Regions III and IV have provided ORSANCO with a grant to carry out a study that investigates the impacts of CSOs on various biological communities as well as bacteria levels in the river. The work was conducted in the Wheeling (WV/OH) and Huntington/Ashland/Ironton (WV/KY/OH) areas. The fieldwork associated with these studies concluded in November 1994. The knowledge and experience gained from this effort was useful in the development of the monitoring strategies for this demonstration study.

The Ohio River Basin is an area with a substantial concentration of our nation's CSOs but with very limited information or tools available to evaluate impacts and guide the selection and design of controls. It is this dichotomy that prompted the project team to develop this study.

1.2 STUDY PURPOSE AND OBJECTIVES

A U.S. EPA study estimates that $46.7 billion will be necessary to control the nation’s 9,471 CSOs located throughout 772 communities. At the same time, the expected environmental benefits from such controls are not clear, including whether implementation of all controls will result in attainment of water quality objectives. It is anticipated that certain communities will experience significant socioeconomic burden resulting from CSO control requirements.

The primary goal of this study is to develop a methodology for the evaluation of CSOs and other wet weather water quality impacts and effects of controls on large rivers that is applicable and transferable to other large rivers. The study more specifically defines, for the Cincinnati, Ohio/Northern Kentucky urban segment of the Ohio River: 1) The extent and severity of urban wet weather water quality impacts on the Ohio River; 2) The causes and sources of impacts; 3) The relative importance of the identified wet weather pollutant sources, and; 4) The resulting improvements in water quality from various CSO control scenarios. Additional objectives of the study include an evaluation of biological monitoring as a means of identifying wet weather water quality impacts, and evaluation of wet weather impacts on drinking water utilities primarily regarding *Giardia* and *Cryptosporidium*.

1.3 PROJECT COMPONENTS

A number of major project elements were necessary to meet the study objectives, including:

1) Water Quality Surveys

- Dry weather water quality surveys were conducted to characterize baseline water quality conditions within the study area, free from the influences of CSOs and other wet weather pollution sources. The data will be used for river model calibration/verification.

- Wet weather water quality surveys were conducted to determine pollutants of concern, characterize wet weather water quality conditions, and calibrate/verify the river model.

- Biological studies including fish and macroinvertebrate population surveys were conducted to evaluate biological monitoring approaches for identification of impacts from CSOs.

- A study of water supply concerns for wet weather impacts involved water quality surveys of pathogens including *Giardia* and *Cryptosporidium* as well as other parameters.

2) Pollutant Loading Estimates

- CSO system modeling was conducted separately for the Cincinnati and Northern Kentucky systems to generate CSO loads at for a "typical year."

- Nonpoint source pollutant loading estimates were generated using a combination of modeling, flow and event mean concentrations, and monitoring data.

3) Estimation of River Conditions for a "Typical Year"

A detailed river model was set up, calibrated/verified, and run for a "typical year" to estimate river water quality with CSO and nonpoint source loading estimates as input.

4) Evaluation of CSO Control Scenarios

The river model was re-run with CSO loading reduction scenarios of 25, 50, and 75 percent to evaluate resulting improvements in water quality.

5) Information Delivery

- A computer-based map viewer with animation capabilities was developed to display river model results in terms of duration and severity of water quality impacts.

- A Geographic Information System (GIS)-based data viewer was developed to display water quality data generated in the wet and dry weather surveys.

6) Additional Studies

- Various mini-studies were conducted to evaluate certain aspects of bacteria analyses.

1.4 PROJECT MANAGEMENT

To successfully undertake and complete a major comprehensive study of CSO and nonpoint source impacts in the Cincinnati/Northern Kentucky area, several agencies and organizations were utilized. ORSANCO provided project management and employed a consultant team for a sizeable portion of the work. The consultant team was comprised of representatives from Limno-Tech, Inc., XCG Consultants, Ltd. and URS who have considerable experience in model development and application to a wide range of problems. The Metropolitan Sewer District of Greater Cincinnati and Northern Kentucky Sanitation District No. 1 actively participated and provided project funds and staffing. The U.S. EPA research facility (Andrew W. Briedenbach Research Center) in Cincinnati provided technical expertise particularly regarding bacteria analyses and quality assurance issues. The University of Cincinnati Department of Civil and Environmental Engineering also participated in an advisory capacity. ORSANCO's Technical Committee, composed of state and federal agency regulatory personnel, were also kept appraised of project progress.

1.5 STUDY AREA DESCRIPTION

The Ohio River is one of the "Great Rivers" of the U.S. and hence a visibly appropriate site for a demonstration case study on CSO impacts and controls on large rivers. It is well suited not only because of its size and abundance of CSOs but also because of hydraulic conditions.

The pools formed by the navigation dams on the Ohio River provide logical study units while the Cincinnati/Northern Kentucky area provides a unique opportunity to study the impacts of wet weather discharges in general, and CSOs in particular. There are approximately 350 CSOs within the study area, as well as 5 municipal wastewater discharges and 40+ other permitted point sources (see Figure 1-1). The study area is located entirely within the Markland Pool, which extends 95 miles from the Meldahl Dam (36 miles above Cincinnati) to the Markland Dam. The Markland Pool receives three major tributaries--the Little Miami and Great Miami rivers from the north and the Licking River from the south--as well as numerous smaller streams. Several of the smaller streams in urban areas, such as Bank Lick Creek in Kentucky and Mill Creek in Ohio, are severely affected by CSOs. The study area encompasses two states (Kentucky and Ohio) as well as two U.S. EPA Regions (Region 4–Atlanta and Region 5-Chicago).

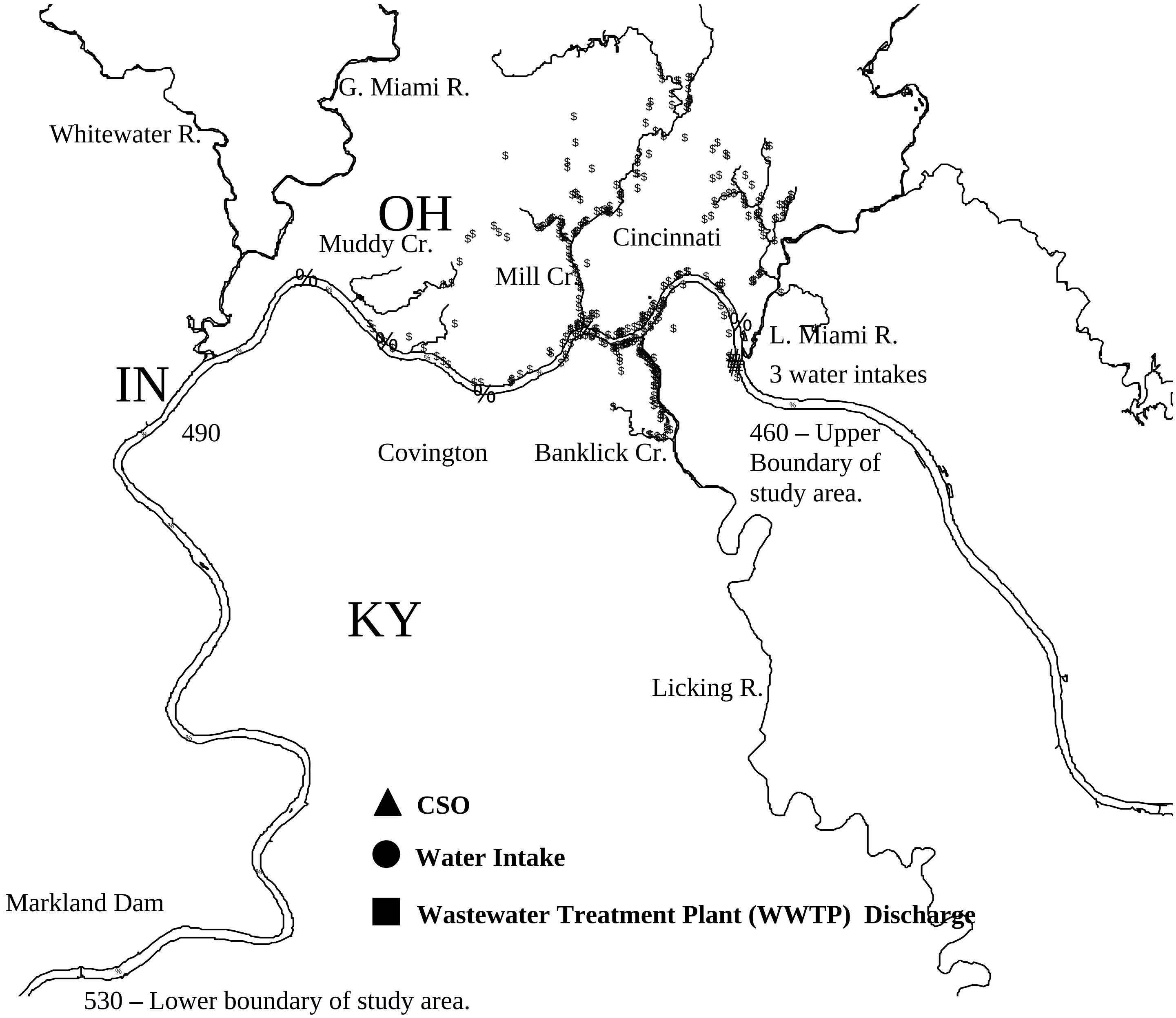


Figure 1-1. Study Area

Flow within the study area varies due to significant increases from the major tributaries, however the long-term average flow for the Ohio River at Cincinnati is approximately 102,000 cubic feet per second (cfs), and at Markland the long-term average flow is approximately 116,500 cfs. Table 1-1 and 1-2 provide selected information on the Markland Pool and major tributaries, respectively, within the study area.

Table 1-1. Markland Pool Information

Pool Length:	95.3 miles (436.2 – 531.5)
Normal Pool Elevation:	455 ft
Average Depth:	31 ft
Average Width:	1,594 ft
Bottom Slope:	0.4 ft / mile
Normal Pool Stage:	12 ft
Flood Stage:	51 ft
Minimum 7-Day 10-year Low-Flow:	*10,600 cfs
Harmonic Mean Flow:	45,300 cfs

Long Term Flow Data (1994-2001)

Station	Location	Avg. Flow (x1000 cfs)	Avg. Velocity (mph)
OR11	Meldahl Dam:	96.30	2.10
OR12	California:	98.21	1.67
OR13	Cincinnati:	103.79	1.73
OR14	Markland Dam:	111.26	1.92
LM01	Little Miami River at Beechmont Levy:	1.80	1.39
LR01	Licking River at Covington:	4.76	1.31

*From Meldahl Dam (436.2) to McAlpine Dam (606.8)

Table 1-2. Tributary Information

Tributary	Confluence Mile Point	Stream Length, mi.	Drainage Area, Sq. mi.
Little Miami R.	464.1	90	1670
Licking R.	470.2	320	3670
Mill Cr.	472.5	28	166
Great Miami R.	491.1	161	5400

In summary, a number of factors including the high concentration of CSOs, the interstate, the multi-regional nature of the study area, the severe stage fluctuations and the tremendous volume of flow in the Ohio River, along with the amount of supporting data available in the Northern Kentucky/Cincinnati area make this location ideal for a large river demonstration study.

2.0 WATER QUALITY SURVEYS

A major component of this demonstration study involved water quality surveys. A number of studies were completed including dry weather monitoring, wet weather monitoring, biological monitoring, and *Giardia*/*Cryptosporidium* monitoring. A large number of parameters were analyzed in this study. In the end, it was determined that bacteria were the primary pollutants of concern, however this was not known prior to this study. The same conclusion may or may not apply to other large river urban areas. ORSANCO designed, coordinated and completed all water quality monitoring surveys.

2.1 DRY WEATHER WATER QUALITY SURVEYS

The primary objective of this task was to provide sufficient baseline water quality data to determine water quality conditions free from the influences of CSOs and wet weather events, and for water quality model calibration/verification. This task includes the collection of dry weather samples from the Ohio River and selected tributaries at designated locations in the Markland Pool. Dry weather sampling was defined in this project as having a minimum 72-hour antecedent dry period. Three dry weather surveys were completed in 1995.

Surveys were conducted in the Markland Pool (Meldahl L&D – Ohio River mile point (OMRP) 436 downstream to Markland L&D - ORMP 531) of the Ohio River. A 30-mile section of this pool, ORMP 462 to 492, will be used for the cross-sectional surveys, while a 70-mile section of the pool, ORMP 460 to 530, was used for the longitudinal surveys. Figures 2-1 and 2-2 display the study area and sampling locations. This area contains the boundaries of three states: Indiana, Kentucky, and Ohio. Table 2-1 displays selected information by river mile points.

Investigations were conducted to develop and document profiles for pH, conductivity, dissolved oxygen, temperature, turbidity, fecal coliform, *Fecal streptococci*, *E. coli*, BOD_5(five day biochemical oxygen demand), $CBOD_5$, total suspended solids (TSS), total dissolved solids (TDS), total phosphorous, orthophosphate, nitrate-nitrite, total Kjeldahl nitrogen (TKN), ammonia, alkalinity, total hardness, metals (arsenic-As, barium-Ba, beryllium-Be, cadmium-Cd, chromium-Cr, copper-Cu, lead-Pb, mercury-Hg, nickel-Ni, selenium-Se, silver-Ag, thallium-Tl, zinc-Zn), and chlorophyll *a*. These profiles were constructed with surface grab samples collected from the river starting upstream of the CSOs and continuing to a point downstream of the last CSOs in the Cincinnati/Northern Kentucky area. The objective is to bracket locations of CSO clusters, tributaries with CSOs, and associated publicly owned treatment work (POTW) discharges, to determine background water quality conditions in the river.

Dry weather sampling consisted of cross-sectional surveys focusing on the upper 30 miles of the study area followed by longitudinal surveys covering the entire 70-mile study area.

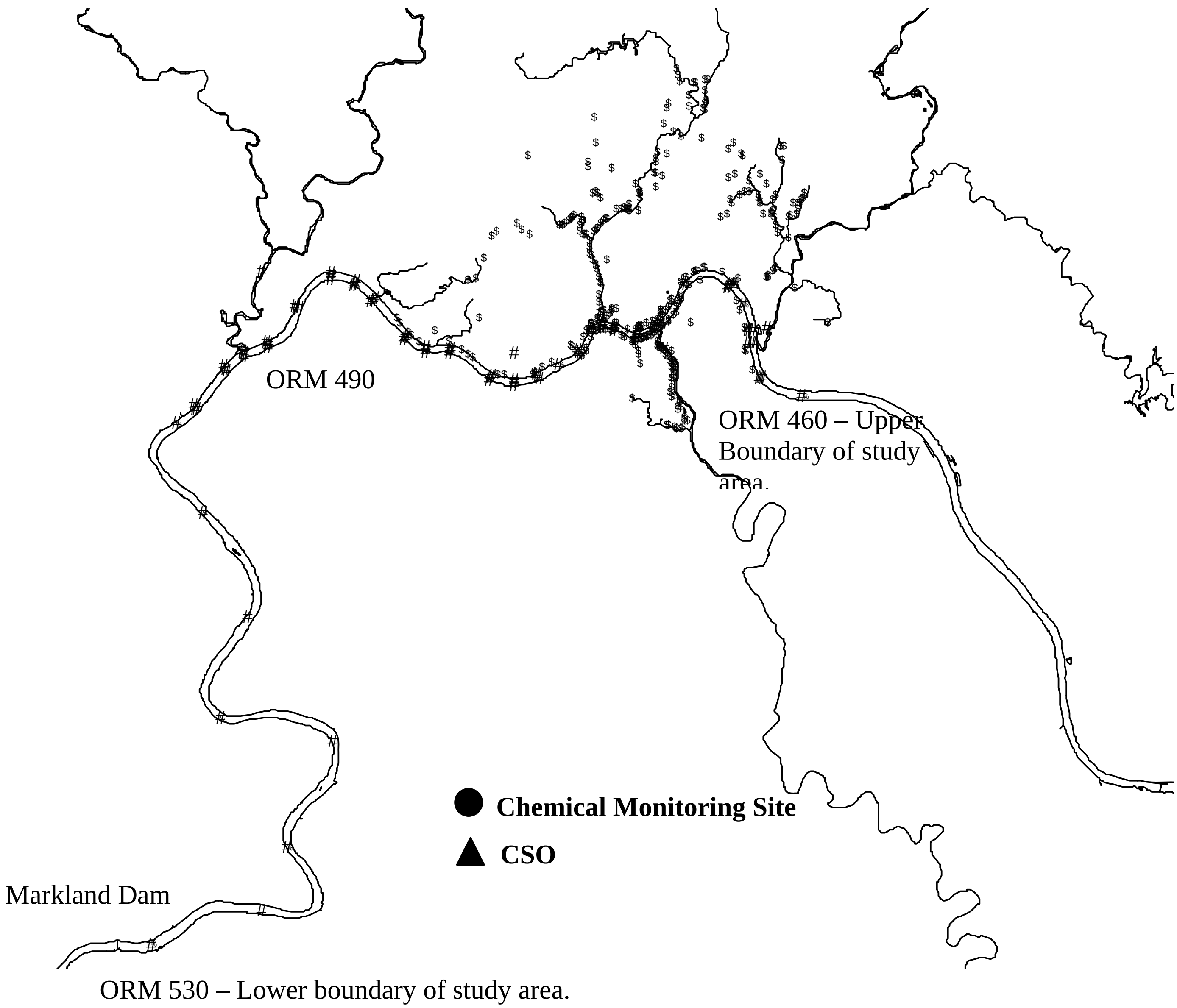


Figure 2-1. Study Monitoring Locations

Table 2-1. Selected Information on Sources in the Study Area.

Bacteria Monitoring Stations		
ORMP 462.8	Cincinnati WTP	
ORMP 477.5	ORSANCO (Anderson Ferry)	
WTP		
		Pumping Rate
ORMP 462.8	Cincinnati, OH	124.0 MGD
ORMP 462.9	Kenton County – Fort Thomas	24.0 MGD
ORMP 463.2	Newport, KY	12.0 MGD
POTW Discharges		
		Design Flow
ORMP 449.9	New Richmond, OH	0.3 MGD
ORMP 464.5	Little Miami – Hamilton Co., OH	55.0 MGD
ORMP 472.5	Mill Creek – Hamilton Co., OH	170.0 MGD
ORMP 477.4	Dry Creek – Campbell/Kenton Co., KY	46.5 MGD
ORMP 482.0	Muddy Creek – Hamilton Co., OH	15.0 MGD
ORMP 486.0	Indian Creek – Hamilton Co., OH	0.5 MGD
ORMP 493.0	South Dearborn Regional, IN	3.5 MGD
ORMP 506.0	Rising Sun, IN	0.4 MGD
ORMP 519.5	Patriot, IN	< 0.1 MGD
ORMP 530.0	Warsaw, KY	0.1 MGD
Approximate Ohio River Mile Points of CSOs		
		LAT / LON
ORMP 465 – 483	Cincinnati, OH (68 Ohio River CSOs)	Yes
*ORMP 463.5	Little Miami River (3 CSOs)	
	Little Miami Tributaries (47 CSOs)	
*ORMP 472.5	Mill Creek (57 CSOs)	
	Mill Creek Tributaries (45 CSOs)	
*ORMP 480.9	Rapid Run (1 CSO)	
*ORMP 484.0	Muddy Creek (5 CSOs)	
ORMP 467 – 475	Campbell/Kenton Co., KY (47 Ohio River CSOs)	Yes
*ORMP 470.2	Licking River – (42 CSOs)	
	Licking River Tributaries (15 CSOs)	
ORMP 497.0	Aurora, IN (2 Ohio River CSOs)	No
*ORMP 496.8	Hogan Creek (3 CSOs)	
	Stoney Lonesome Creek (1 CSO)	

*Indicates confluence mile point
OMRP-Ohio River Mile Point
MGD-Million Gallons per Day

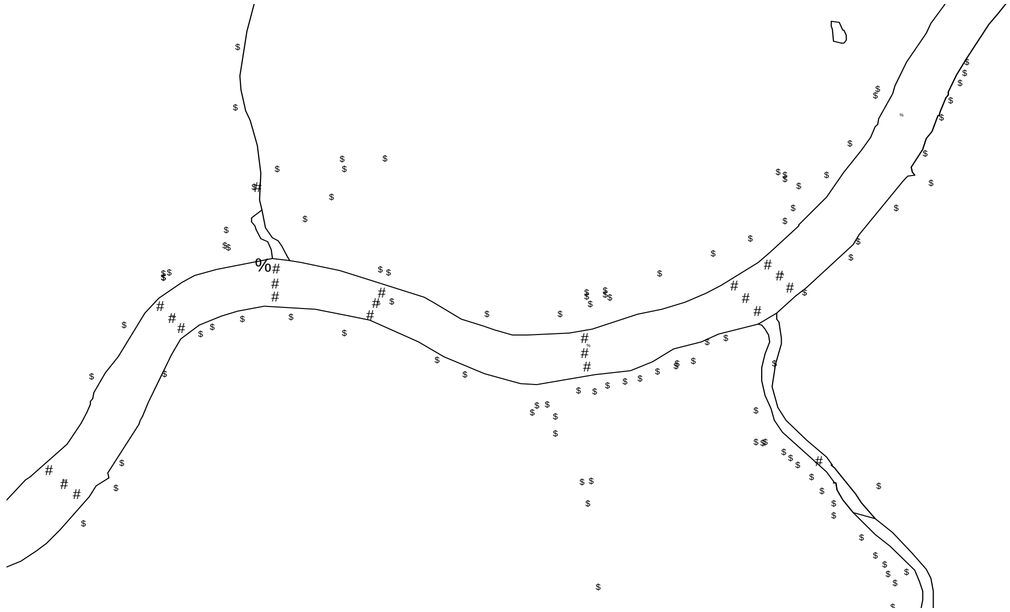


Figure 2-2. Detailed View of Mainstem Monitoring Sites.

2.1.1 MAINSTEM AND TRIBUTARY CROSS-SECTIONAL SURVEYS

Two cross-sectional surveys were conducted at sixteen main stem sites and fourteen tributary sites in the study area. Table 2-2 lists the main stem cross-section sampling sites, as well as tributary sites. Past studies conducted by ORSANCO on the main stem for numerous water quality parameters have not indicated significant vertical stratification, but have shown substantial variability across the stream. Therefore, main stem and tributary cross-section sites consist of three points across the stream at one foot below the surface (left third, midstream, and right third). Table 2-3 lists the parameters analyzed for cross-sections.

Table 2-2. Mainstem Dry Weather Cross-Section Sampling Sites.
(WWTP-Waste Water Treatment Plant)

Mile Point	**Sampling Site Description**	**Site Rationale**
462.0	I-275 Bridge Upstream	Upstream all CSOs, L. Miami R., and intakes
463.5 *	L. Miami R. @ US 52 Bridge	1.5 miles from confluence with Ohio R.
464.0	Aquaramp Boat Dock	Downstream L. Miami R.
466.0	Arcadian Corp. (Downstream)	Downstream L. Miami WWTP discharge
468.0	Queen City River Boats	
470.0	US 27 Bridge (upstream)	Upstream of Licking R.
470.2 *	Licking R. @ 12th St. Bridge	1 mile from Ohio R. confluence
472.0	Hatfield Terminal	Downstream Licking R., upstream Mill Cr. WWTP

		discharge
472.5 *	Mill Cr @ Bridge	0.5 miles from Ohio R. confluence
474.0	Pleasant Run confluence	Downstream Mill Cr. WWTP discharge
476.0	Cincinnati Police Boat Club	Upstream Dry Cr. & Dry Cr. WWTP discharge
478.0	Anderson Ferry (downstream)	Downstream Dry Cr. & Dry Cr. WWTP discharge
480.0	Cargill Inc. (downstream)	
482.0	Eligah Cr.	Upstream Muddy Cr. WWTP discharge
484.0	Fore & Aft Restaurant/Marina	Upstream Muddy Cr., downstream Muddy Cr. WWTP discharge
486.0	Consolidated Grain & Barge	Downstream Muddy Cr., upstream Indian Cr. WWTP discharge
488.0	Koch Asphalt Co.	Downstream Indian Cr. WWTP discharge
490.0	Dark Hollow Run (downstream)	Upstream Great Miami R.
491.1 *	Great Miami R. @ Lost Bridge	5.2 miles upstream of Ohio R. confluence
492.0	I-275 Bridge – Downstream	Downstream Great Miami R.

Table 2-3. Samples Collected for a Dry Weather Cross-Section Survey.

PARAMETER	SAMPLES/ SURVEYS	BLANKS/ SURVEY	NUMBER OF SURVEYS	TOTAL SAMPLES
Fecal coliform	90	4	2	188
Fecal streptococci	15	2	2	34
E. coli	22	4	2	52
TSS	90	4	2	188
$CBOD_5$	22	4	2	52
Total Phosphorous	22	4	2	52
Orthophosphate	22	4	2	52
Nitrate-Nitrite	22	4	2	52
TKN	22	4	2	52
Ammonia	22	4	2	52
Total Hardness	22	4	2	52

Samples were collected at three points across the stream at each main stem and tributary sampling site. As shown in the above table, fecal coliform and TSS analyses were conducted on samples collected from every sampling location, while samples for the other water quality parameters of concern were only collected at a select number of sites. *Fecal streptococci* were collected only on the Great Miami River to determine if the bacteria loadings were of human origin.

All Ohio River bacteria samples were taken by plunging the sample container into the stream in an upright position to a depth of one foot. A bacteria method field blank was generated after each survey. The remaining samples plus all the tributary samples were collected with a Kemmerer sampling device. The Kemmerer is acid rinsed between sampling sites to eliminate contamination between locations. Method field blanks for the remaining parameters were also collected.

In addition to stream samples, physical parameters were recorded using a multi-parameter probe. Conductivity, pH, dissolved oxygen, and temperature were recorded at each point where stream samples were collected. This instrument was both pre- and post-calibrated for each survey. A Secchi disk measurement was also taken at each Ohio River midstream sampling site.

2.1.2 DRY WEATHER LONGITUDINAL SURVEYS

Longitudinal surveys were conducted the day after each of the two cross-sectional surveys. These longitudinal surveys consist of two distinct phases. The first phase utilizes water sampling with a pitot tube and a flow-through sampling system mounted on a small watercraft traversing the pool in a downstream direction. This system consists of a multi-parameter probe and a data-logging unit. The following data was collected at the midstream: physical parameters, bacteria, nutrients and chlorophyll *a*. The second phase of the longitudinal surveys entailed completion of ten vertical cross-sections (physical parameters only) at midstream, at three different depths: surface, mid-depth and bottom.

During the first phase of longitudinal surveys, data logging equipment recorded data at 20-second intervals while the boat traversed the 70-mile study segment at approximately thirty miles per hour. This resulted in approximately 2.4 hours of sampling time, 432 readings per parameter, and a resolution of 6.2 readings per parameter per mile. In an effort to investigate correlations between bacteria levels, nutrients, chlorophyll *a*, and the physical parameters, single point grab samples were taken at fifteen locations during this phase to be analyzed for bacteria, nutrients and chlorophyll *a*. These grab samples were taken at locations where "peaks" or "sags" occur in the physical parameters such as dissolved oxygen. If no deflections in the data occurred, the grab samples during Phase 1 were taken at five-mile intervals. Table 2-4 lists the sampling site locations. Method field blanks were generated before the start of each survey for bacteria, nutrients and chlorophyll *a*.

Table 2-4. Dry Weather Longitudinal Survey Sampling Sites.

Sampling Mile Point	Site Description
460.0	Cargill Inc.
465.0	Ice Piers
470.0	US 27 Bridge
475.0	Schwab Industries
480.0	Cargill Inc.
485.0	Aerial Power Crossing
490.0	Dark Hollow Run
495.0	Petersburg Public Ramp
500.0	Kirby Rocks Light & Daymark
505.0	1 mile upstream of Rising Sun, IN
510.0	North Light & Daymark
515.0	Hamilton Light & Daymark
520.0	Fish Creek
525.0	Lancis Hollow
530.0	Craigs Creek

Table 2-5 lists samples collected/analyzed for a dry weather longitudinal survey.

Table 2-5. Samples Collected for a Dry Weather Longitudinal Survey.

PARAMETER	SAMPLES / SURVEY	BLANKS / SURVEY	NUMBER OF SURVEYS	TOTAL SAMPLES
Fecal coliform	15	1	2	32
E. coli	15	1	2	32
Total Phosphorous	15	1	2	32
Orthophosphate	15	1	2	32
Nitrate - Nitrite	15	1	2	32
TKN	15	1	2	32
Ammonia	15	1	2	32
Chlorophyll *a*	15	1	2	32

The second phase of longitudinal surveys follows completion of Phase 1 and involved completion of 10 vertical cross-sections. Each of these sites was tested with the multi-parameter probe at midstream at three depths (surface, mid-depth and bottom). Table 2-6 lists the sampling site locations. Only physical parameter information and Secchi disk readings were recorded at these sites. These surveys attempted to determine background conditions for physical parameters, bacteria and chlorophyll *a* during dry periods.

The multi-parameter probe (used for both phases) will measure the following physical parameters: pH, conductivity, dissolved oxygen and temperature. This instrument was pre- and post-calibrated for each survey.

Table 2-6. Vertical Cross-Sectional Dry Weather Sampling Sites.

Sampling Mile Point	Sampling Site Description
460.0	Cargill Inc.
475.0	Schwab Industries
490.0	Dark Hollow Run
500.0	Kirby Rocks Light & Daymark
505.0	1 mile upstream Rising Sun, IN
510.0	North Light & Daymark
515.0	Hamilton Light & Daymark
520.0	Fish Creek
525.0	Lancis Hollow
530.0	Craigs Creek

2.2 WET WEATHER MONITORING PROGRAM

The primary objectives of the wet weather monitoring program are to identify parameters of concern associated with wet weather and calibrate/verify a water quality model. Wet weather surveys consist of: 1) main stem cross-sectional surveys focusing on the upper 30 miles of the Ohio River, 2) tributary surveys, and 3) longitudinal surveys covering the entire study area. Wet weather surveys were generally five days in duration – two daily main stem cross-sectional surveys, and three daily longitudinal surveys. Requirements for a wet weather event generally involved approximately one inch of rainfall over a six-hour period, covering a substantial portion of the study area, and a 72-hour antecedent dry period. Four wet weather events were completed in 1995, and one event each in both 1999 and 2000.

2.2.1 TRIBUTARY WET WEATHER MONITORING

Four tributary basins within the study area were monitored including the Little Miami River, Licking River, Mill Creek, and the Great Miami River. Table 2-7 details the sampling locations.

Table 2-7. Tributary Monitoring Sites

Sampling Mile Point	Confluence Mile Point	Tributary Basin	Tributary	Site Description	Site Designation
1.4	463.5	Little Miami	Little Miami River	Kellogg Avenue Bridge	Primary
1.0	470.2	Licking River	Licking River	12th Street Bridge	Primary
0.5	472.5	Mill Creek	Mill Creek	Gest Street Bridge	Primary
5.1	491.1	Great Miami	Great Miami River	Lost Bridge	Primary
1.6	6.2	Great Miami	Whitewater River	Suspension Bridge Road	Secondary
7.9	491.1	Great Miami	Great Miami River	Route 50 Bridge	Secondary

Monitoring from the six tributary sites occurred for up to five days after the initiation of rainfall. One site from each of the four tributary basins was designated as a “primary site.” These sampling locations were closest to the Ohio River, yet upstream of backwater conditions. Two additional tributary sites within the Great Miami River Basin were designated as “secondary sites.” Secondary sites were added to the Great Miami River Basin (because of its large size -- 5,350 square miles) to further refine pollutant loadings.

2.2.2 TRIBUTARY CROSS-SECTIONAL MONITORING

Prior to the collection of stream samples, physical parameters were recorded using a multi-parameter probe. Temperature, pH, dissolved oxygen, and conductivity were recorded on data sheets at each point where stream samples were collected.

Sampling consisted of grab samples collected at three points across the specified tributary site (left descending third, midstream and right descending third). All grab samples, duplicates and blanks were collected with a stainless steel bucket. The bucket was rinsed with deionized water before each sample was collected. Table 2-8 shows the parameters collected for each survey.

TABLE 2-8. Tributary Samples per Survey

Parameter	Samples per Circuit	Duplicates per Circuit	Blanks per Circuit	Number of Circuits	Total Samples Per Survey
Fecal coliform	246	36	34	1	316
E. coli	82	12	34	1	128
TSS	246	36	34	1	316
$CBOD_5$	44	4	34	1	82
Total Phosphorus	44	4	34	1	82
Nitrate-Nitrite	44	4	34	1	82
TKN	44	4	34	1	82
Ammonia	44	4	34	1	82
Total Hardness	44	4	34	1	82

The tributary sampling program consisted of the collection of “full” and “partial” sample sets as described in Table 2-9.

TABLE 2-9. Tributary Sample Sets

Set Designation	**Left Third**	**Midstream**	**Right Third**
Full Sample Set	Fecal coliform TSS	Fecal coliform, E. coli, TSS, $CBOD_5$, Nutrients, Hardness	Fecal coliform TSS
Partial Sample Set	Fecal coliform TSS	Fecal coliform, E. coli, TSS	Fecal coliform TSS

Once the tributary monitoring was initiated (sampling hour 0), field crews collected samples at each of the tributary sites according to the following schedules as described in Table 2-10 and 2-11.

TABLE 2-10. Tributary Monitoring Schedule – Primary Sites.

Sample Set Type	F	P	P	P	P	P	F		P		P		F
Sample Duplicate	----	----	----	----	----	SD	----		----		----		SD
Sample Number	1	2	3	4	5	6	7		7		9		10
Hour	**0**	**2**	**4**	**6**	**8**	**10**	**12**	14	**16**	18	**20**	22	**24**
Day	Day 1												

Sample Set Type				F				P				F
Sample Duplicate				----				SD				----
Sample Number				11				12				13
Hour	26	28	30	**32**	34	36	38	**40**	42	44	46	**48**
Day	Day 2											

Sample Set Type	F	F	F
Sample Duplicate	----	----	----
Sample Number	14	15	16
Hour	**D3**	**D4**	**D5**
Day	Day 3	Day 4	Day 5

All primary tributary sites were sampled for "full sample sets" at hours 0, 12, 24, 32, 48, D3, D4 and D5. All remaining sample times consisted of "partial sample sets."

TABLE 2-11. Tributary Monitoring Schedule – Secondary Sites.

Sample Set Type		F			P			F			P		
Sample Number		1			2			3			4		
Hour		**1**	3	5	**7**	9	11	**13**	15	17	**19**	21	23
Day	Day 1												

Sample Set Type			F					P				
Sample Number			5					6				
Hour	25	27	**29**	31	33	35	37	**39**	41	43	45	47
Day	Day 2											

Sample Set Type	F	F	F
Sample Number	7	8	9
Hour	**D3**	**D4**	**D5**
Day	Day 3	Day 4	Day 5

Both secondary tributary sites wiere sampled for "full sample sets" at hours 1, 13, 29, D3, D4 and D5. All remaining sample times consisted of "partial sample sets."

2.2.3 OHIO RIVER MAINSTEM WET WEATHER MONITORING

Monitoring consisted of cross-sectional circuits focused on the upper 32 miles of the study area (Ohio River mile points 462 – 494) during the first two days of the event and longitudinal circuits covered the entire 70 miles of the study area (Ohio River mile points 460 - 530) during days three through five.

2.2.4 CROSS-SECTIONAL MONITORING

Two cross-sectional circuits were conducted for each wet weather survey (the first circuit on day one of the event and a second circuit on day two of the event). Each cross-sectional circuit consisted of 16 main stem monitoring sites in the upper 32-mile section of the study area. Table 2-12 lists locations of the cross-section sites. The Ohio River cross-sectional samples were collected at three points across the stream (50 - 100' from the left descending bank, midstream and 50 - 100' from the right descending bank) at approximately one foot below the surface.

TABLE 2-12. Ohio River Cross-sectional Monitoring Sites

Sampling Mile Point	Site Description	Reason for Sampling Site
462	I-275 Bridge	Upstream of all CSOs, Little Miami River, WTP Intakes
464	Aquaramp Boat Dock	Upstream of Little Miami WWTP Discharge
466	Arcadian Corp.	
468	Queen City River Boats	
470	US 27 Bridge	Upstream of Licking River
470.6	US 42 Bridge	Downstream of Licking River
472	Hatfield Terminal	Upstream of Mill Creek WWTP Discharge
473	Downstream of Daymark	Downstream of Mill Creek WWTP Discharge
477	Kenton Marina	Upstream of Dry Creek (Dry Creek WWTP Discharge)
480	Cargill Inc.	Upstream of Rapid Run
481	Ashland Oil Terminal	Upstream of Muddy Creek WWTP Discharge
484	Fore & Aft Restaurant & Marina	Upstream of Muddy Creek
485	Aerial Power Line Crossing	Upstream of Indian Creek WWTP Discharge
490	Dark Hollow Run	Upstream of Great Miami River
492	I-275 Bridge	Downstream of Great Miami River
494	Tanners Creek Power Station	

Prior to the collection of stream samples, physical parameters were recorded using a multi-parameter probe. Temperature, pH, dissolved oxygen and conductivity were recorded on data sheets at each point where stream samples are taken. A Secchi disk measurement also was taken at three points across the stream at each monitoring site. Table 2-13 lists samples collected for Ohio River cross-sectional surveys.

TABLE 2-13. Ohio River Cross-Sectional Samples

Parameter	Samples per Circuit	Duplicates per Circuit	Blanks per Circuit	Number per Circuit	Total Samples Per Survey
Fecal Coliform	48	6	2	2	112
E. coli	16	2	2	2	40
TSS	48	6	3	2	114
$CBOD_5$	8	2	3	2	26
Total Phosphorus	8	2	3	2	26
Orthophosphate	4	1	3	2	16
Orthophosphate	1	0	0	2	2
Nitrate-Nitrite	8	2	3	2	26
TKN	8	2	3	2	26
Ammonia	8	2	3	2	26
Total Hardness	8	2	3	2	26
Chlorophyll *a*	4	1	3	2	16

The Ohio River sampling program consisted of the collection of "full sample sets" and "partial sample sets" as described in Table 2-14.

TABLE 2-14. Ohio River Sample Set Designation

Set Designation	**Left Bank**	**Midstream**	**Right Bank**
Full Sample Set	Fecal coliform TSS	Fecal coliform, E. coli, TSS, $CBOD_5$, Nutrients, Hardness (Orthophosphate and chlorophyll *a* will be collected at selected sites)	Fecal coliform TSS
Partial Sample Set	Fecal coliform TSS	Fecal coliform, *E. coli*, TSS	Fecal coliform TSS

"Full Sample Sets" were collected at every other location starting at monitoring site 462. "Partial Sample Sets" were collected at the remaining sites. Chlorophyll *a* and orthophosphate samples were collected at the midstream of sampling sites 462, 470, 477, and 485. An orthophosphate sample was collected at sampling site 494 for each circuit.

2.2.5 OHIO RIVER LONGITUDINAL WET WEATHER MONITORING

Longitudinal monitoring was initiated approximately two days after the beginning of the storm event. Consecutive days of longitudinal circuits were conducted until it was estimated that the wet weather impacts in the lower section of the study area were diminished (three days). These longitudinal circuits consisted of two distinct phases. The first phase utilized water collection with a flow-through sampling system mounted on a small watercraft traversing the pool in a downstream direction. The second phase of the longitudinal circuits involved the completion of ten vertical profiles (physical parameters only) at midstream, at three different depths -- surface, mid-depth and bottom. Table 2-15 lists sampling sites for the first phase of longitudinal wet weather surveys in which a flow-through system connected to a multi-parameter probe and a data logging unit was used to acquire physical parameter data and water samples.

TABLE 2-15. Ohio River Longitudinal Phase 1 Monitoring Sites

Sampling Mile Point	Site Description
460	Cargill Inc.
465	Ice Piers
470	US 27 Bridge
475	Schwab Industries
480	Cargill Inc.
485	Aerial Power Crossing
490	Dark Hollow Run
495	Petersburg Public Ramp
500	Kirby Rocks Light & Daymark
505	1 mile upstream from Rising Sun, IN
510	North Light & Daymark
515	Hamilton Light & Daymark
520	Fisk Creek
525	Lancis Hollow
530	Craigs Creek

Data logging equipment was programmed to record data at 20-second intervals while the boat traversed the 70-mile study segment at approximately 30 miles per hour. This resulted in approximate resolution of six readings per parameter, per mile. Sample water was collected in a stainless steel pitcher (except for chlorophyll *a*, which was collected directly from the sample port) from the flow-through system's sample port. Parameters for longitudinal surveys are listed in Table 2-16.

TABLE 2-16. Ohio River Longitudinal Samples Per Survey

Parameter	Samples per Circuit	Duplicates per Circuit	Blanks per Circuit	Number of Circuit	Total Samples per Survey
Fecal coliform	15	2	5	3	66
E. coli	15	2	5	3	66
TSS	15	2	5	3	66
$CBOD_5$	15	2	5	3	66
Total Phosphorus	15	2	5	3	66
Orthophosphate	10	1	5	3	48
Orthophosphate	2	0	1 – 3rd Circuit Only	3	7
Nitrate-Nitrite	15	2	5	3	66
TKN	15	2	5	3	66
Ammonia	15	2	5	3	66
Total Hardness	15	2	5	3	66
Chlorophyll *a*	15	2	2	3	57

All parameters were collected from the midstream at each site, except for orthophosphate. Orthophosphate samples were not collected at sites: 465, 470, 480, 485, and 495. Orthophosphate samples were collected at sampling sites 490 and 515.

The second phase of longitudinal surveys following the completion of Phase 1, included vertical profiles collected at ten locations. Each of these sites was sampled with the multi-parameter probe at the midstream at three depths (surface, mid-depth and bottom). Phase 2 wet weather longitudinal sampling sites are listed in Table 2-17.

TABLE 2-17. Ohio River Wet Weather Longitudinal Phase 2 Monitoring Sites

Sampling Mile Point	Site Description
460	Cargill Inc.
475	Schwab Industries
490	Dark Hollow Run
500	Kirby Rocks Light & Daymark
505	1 mile upstream from Rising Sun, IN
510	North Light & Daymark
515	Hamilton Light & Daymark
520	Fisk Creek

525	Lancis Hollow
530	Craigs Creek

Only physical parameter readings and Secchi disk readings were recorded at these sites. The multi-parameter probe (used for both phases) measured the following physical parameters: temperature, pH, dissolved oxygen and conductivity.

2.3 FIELD SAMPLING QUALITY ASSURANCE AND QUALITY CONTROL

The monitoring team used four types of QA/QC samples collected in the field to assist in validating biological and chemical data sets--sample duplicates, equipment blanks, method blanks and field blanks. In addition, equipment calibration procedures were utilized to assist in validating the physical parameter data sets.

Sample duplicates were collected for laboratory analysis for each parameter. The purpose of these analyses was to evaluate sample collection precision by comparing the duplicate analytical results. These duplicate samples were collected sequentially in the field in two separate sample containers. Approximately ten percent of the samples were collected in duplicate.

Equipment blanks were collected for laboratory analysis for all parameters. The purpose of these analyses was to assess potential cross-contamination of samples by the equipment. These blanks were taken before sampling and at the conclusion of sampling for each day for all equipment used by the field crews (i.e., stainless steel buckets for the tributary crews and stainless steel Kemmerers and pitchers for the Ohio River crews).

Method blanks were collected for laboratory analyses for the bacteria parameters. The purpose of these analyses was to assess potential cross-contamination of samples by the method used to collect the bacteria samples (Glove Method). These blanks were taken at the conclusion of each Ohio River cross-sectional circuit.

Field blanks were collected for laboratory analysis for all parameters. The purpose of these analyses was to determine if samples collected have been contaminated. Each monitoring crew collected these blanks at the conclusion of the monitoring shift.

During tributary and Ohio River monitoring, physical parameters were measured in stream by multi-parameter probe instruments and recorded on data sheets. These instruments were calibrated each sampling day before monitoring began, according to the manufacturer’s operating manual. At the conclusion of the monitoring day, each instrument was checked with the standards used during calibration. The purpose of these readings was to evaluate the instrument’s precision (electronic drift) by comparing the readings recorded during calibration and the readings recorded during the check at the end of the monitoring day. At the conclusion of each monitored event, all calibration sheets were submitted to the ORSANCO Monitoring Leader to serve as a record of the instrument’s performance during the monitored event.

Field crews completed chain-of-custody forms to document the transfer of sample custody to the designated custodian and subsequent personnel. Signatures of all personnel involved in the collection, transport and receipt of each sample were recorded on the chain-of-custody forms. In certain instances, sample custody was transferred to runners to transport the samples to a drop-off point or directly to the laboratory at the end of each monitoring day. The chain-of-custody forms outline sample locations, identification, collection times and dates, and specific parameters to be analyzed. Properly completed chain-of-custody forms were required to accompany all samples.

2.4 RESULTS OF FIELD STUDIES

Selected results from 1999 and 2000 are presented in this section and supporting graphs are located at the end of the section due to their large number. The primary purpose of these surveys was for model calibration/verification, but some important observations can be made from the data. Figures 2-3 through 2-13 apply to the 1999 wet weather survey, while figures 2-14 through 2-23 apply to the 2000 wet weather survey. Refer to figures 2-1 through 2-3 for study area maps including sampling locations.

All pertinent data collected during the project is included on a CD with the report in a GIS-based data viewer called Rouge River Project Office (RPO) Data View. Appendix A includes a users guide for RPO Data View. This work was completed through in-kind contributions from the RPO.

2.4.1 1999 WET WEATHER EVENT

Figure 2-3 graphs the rainfall data for the 1999 wet weather event. This was a rather unusual storm event in that a large amount of rain occurred over a short period of time (1.4 inches) following an unusually long antecedent dry period. A total of 2.04 inches of rain occurred over the entire event period.

Figures 2-4 through 2-6 show Ohio River cross-sectional fecal coliform data for the first three days of the event in the downtown urban area. Ohio River fecal coliform concentrations were quite high, in the tens of thousands of colony forming units (CFU) per 100 mL for the first two days in the downtown area, then decline rapidly to less than 1000 CFU per 100 mL. Concentrations on the Ohio (North) shore of the Ohio River tended to be substantially higher than on the Kentucky (South) shore.

Figures 2-7 through 2-9 show Ohio River longitudinal fecal coliform surveys for days four through six for the entire study area. They show higher fecal coliform concentrations moving downstream, out of the downtown urban area during days four and five, with maximum concentrations of approximately 500 CFU per 100 mL. These levels are just above the 400 CFU per 100 mL instantaneous maximum stream criterion for the protection of human health from contact recreation. Concentrations spiked again in the downtown area on the sixth day with concentrations around 3000 CFU per 100 mL. This may have been the result of additional rain that occurred during the period.

Figures 2-10 through 2-13 show a time series of bacteria concentrations for the major tributaries within the study area. Bacteria concentrations in the tributaries spiked quickly and began to tail off shortly after the rain event. The Mill Creek had the highest bacteria levels of the tributaries, with fecal coliform concentrations as high as 300,000 CFU per 100 mL. This corresponds with the tributary’s high density of CSOs—the highest of the tributaries in the study area. The Little Miami and Licking rivers had similar bacteria levels, with peak fecal coliform concentrations below 100,000 CFU per 100 mL, and concentrations declining shortly after the rain event. The Great Miami River had the lowest bacteria levels, with peak fecal coliform concentrations below

10,000 CFU per 100 mL, and concentrations declining less rapidly than the other tributaries. These observations correspond more closely with a tributary catchment having no CSOs. Therefore, the majority of bacteria are assumed to originate from nonpoint sources.

2.4.2 2000 WET WEATHER EVENT

Figure 2-14 graphs the rainfall data for the 2000 wet weather event. The event was characterized by 0.97 inches falling within a six-hour period, with total rainfall of 1.42 inches. This was considered a "good" rain event in terms of CSOs discharging. This event was used to calibrate the river model.

Figures 2-15 through 2-16 show Ohio River cross-sectional fecal coliform data for the first two days of the event in the downtown urban area. Ohio River fecal coliform concentrations were quite high, in the 14,000 to 16,000 CFU per 100 mL range on the first day, and declining substantially to generally around 2,000 CFU per 100 mL or less by the second day. Higher levels noticeably moved downstream of the urban area by the second day. Concentrations on the Ohio (North) shore of the Ohio River tended to be slightly higher than on the Kentucky (South) shore.

Figures 2-17 through 2-19 show Ohio River longitudinal fecal coliform surveys for days three through five for the entire study area. Fecal coliform concentrations tended to be somewhat lower in the downtown area than further downstream, with concentrations not exceeding 2000 CFU per 100 mL and declining daily to levels no higher than 200 CFU/100 mL by day five.

Figures 2-20 through 2-23 show a time series of bacteria concentrations for the major tributaries within the study area. Bacteria concentrations in the tributaries spiked quickly and began to tail off shortly after the rain event. The Mill Creek had the highest bacteria levels of the tributaries, with maximum fecal coliform concentrations exceeding $1x10^6$ CFU per 100 mL. This corresponds with the tributary's high density of CSOs--the highest of the tributaries in the study area. The Little Miami and Licking rivers had similar bacteria levels, with peak fecal coliform concentrations in the range of 40,000 to 50,000 CFU per 100 mL. The Great Miami River had peak fecal coliform concentrations exceeding 100,000 CFU per 100 mL. This phenomenon is not easily explained since the Little Miami and Licking rivers have many CSOs and the Great Miami River has none. Therefore, the majority of bacteria were assumed to originate from nonpoint sources.

2.4.3 WET WEATHER VERSUS DRY WEATHER

Several wet weather and dry weather surveys were conducted in 1995. Figure 2-24 shows Ohio River fecal coliform concentrations for the "worst case" wet event versus the "best case" dry event. As can be seen from the comparison, fecal coliform concentrations are generally similar except in the downtown area where the most CSO outfalls are located. In the downtown area, Ohio River fecal coliform concentrations are an order of magnitude greater during the wet event that the dry event. Note the spikes in fecal coliform concentrations during the dry event downstream of the confluences with the Little Miami River, Licking River, and Mill Creek. These levels exceed the criterion for the protection of human health due for contact recreation, even during dry weather conditions.

Figure 2-25 is a comparison of "worst case" wet weather versus "worst case" dry weather Ohio River bacteria levels. In this case, spikes in bacteria levels during dry weather downstream of the Licking River and Mill Creek result in levels as high as seen during wet weather. These fecal coliform concentrations are in the range of 10,000 CFU per 100 mL which are two orders of magnitude above the stream criterion, even during dry weather.

2.4.4 DISSOLVED OXYGEN

One of the primary parameters of concern related to urban wet weather impacts, other than bacteria, is dissolved oxygen. Figures 2-26 and 2-27 show Ohio River dissolved oxygen levels for the 1999 and 2000 events. For the 1999 event, Ohio River dissolved oxygen levels did not fall below 7 mg/L, while Ohio River levels did not fall below 6.5 mg/L during the 2000 event. The level of concern is 5 mg/L for the protection of aquatic life. Ohio River dissolved oxygen concentrations tended to follow a decreasing trend in a downstream direction for both the 1999 and 2000 events.

In addition to the evaluation of 1999 and 2000 survey results, correlations between precipitation (CSO discharge) and historical Ohio River dissolved oxygen data were evaluated to determine whether CSOs impact Ohio River dissolved oxygen levels. Appendix B contains the results of this evaluation, further confirming that dissolved oxygen is not a problem particular to wet weather impacts, therefore modeling is not needed for this parameter.

2.4.5 OTHER PARAMETERS

A large number of parameters were analyzed in the field surveys, including several bacteria indicators, solids, hardness, CBOD, nutrients, and metals (see Chapters 2.1 and 2.2). With the exception of bacteria, none of the other parameters in this case turned out to be of concern.

2.4.6 GENERAL CONCLUSIONS

A large number of parameters were collected in conjunction with this study. While it was necessary to collect such information to ascertain whether particular pollutants were or are of concern, a lengthy parameter list in the future may not be necessary for the evaluation of urban wet weather impacts, following initial surveys to confirm such a fact. However, site-specific considerations should be kept in mind when selecting parameter sets.

Additional bacteria monitoring data for tributaries upstream of the CSO drainage areas were needed to characterize tributary bacteria loads from upstream catchment areas, especially for the typical year modeling application (discussed later). Limited historical in stream bacteria data was used to estimate fecal coliform concentrations on tributaries upstream of CSO catchment areas, as well as “near the mouth” bacteria data from wet and dry weather surveys. Long-term, routine bacteria sampling on the major tributaries upstream of the CSO catchment areas, as well as near the confluences with the Ohio River, would have generated more valuable data.

Figure 2-3. 1999 Wet Weather Event Rainfall Summary
October 8 - October 14

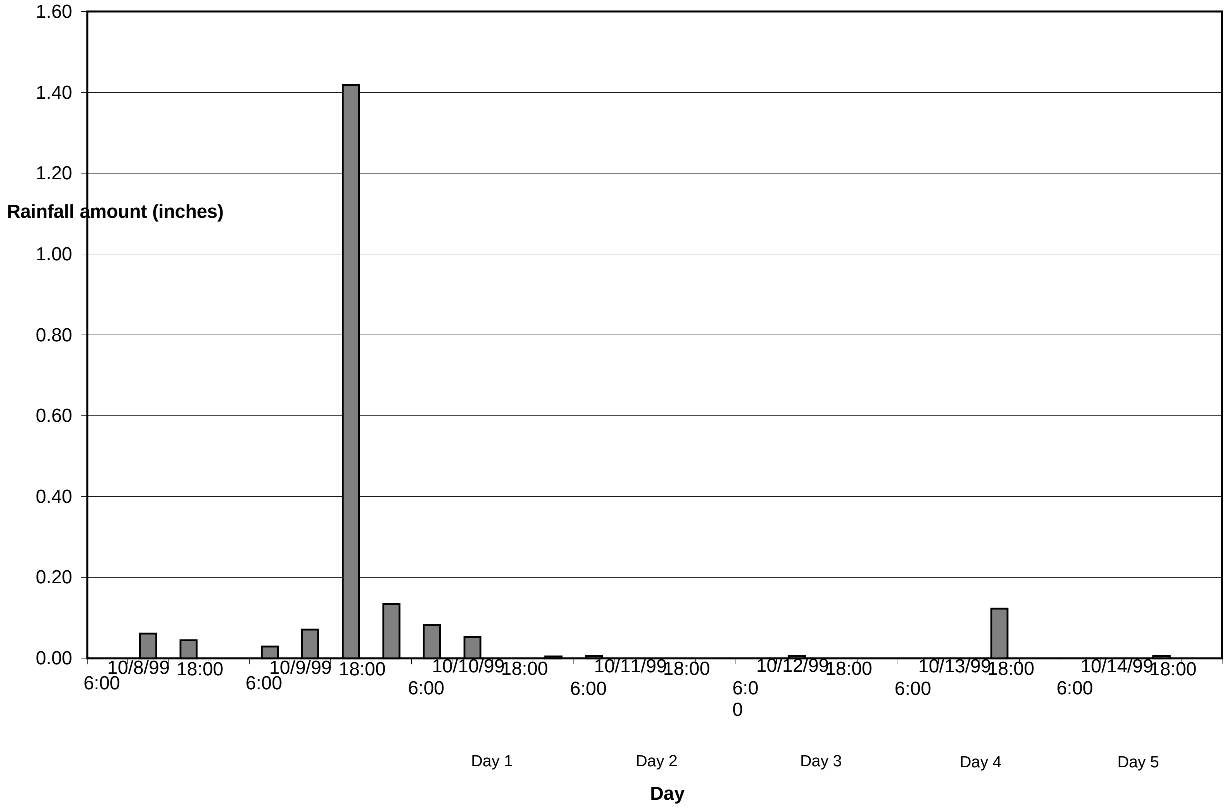


Figure 2-4. Ohio River Cross Section Day 1
Ohio River Fecal Coliform Data 10/9/99

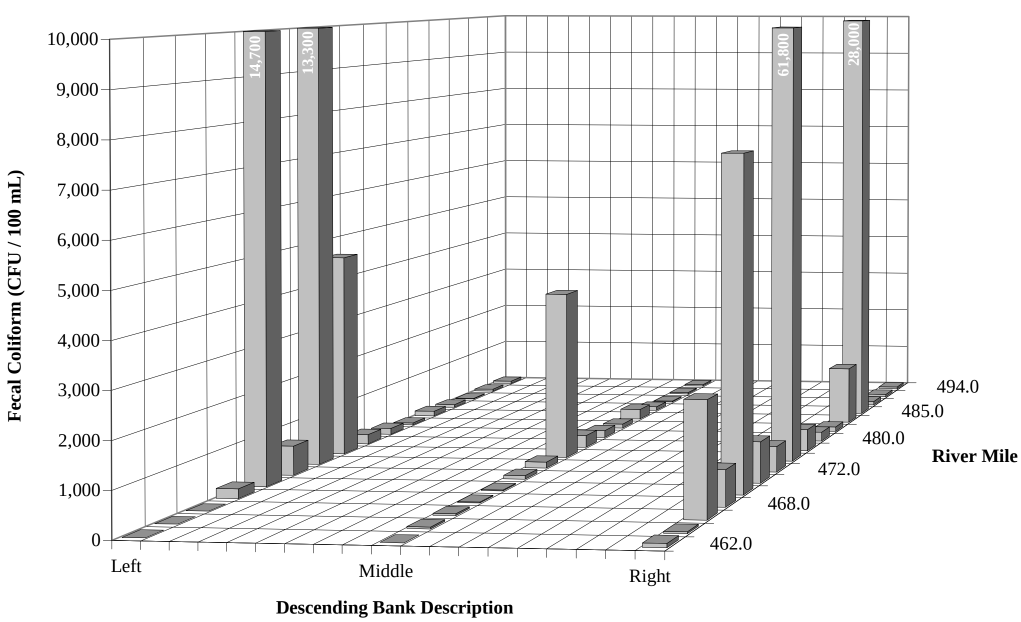


Figure 2-5. Ohio River Cross Section Day 2
Ohio River Fecal Coliform Data 10/10/99

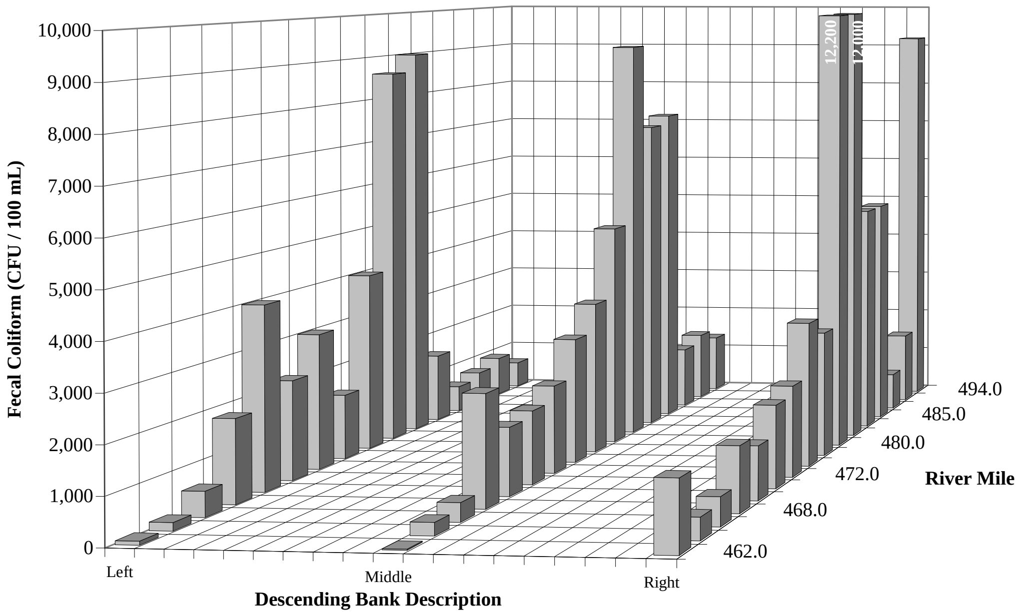


Figure 2-6. Ohio River Cross Section Day 3
Ohio River Fecal Coliform Data 10/11/99

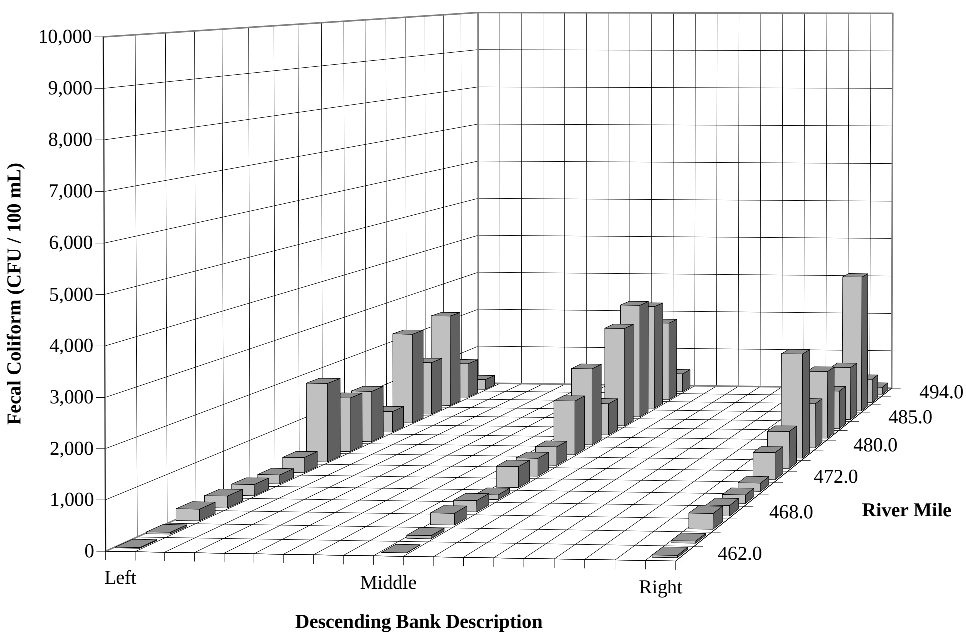


Figure 2-7. Ohio River Longitudinal Survey Day 4
Ohio River Fecal Coliform Data 10/12/99

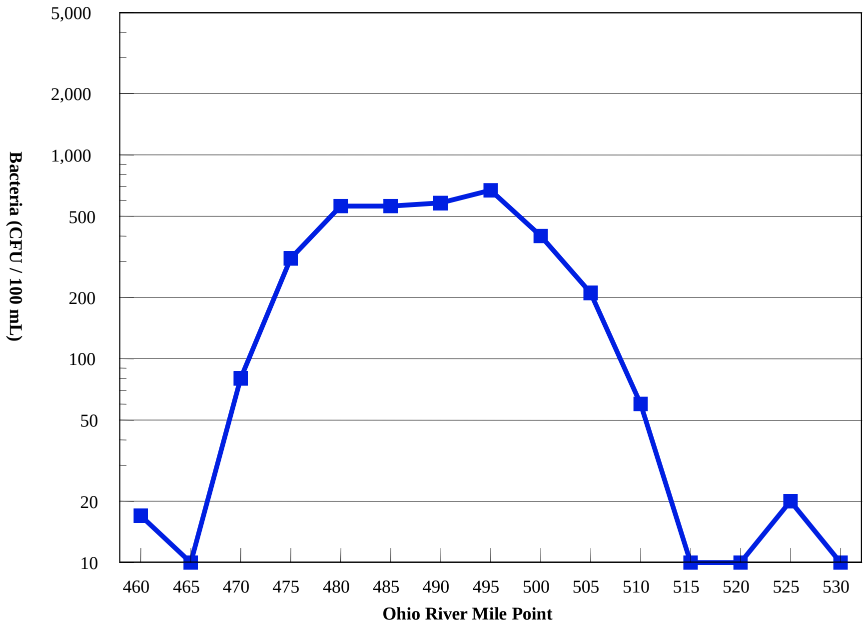


Figure 2-8. Ohio River Longitudinal Survey Day 5
Ohio River Fecal Coliform Data 10/13/99

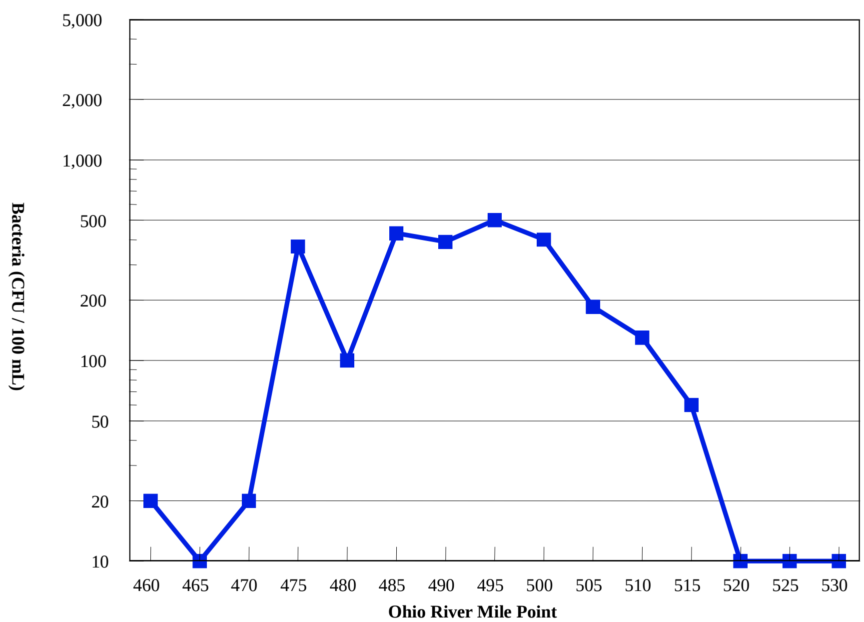


Figure 2-9. Ohio River Longitudinal Survey Day 6

Ohio River Fecal Coliform Data 10/13/99

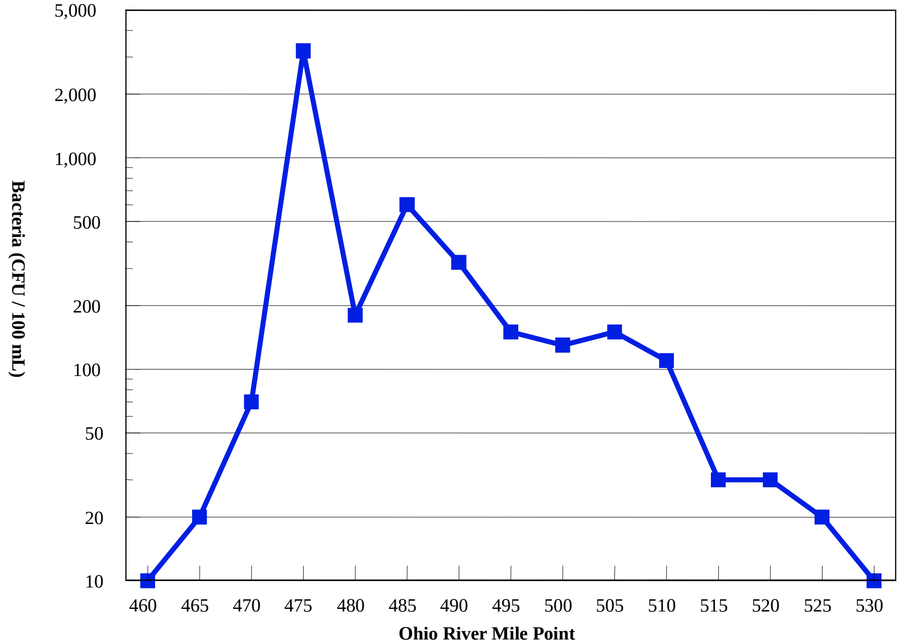


Figure 2-10. Little Miami River Cross Section Time Series

Wet Weather Event (10/09/99 – 10/14/99)

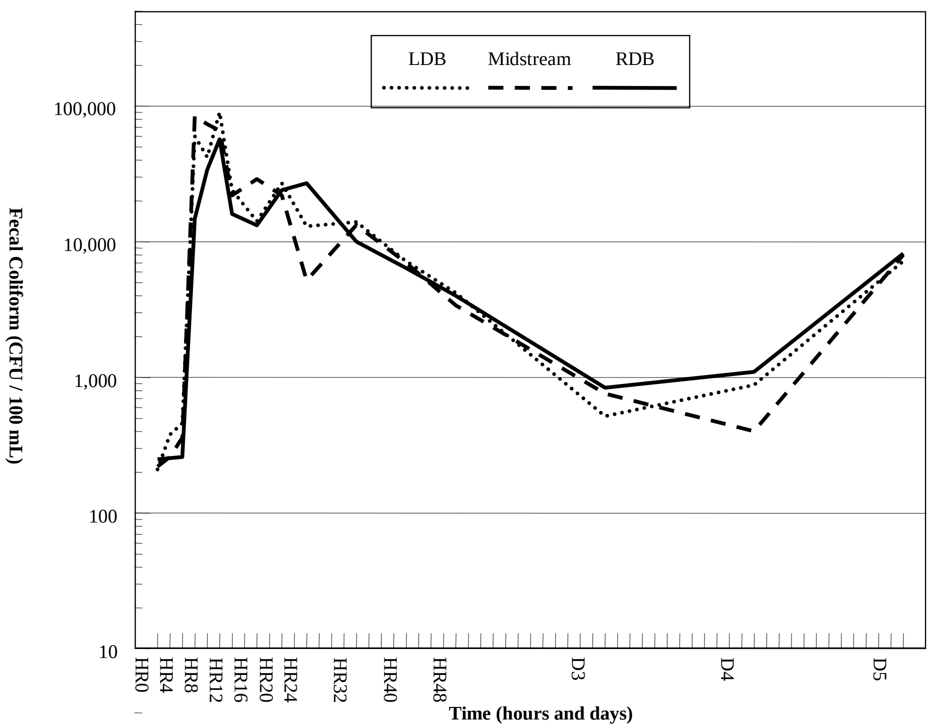


Figure 2-11. Licking River Cross Section Time Series

Wet Weather Event (10/09/99 – 10/14/99)

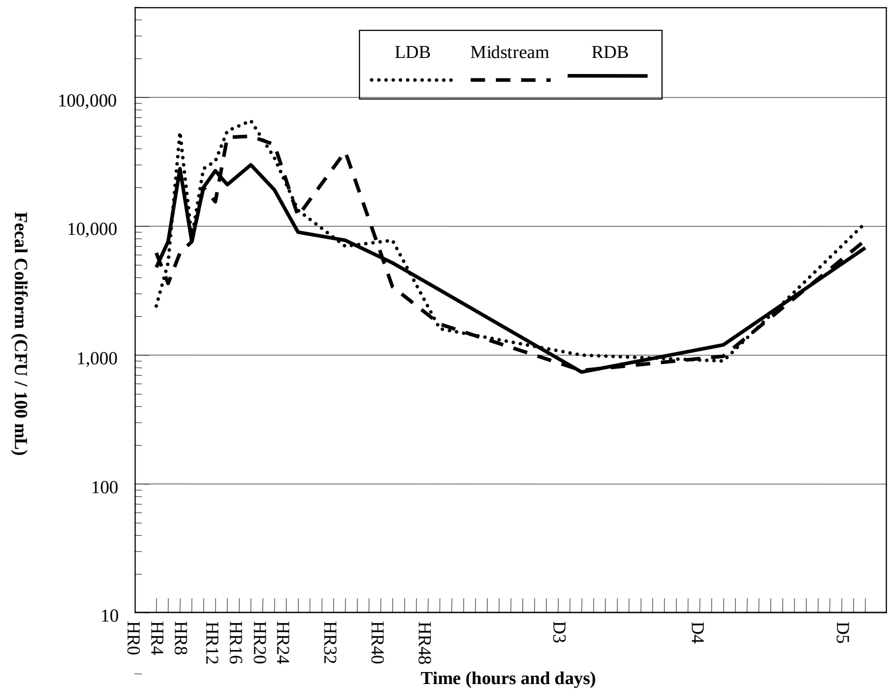


Figure 2-12. Mill Creek Cross Section Time Series

Wet Weather Event (10/09/99 – 10/14/99)

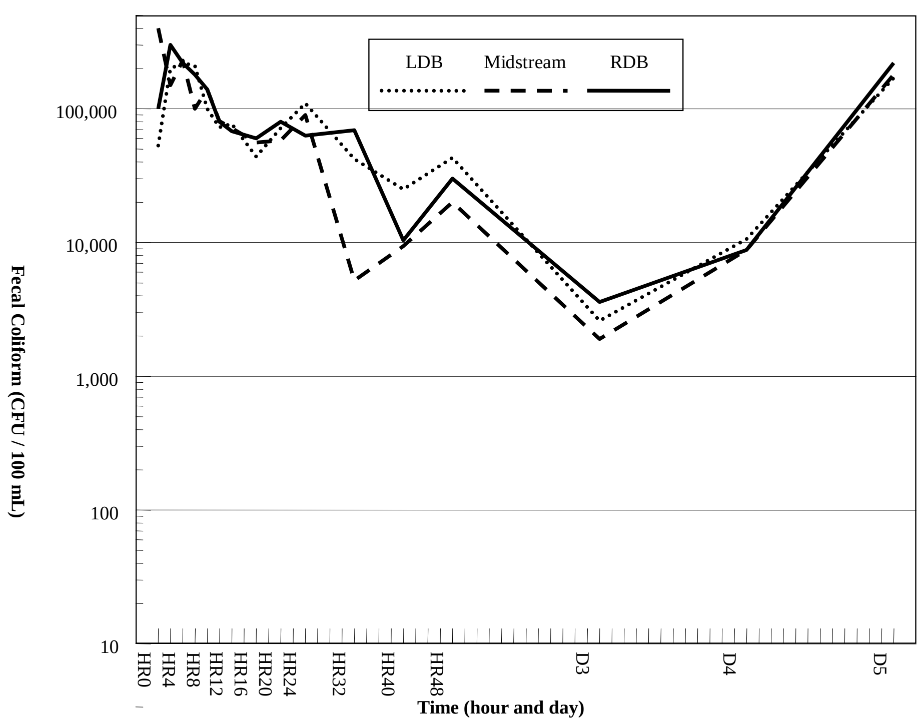


Figure 2-13. Great Miami River Cross Section Time Series

Wet Weather Event (10/09/99 – 10/14/99)

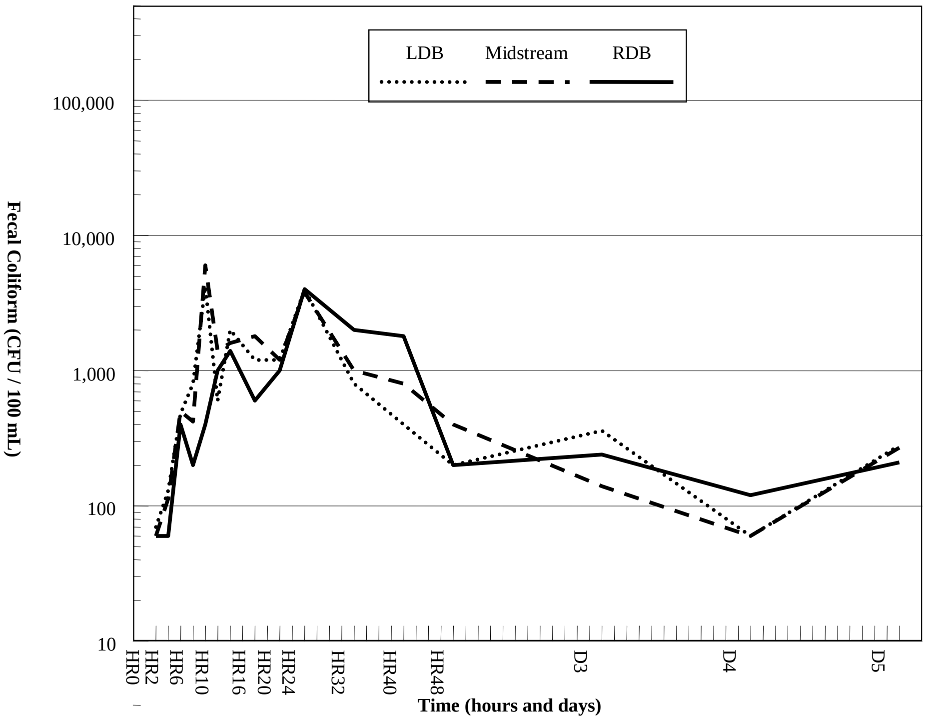


Figure 2-14. 2000 Wet Weather Event Rainfall Summary
May 26 - June 1

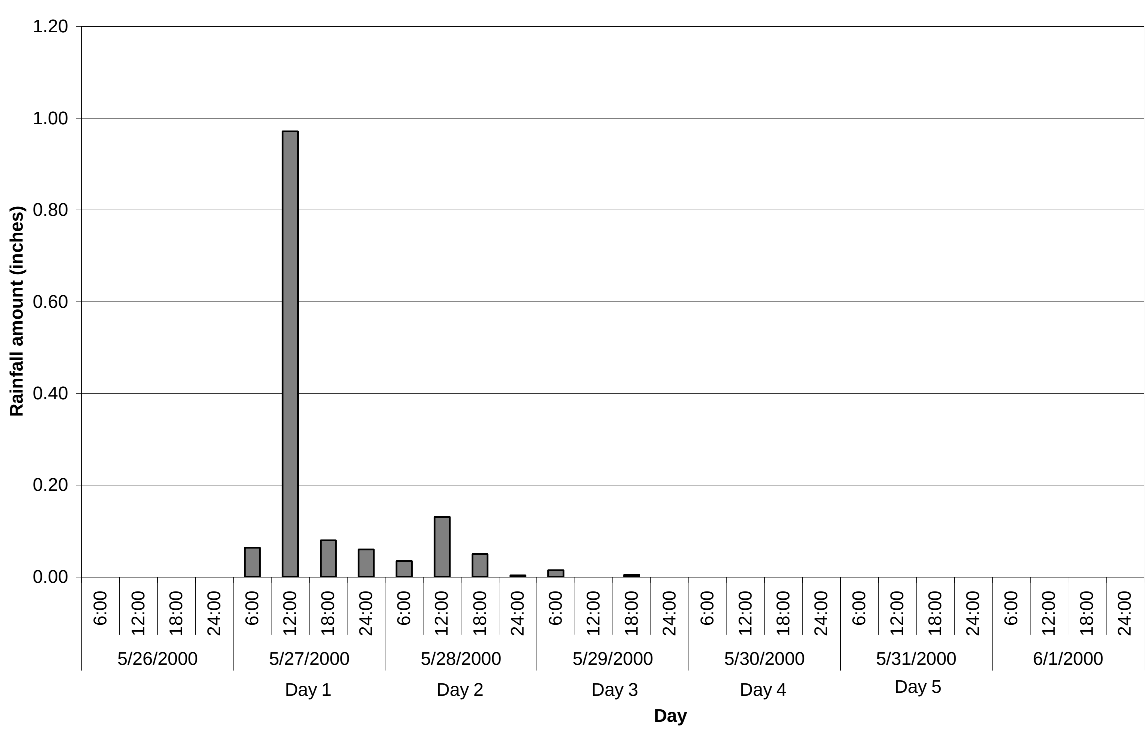


Figure 2-15. Ohio River Cross Section Day 1
Ohio River Fecal Coliform Data 5/27/00

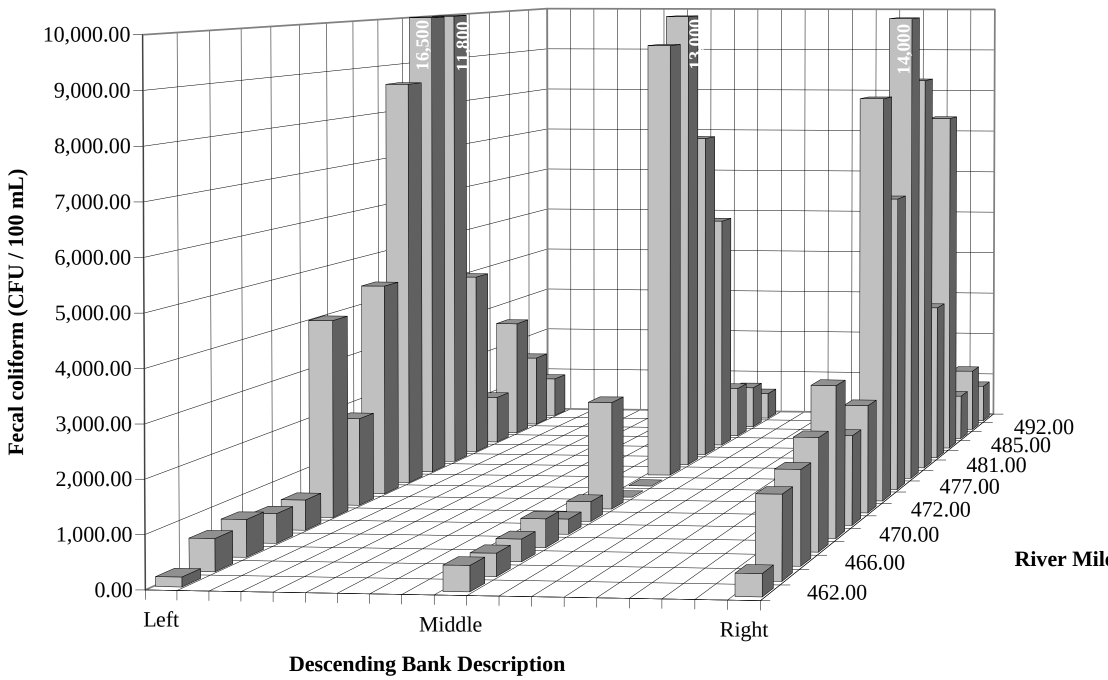


Figure 2-16. Ohio River Cross Section #2
Ohio River Fecal Coliform Data 5/28/00

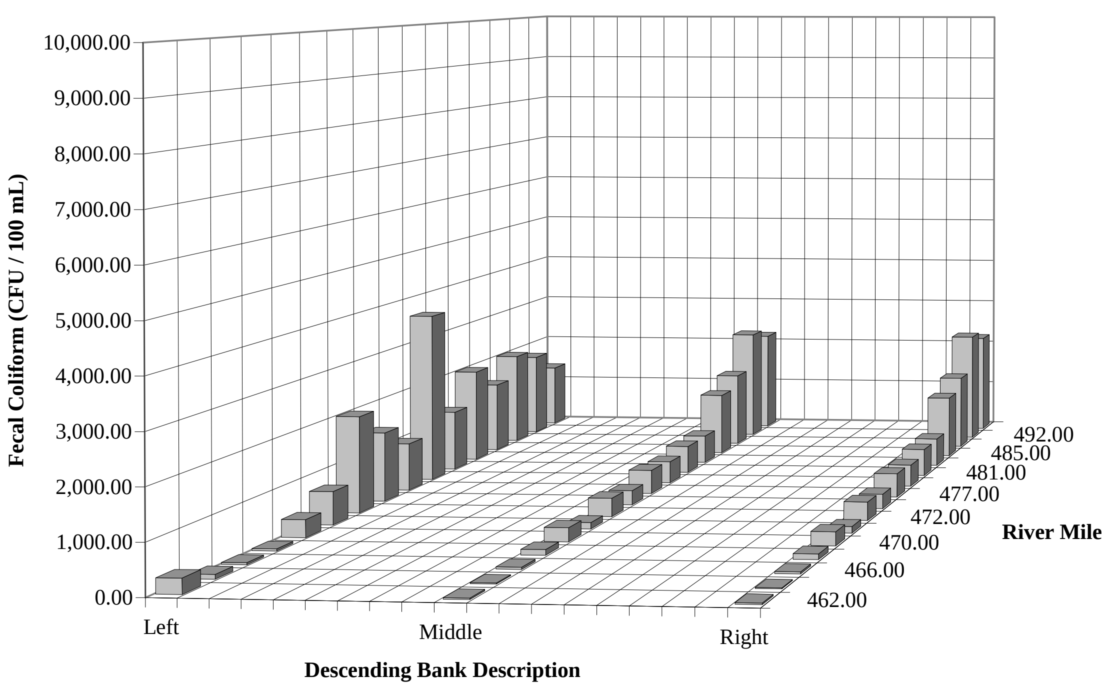


Figure 2-17. Ohio River Longitudinal Survey Day 3

Ohio River Fecal Coliform Data 5/29/00

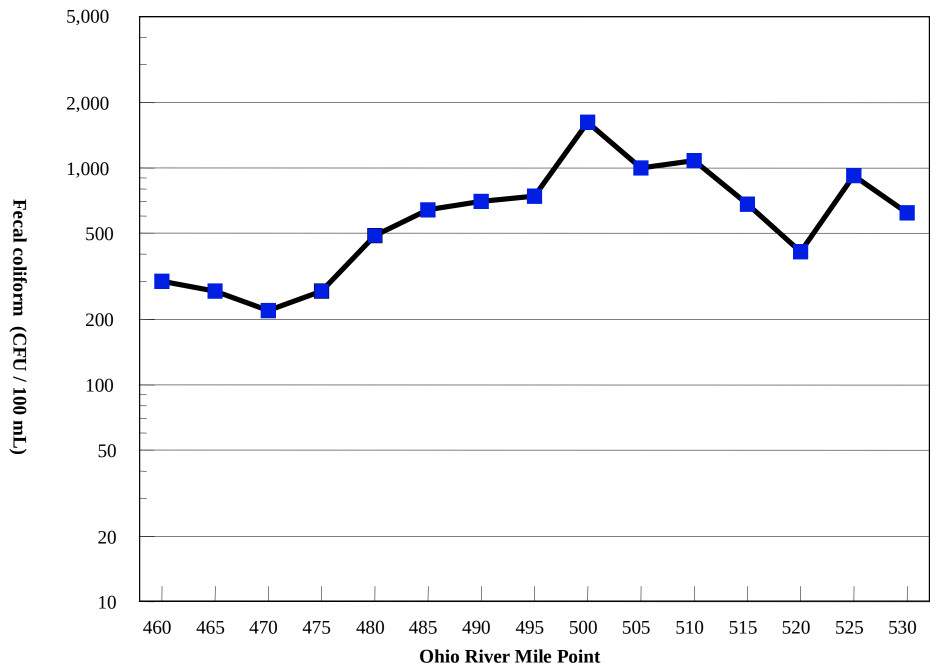


Figure 2-18. Ohio River Longitudinal Survey Day 4

Ohio River Fecal Coliform Data 5/30/00

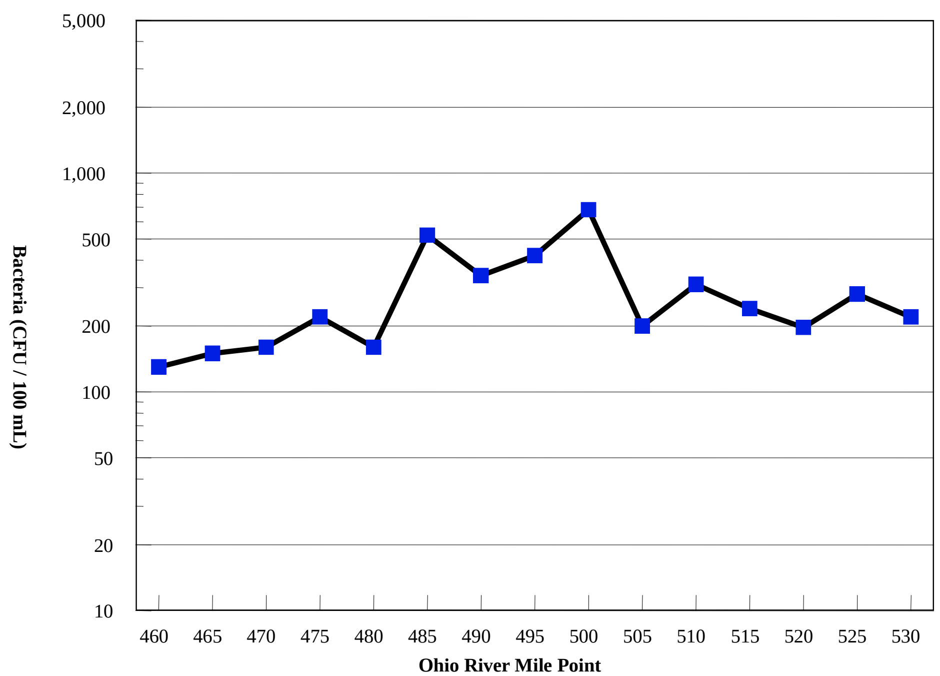


Figure 2-19. Ohio River Longitudinal Survey Day 5
Ohio River Fecal Coliform Data 5/31/00

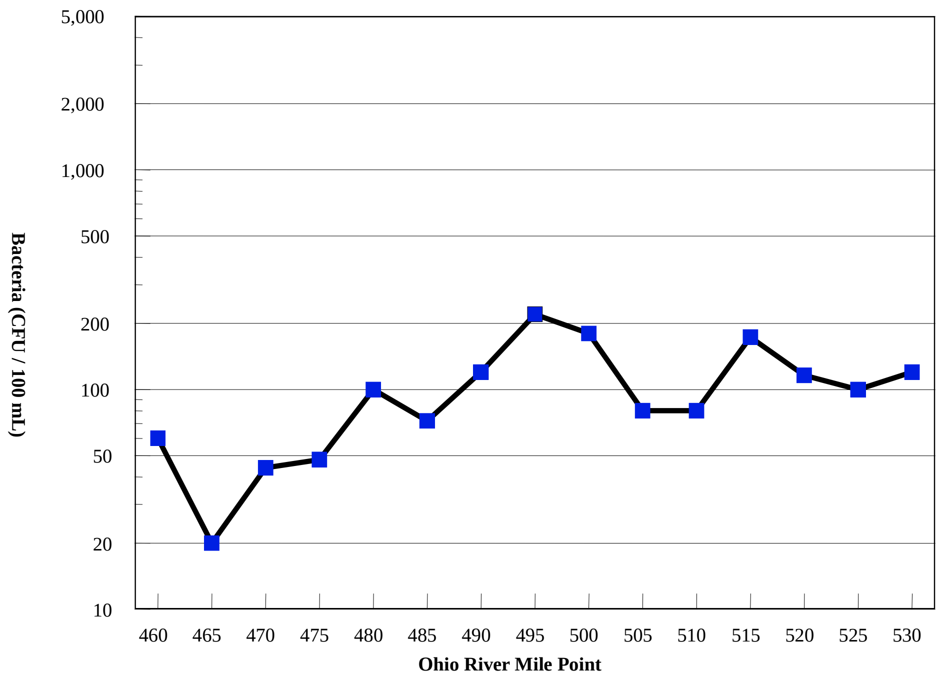


Figure 2-20. Little Miami River Cross Section Time Series
Fecal Coliform Data 5/27/00 – 5/31/00

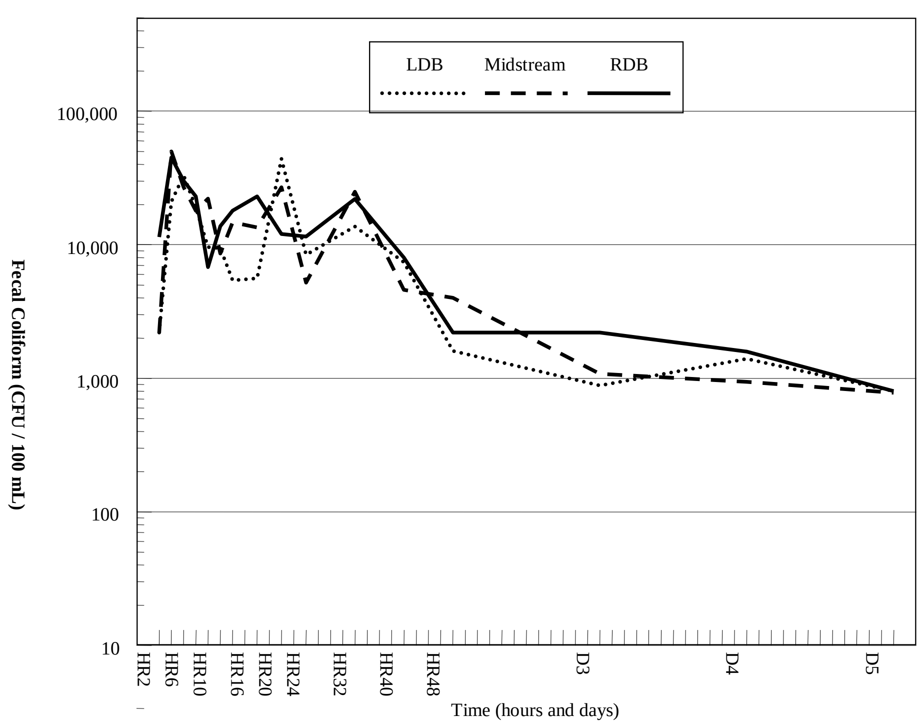


Figure 2-21. Licking River Cross Section Time Series
Fecal Coliform Data 5/27/00 – 5/31/00

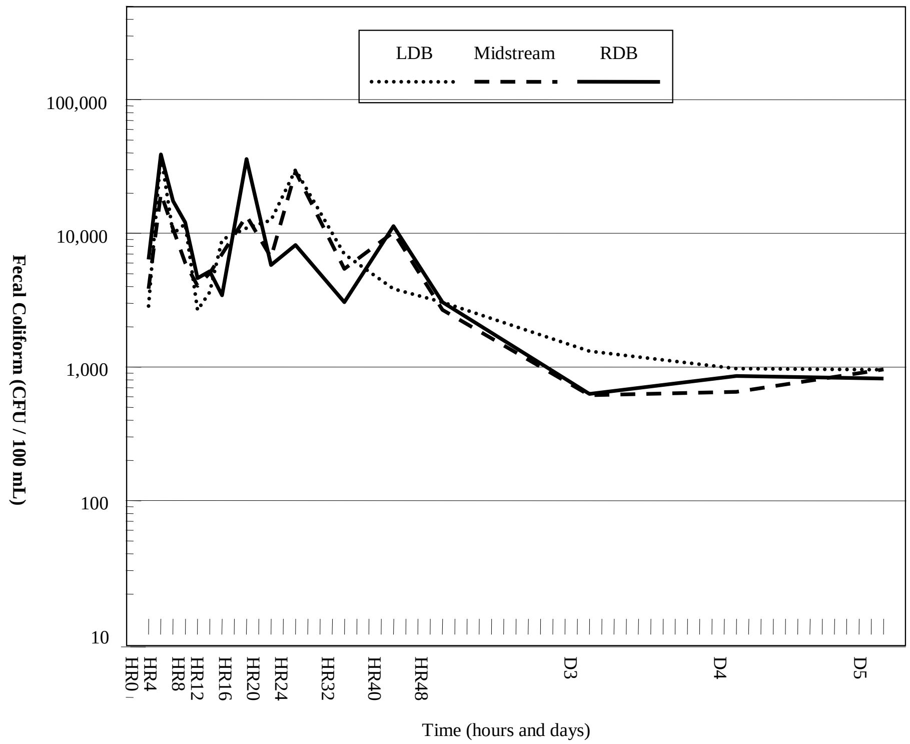


Figure 2-22. Mill Creek Cross Section Time Series
Fecal Coliform Data 5/27/00 – 5/31/00

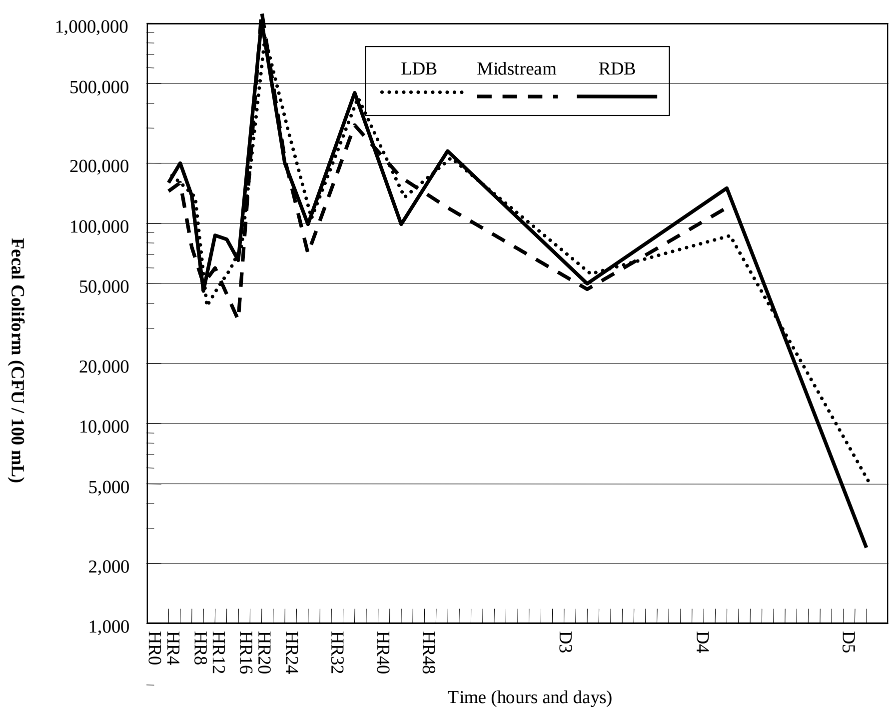
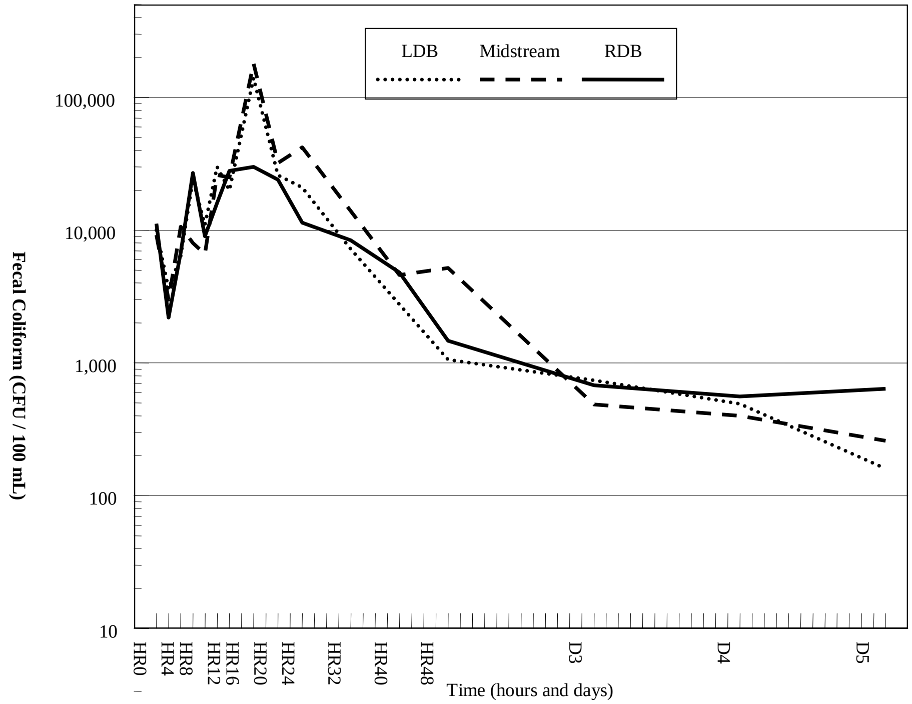


Figure 2-23. Great Miami River Cross Section Time Series
Fecal Coliform Data 5/27/00 – 5/31/00



3.0 LAND-SIDE MODELING FOR LOAD ESTIMATION

3.1 DEVELOPMENT OF CINCINNATI WET WEATHER LOADS

3.1.1 INTRODUCTION

The goal of this segment of the project was to develop a continuous water quality model simulating the Ohio River as part of the wet weather demonstration study. Wet weather loads were developed for the Cincinnati Metropolitan Sewer District combined sewer system and catchment areas. Loads were developed for the Muddy Creek, Mill Creek and Little Miami River basins. Loads for the Great Miami River Basin were derived directly from gauged flows and from available bacteria water quality data.

3.1.2 SCOPE

XCG was responsible for modeling the pollutant loads and flows for Ohio side tributaries and overflows discharging into the Ohio River. The three major sub-tasks associated with this work were:

1. Updating existing models from the XP version of U.S. EPA's Surface Water Management Modeling (XP-SWMM) program.
2. Verifying model predictions.
3. Generating loads for river model (flows and fecal coliform bacteria loads).

3.1.2.a UPDATING EXISTING XP-SWMM MODELS

The original XP-SWMM models, prepared in 1994, were updated in 1996. It was also necessary to update the models to include upstream flows for both Mill Creek and the Little Miami River.

3.1.2.b VERIFICATION OF MODEL PREDICTIONS

Once the updated XP-SWMM engine was installed, the XP-SWMM models were run and compared to results obtained previously for selected calibration events observed in 1993 and 1994, in order to demonstrate that the existing calibration was still valid.

This work included:

- preparation of computer data files for XP-SWMM runs (rainfall data, for example).
- inspection of overflow volumes and load estimates with previous results from the calibrated model.
- calibration adjustments (to include upstream flows).

3.1.2.c GENERATION OF LOADS FOR OHIO RIVER MODEL

The objective of this modeling work was to generate pollutant loads in support of the Ohio River water quality modeling effort. Updated XP-SWMM models were used for this purpose. Major components of this task included:

- development of analysis scenarios.
- preparation of XP-SWMM input data files.
- completion of model runs.
- coordination with river model team.

3.1.3 MODEL DESCRIPTION

3.1.3.a APPROACH

Urban combined sewer overflows and storm water runoff volumes were simulated using an existing XP-SWMM model, a proprietary version of SWMM, described in more detail below. The model generated flow and quality time series for each direct point source to the Ohio River, specifically all regulators that discharge directly to the Ohio, as well as Muddy Creek, the Little Miami River and Duck Creek. Treated wastewater flow volumes were also generated.

3.1.3.b DESCRIPTION OF SWMM

The model employed to generate wet weather loads is XP-SWMM, a proprietary version of SWMM. XP-SWMM is a graphics based storm water and wastewater model, derived from the original, public domain SWMM model.

SWMM was originally developed for U.S. EPA in the early 1970s. The current version (version 4) was first published in August 1988, and received minor updates through the 1990s. Although SWMM is used primarily for urban runoff and urban pollutant loading analyses, it has been used successfully for large-scale watershed analyses.

SWMM comprises four service modules (RAIN, TEMPERATURE, COMBINE and STATISTICS), and four hydraulics/hydrology modules (RUNOFF, TRANSPORT, EXTRAN and storage). Not all are required for simple applications. In the current application of SWMM, only the RAIN, RUNOFF and TRANSPORT modules were required. Transactions between modules are handled by means of interface files. SWMM can be run as a single-event model, or in a continuous simulation mode. Output consists of computed hydrographs and if water quality is simulated, pollutographs.

Precipitation is the driving force for a SWMM run. The RAIN module reads a long time series of precipitation, and generates a precipitation interface file, which is input into RUNOFF. The

RAIN module has the capability to read precipitation data in several formats, as well as any user-generated precipitation time series.

The RUNOFF module generates runoff from the rainfall using a non-linear reservoir method. The non-linear reservoir is established by coupling the continuity equation with Manning's equation. Rainfall is "lost" due to evaporation and infiltration. Depression storage volume must be filled prior to the occurrence of runoff on both pervious and impervious areas. Pollutants are simulated using an event mean concentration (EMC) approach.

Runoff flow and pollutant time series are then used as inputs to the TRANSPORT module.

The TRANSPORT module simulates non-surcharged flow of water and pollutants (including bacteria) through dendritic sewer systems and natural channels.

3.1.3.c TRIBUTARY SOURCE MODELS

Three individual XP-SWMM models support the three major catchments draining into the Ohio River in the study area. Urban XP-SWMM models are available for the Little Miami River, Mill Creek and Muddy Creek drainage areas.

In general, the models include areas serviced by separated and combined sewers. Wastewater is routed to wastewater plants, with storm flow and overflows from both combined and sanitary sewers routed to stream channels. Flow and bacteria time series at the Ohio River were saved in ASCII format, and were provided for input into the Ohio River model. A general schematic of the model structure is provided as Figure 3-1.

In the cases of Mill Creek and the Little Miami River, there are large upstream boundary catchment areas, each simulated by a single catchment in the 1996 models.

A single, large catchment is adequate to generate upstream loads for event-based modeling, i.e., large, short-term (e.g., less than one week) flows associated with rain events may be reasonably simulated using this approach. However, the approach neglects the longer-term process of rainfall infiltration, soil storage of infiltrated water, and gradual discharge to stream bodies.

In the case of continuous simulation (e.g., for an entire year), a single catchment model will generate appropriate flow volumes during rain events, but at the end of the rain event predicted flows quickly decline to zero, below the observable stream base flows.

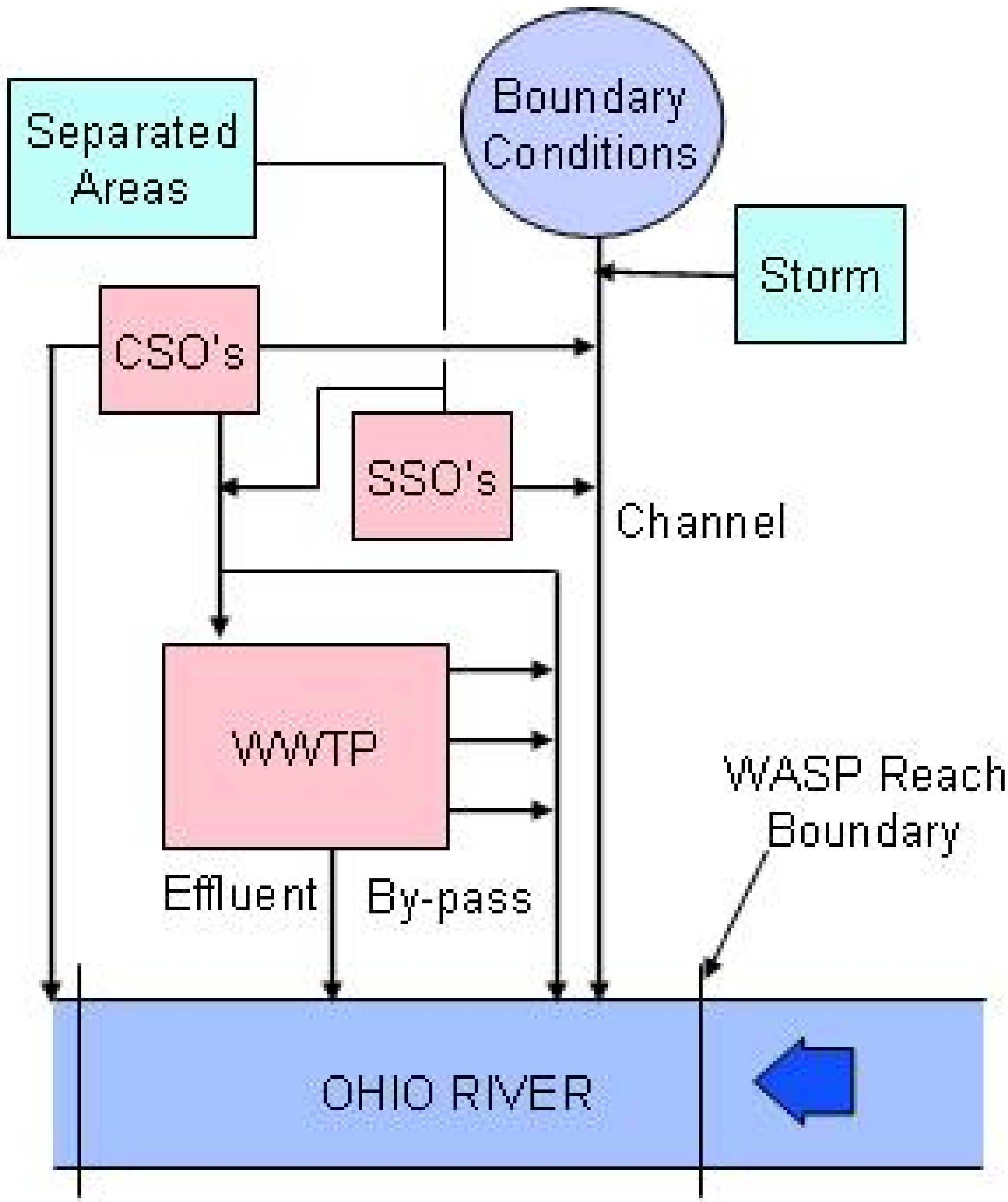


Figure 3-1. XP-SWMM Model Conceptual Schematic

XCG therefore elected to develop a time series for the upstream flows for use in continuous simulation based on 1971 gauged flows and EMCs for bacteria loads. Gauged flows were based on the gauges at Milford (Little Miami River) and Mill Creek at Carthage (Mill Creek). The EMC was based on published bacteria observations, collected between May and October. No observations were available prior to May or after October. These gauged flows were then combined with modeled flows and loads using a post-processor developed by XCG.

3.1.3.d DEVELOPMENT OF EMCs

EMCs used by XCG in the SWMM models are outlined in Table 3-1.

Table 3-1. Event Mean Concentrations Used to Develop Ohio River Loads

Location	EMC	Basis
Combined or Sanitary Overflows	1,000,000 FCU/100mL	Developed during 1996 model calibration.
Stormwater	53,000 FCU/100mL	Developed during 1996 model calibration.
Mill Creek (upstream area)	743 FCU/100mL	Based on a geometric average of available, published bacterial water quality, 1995-2000.
Little Miami River (upstream area)	340 FCU/100mL	Based on a geometric average of available, published bacterial water quality, 1995-2000.

3.1.4 ESTIMATION OF WET WEATHER LOADS

Calibrated source models were applied to generate estimates of pollutant loads for rain events, beginning on May 27, 2000. Loads for these events were used by LTI to calibrate their Ohio River model. The source models were then used to generate loads for all of 1971, which was selected to represent the "typical year."

The XP-SWMM models representing the Little Miami River, Mill Creek and Muddy Creek drainage areas provide independent estimates of CSOs, SSOs and WWTP loads.

The final results, in the form of hourly time series of flow and bacteria quality for each direct overflow and tributary to the Ohio River were provided to LTI to provide the necessary input to the Ohio River WASP model.

3.1.4.a MUDDY CREEK

The Muddy Creek and Rapid Run Creek drainage areas represent a total area of approximately 30 square miles. Both drainage areas are served by a single WWTP, the Muddy Creek WWTP. Muddy Creek discharges into the Ohio River at Mile Point 484.1, while Rapid Run discharges at Mile Point 480.8.

The drainage area is characterized by rolling terrain with elevations varying from 925 feet to 455 feet at the Ohio River. About 25% of the area has ground slopes unsuitable for development.

A summary of the characteristics of the Muddy Creek watershed is provided in Table 3-2.

Table 3-2. Description of the Muddy Creek Drainage Area

Characteristic	Description
Major Water Courses	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 either side of River Road provides an additional 6 square miles of drainage area.
Land Use	About 70% of the drainage area is urban land use (residential, commercial or industrial).
Sewers	About 41% of the drainage area is served by a combined sewer system.
CSOs	There are 20 CSO regulating structures in the Muddy Creek drainage basin. The CSOs are either diversion dams or drop structures.

The original XP-SWMM model, developed and applied for the analysis of the combined sewer system, including all tributary drainage areas to Muddy Creek, Rapid Run Creek and River Road, was prepared by W_2O in 1994. The modeled system included all combined sewer regulators and diversion structures, interceptor sewers, outfall sewers, the Muddy Creek WWTP, as well as selected segments of the trunk sewers related to specific regulators. A total of 84 nodes (or representative manholes), 118 links (or representative conduits), and 27 catchments were included in the XP-SWMM model.

Figure 3-2 illustrates the location of all major overflow structures.

In 1996, a detailed hydraulic analysis was completed using the EXTRAN block of the XP-SWMM program to determine the hydraulic capacity of specific elements, such as individual CSOs, under dynamic flow conditions. The results of this hydraulic analysis were applied to build a continuous XP-SWMM model. This continuous model was applied to estimate representative bacteria loadings for 1971. These loadings consisted of flow and fecal coliform time series for each point source, for all of 1971.

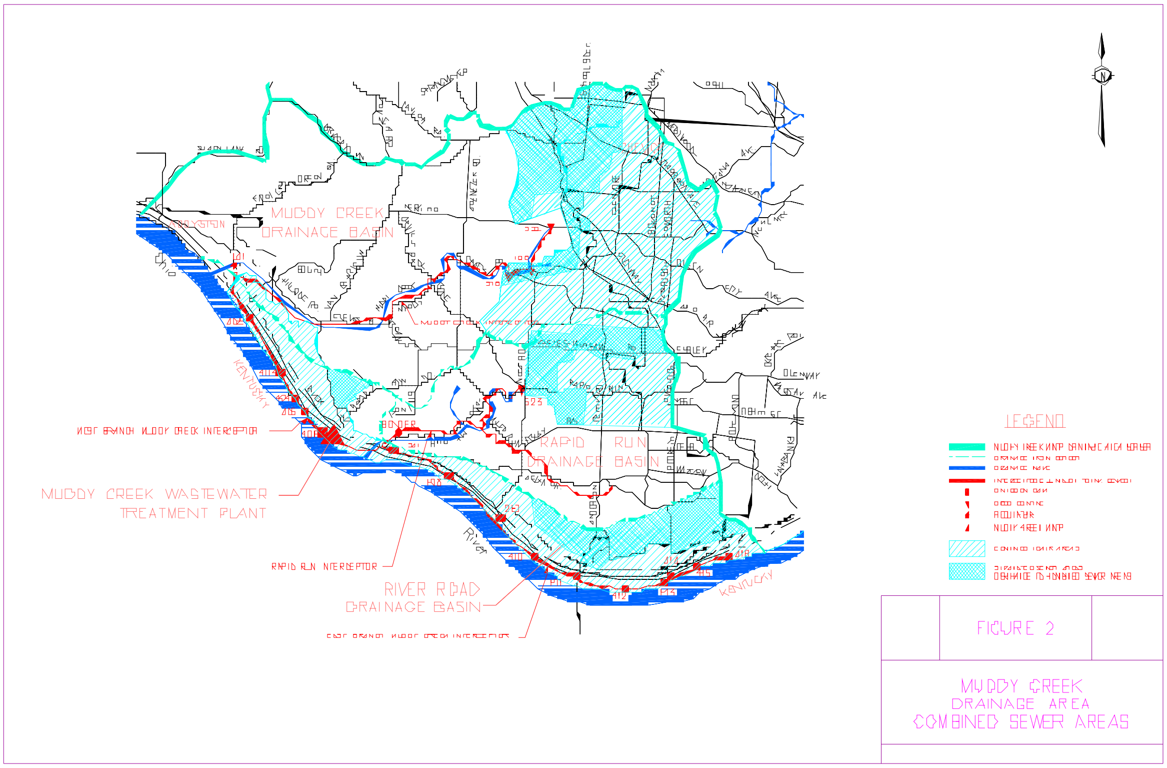


Figure 3-2. Muddy Creek CSO System

3.1.4.b MILL CREEK

The Mill Creek watershed is approximately 166 square miles and the creek discharges into the Ohio River at Mile Point 472.5. The drainage area is bordered by the Muddy Creek and Taylor Creek drainage areas to the west, the Ohio River to the south, and by the Duck Creek drainage area to the east. The area is characterized by rolling terrain with steep stream valleys sloping toward Mill Creek. The elevations of the drainage area range from 950 feet (Mt. Airy) to 455 feet above mean sea level (MSL) at the Ohio River.

Bedrock in the area consists of alternating layers of sandstone, shale, limestone and dolomite dipping toward the north and east. The depth of bedrock varies from 2.5 to 200 feet. Soils covering the bedrock are Illinoisan till (an undifferentiated layer of limestone and mudstone) and silt loams (formed from silty material transported by wind).

A summary of the characteristics of the Mill Creek watershed is provided in Table 3-3.

Table 3-3. Description of the Mill Creek Drainage Area

Characteristic	Description
Major Water Courses	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.
Upstream Boundary Inflow	Upstream boundary inflow was based on gauged flows for 1971 from the USGS Gauge: Mill Creek at Carthage Upstream area 62 square miles was used to prorate the gauged area of 115 square miles. An event mean concentration of 7430 FCU/100mL was applied.
Land Use	South Mill Creek: About 85% of the drainage area is urban land use (residential, commercial or industrial). Only 15% is open space or undeveloped land. 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	South Mill Creek: About 75% of the drainage basin is served by a combined sewer system. Separate sanitary sewers or unsewered serve the remaining areas. West Branch Mill Creek: Only 7% of the drainage basin is served by combined sewers. Most of the center and northern portion of the drainage basin is unsewered. East Branch Mill Creek: This drainage basin is primarily served by a separate wastewater collection system.
CSOs	Of the 158 CSO regulating structures in the drainage basin, 47 are mechanical regulators, 57 are drop grates and 54 are diversion dams.

The original XP-SWMM model was developed and applied for the analysis of the combined sewer system. This model included all tributary drainage areas to Mill Creek and was prepared by W_2O in 1994. The modeled system included all combined sewer regulators and diversion structures, interceptor sewers, outfall sewers, the Mill Creek WWTP, as well as selected segments of the trunk sewers related to specific regulators. A total of 591 nodes (or representative manholes), 733 links (or representative conduits), and 154 catchments were included in the XP-SWMM model.

Figure 3-3 illustrates the location of all major overflow structures. In 1996, a detailed hydraulic analysis, similar to the analysis performed for the Muddy Creek watershed, was completed to determine the hydraulic capacity of specific elements, such as individual CSOs, under dynamic flow conditions. The results of this hydraulic analysis were applied to build a continuous XP-SWMM model.

Upstream boundary inflows were added to the original model to create a continuous model. An event mean concentration of 743 FCU/100mL was used to represent boundary water quality, based on a review of historical monitoring results available on the STORET database. The continuous model was applied to estimate representative bacterial loadings for 1971. These loadings consisted of flow and fecal coliform time series for each point source, for all of 1971.

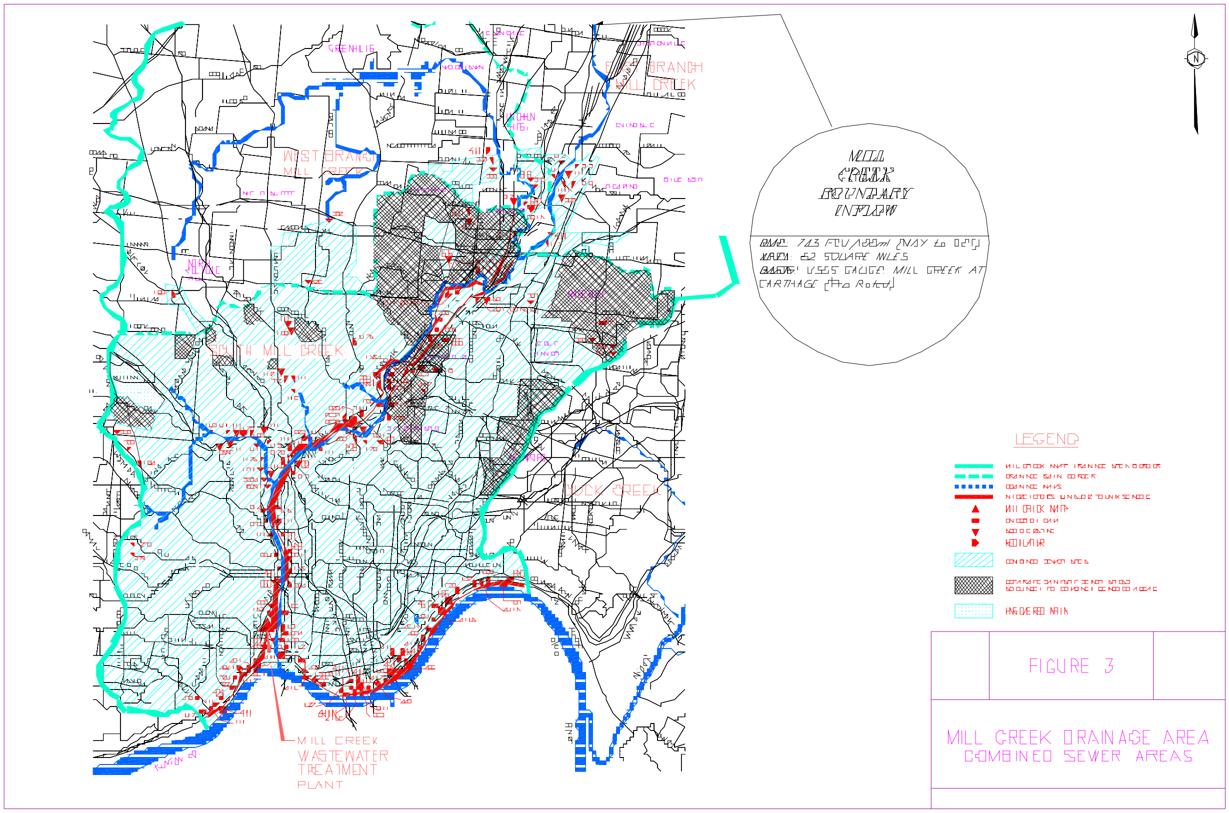


Figure 3-3. Mill Creek CSO System

3.1.4.c Little Miami River

The Little Miami River discharges into the Ohio River at Mile Point 463.5. The total drainage area is approximately 1,670 square miles and the watershed is located in the southeastern quadrant of Hamilton County. The topography generally is characterized by rolling terrain, typical of southern Ohio. Land surface elevations vary from about 850 to 455 feet above MSL.

A summary of the characteristics of the Little Miami River watershed is provided in Table 3-4.

Table 3-4. Description of the Little Miami River Watershed

Characteristic	Description
Major Water Courses	Duck Creek: drainage area of 27.5 square miles. Of the 18 sub-watersheds contributing flow to Duck Creek, 14 drain to combined sewer interceptors, transporting flow to the Little Miami WWTP. Lower Little Miami River: drainage area of 51.9 square miles. Upper Little Miami River: drainage area of 1591 square miles.
Upstream Boundary Inflow	Upstream boundary inflow was based on gauged flows for 1971 from the USGS Gauge: Little Miami River at Milford. An event mean concentration of 340 FCU/100mL was applied.
Land Use	Duck Creek: Residential and commercial land use occupies 71% of the drainage area. Lower Little Miami River: 53% of the drainage area is developed. About 18% of the area is not considered developable as result of slope restrictions and floodplain area. Upper Little Miami River: Mostly rural an agricultural land use.
Sewers	Duck Creek: Approximately 82% of the drainage basin is sewered. About 60% of the sewered area is served with combined sewers, while the remaining 40% is served with separate sewers. Lower Little Miami River: About 34% of the drainage area is sewered with less than 1% of the sewered area served by combined sewers.
Pumping Stations	There are 27 wastewater pumping stations in the Little Miami Creek drainage area. The majority of the pumping stations are in the East Little Miami drainage area in areas not served by gravity sewers.
SSOs	There are 19 SSOs which discharge to adjacent storm sewers or receiving streams.
CSOs	There are 56 CSO regulators: 10 mechanical regulators, 33 drop grates, 13 diversion dams. 11 CSOs overflow as a result of high stage in the Ohio River.

Using XP-SWMM, the original model was developed and applied for the analysis of the combined sewer system. This model addressed the Duck Creek and lower Little Miami River drainage areas and was prepared by W_2O in 1994. The modeled system included all combined sewer regulators and diversion structures, interceptor sewers, outfall sewers, the Little Miami WWTP, as well as selected segments of the trunk sewers related to specific regulators. A total of

314 nodes, 370 links (or representative conduits) and 77 catchments were included in the XP-SWMM model.

Figure 3-4 illustrates the location of all major overflow structures. Using the EXTRAN block of the XP-SWMM program, a detailed hydraulic analysis was completed to determine the hydraulic capacity of specific elements, such as individual CSOs, under dynamic flow conditions. The results of this hydraulic analysis were applied to build a continuous version of the XP-SWMM model.

Upstream boundary inflows were added to the original model to create a continuous model. The continuous version of the XP-SWMM model was applied to estimate average annual CSO loadings. An EMC of 340 FCU/100mL was used to represent boundary water quality. The 1971 rainfall record was applied for continuous XP-SWMM model application.

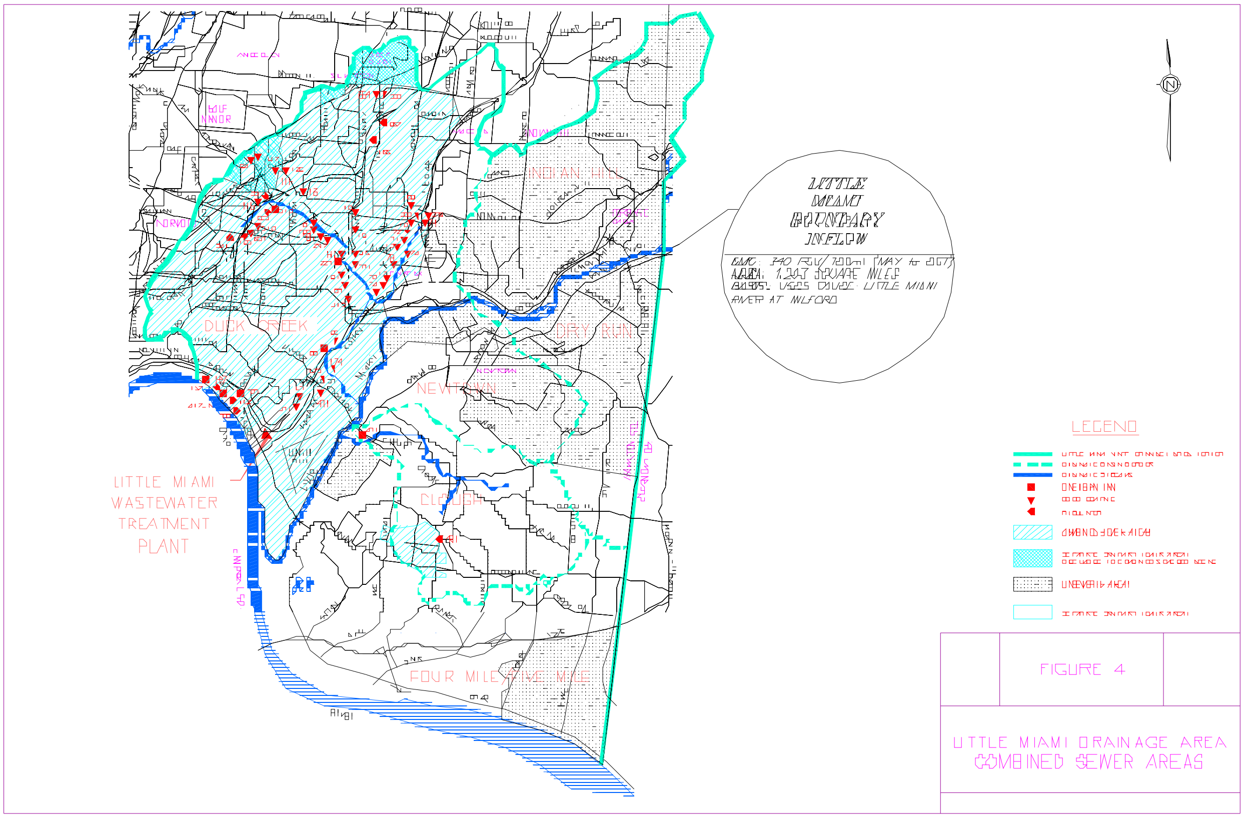


Figure 3-4. Little Miami River CSO System

3.1.5 QUALITY ASSURANCE

The XCG Quality Assurance Plan (QAP) was designed to ensure that the final source models developed over the course of the project represent reliable and accurate predictive tools for analysis of pollutant sources. Model defensibility is dependent upon: the appropriateness of source model design, development, and application; and the suitability of model calibration for flow and quality.

3.1.5.a MODEL DESIGN AND DEVELOPMENT

All source models for this project were based on the XP-SWMM computer model. The integrity of the source model predictions was essential for overall success of the wet-weather demonstration study.

The appropriateness of the source model design was ensured by reviewing the following:

Use of the EXTRAN module of XP-SWMM to define hydraulic approximations of various overflow structures for the TRANSPORT module.
Land use definition.
Hydraulic definition of individual wastewater treatment facilities.
Model assumptions.

To ensure the integrity of all computer data, all computer files were routinely backed up.

3.1.5.b SUITABILITY OF CALIBRATION

The model was originally calibrated in 1995 using flow data collected by USGS. Water quality data for CSOs were obtained from sampling conducted in the plant influent. Storm water data was obtained from a sampling program conducted in the City of Cincinnati in 1994. Since then, the modeling software has been upgraded three times.

Two example calibration plots are included as Figures 3-5 and 3-6. Both are for the October 3, 1995 event. Figure 3-5 shows the relationship between predicted and observed bacterial water quality in Mill Creek. Figure 3-6 shows the relationship between predicted and observed bacterial water quality in the Little Miami River.

Model verification was completed by comparing results for 1971 with the current model and with results published in 1995.

Figure 3-5. Calibration - October 3, 1995
Mill Creek at Guest Street

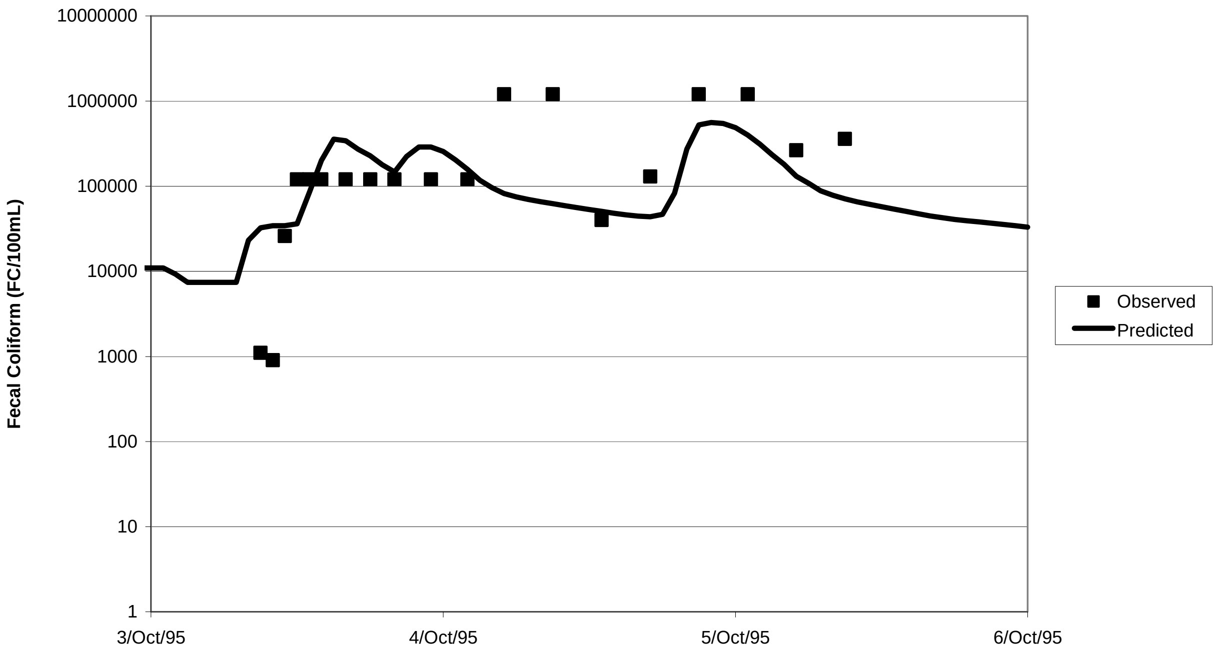
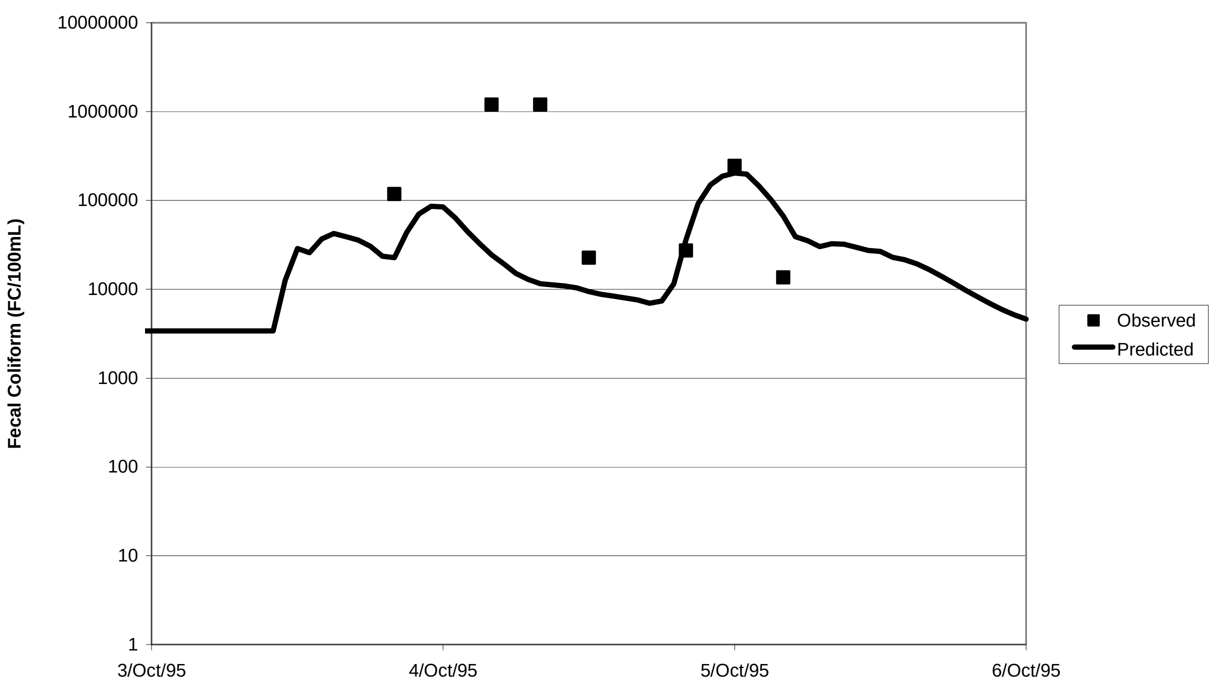


Figure 3-6.
Calibration - October 3, 1995
Little Miami River at Kellogg Street



3.1.6 CONCLUSIONS

General conclusions include:

XP-SWMM models have been developed for three major Ohio-side tributaries in and around Cincinnati, that discharge to the Ohio River. These models include the Little Miami River, Mill Creek, and the Muddy Creek watersheds and are designed to simulate flow and fecal coliform loads on a continuous basis. In addition to upstream rural drainage areas, the models include major elements of the combined sewer system and all significant combined sewer overflows.

For the representative rainfall year 1971, the XP-SWMM models were applied to generate complete time series of flow and fecal coliform loading for each tributary. In turn, time series information was used to support water quality modeling of the Ohio River (an independent WASP model developed by LTI was used for this purpose).

During the calibration of the individual XP-SWMM models, comparisons were made between predicted and measured fecal coliform concentrations at the confluence of the Little Miami and Ohio rivers, and at the confluence of Mill Creek and the Ohio River. EMCs, for fecal coliform loads were derived, resulting in a reasonable agreement between predicted and measured fecal coliform concentrations.

Although the XP-SWMM models are reasonably comprehensive in scope, some limitations exist. For example:

The EMC approach yields a reasonable prediction of fecal coliform loads on average, however, individual rainfall events may have significantly different effective mean fecal coliform concentrations as a result of differences in antecedent periods, differences in temperature and differences in surface and pipe velocities.

Physical changes to individual overflow regulators during or prior to a rainfall event, such as clogging with debris, may influence overflow volumes.

For modeling purposes, rainfall was assumed to be uniform over relatively large areas. In some cases, the actual rainfall will be more heterogeneous with some localized differences.

The tributaries were modeled as simple trapezoidal channels with limited routing. For small rainfall events, travel times may be large and as result, actual bacterial die-off may be greater than the XP-SWMM model would predict. Therefore, for some small events, the XP-SWMM model may over-estimate fecal coliform loads at the confluence of the Ohio River.

The models need to be periodically updated to reflect any significant changes in infrastructure such as overflow closings or reconstruction.

3.1.7 RECOMMENDATIONS

The complexity of the individual XP-SWMM models was appropriate for the extent of available monitored data. Refinements or improvements to the XP-SWMM models may be possible if additional monitoring information becomes available. In particular, future monitoring should address flow monitoring (during wet and dry weather conditions) at the confluence of each tributary. Flow measurements during wet weather should be made at 30 minute or less intervals to capture the form of the flow hydrographs.

Existing fecal coliform monitoring addresses wet-weather concentrations during the late summer and fall. Additional fecal coliform monitoring should be completed to address tributary water quality during the remainder of the year.

3.2 NORTHERN KENTUCKY LANDSIDE MODELING

3.2.1 INTRODUCTION

The goal of the Northern Kentucky landside CSO model was to calculate the overflow loadings for a typical year of rainfall. This was accomplished using a hydrologic and hydraulic computer model and calibrating the model using flow monitoring data. The hydrologic parameters for the computer model included the catchment area, percent imperviousness, catchment width and slope. The hydraulic parameters for the computer model included physical data for the conduits, manholes, regulator structures and pump stations that comprise the CSO system. The typical year of rainfall was used in a continuous model simulation to calculate the volume of overflow.

The combined sewer area of Northern Kentucky is located in the northern portion of Campbell and Kenton counties and covers approximately nine square miles. This area includes approximately 100 CSOs and SSOs which discharge into either the Ohio River, Licking River or Banklick Creek. There are six CSO outfalls on Banklick Creek, 26 CSO outfalls on the Licking River and 41 CSO outfalls on the Ohio River. The combined sewer area includes five major combined sewer pump stations and two smaller, separate sewer pump stations. The majority of the combined sewers are located in the cities of Bromley, Covington and Ludlow in Kenton County and the cities of Newport, Bellevue and Dayton in Campbell County. Separate sewer systems from various municipalities are located upstream and discharge into the combined sewers. The summation of the combined sewer areas and the separate sewer areas located upstream comprise the CSO study area.

The software chosen to analyze the Northern Kentucky combined sewer system was XP-SWMM. In this application, the RUNOFF module in XP-SWMM was used to generate the inflow hydrographs for both the separate sewer and combined sewer areas. The runoff hydrographs were originally routed through the system using the TRANSPORT module in XP-SWMM. The TRANSPORT module was used initially because of excessive runtimes for continuous simulation using the EXTRAN module. EXTRAN was used later to route the hydrographs as the computation time decreased with improved versions of the software and faster computers. A summary report from the computer output tabulates the amount of flow discharged from the CSOs and SSOs within the study area. The model consists of 813 conduits and 897 nodes. More nodes exist in the model than conduits because the nodes are located at both the intersections and the ends of the conduits.

3.2.2 XP-SWMM

3.2.2.a RUNOFF MODULE

The RUNOFF module in XP-SWMM utilizes the RAIN interface file generated in the Rainfall Utility to construct a runoff hydrograph from each catchment. A runoff hydrograph is generated by using four parameters that characterize the physical attributes of a given catchment. Those four parameters are area, percent imperviousness, width and slope of the catchment. The area is the number of acres included in the catchment. The percent imperviousness is defined as the percent of the total area considered impervious and is directly connected to a drainage system. The width is defined as the physical width of overland flow assuming that the catchment is an idealized rectangular catchment. Because each drainage area is not an idealized rectangle, the width is estimated by dividing the total catchment area by the average path length of overland flow. The slope is the average slope of overland flow to the model inlet locations.

3.2.2.b TRANSPORT MODULE

The TRANSPORT module in XP-SWMM uses a basic kinematic wave routing approach that means that backwater effects are not modeled beyond the realm of a single conduit. The effect of that limitation means downstream conditions do not affect the flow conditions in upstream conduits. Surcharging is a condition where flow exceeds the capacity of the conduit. It is represented in TRANSPORT by storing the excess flow at a manhole node until there is adequate capacity in the downstream conduit.

TRANSPORT accepts the SWMM interface file created in RUNOFF and then routes the hydrographs through the modeled system. TRANSPORT also has the capability to incorporate its own user input hydrographs at any node via the “Sewer Inputs” option.

Two important features incorporated into the TRANSPORT module include the ability to add flow dividers at manholes and the option to automatically re-size conduits. The ability to incorporate flow dividers into the modeled system allows the user to simulate flow lost due to surcharging and to regulate the amount of flow which will be allowed into the system at certain locations. The flow divider can be used to model a regulator such as a CSO structure or to represent the capacity of a pump station. To enable TRANSPORT to design the undersized conduits, the box named “Design Undersized Conduits” located in the Job Control Menu under Options must be checked. TRANSPORT then determines the required capacity and corresponding diameter needed to handle the peak flow rate in each conduit in the system.

3.2.2.c EXTRAN MODULE

The EXTRAN module in XP-SWMM uses gradually varied St. Venant equations to model flows. The EXTRAN module in XP-SWMM can perform backwater calculations, which allows it to handle surcharged and high tail water conditions. The complexity of the calculations in EXTRAN leads to much longer model run times for larger systems. Hydrographs created in RUNOFF are input via an interface file into EXTRAN and then routed. Flow diversions can be modeled using orifice or weirs. Pump stations are modeled using pump data information such as on/off elevations and pump curves.

3.2.3 DESCRIPTION OF MODELED AREA

The majority of the combined areas in Northern Kentucky are located within the cities of Covington, Newport, Bellevue and Dayton. There also are some combined areas in Park Hills, Woodlawn and Ludlow. There are two major combined sewer interceptors in Campbell County, the Ohio River Interceptor (ORI) and the Metropolitan Outfall Sewer (MOS). The ORI is located along the south bank of the Ohio River. The MOS line follows an unnamed creek and connects to the ORI in Bellevue. The separate sewer areas in northern Campbell County flow into the combined sewer system at three different locations. The eastern section is pumped via Silver Grove and Highland Heights pump stations to the ORI. The northern section flows by gravity into the MOS line and then into the ORI. The central section flows through the Three Mile Interceptor by gravity to a river crossing located at the Licking River and then discharges into the Licking River Interceptor (LRI). A majority of the separate sewer areas in Campbell County have severe infiltration and inflow (I/I) problems during rain events. During a rain event, many SSO bypasses and overflows will occur due to the excessive amount of I/I, which enters the system.

The three major combined sewer interceptors located in Kenton County include the continuation of the ORI from Campbell County, the LRI and the Willow Run Interceptor (WRI). The LRI runs along the west bank of the Licking River and includes three combined sewer pump stations; Banklick, Patton Street and Eighth Street pump stations. These pump stations can be major sources of bypassing when pump station capacity is exceeded or when the system is flooded during high river stages. The WRI services Park Hills and a portion of Covington. Unlike the ORI and the LRI, the combined system for the WRI does not have many individual CSO locations. Instead, the combined flow is collected in one pipe and separation of dry weather and wet weather flow in the upstream portion of the system occurs at a large diversion dam. The wet weather flow is transported to the Ohio River through a large diameter overflow pipe. To transport the flow for such a large area, the overflow pipe diameter is a maximum of eight feet. Overflow is also stored in a large detention basin near I-71/75 in Park Hills. Several areas in Park Hills have both separate and combined sewers in the same sewershed.

The separate sewer areas in the communities of Fort Wright, Fort Mitchell and portions of Villa Hills located in Kenton County, discharge into the ORI immediately upstream of the Bromley Pump Station. This area also experiences some I/I related problems during rain events. Another separate area that discharges into a combined area is located on the south bank of the Banklick Creek. The extent of the I/I problems in these basins is not known because they were not monitored as part of the data collection for calibration in 1995 or 1996. See Figure 3-7 for a map of the combined, separate and mixed sewersheds.

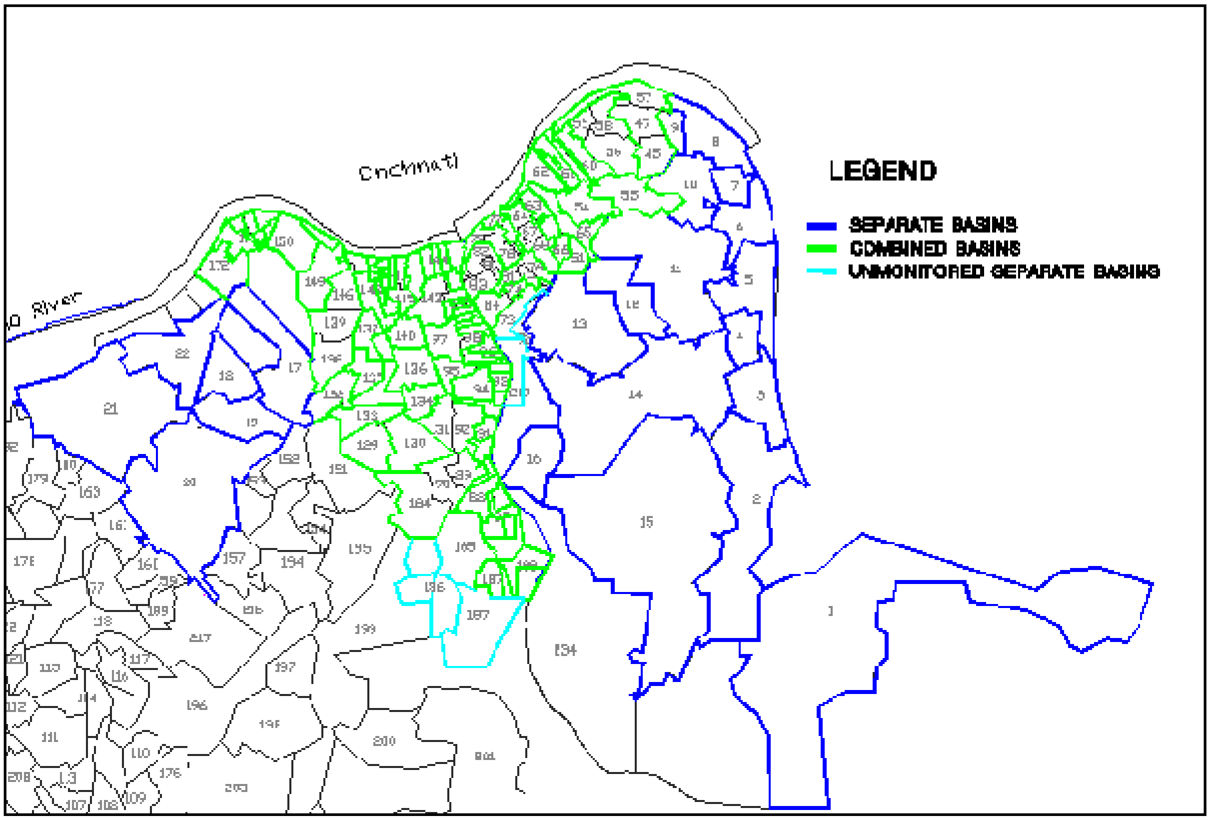


Figure 3-7. Sanitation District No. 1 Sewersheds

3.2.4 DRY WEATHER FLOW

The dry weather base flow is entered into the CSO model using the "Sewer Inputs" option in TRANSPORT and the "User Inflow" option in EXTRAN. In the combined areas, the dry weather base flow makes up a small percentage of the total combined sewer flow during a rain event. Therefore, the dry weather flow was entered as a constant flow rate for the duration of the model simulation.

The 1995 flow monitor results were used to estimate the dry weather flow from the separate areas and then matched with the 1996 flow monitor results that were placed on the combined sewer interceptors. It turns out that the sum of the average daily flows from the 1995 monitoring results were greater than the 1996 monitoring results on the interceptor. The average daily flow from the 1996 monitor was used and divided among the inflow nodes according to the 1995 percentage of flow. A custom software application, XP-SWMM Management System (XMS), was used in several locations that had no monitoring data to estimate the amount of dry weather flow generated from a particular sewershed. Dry weather flows were estimated using unit hydrographs for commercial, public, and residential land uses. Flows generated by XMS were also adjusted proportionally to match the metered data from the 1996 monitors. The total dry weather base flow to Bromley Pump Station is 23 cfs or approximately 15 mgd.

3.2.5 SEPARATE SEWER AREAS

Wet weather flows from separate sewer areas, located upstream of the combined areas, were calibrated separately from the monitored CSO locations. The 1995 flow monitoring of separate sewer areas provided a large amount of wet weather data to be used for calibrating separate areas. Separate sewer areas were lumped together into large drainage basins to reduce the number of meters that had to be calibrated. Combining the separate sewersheds into large drainage basins did not add a significant amount of error due to the relatively small amount of flow generated in the separate areas during wet weather events. Table 3-5 shows the new separate sewer basins, their included sewersheds and the meters that were used in the 1995 monitoring. The sewershed numbers correspond to the numbers shown on Figure 3-7.

Table 3-5. Separate Sewer Areas, Sewersheds and Meters

Separate Sewer Area	Sewersheds	**Meter(s)**
1	1, 2, 190, 192 & 215	3, 18 & 19
2	4-7, 12 & 13	6 & 7
3	3, 20, 21 & 85	13
4	28 & 29	20
5	30 & 31	28
6	32 & 33	27
7	35	31
8	36	None
9	46	None
10	39, 44 & 100	34
11	37, 38, 40, 41, 53, 99, 101 & 102	49
12	42 & 52	48
13	48-50, 69-71	47
14	15C, 18, 19, 22-27 & 193	64
15	8-11, 16 & 17	65
16	86	None
17	169 & 170	114
18	168	109

Separate Sewer Area	Sewersheds	Meter(s)
19	167	108
20	155, 156, 158, 162 164B, 165 & 166	105
21	164A, 181 & 229	130
22	173C	None

The 1995 data was used to generate four individual, rain-affected I/I hydrographs for each separate sewer area. The rain-affected I/I hydrographs were generated by subtracting the base dry-weather hydrograph from the monitored flow during each rain event. The base dry weather hydrograph is defined as the average hourly dry weather flows recorded during the dry weather period of the 1995 monitoring. The rain-affected hydrograph represents the amount of flow, above the dry weather base flow, entering the separate sewer system during and immediately after a rain event. The monitored flow rates and rainfall values, taken during the 1995 monitoring period, were summarized using hourly averages.

The difference between the dry-weather base flow and the monitored flows during a rain event is the rain-affected I/I hydrograph from the monitored basin. Figure 3-8 shows the dry-weather base flow as compared to the monitored flows from separate sewer area #13 for the rain event on May 24, 1995.

Figure 3-9 shows the difference between the dry weather base flow and monitored flows during the rain event. This is the rain-affected I/I hydrograph for the May 24 storm. Only the flow directly attributable to the rain event, hour 45 through hour 75, was used in the calibration. The rain-affected hydrographs from four, selected storm events were used in the calibration of each separate sewer area.

Several good storm events were captured during the 1995 monitoring period, from the end of April through May and June 1995. The rain events used in the calibration included April 23, May 1, May 9, May 13-14, May 17-18, and May 24. An attempt was made to choose four different types of storms to get a diverse sample of rain-affected hydrographs. The four best storms of this group were used in the calibration of a particular sewershed.

The calibration of each separate sewer area was performed through a trial and error process. An external rainfall data file was created with the rainfall records of all four storm events. The rainfall data file was created by evenly spacing the four storms over a 12-day period. The rain-affected hydrograph for each of the four storms was created. The four rain-affected hydrographs were entered into a monitored data file for use in XP-SWMM. The RUNOFF module was loaded with the total catchment area and catchment slope as determined from topographic maps of the catchment. A best estimate of the percent imperviousness and catchment width was made for the first simulation. After the simulation was run, the modeled output was compared to the

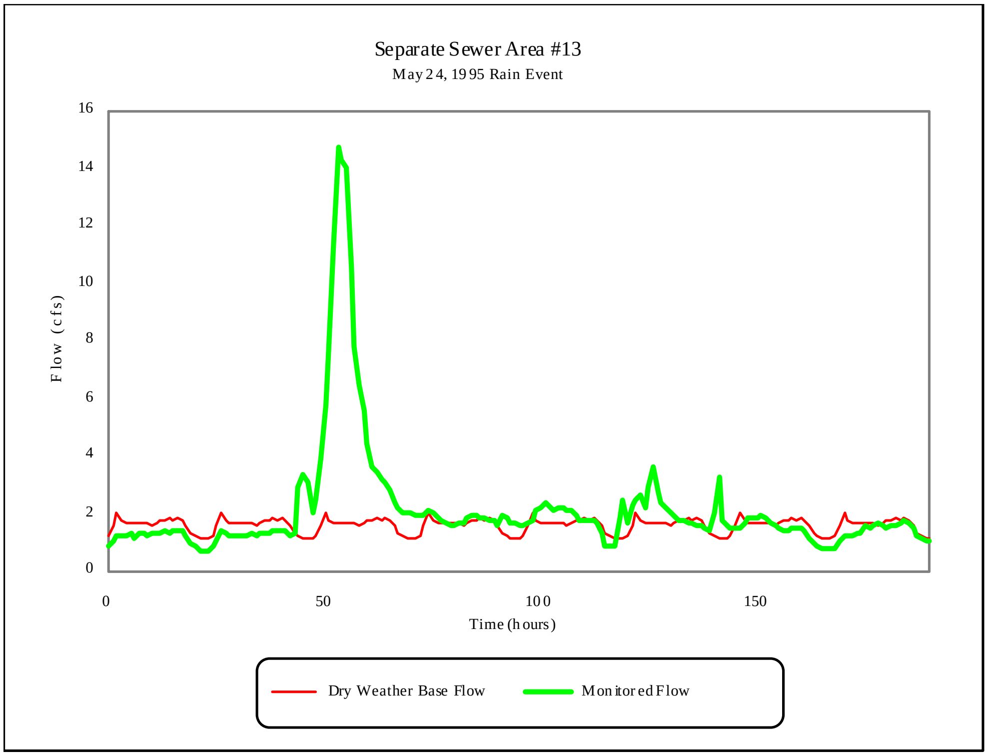


Figure 3-8. Base Flow and Monitored Flow Comparison

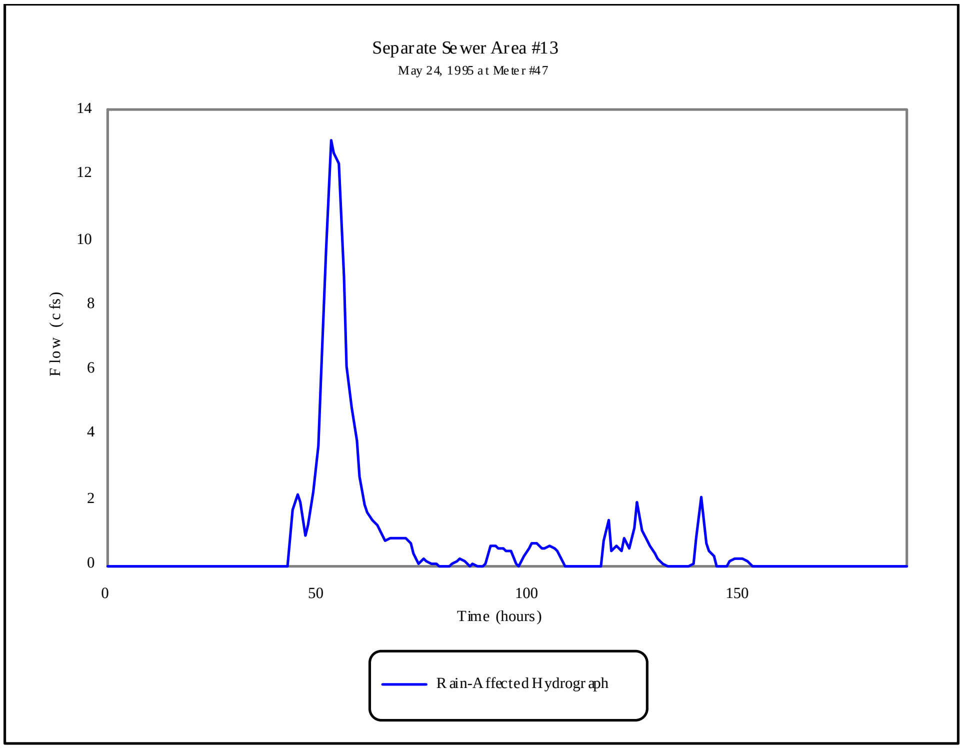


Figure 3-9. Base Flow Separation from Monitored Flow

monitored data, and the percent imperviousness and width were changed until the modeled output best represented the monitored data. The goal of the calibration was to provide the most accurate representation of the monitored data, taking into account the total volume and peak flow rate. However, due to the effects of antecedent conditions and rainfall variability, sometimes it was necessary to disregard a storm event and calibrate the area using only three storm events.

The results of the calibration show that the final percent imperviousness values were in the range of 2%-10%. The percent imperviousness parameters indicate the relative amount of inflow sources directly connected to the separate sewer system. These types of sources behave like storm drainage systems because the flow enters the system quickly and creates peak flows that occur rapidly. In essence, the calibrated percent imperviousness value represents the total amount of area that is directly connected via inflow sources to the separate sewer.

Width is an indicator of the amount of infiltration sources present in a separate sewer area. The shorter the width, the more likely it is that a basin has infiltration problems. As discussed earlier, a short width not only will increase the time to peak, but also will increase the duration of the rain-affected hydrograph. Entering a shorter width into RUNOFF will stretch the inflow hydrograph and allow the hydrograph to represent those infiltration sources not directly connected to the separate sewer system.

It is important to remember that the calculations performed within the RUNOFF module were designed to generate a surface runoff hydrograph for a catchment that is connected to a storm water drainage system. Separate sewer systems are not storm water drainage systems. Because RUNOFF was used to model wet weather flows in a separate sewer, the calibrated percent impervious and width parameters do not represent actual, measured values. These parameters were changed to empirically represent the quantity of I/I that makes its way into the separate sewer system during a rain event.

3.2.5.a SILVER GROVE AND HIGHLAND HEIGHTS PUMP STATIONS

Two separate sewer pump stations lay within the study area. Both pump stations, Silver Grove and Highland Heights, are located in eastern Campbell County near the Ohio River. The Silver Grove Pump Station pumps directly into the wet well at Highland Heights Pump Station. Highland Heights then pumps through a 14-inch force main for approximately three miles and then discharges into the ORI. There are four locations along the force main where gravity lines from separate sewer areas enter the 14-inch-diameter force main. Each location has a large elevation difference between the last manhole on the gravity line and the junction with the force main. An overflow pipe was installed at each of the four manholes located at the end of the gravity line. The large elevation difference between the gravity line and the force main prevents overflow when the pump station is operating during dry weather.

The Silver Grove Pump Station data sheet indicates that an overflow pipe previously existed at the wet well but was sealed. A bypass at the Highland Heights Pump Station is assumed to flow from the two overflow pipes located at the wet well.

3.2.5.b UNMONITORED SEPARATE AREAS

As displayed in Table 3-5, several separate sewersheds were initially classified as combined areas during 1995 monitoring and were not metered. Further investigation as a part of CSO model construction indicated that several areas are entirely separate or are a mixture of separate and combined sewers. Several sources of information were used to determine if a basin contains separate, combined or mixed sewer lines. One source of information was the smoke testing data performed as part of the sanitary sewer evaluation study (SSES) program in 1995 and 1996. Basin 187 was determined to be separate based on the smoke testing data performed in that area. Another source of information was the Northern Kentucky Sanitation District No. 1 GIS maps, showing whether or not catch basins were connected to manholes as well as the existence of storm sewers in the basin. Basin 54 was determined to be mixed in some areas based upon the existence or non-existence of catch basins. The third source of information was Sanitation District No. 1 personnel who provided comments on suspected areas that could not easily be classified.

For those basins determined to be completely separate but were not included in 1995 monitoring, no calibration data was available and a best estimate of percent impervious had to be made. The percent imperviousness for these unmonitored, separate basins was assumed to be 3%. The sewersheds determined to have some separate and some combined were divided in half and the proper percent imperviousness and width parameters were added to the combined and separate areas.

3.2.6 COMBINED SEWER AREAS

Instead of creating large drainage basins similar to the separate areas, every connection to the modeled interceptor was entered as an inflow node in RUNOFF. This was done to improve model accuracy and to provide the option of modeling every CSO located in the study area. The calibration of the individual CSO structures was based entirely on the CSO monitoring performed by Pitometer in 1995. Fifteen meters were placed on the largest CSO outfall pipes located in both Campbell and Kenton counties. CSO calibration was similar to the process used to calibrate separate sewer areas.

3.2.6.a CATCHMENT PARAMETERS

The area of the catchment was considered to be the entire sewershed area. It was not adjusted for overland flow discharging directly into a stream or creek without entering the combined sewer pipes. Slope was calculated by tracing the total flow path on the watershed base map and taking the difference in elevations at 10% and 85% of the total distance and dividing by the total distance. The Mannings roughness coefficient used was 0.013.

The percent imperviousness parameter for all catchments in the combined sewer area was calculated. To aid in the calculation, a land use map developed in GIS was used to generate the individual land use areas for each sewershed. The GIS map divided the study area into several different land use categories such as low density residential, high density residential, low density public, high density public, commercial, industrial, agricultural and open space. Table 3-6 illustrates the actual percent imperviousness values used to calculate the composite percent imperviousness for use in RUNOFF. The selection of average percent imperviousness values for each land use type was made using values published in Soil Conservation Service TR-55.

Table 3-6. Percent Imperviousness for the Land Use Categories

GIS Land Use Type	**Percent Imperviousness**
Low Density Residential	35%
High Density Residential	65%
Low Density Public	5%
High Density Public	30%
Commercial	80%
Industrial	70%
Agricultural	0%
Open Space	0%

Low density residential land use type was the most common land use found within the combined sewer area. The value of 35% was determined from the assumption that the lot sizes were between 1/4 and 1/3 of an acre. Several residential areas in the CSO model were selected for further examination to verify the accuracy of the low density residential percent imperviousness value. Four sample areas were selected and the average percent impervious for the four selected areas was 38%.

Catchment width was calculated by dividing the total catchment area by the total flow path from the furthest upstream location of the catchment. The total flow path length was measured from GIS topographic maps of the study area.

3.2.6.b CSO REGULATORS

A majority of the CSO regulators in the Northern Kentucky area, especially along the Licking River in Kenton County, are leaping weirs. Information on all of the regulators can be found in the *CSO Data Collection Summary Report*, December 1996. These structures consist of a stainless steel plate located in the bottom of the combined sewer which can be adjusted to regulate the amount of flow diverted to the interceptor. During wet weather events, larger flows tend to pass over the plate opening due to higher velocities and are discharged to a receiving stream. The only data available on these structures are the plate opening dimensions, the combined sewer inflow pipe diameter, and the outfall pipe diameter. The maximum flow capacity that enters the interceptor before it leaps over the plate opening was calculated. The leaping weir CSO regulators were modeled as bottom opening orifice structures. Since the orifice equation does not accurately represent leaping weir hydraulics, the discharge coefficient ($C_{d)}$ was modified based on the ratio of leaping weir flow to orifice flow.

The other CSO structures, such as dams or sluice gates, were entered in EXTRAN with data as found in the field. For the TRANSPORT module these structures were examined in EXTRAN on an individual basis to determine the CSO capacity. Flow was ramped into the structure to determine the flow rate at which bypassing occurred. More unique structures had to be simplified and the flow capacity estimated using basic hydraulic equations, such as the weir equation, to estimate the CSO structure capacity for the TRANSPORT module.

At manhole 036018 is a 21-inch-diameter, elevated overflow pipe that serves to relieve the flow from the interceptor. Another constriction point on the interceptor is located along the Licking River between the Banklick and Patton Street pump stations. The 24-inch-diameter LRI begins to surcharge at approximately eight cfs, based on a ramping performed in EXTRAN. The flow begins to back up, triggering an overflow at manhole 087019. A flow split is already in place for the elevated overflow pipe at manhole 087019, therefore the interceptor regulator conduit was named L0870192.

As described in Section 3.2.3, the Willow Run outfall sewer is regulated in the upstream portion with a large diversion structure consisting of a dam with grit chamber. It provides the means for intercepting dry weather flow. The dam runs perpendicular to the flow and has a crest elevation of 470.62. The grit wall acts as a side flow weir with an elevation of 470.12 which controls the amount of flow into a 30-inch-diameter sanitary pipe. The weir length of the grit chamber wall is 7’11” tall eight inches thick.

Interceptor surcharges and bypasses at some of the CSO regulator locations complicates the calculation of CSO capacity. In effect, there could be two capacity values for a given CSO: its “design capacity” and its “hydraulic capacity.” The design capacity is determined using the methods outlined above without taking into account the effects of surcharging in the interceptor. The hydraulic capacity takes into account the interceptor and its effect on the flow direction and amount of bypassing at a particular CSO location. For example, the design capacity of a CSO regulator structure may be determined to be 3.0 cfs. However, the flow through the regulator structure never reaches its design capacity because the interceptor surcharges and overflows at that location before the structure can reach its design capacity. This is extremely difficult scenario to represent in TRANSPORT because it cannot model pressure flow conditions. The condition with the interceptor surcharge affecting the CSO regulator discharge was modeled in the EXTRAN module.

To model these conditions in TRANSPORT, it was decided to enter the design capacity at each CSO location regardless of the impact the interceptor has on its hydraulic capacity. The resize conduit option is utilized in TRANSPORT to eliminate any of the surcharged conditions in the model. Then interceptor regulators were entered in the TRANSPORT module along sections of the interceptor, such as pump stations and choke points, where the hydraulic capacity was known. The assumption is that any flow that is bypassed at these interceptor regulator points would have been lost via the CSOs or through manhole overflows further upstream. This assumption eliminates the spatial accuracy of the overflow locations, but is accurate in terms of the total bypassed volume. The effect of this assumption is negligible in areas where the interceptor regulators are close enough together that they do not affect the loading location in the receiving stream model. The stream model is broken into model segments where the loadings are added. In fact, at each interceptor regulator location on the Licking River and Banklick Creek, the bypassed volume is added into the same river model segment regardless of where the actual overflow occurs. This was true for both the EXTRAN and TRANSPORT modules.

3.2.7 PUMP STATIONS

Five combined sewer pump stations in the CSO model: Banklick, Patton Street, Eighth Street, Second Street and Bromley. TRANSPORT is capable of modeling pump stations based on wet well volumes; however it was decided to represent the pump stations as a flow diverter with a fixed capacity. To represent these pump stations in the TRANSPORT module as constrictions to flow, it was necessary to determine the maximum capacity of each pump station in the study area. This was accomplished by analyzing the pumping characteristics of each station. A system curve was developed for each station and a simple analysis between it and the pump curve determined the maximum amount of flow that could be pumped from each station.

In the EXTRAN module, pump stations were modeled using pump curve data and pump on/off elevations. This information was obtained from Sanitation District No. 1 personnel and site visits. During high river stage at elevation 470.5, the Bromley, Second Street, Eigth Street, and Patton Street pump stations are shutdown to minimize the amount of river water entering the sanitary sewer interceptor. This condition was modeled in XP-SWMM by placing a dummy valve on the influent pipe. The dummy valve was closed during the days with a river stage of 470.5 during the continuous simulation for the typical rainfall year. For the year 1971, this condition occurred on 22 days, but only nine of those days had significant rainfall

Once the pump station capacity at Patton Street and Eighth Street was exceeded, the excess flow was bypassed at the pump station and discharged directly to the Licking River. There also were several CSO locations which may have overflowed due to the backwater created by the pump station. Once the capacity of Banklick pump station is exceeded the excess flow backs up in the gravity line leading to the pump station and overflows at manhole 185140 or at the Church Street CSO (manhole 185150). A dummy overflow pipe to Banklick Creek was created at manhole 185140 because of the large volume of surcharged flow. The flow that cannot be pumped at the Second Street pump station is bypassed at either 064084 or at the 4th Street Chamber (manhole 079007).

Bromley pump station is different than the other combined sewer pump stations. There are four pumps at the Bromley pump station. Two are variable speed pumps rated at 20,000 GPM and two are constant speed pumps rated at 6,500 GPM. Under normal conditions only one of the variable speed pumps is running. Occasionally, one variable speed pump and one constant speed pump will run at the same time during high flows. The two variable speed pumps are not designed to operate simultaneously because this would overwhelm the Dry Creek WWTP.

Bypassing can occur from the influent chamber of the pump station. There are several CSOs that will be activated before the influent chamber wastewater level is high enough to cause an overflow. The overflow at the influent chamber at Bromley Pump Station is at elevation 473. There are seven CSOs located upstream of Bromley which have invert elevations lower than elevation 473.

3.2.8 CALIBRATION RESULTS

3.2.8.a CSO CALIBRATION

The RUNOFF portion of the CSO model was calibrated by adjusting parameters such as percent imperviousness and width. TRANSPORT was run and results were compared to monitored values in the outfall link. Some of the regulator parameters were modified to calibrate the TRANSPORT module. Since the RUNOFF module was already calibrated using TRANSPORT, the RUNOFF parameters were not recalibrated when the EXTRAN module was later used to determine the overflow volumes for the typical year.

A large amount of flow monitoring data was available for use in the calibration of individual CSO locations. There were 15 monitors in place from September to early November of 1995 and 5 monitors in place from June to September 1996. The five monitors in 1996 were located at the same CSO locations monitored in 1995. Table 3-7 summarizes the meter numbers and locations in 1995 and 1996.

Table 3-7. Meter Location and Meter Number

CSO Name	District ID	1995 Meter	1996 Meter
Lagoon Street	172-005	1	None
4th Street	148-108	2	None
8th and Philadelphia	148-129	3	None
Dalton Street	148-123	4	None
Main Street	147-052	5	3
Johnson Street	147-072	6	None
Washington Ave. Chamber	064-084	7	4
Riverside Drive	063-001	8	None
4th Street Chamber	079-007	9	5
Twelfth Street & Lowell Street	073-009 & 028	10	2
Seventeenth Street	093-026	11	None
Oakland and Florist, Eastern Ave (3)	091-005, 25, 27 & 31	12	None

CSO Name	District ID	1995 Meter	1996 Meter
Ashland Oil	091-064	13	None
Church Street-West, East & North	185-024, 32 & 150	14	1
DeCoursey Avenue	187-025	15	None

The first step in the calibration of the CSO locations was to determine the "capacity" of each CSO regulator. The capacity of the CSO is defined as the amount of flow that may enter the CSO regulator through the combined sewer line before it begins to bypass. In many cases, there was a lack of adequate data needed to perform an in-depth hydraulic analysis of each CSO structure. At some locations the lateral line which connects the CSO to the interceptor was the controlling factor in determining the amount of flow that may have entered the interceptor. If this was the case, the CSO capacity was set equal to the capacity of the lateral pipe in the TRANSPORT module. For the EXTRAN module, the CSO structure input used the actual diversion data and pipe sizes.

Once the CSO regulator capacity was determined for each location, the calibration to the 1995 and 1996 meters was quite simple. Unlike separate sewer areas, the RUNOFF input parameters were estimated easily because RUNOFF was designed to model these types of systems. To calibrate an individual CSO, the catchment parameters were entered into RUNOFF and the weir capacity was set in TRANSPORT using the flow divider option. The flow divider allowed only the specified amount of flow to pass through the lateral link before it begins to divert flow to the outfall link. Five storms were chosen from the 1995 monitoring period to be used in the calibration. These rain events were September 12, September 13, September 20, October 5, October 20 and November 1. The XP-SWMM simulation was set up to run the five storms consecutively over a period of 2 days. After running the simulation, the modeled flow values were compared to the monitored flow values in the outfall link. Similar to the separate sewer calibration, the results were examined to determine if the modeled flow accurately represented the monitored results, taking into account the peak flow rate and total overflow volume. The width and percent imperviousness were changed to achieve the best overall calibration for all five storm events.

3.2.8.b 1995 CSO MONITORING

The 1995 CSO monitoring involved 15 flow monitors and five rain gages located throughout northern Campbell and Kenton Counties. Several meters required some explanation of the data and the results. If no comments were made, the meter calibrated well and the percent imperviousness and width estimates were used. The comments for individual flow meters from the 1995 CSO calibration are listed below.

Meter 1: The estimate of percent imperviousness and width were used at this location. There did not appear to be good correlation between the large storms and the smaller ones. No changes were made because the smaller storms appeared to calibrate fairly well. The smaller storms were identified as being more important than the larger storms in terms of long term simulation results.

Meter 3: The monitored flow for the five storms varied dramatically. The October 5 storm displayed a tendency to bypass for an extended period of time with a relatively low peak flow. The smaller storms, while more intense, did not display the characteristics shown in the longer storm. This meter was also a very small drainage area which decreases the accuracy of the estimated parameters.

Meter 4: The monitored flows at this location never exceeded 0.2 cfs. No calibration was performed at this location.

Meter 8: The monitored flows at this location did not fit the volume of flows which were calculated using XP-SWMM. There was some indication that the upstream area originally assigned to this CSO may actually be flowing into 064-084. Therefore, sewershed 66 was subtracted from 063-002 and added to 064-084 and the calibration was much better.

Meter 12: The sewer maps of this area indicate that 195 acres of residential area are located upstream of this monitoring location. The meter reconnaissance sheet provided by Pitometer indicated that the meter was properly installed downstream of manhole 091-018 in the 60-inch-diameter outfall pipe. The monitored flows from this meter were much too small to be generated by this large area. It was assumed that these flows could not possibly be correct. The monitored data was disregarded and the estimated percent imperviousness and width were used to generate the runoff hydrographs.

Meter 13: The monitored flow at this location indicated that overflow continues for sometime after the rainfall has stopped. To accurately represent this in RUNOFF, the catchment width was decreased to increase the time to peak and duration of runoff.

3.2.8.c 1996 CSO MONITORING

The 1996 CSO monitoring included five selected sites which were also monitored in 1995. To verify the results of the 1995 calibration, the same catchment parameters were used and RUNOFF was loaded with the 1996 rainfall data. At four of the five locations, the correlation between the 1995 and 1996 monitored results was very good. Those meter locations are at Twelfth Street and Lowell Street, Main Street, the Washington Avenue Chamber, and the 4th Street Chamber. The results from the Church Street meter location indicated that dramatically less flow was bypassed in 1996 as compared to 1995. After some investigation, it was determined that the 1996 flow meter was not placed in the same location as the 1995 flow meter. The 1995 meter was located in the proper location in the 60” diameter outfall pipe while the 1996 meter was not placed to receive the overflow from two downstream CSOs that discharge to the same outfall pipe. The 1995 calibration was used in the CSO model.

3.2.8.d 1996 SHORT TERM INTERCEPTOR MONITORING

Several meters were placed on the combined sewer interceptor for a short period in 1996. The meters were not in place long enough to allow for a calibration of the interceptor but the results were used to verify flows. Meter 27 was located downstream of the Second Street Pump Station and indicated that for three of the monitored storms, the flow did not exceed 14 cfs. Meter 16 was located downstream of the 4th Street Chamber and indicated that the flow did not exceed 4 cfs. Meter 28 was located in the combined line which enters manhole 147003. This is the only location where the flow into a CSO pipe was monitored. A calibration check was run in the TRANSPORT module on this location and the results showed a good correlation between the modeled and monitored flows for this small catchment area.

3.2.8.e WET WEATHER CALIBRATION STORM EVENTS

Four storms from 1996 were chosen to generate loads for the Licking River to calibrate the stream model. The storm events which were used include July 14th, July 29th and 30th, September 9th and September 29th. Three rain gages were in place during the 1996 CSO monitoring. Each catchment was assigned to the proper rain gauge.

Once the rainfall data files were created, an XP-SWMM simulation was run to generate a summary output file for each of the CSO outfall links. The results from the 1996 flow monitors were compared to the results of the simulation for each storm event. As stated earlier, the monitor at the Church Street CSO was not properly installed so it is not possible to compare the modeled to the monitored values for this location. Table 4-8 compares the total monitored overflow volume versus the total modeled overflow volume for each one of the four storm events. The actual calibration was performed on the 1995 data, not the 1996 storms. Consequently, these results illustrate the ability of the model to represent the overflow volumes for four randomly selected storms from 1996.

Table 3-8. Monitored and Modeled Overflow Volumes

Storm Event	Monitored Volume	Modeled Volume	% Error
July 14, 1996	407,000 ft^3	440,000 ft^3	+8%
July 29 and 30, 1996	456,600 ft^3	545,000 ft^3	+6%
September 9, 1996	115,000 ft^3	93,000 ft^3	-23%
September 16, 1996	1,453,000 ft^3	1,433,000 ft^3	-1%

The large percent error on the September 9 storm may have been caused by the lost data at the 4th Street chamber. The percent error for the September 9 storm event was based only on the monitoring data from the three remaining CSO sites. It also appears that the larger storms tended to calibrate better than the smaller storms.

3.2.8.f WET WEATHER CALIBRATION FOR CONTINUOUS SIMULATION

Another goal of the model was to estimate the number of overflow occurrences and overflow volume from individual CSOs over a long period of time. The year long or continuous simulations were much more complex than the event storm calibrations. Parameters such as evaporation, infiltration and depression storage entered into the calibration. Instead of placing four or five storms back to back to get a good estimate of the overflow volume, every storm event recorded on the meter was included in the calibration. The model was set up to run using the rainfall record and monitored data from the entire 1995 and 1996 monitoring periods.

In the event storm calibration, the infiltration parameters were kept constant because they have little impact on single storm events. For the continuous simulation, the infiltration parameters were a key part of the calibration because of their ability to either over estimate or under estimate the smaller storms. The default infiltration parameters used in the single event storm are displayed in Table 3-9.

Table 3-9. Default Infiltration Parameters for the Single Event Storm Model

Infiltration Parameter	Default Value
Depression Storage - Impervious Area	0.078 inches
Manning's "n" - Impervious Area	0.02
Depression Storage - Pervious Area	0.157 inches
Manning's "n" - Pervious Area	0.30
Percent Zero Detention	25
Maximum Infiltration Rate	3.0 inches/hour
Minimum Infiltration Rate	0.15 inches/hour
Decay Rate of Infiltration	0.00083
Regeneration of Horton Infiltration Capacity	0.01

Fifteen meters were in place during the 1995 monitoring period and results for all 15 meters were used in the calibration of the continuous simulation. The event storm calibration values for area, percent imperviousness, width and slope were used initially for the continuous period calibration. The default infiltration parameters listed in Table 4-9 were also used initially. The model was run from September 9, 1995 to November 13, 1995, the amount of time the flow monitors were in place in 1995.

Continuous calibration was performed using the linear regression plots. These plots showed the relationship between total rainfall and overflow volume for each overflow event recorded on a given meter. A linear regression line was drawn through the data points to establish a trend line. The model output was plotted and compared to the monitored data for each of the overflow events recorded on the meter. The total modeled overflow volume was also calculated for each storm event. The modeled overflow volume and corresponding total rainfall was plotted on the same graph that was generated using the monitored data. A linear regression was performed on the modeled data and compared to the trend line from the monitored data. Figure 4-10 shows the monitored data overlaid with the modeled data points for the Church Street CSO location.

Calibration was performed by changing one or more of the following parameters; area, percent imperviousness, width, depression storage and percent zero detention. After each iteration of the model run, the data was plotted to compare the results. As a rule of thumb, if a smaller storm was not generating overflow, then the depression storage was decreased and the percent zero detention was increased. If the slope of the line was too steep, then the percent imperviousness was decreased to match the monitored data. If the percent imperviousness was outside an acceptable range, then it was assumed that the catchment area was not properly defined and the area was adjusted as needed. Although the regression plot was a very important tool in the calibration, the hydrographs for each storm event were also plotted to make sure that the shapes of the hydrographs were similar to the monitored data. This check was a secondary type calibration that was usually helpful in determining which parameter needed to be changed in the next iteration. Table 3-10 summarizes the calibration results for the 1995 monitoring.

Table 3-10. Calibration Results for the 1995 Monitoring Period

CSO Location	**Meter Number**	**1995 Slope**	**1995 Y-Inter**	**Model Slope**	**Model Y-Inter**
Lagoon Street	1	0.55	-0.15	0.56	-0.15
4th Street	2	0.10	-0.03	0.12	-0.04
8th and Philadelphia	3	0.15	-0.03	0.22	-0.05
Dalton Street	4	N/A	N/A	N/A	N/A
Main Street	5	1.00	-0.25	0.99	-0.24
Johnson Street	6	N/A	N/A	N/A	N/A
Washington Ave. Chamber	7	2.11	-0.17	2.44	-0.47
Riverside Drive	8	0.13	-0.04	0.17	-0.07
4th Street Chamber	9	2.10	-0.41	2.67	-0.68
Twelfth Street and Lowell Street	10	0.35	-0.04	0.68	-0.19
Seventeenth Street	11	0.36	-0.05	0.55	-0.16
Oakland and Florist, Eastern Ave (3)	12	N/A	N/A	N/A	N/A
Ashland Oil	13	2.45	-0.06	1.71	0.06
Church Street-West, East & North	14	1.71	-0.50	1.82	-0.50
DeCoursey Avenue	15	0.04	0.01	0.05	0.00

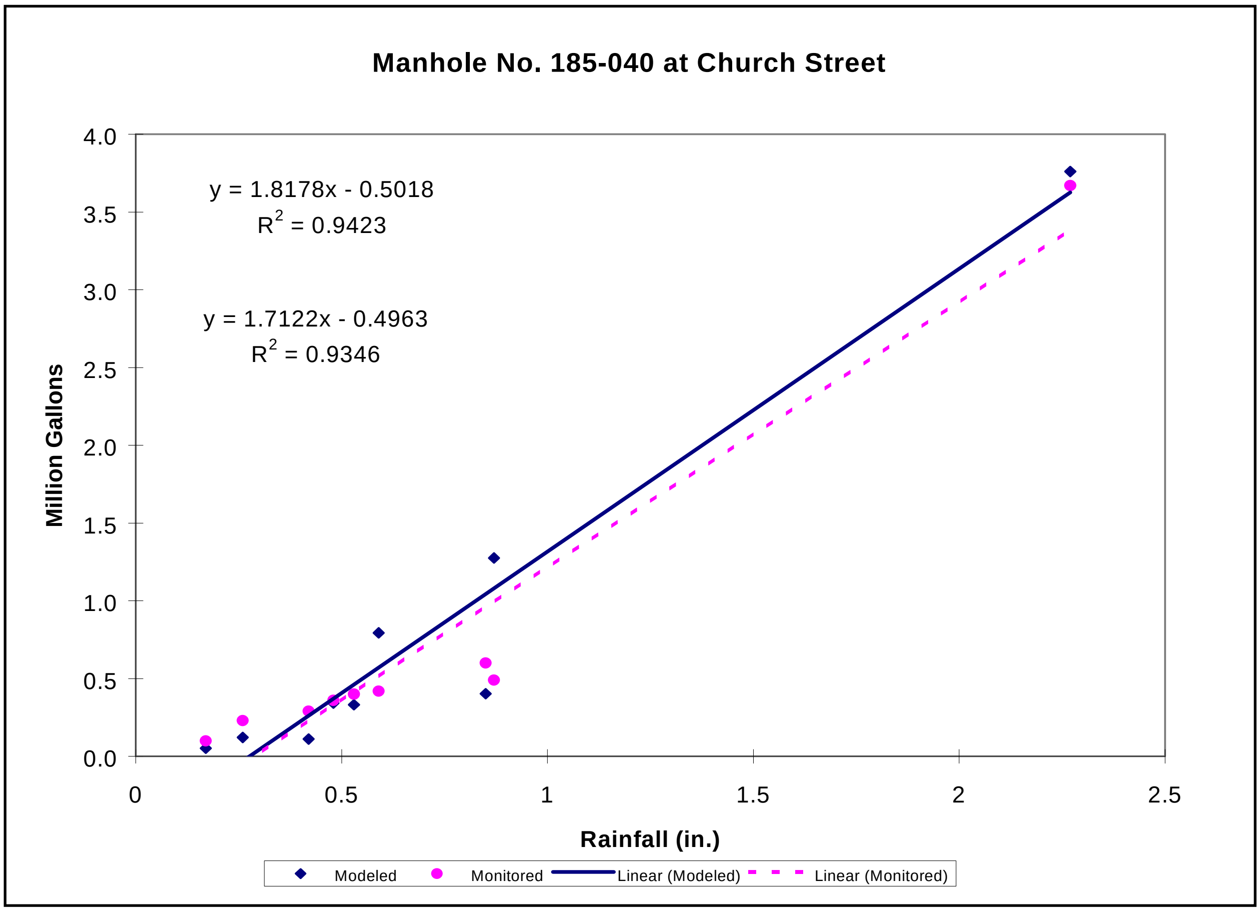


Figure 3-10. Linear Regression of Modeled Data Compared to Monitored Data

4.0 WATER QUALITY MODELING

4.1 INTRODUCTION

This chapter describes the development of the hydrodynamic and water quality models used to assess the water quality impacts of CSOs on the Ohio River in the Cincinnati metropolitan area, which includes portions of northern Kentucky.

Models of receiving waters are needed as assessment tools to provide a causal linkage between the discharge of CSO pollutants and impacts on water quality. They provide complete assessments of water quality conditions than data alone by filling gaps between sampling locations and collection times. The models also provide the capability to forecast relative improvements in water quality conditions resulting from various CSO controls. Water quality models are useful tools for predicting future water quality conditions in response to alternative pollutant loading rates or environmental conditions.

Hydrodynamic models describe the physical movement of water within a river system. Water quality models describe the transport, chemical transformations and degradations of pollutants within the system. Models of the combined sewer system (described in Chapter 4) are used to generate estimates of pollutant loads entering the river system. Pollutant loads from other sources, such as wastewater treatment plants and nonpoint source runoff, are also input into the water quality model. Figure 4-1 illustrates how these models are used together to simulate the Ohio River system studied in this project.

The study area includes the stretch of the Ohio River beginning at river mile 460, which is upstream of the Cincinnati metropolitan area, downstream to Markland Dam at river mile 530. The study area includes inputs from four major tributaries, the Little Miami River, Mill Creek, the Great Miami River, and the Licking River, as well as from the combined sewer areas of the Cincinnati Metropolitan Sewerage District (Cincinnati MSD) and the Sanitation District No. 1 of Northern Kentucky (SD No.1).

This project was initially conceived as a two-year study, funded in large part by the USEPA and ORSANCO. A separate, but coordinated, study by the SD No.1 was also conducted during this time period. The development and application of these models actually occurred over a six-year period, from 1995 through 2001. Unavoidable delays occurred primarily due to quality control problems with data collected in the second year of the project. A consequence of the extended schedule is that the chronology of the model development and application did not occur in a straightforward sequence. However, the key steps in the project process related to the modeling are bulleted below:

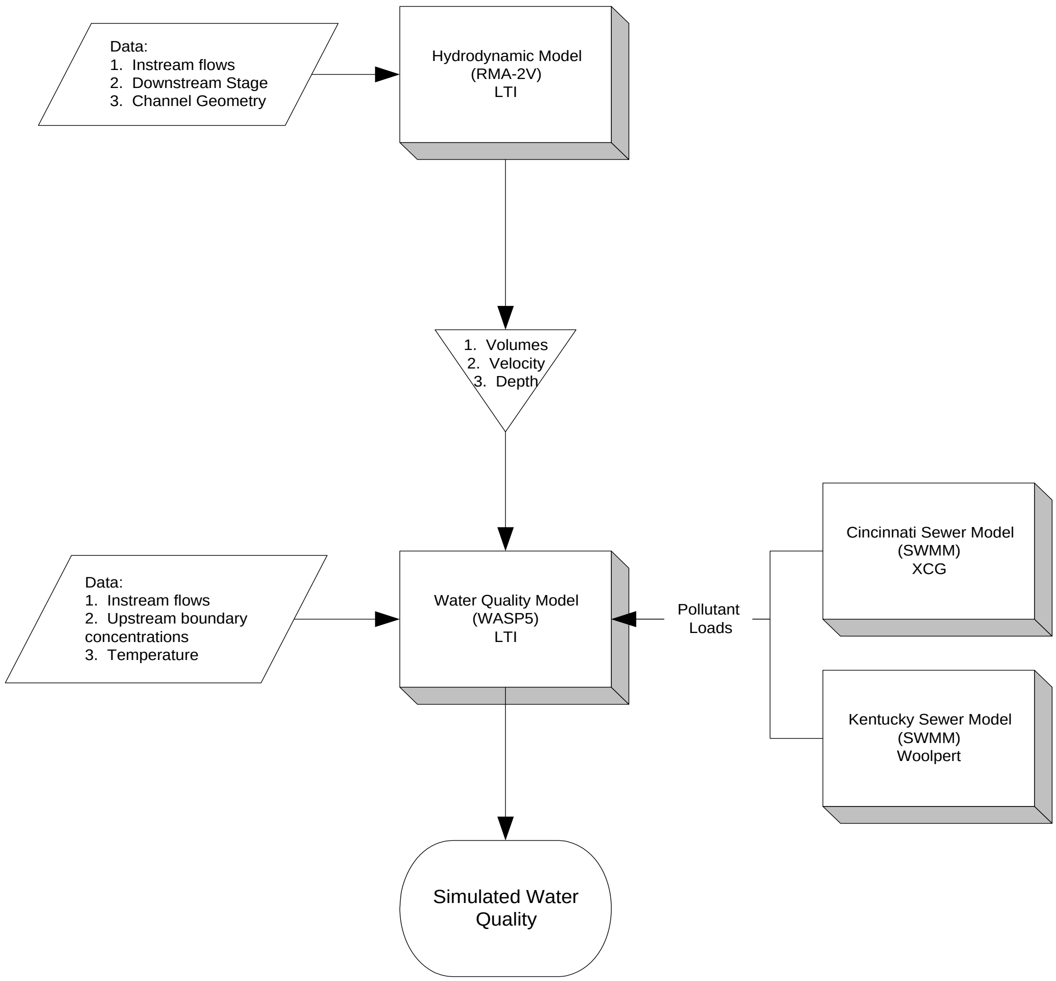


Figure 4-1. Modeling Flow Chart
(and Organization Responsible for Model Application)

1. Year 1 (1995-1996)
- hydrodynamic and water quality models selected;
- two dye surveys conducted;
- four wet weather events sampled;
- data from events used to develop hydrodynamic and water quality models;
- hydrodynamic model calibrated;
- water quality model preliminarily applied for constituents of concern;
- Year 1 report produced;

2. Year 2 (1996-1997)
- Peer review of Year 1 work conducted;
- Two wet weather events sampled and later discarded due to QA/QC problems with the data;
- Responses to peer review, requiring additional modeling with the hydrodynamic model and an evaluation of an alternative water quality model.

3. Sanitation District No. 1 work (1995-1998)
- Sampled dry and wet weather events in 1995-96 in the Licking River and Banklick Creek;
- Extended and modified Ohio River hydrodynamic and water quality models developed under Year 1 work;
- Data from 1996 wet weather events used to calibrate water quality model for Licking River and Banklick Creek;
- Water quality model applied over a "typical" year for Licking River and Banklick Creek;

4. Post-1998 work
- Sampled additional wet weather events in 1999 and 2000. 1999 event not used due to anomalies in antecedent conditions that prevented landside models from simulating the CSO volumes properly;
- Extended the water quality model downstream to Markland Dam at river mile 530;
- Calibrated the Ohio River portion of the water quality model version from Santitation District #1 to the 2000 wet weather event;
- Validated the water quality model to two of the 1995 wet weather events;
- Applied the water quality model to a "typical" year for five loading reduction alternatives;
- Documented the modeling portion of the project in its entirety in this report.

This chapter is organized in three major sections that follow a normal sequence of model development and calibration. First was the selection of the hydrodynamic and water quality models used in this study (Section 4.2). Once the models were selected, the next step was to simulate the movement of water in the system (Section 4.3) using the hydrodynamic model. The hydrodynamic model results were used as inputs into the water quality model, in which the water quality constituents of concern were simulated (Section 4.4). Rather than a chronological description, relevant information over the course of the project is included in each of the chapter sections, which describe:
- Selection of the hydraulic and water quality models;
- Hydrodynamic model development, calibration and application; and
- Water quality model development, calibration and validation.

Figure 4-2 illustrates the steps in model development, calibration and validation for the Ohio River models described in this chapter. Application of the water quality model to evaluate CSO reduction alternatives is presented in Chapter 5.

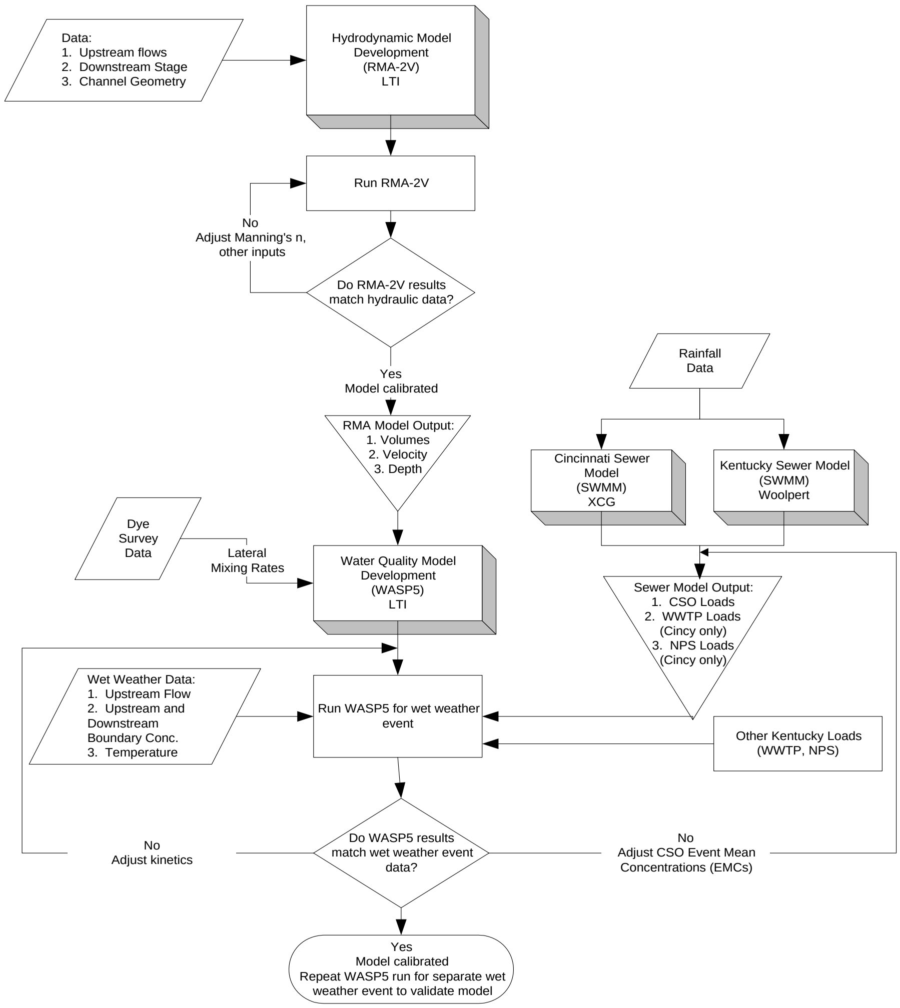


Figure 4-2. Model Development and Calibration

4.2 MODEL SELECTION

A variety of water quality models, ranging from very simple to very complex, are available and have been used in the past to model the Ohio River. Factors considered in selecting a water quality model include: management objectives; project constraints; site-specific characteristics. Specifics on how these factors are incorporated into the model selection process are detailed elsewhere (ORSANCO, 1999). However, primary emphasis in model selection is given to the study's modeling objectives, which can be summarized as follows:

1. Define the parameters that violate water quality standards during wet weather in the Ohio River under present conditions. Parameters considered include fecal coliform, heavy metals and oxygen demanding constituents.
2. Estimate the duration of criteria exceedance for all parameters.

3. Provide a description of the spatial extent (i.e., area) of exceedance.
4. Serve as a template for other wet weather studies in large rivers.

Based upon these objectives, project constraints and site-specific characteristics of the Ohio River, the "Water Quality Analysis Simulation Program" (WASP) was selected for use in this study. This model is supported by the U.S. EPA and has been widely used and demonstrated. It has the capability to simulate all of the parameters of concern in this study, to provide time variable simulations capable of defining the duration of criteria exceedances, and to simulate two-dimensional concentration gradients important in large rivers. The use of the WASP model for this study is described further in Section 4.4.

Because lateral gradients are important in the Ohio River, the U.S. Army Corps of Engineers' hydrodynamic model, RMA-2V, was applied to properly route the water flowing through the river. RMA-2V simulates lateral and longitudinal variability in river hydraulics. The use of the RMA-2V model for this study is described further in Section 4.3. The results from this model were incorporated into the WASP water quality model as described in section 4.4.2.

Other water quality models considered for use in this project include QUAL-2E and CE-QUAL-W2. These were ultimately rejected because of their inability to consider lateral variations in water quality. The water quality companion model to the RMA-2V hydrodynamic model, RMA4, was tested as an alternative model for simulating fecal coliform because of its ability to simulate hydrodynamics and water quality in a single software package. However, it was also rejected for use in this study because it was unable to generate more accurate results than the existing WASP model framework. Achieving more realistic simulations with RMA4 would have required extensive modifications to the existing RMA model grid and artificial adjustments to constituent loading rates.

4.3 HYDRODYNAMIC MODEL

This section describes the development and application of a hydrodynamic model to the Ohio River study area near Cincinnati. The hydrodynamic model used to simulate the flows is the U.S. Army Corps of Engineers' RMA-2V. RMA-2V computes vertically-averaged velocities and water surface elevations in the flow field at specific locations called nodes. All of the nodes comprise the finite element grid, which encompasses the section of the river and floodplain under study. The resolution of the grid is based on the flow field variations and river bathymetry. This model has been extensively studied and applied to many different rivers and estuaries in the United States (Berger, 1990; Lin and Richards, 1993; McAnally et al., 1984; Richards, 1990).

4.3.1 DESCRIPTION

RMA-2V is a two-dimensional, depth-averaged, finite element model that computes velocities and water surface elevations in the flow field. It uses the principles of conservation of mass and conservation of momentum in both the x and y directions. It also computes the dynamic boundary between wet and dry regions in the model. Flow separations and eddies are accurately modeled.

Dependent state variables that the model solves for are the horizontal velocities of flow in the x and y directions (*u* and *v*) and water depth (*h*). Three equations are needed to solve for these three variables.

1. Continuity
$$\frac{\delta h}{\delta t}+\frac{\delta(uh)}{\delta x}+\frac{\delta(vh)}{\delta y}=0$$
2. Momentum in the x-direction (longitudinal)
$$\frac{\delta u}{\delta t}+u\frac{\delta u}{\delta x}+v\frac{\delta u}{\delta y}+g\frac{\delta h}{\delta x}+g\frac{\delta a_o}{\delta x}+C_f q\frac{u}{h}=\frac{1}{\rho}\left(E_{xx}\frac{\delta^2 u}{\delta x^2}+E_{xy}\frac{\delta^2 u}{\delta y^2}\right)$$
3. Momentum in the y-direction (lateral (transverse))
$$\frac{\delta v}{\delta t}+u\frac{\delta v}{\delta x}+v\frac{\delta v}{\delta y}+g\frac{\delta h}{\delta y}+g\frac{\delta a_o}{\delta y}+C_f q\frac{v}{h}=\frac{1}{\rho}\left(E_{yx}\frac{\delta^2 v}{\delta x^2}+E_{yy}\frac{\delta^2 v}{\delta y^2}\right)$$

where:

h	=	water depth
u	=	depth-integrated flow in the x-direction (longitudinal)
v	=	depth-integrated flow in the y-direction (lateral)
x	=	longitudinal distance
y	=	lateral distance
t	=	time
g	=	acceleration due to gravity
a_o	=	bottom elevation
C_f	=	flow roughness coefficient
E_{xx}	=	normal turbulent exchange coefficient in the x direction
E_{xy}	=	tangential turbulent exchange coefficient in the x-direction
E_{yy}	=	normal turbulent exchange coefficient in the y direction
E_{yx}	=	tangential turbulent exchange coefficient in the y direction
□	=	water density
q	=	resultant velocity = $\left(u^2+v^2\right)^{1/2}$

Because the RMA-2V model was run for steady-state conditions, the model actually solved the above equations with the time derivatives equal to zero. Two forces, Coriolis and wind stress, are sometimes included but they are small compared to other river forces, and thus were not included here. A more rigorous description of the governing equations used in the model is available in the user's manual (USACE WES, 1997).

Ohio River hydraulics are controlled by the dams in the river which were constructed to maintain navigation channels for barge traffic while passing the natural flow of the river. Ohio River hydrodynamics near Cincinnati (approximately river mile 460 to river mile 490) are controlled by the downstream Markland Dam, at approximately river mile 530.

The RMA-2V hydrodynamic model was constructed in two phases. The first phase included only the Ohio River and was developed in 1995-96. The spatial extent of the model started at river mile 460 and extended downstream to approximately river mile 490. The downstream boundary of the model is just upstream of the confluence of the Great Miami River and the Ohio River. Thus, the complication of incorporating the effects of the Great Miami River on the hydrodynamics of the Ohio River was eliminated. The largest tributaries in the 30-mile stretch of the modeled river are the Licking River and the Little Miami River, which together comprise less than 2 percent of the Ohio River flow. The hydrodynamic influence of these tributaries was considered insignificant and was neglected in the initial RMA model simulations.

The hydrodynamic model was extended 5.25 miles upstream in the Licking River in 1996-98 for the Sanitation District #1 in Northern Kentucky to facilitate analysis of combined sewer overflows into the Licking River. Simulations of the expanded RMA model captured the hydrodynamic mixing that occurs at the confluence of the Licking River and Ohio River. This version of the model was used for the calibration of the water quality model described in section 4.4.3.

4.3.2 DEVELOPMENT

The input data required by the model include: 1) river dimensions used to develop the model's segmentation; 2) the river's resistance to flow, parameterized as Manning's roughness coefficient, n; and 3) upstream, downstream and side channel boundary conditions (e.g., flows, water surface elevations). The source and development of each of these inputs is described in this section.

Model Segmentation

River geometry data used to define the model grid was derived from two sources. Bathymetry was obtained from cross-sections used by the U.S. Army Corps of Engineers in their modeling of the Ohio River using the HEC-2 hydraulic model. This data provided cross-sections of the river's flow area approximately every 0.75 miles from Markland Dam to Meldahl Dam. However, this data did not specify the plan view orientation of the cross sections. Latitude and longitude for the shape of the river were obtained from the U.S. EPA Reach File Version 3.0. This provided Geographic Information System (GIS) information defining the outline of the riverbanks. To determine how the HEC-2 cross-sections fit the plan view of the river, bank outlines were assumed to correspond to an elevation of 455 feet, the normal pool level of the river (U.S. Army Corps of Engineers, 1995). HEC-2 cross-sections were then placed perpendicular to the bank outlines and positioned so that the assumed bank elevation of 455 feet fit the HEC-2 cross-section.

The RMA-2V model segmentation, or model grid, for the main channel is based on the HEC-2 cross-sections and the U.S. EPA Stream Reach GIS data. The model uses both a six-node triangular and eight-node quadrilateral element scheme to describe the physiography of the Ohio River. There are 1,257 elements in the model grid. Each node is defined by an x-y coordinate and its corresponding elevation. The vertically averaged velocity is calculated at each of these nodes for a given flow and downstream head condition.

The model geometry was checked with Ohio River "pool sheets" containing bathymetric data from the U.S. Army Corps of Engineers. These "pool sheets" give the Ohio River bottom elevations below pool (i.e., below elevation 455 ft) every 0.25 miles and were used to check the elevations of the finite element grid. During calibration, the finite element grid of the river was divided into two sub-grids so that the model could be developed faster and run more easily. Figure 4-3 illustrates the final finite element grid used for the model domain.

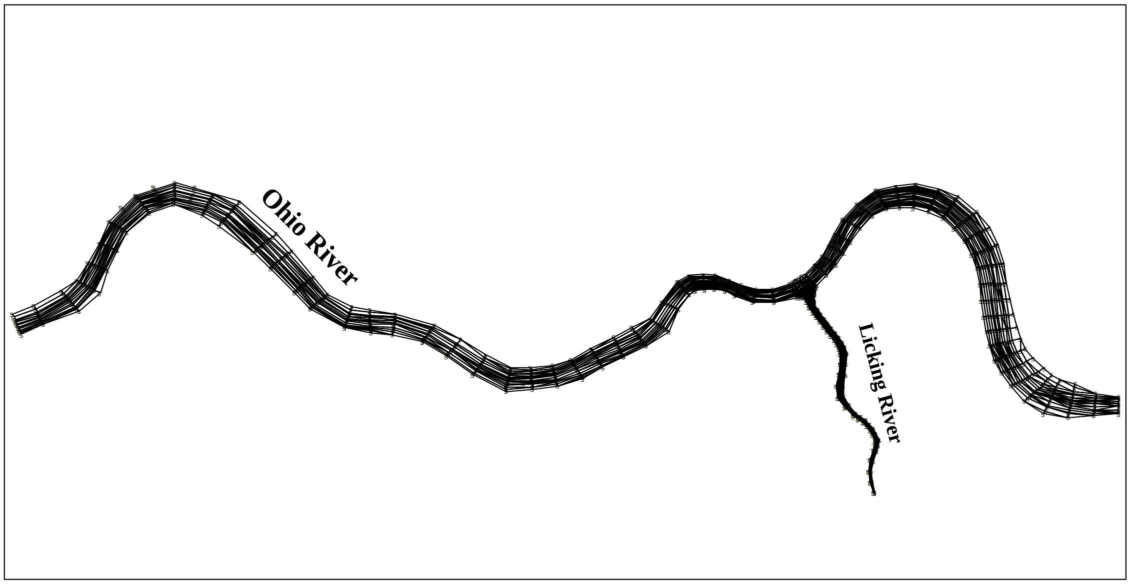


Figure 4-3. RMA-2V Model Grid Domain.

Manning's Roughness Coefficient (n)
The input parameter Manning's 'n' expresses the river's roughness or resistance to flow. Conceptually, the resistance to flow is a function of the sediment characteristics and nature of the flow pathways. It is commonly used as a calibration parameter since its value cannot be accurately determined using measurements of the physical dimensions of the river or from a description of the sediment characteristics. The Manning's 'n' was initially assumed to be 0.03, equal to the value used in the HEC-2 modeling. This value was adjusted during model calibration. The values used for Manning's 'n' are in agreement with those values used by the U.S. Army Corps of Engineers in their HEC-2 modeling.

Boundary Conditions
The flow specified at the upstream boundary is the principal forcing function in the RMA-2V model. The model was developed and refined initially for three different flows: 30,000, 50,000 and 80,000 cubic feet per second (cfs). During the second phase of the RMA-2V model development when the Licking River hydraulics were added to the grid, the model was run for a wider range of flows, 18,000 cfs, 65,500 cfs and 350,000 cfs, representing low, median and high flow conditions, respectively, in the Ohio River over a typical year. The model was refined through numerous adjustments to the finite element grid so that flow continuity was satisfied throughout the length of the river.

The model was applied assuming that the flow was at steady state (i.e., Ohio River flow did not vary significantly over the duration of any simulated event). This assumption was judged to be adequate for the initial application of the hydrodynamic and water quality models, especially given that the water quality effects of CSOs are exerted primarily in the first two days. This assumption was further verified by a comparison of the hydrodynamic results from a fully dynamic application of RMA-2V to the hydrodynamic results input to the WASP model. This comparison indicated that the approach used for modeling the hydrodynamics in the water quality model and inputting the hydrodynamic results from RMA-2V into WASP as a series of steady state flows correctly considered time variable conditions.

The downstream boundary, river stage or head, was set assuming that the Markland Dam elevation, at river mile 530, was maintained at 455 feet. Consultation with the U.S. Army Corps of Engineer officials indicate that the Ohio River surface elevation of approximately 455 feet at Markland Dam is mandated to maintain a “pool level” for navigation. The hydrodynamic model’s downstream boundary stage was estimated by assuming a linear relationship between the gage at Cincinnati and the surface water elevation gage maintained at Markland Dam. A stage-discharge rating curve developed by the USGS at the suspension bridge in Cincinnati (Papadakis, 1994) was used to estimate the downstream boundary head for high flow simulations (when the river flow was greater than 98,000 cfs).

4.3.3 CALIBRATION AND VALIDATION

Velocity data from the October 17, 1995 dye survey were used to calibrate the hydrodynamic model. The river flow on that day was approximately 41,000 cfs. The model was run with a downstream boundary head of 455.4 feet. Manning’s ‘n’ was initially set to 0.03 in the main channel and 0.06 in the floodplain. The other primary calibration parameter, the turbulent exchange coefficient, was set to 200 lb-sec/ft^2, which is within the recommended range of 50-200 lb-sec/ft^2 from the literature (Thomas and McNally, 1990). Because this parameter is not a true physical parameter, reflecting the flow field, model grid and numerical solution technique of RMA-2V, it was not altered during the calibration or validation.

During the dye survey, the measured velocities in approximately the center of the river ranged from 0.8 to 1.4 feet per second (fps). The model simulation for the same discharge predicts velocities in the center of the river ranging from 1.0 to 1.4 fps using a Manning’s ‘n’ of 0.02 in the main channel and 0.03 in the flood plain. Although the floodplain Manning’s ‘n’ is smaller than expected, this parameter did not significantly affect the calibration because the flow in the floodplain was very small at the calibration flow.

The model was validated using a flow of 98,000 cfs, which is the lowest flow in the stage-discharge relationship established by the USGS at the suspension bridge in Cincinnati. This rating curve predicts a water surface elevation of 457.6 feet at the bridge. This yielded an elevation of 456.2 feet at river mile 490, which was used as the downstream boundary head condition. The Manning’s ‘n’ value was kept at 0.02 in the main channel and 0.03 in the flood plain for the validation.

The model predicted water surface at the suspension bridge was then compared to the rating curve water level. Note that since the expected result of the model (a water surface elevation of 457.6 ft) was used to determine the downstream water level input into the model, this validation is not strictly appropriate. However, the comparison does give an indication of the reliability of the model.

A separate calibration of the Licking River portion of the hydrodynamic model was done using data collected in 1995-96 for Sanitation District #1 and is detailed elsewhere (Limno-Tech, Inc., 1998).

4.4 WATER QUALITY MODEL

This section describes the development and calibration of a water quality model to the Ohio River study area near Cincinnati. The water quality model used to simulate the pollutant transport is the U.S. EPA model Water Quality Analysis Simulation Program (WASP5). This model has been extensively studied and applied to many different rivers and estuaries in the United States (Di Toro and Connolly, 1980; Thomann and Fitzpatrick, 1982; Di Toro, 1983).

Initially, the primary constituents of concern in this study were fecal coliform, heavy metals and dissolved oxygen. The WASP5 model has the ability to model oxygen-demanding chemicals, such as ammonia nitrogen and carbonaceous biochemical oxygen demand (CBOD) as well as the constituents of concern. However, using the water quality model to simulate the effects of CSO loads on in-river fecal coliform concentrations became the primary focus of the water quality modeling work after preliminary application of the water quality model, described in Section 4.4.2.e. This effort indicated that heavy metal constituent concentrations were well below applicable standards. The model calibration, described in Section 4.4.3, confirmed data-based analyses indicating that dissolved oxygen concentrations in the Ohio River were not impacted by CSO loadings.

4.4.1 DESCRIPTION

WASP5 is a three-dimensional finite difference model that computes constituent concentration in a compartmentalized representation of the physical study area using the principle of conservation of mass. WASP5 can simulate the dynamic response of aquatic systems to pollutant loadings, including CSO discharges.

The model balances water volume and constituent mass in each model segment over space and time using a governing equation that includes the following water quality processes: 1) transport processes, such as advection, diffusion, dispersion and boundary exchanges; 2) external loadings such CSOs; and 3) transformation such as decay. The generalized mass balance partial differential equation applied to the Ohio River study area is:

$$\frac{\delta C}{\delta t} = \frac{-\delta}{\delta x}\left(U_x C\right) - \frac{\delta}{\delta y}\left(U_y C\right) + \frac{\delta}{\delta x}\left(E_x \frac{\delta C}{\delta x}\right) + \frac{\delta}{\delta y}\left(E_y \frac{\delta C}{\delta y}\right) + S_L + S_B + S_K$$

where:

C = Concentration of the water quality constituent state variable, mg/L [M/L^3]

t = time, days [T]

U_x, U_y = vertically-averaged longitudinal and lateral advective velocities, m/day [L/T]

E_x, E_y = longitudinal and lateral diffusion coefficients, m^2/day [L^2/T]

S_L = direct and diffuse external loading rate, g/m^3-day [M/L^3-T]

S_B = boundary loading rate (including upstream, downstream, and sediment), g/m^3-day [M/L^3-T]

S_K = total kinetic transformation rate; positive indicates a source, negative indicates a sink, g/m^3-day [M/L^3-T]

A more rigorous description of the governing equation and water quality processes used in the model is available in the user's manual (Ambrose et al., 1993).

In the Ohio River study, WASP5 was applied in a two-dimensional mode to address lateral and longitudinal variations in concentration. Model simulated concentrations represent a vertically averaged (or depth-averaged) concentration. A conceptual framework of the WASP5 water quality model for the Ohio River study is shown in Figure 4-4. EUTRO5 is a sub-component of the WASP5 model used to simulate conventional pollution such as dissolved oxygen, biochemical oxygen demand, nutrients and eutrophication, while TOXI5 is the sub-model used to simulate toxic pollution resulting from constituents such as metals, organic chemicals and bacteria.

The water quality model was constructed in two phases. The first phase included only the Ohio River and used TOXI5 to simulate bacteria during wet weather events. In the second phase of the modeling, the EUTRO5 model code was modified so that bacteria and dissolved oxygen constituents could be simulated simultaneously in a single model run. This version of the model was used for calibration and validation described in sections 4.4.3 and 4.4.4, respectively.

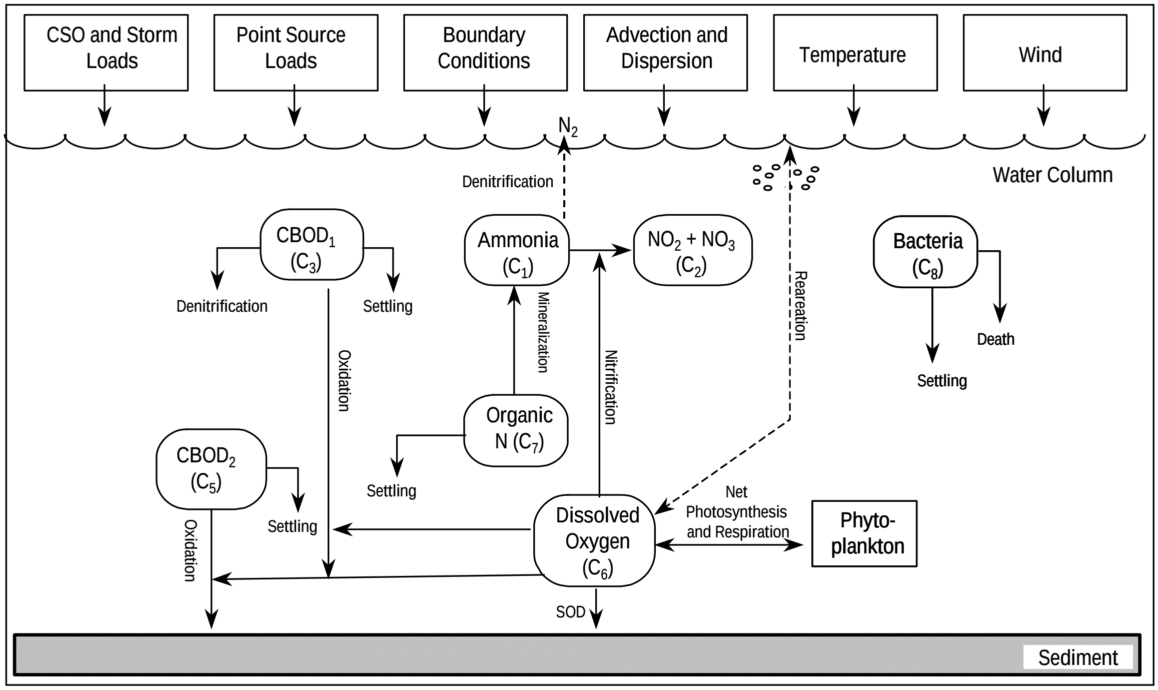


Figure 4-4. Conceptual Framework of the WASP5 Water Quality Model (EUTRO5) as Modified for the ORSANCO Wet Weather Demonstration Project

4.4.2 DEVELOPMENT

This section describes how the generic WASP5 water quality model was modified for use in this Ohio River study. It also includes descriptions of water quality model construction/segmentation and parameterization of the WASP5 model's fundamental transport processes, such as advection and dispersion, using site-specific information. Preliminary applications of the WASP5 model and an alternative water quality model for fecal coliform, RMA4, are also described in this section.

4.4.2.a WASP5 PROGRAM MODIFICATIONS

The site-specific modifications to the EUTRO5 portion of the WASP5 model's kinetic formulations include the following:

- An additional ultimate carbonaceous biochemical oxygen demand ($CBOD_u$) was added to replace the unused inorganic phosphorus state variable to reflect loadings from CSOs. This additional state variable was created so that settleable and highly degradable CSO loads could be tracked separately with appropriate process kinetics from upstream CBOD loads.

- Fecal coliform bacteria were inserted to replace the unused organic phosphorus state variable. A first-order decay (die-off) rate for fecal coliform is used in place of the phosphorus mineralization kinetics.

4.4.2.b MODEL SEGMENTATION

Although the hydrodynamic model domain encompassed the Ohio River from river mile 460 to river mile 490, the water quality model was extended down to river mile 530, where Markland Dam is located, to evaluate dissolved oxygen effects and the downstream impact of fecal coliform loads from the CSOs.

From river mile 460 to river mile 490, the water quality model is two-dimensional, providing concentration variations both laterally and longitudinally. Water quality model results are vertically averaged. This area includes all of the CSOs from both Cincinnati MSD and Sanitation District # 1 discharging directly into the Ohio River as well as tributaries that receive CSO loads from these sewerage districts. Consequently, it is the area where the biggest impacts from CSOs are expected and where near shore effects would be most pronounced.

From river mile 490 to river mile 530, the water quality model is one-dimensional, providing concentration variations longitudinally and averaged concentrations laterally and vertically. This simplification to the water quality model was made because the lateral dispersion study indicated that CSO loads delivered from the Cincinnati/Northern Kentucky metropolitan area would be laterally well-mixed by this downstream location.

The scale required by the RMA-2V model for hydrodynamic stability was too refined to adapt directly for use in the water quality model because it would result in an excessive computational burden. As a result, the WASP5 water quality model segmentation was defined as a subset of the hydrodynamic grid, where the WASP5 segment contained up to six hydrodynamic model elements.

The model’s spatial resolution was based upon discussion with the project’s Technical Advisory Committee, which determined that the model would consist of five lateral segments, approximately divided as follows:

- Bankside channels (one on each shore) ≈10% of each cross-sectional area
- Intermediate channels (one on each side of the centerline) ≈20% of each cross-sectional area
- Center segment ≈40% of each cross-sectional area

The average segment lengths in the two-dimensional portion of the study area were defined by the length of the hydrodynamic elements and were approximately 0.75 miles in length. This length was maintained in the one-dimensional portion of the study area as well. The two-dimensional portion of the WASP5 segmentation is shown in Figure 4-5.

Details regarding the WASP5 model development for Banklick Creek and the Licking River are detailed elsewhere (LTI, 1998; LTI, 2000). The water quality model contains 368 segments in the Ohio River, 72 segments in the Licking River and 11 segments in Banklick Creek.

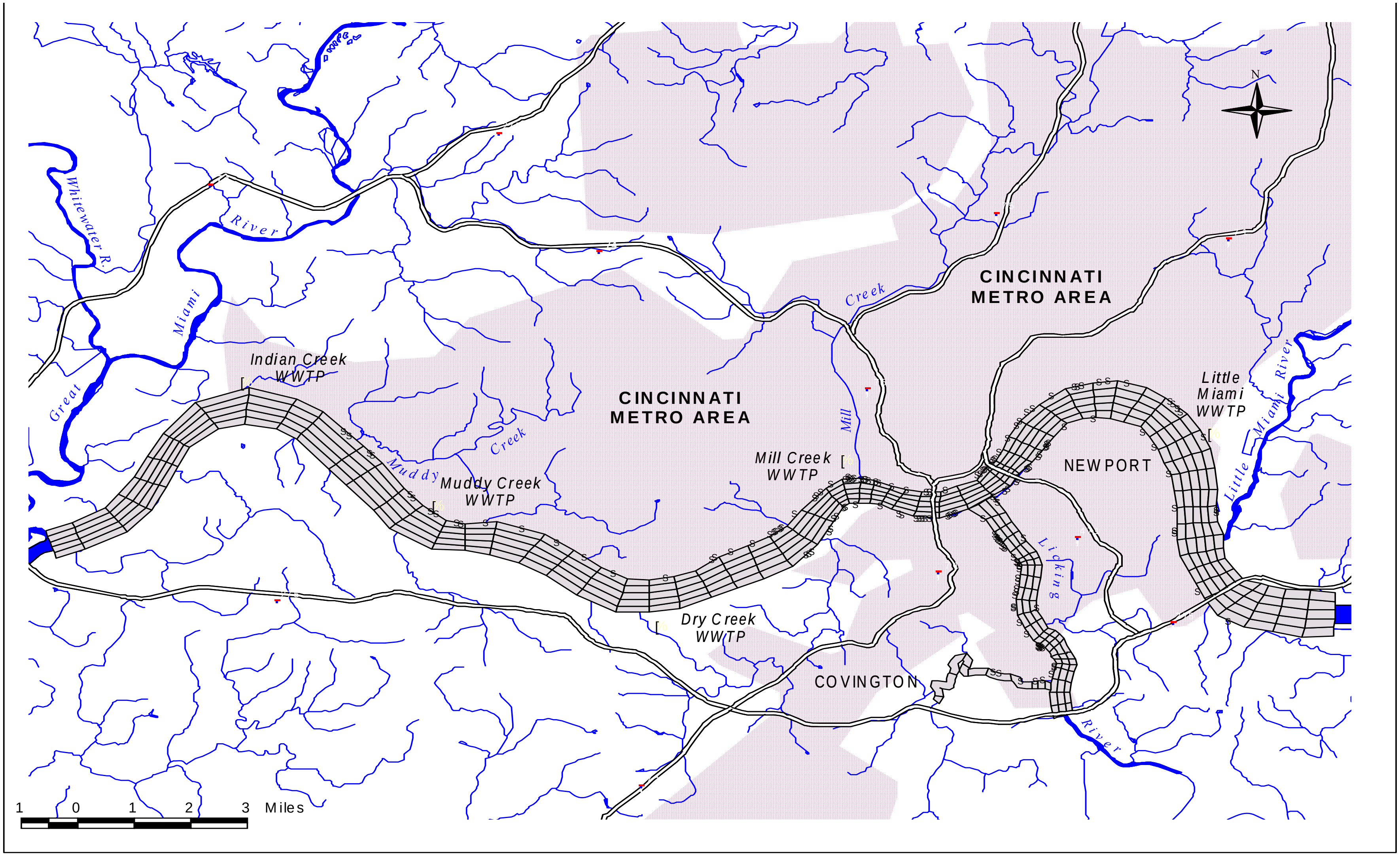


Figure 4-5 .WASP5 2-D Model Grid Domain.

4.4.2.c LINKAGE TO HYDRODYNAMIC MODEL

Hydrodynamic model results were used to drive the transport in the water quality model. However, direct use of the RMA-2V model results into the WASP model was not possible for two reasons. First, the RMA-2V model was spatially defined by a set of nodes whereas the WASP model was spatially defined by a series of segments. The RMA-2V model produced a velocity field defined at the nodes, while WASP5 required a set of balanced and routed steady state flows defined for segment interfaces. Thus, the RMA-2V results had to be translated into WASP5 segment space. The second reason was that RMA-2V conserved momentum but did not inherently conserve water mass, which is required by the WASP5 model.

A series of three programs were created to transform the RMA-2V model results into inputs for the WASP5 model. These programs performed the following operations:

1. Converted strings of RMA-2V nodes into WASP5 segment interfaces;
2. Smoothed (balanced) the inter-segment flows calculated by RMA-2V for the WASP5 segment interfaces;
3. Converted the individual smoothed segment flows into flow routings through the WASP5 model so that water mass was balanced in each water quality model segment.

As expected for a large river system, the linkage between the RMA-2V model and the WASP model routed the majority of the flow downstream from one segment to another immediately downstream, rather than laterally to an adjacent segment.

An additional program was written to convert finite element nodal information from the hydrodynamic model into water quality model segment volumes and dispersion areas and lengths.

4.4.2.d LATERAL MIXING CALIBRATION TO DYE SURVEYS

While the RMA-2V hydrodynamic model can describe lateral and longitudinal movement of water through the study area, it cannot describe the mixing of water quality constituents caused by dispersion. The term “dispersion” is used here to include the effects due to molecular and turbulent diffusion and dispersion resulting from velocity gradients. ORSANCO conducted two dye surveys in the Ohio River during the fall of 1995 to determine the magnitude of this mixing under a range of flow conditions. The results from these surveys were used to calibrate dispersion coefficients in the WASP5 water quality model as described below.

October 17, 1995 Dye Survey

The first dye survey was conducted on October 17, 1995 with an Ohio River flow of 41,100 cfs. Rhodamine-WT dye (20% solution) was injected into the discharge of the Mill Creek Wastewater Treatment Plant continuously over the time period 11:10 a.m. to 3:25 p.m. A total of 100 pounds of dye was injected, which corresponded to a dye injection rate of 0.392 pounds/minute. Samples were collected in the Ohio River starting one hour after the beginning of the dye injection at 37 locations downstream of the Mill Creek WWTP outfall. At each location, one grab sample was collected approximately one foot below the water surface and one grab sample was collected approximately two feet above the bottom of the river.

Results of the dye survey are shown in Figure 4-6. Although there is some variation in the dye concentrations in the direct vicinity of the outfall, in general, the concentrations show a gradual decline as the distance from the outfall increases.

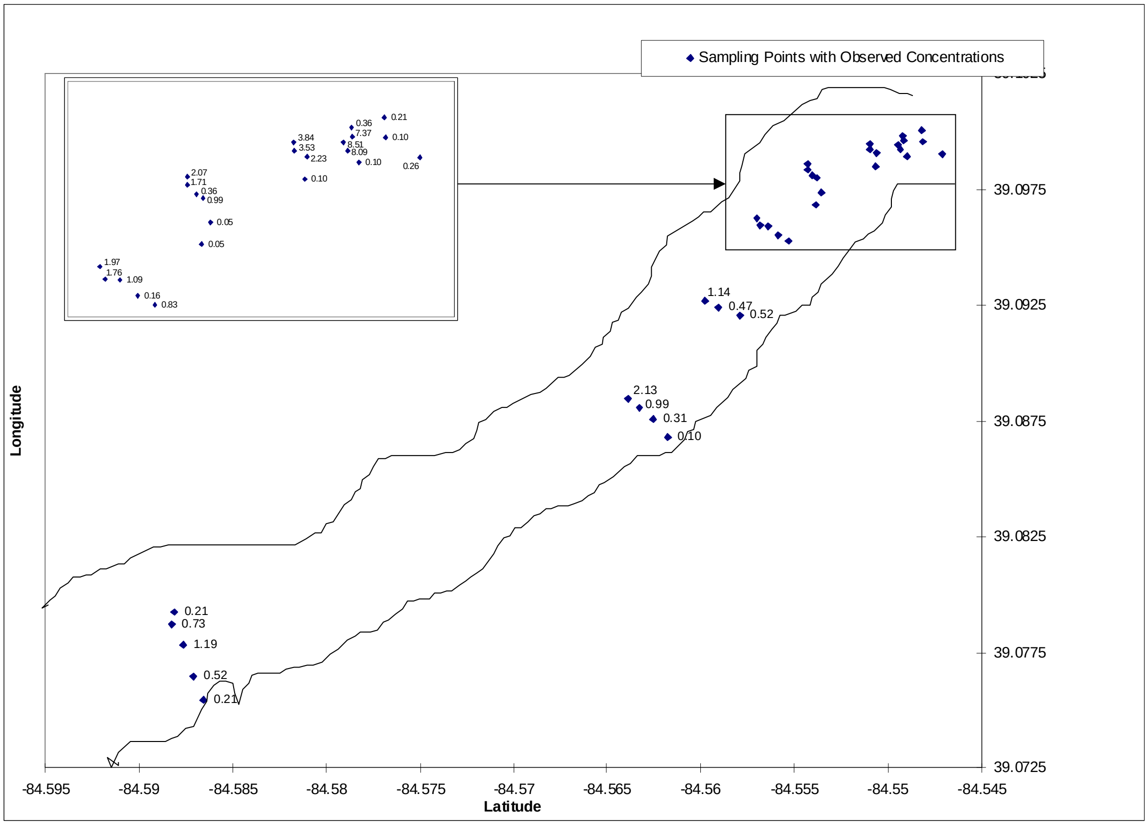


Figure 4-6. October 17, 1995 Dye Survey Transects.

November 28, 1995 Survey

The second dye survey was conducted on November 28, 1995 with an Ohio River flow of 67,900 cfs. Rhodamine-WT dye (20% solution) was injected into the discharge of the Mill Creek Wastewater Treatment Plant continuously over the time period 10:15 a.m. to 2:30 p.m. A total of 132 pounds of dye was injected, which corresponded to a dye injection rate of 0.517 pounds/minute. Samples were collected in the Ohio River starting one hour after the beginning of the dye injection at 36 locations downstream of the Mill Creek WWTP outfall. The sample collection methodology was the same as the October dye survey.

Results of this dye survey are shown in Figure 4-7. As with the October survey, variation in the dye concentrations near the outfall were observed but concentrations show a gradual decline as the distance from the outfall increases.

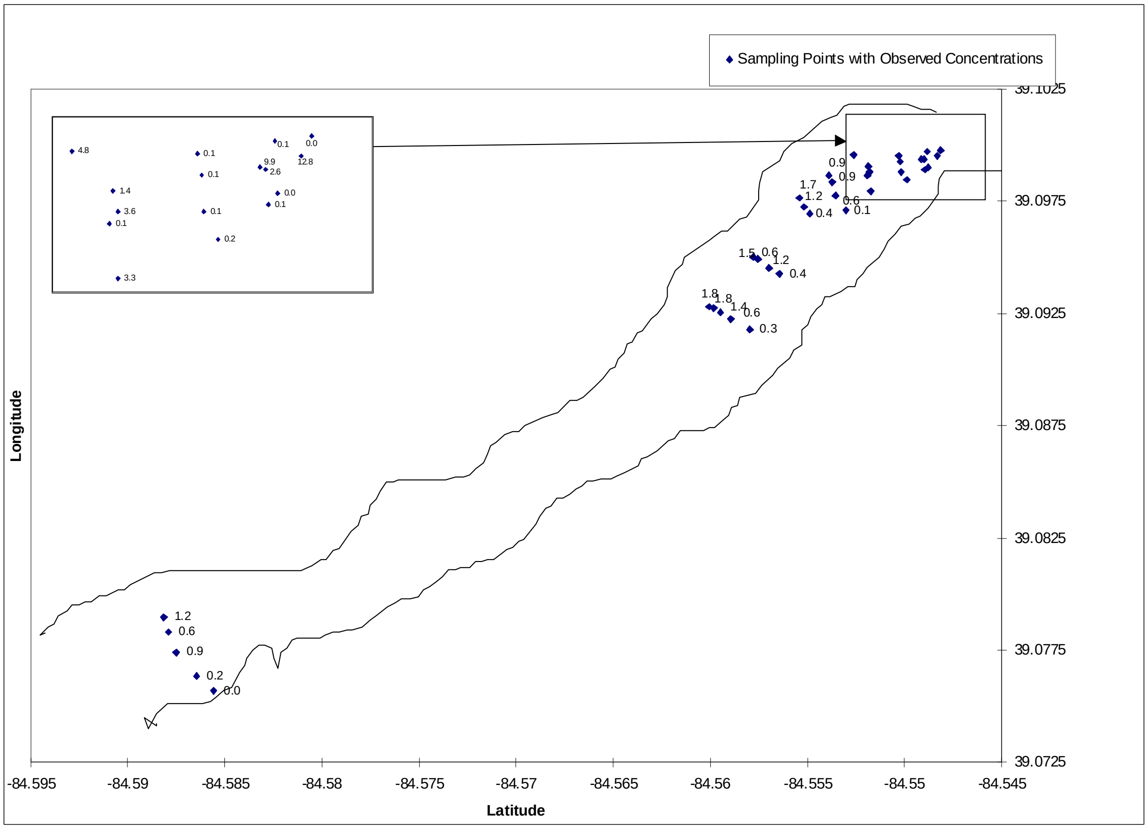


Figure 4-7. November 28, 1995 Dye Survey Transects.

Dispersion Calibration

The dye surveys were simulated using the WASP5 water quality model and used the model dispersion coefficient as the calibration parameter for fitting the data. Loads of 47.3 kg/day for the October survey and 83.3 kg/day for the November survey were entered into the WASP5 model at segment 253. The model was run to steady state and concentrations calculated for the WASP5 model segments corresponding to sampling locations were compared to the data from each survey.

A constant value was used for the dispersion coefficient for all dispersive exchanges. The data falling in the farthest downstream cross section was chosen as the target data so that the degree of mixing of the dye solution with the river flow would be greatest. Because the objective was to determine the coefficient which would best represent lateral mixing, rather than to model dye concentrations per se, the criterion chosen for calibration was the spread of concentrations across the target cross section. The spread was calculated as the standard deviation of the observed or the calculated concentrations; observed concentrations were segregated by depth. A dispersion coefficient ranging between 0.30 and 0.36 m^2/s provided the best match, as shown Figure 4-8.

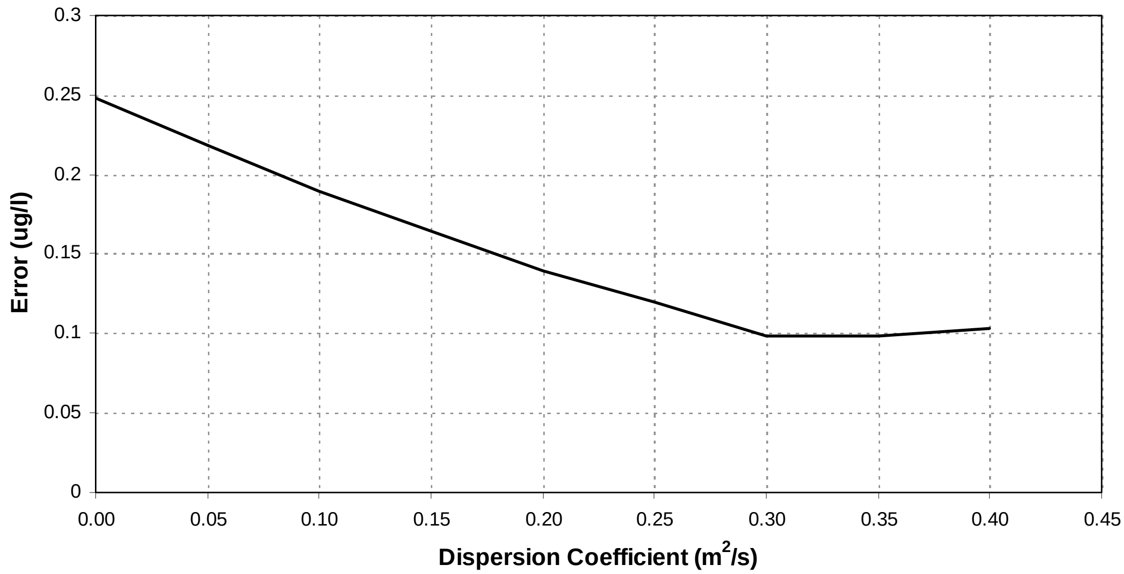


Figure 4-8. Revised Dispersion Calibration Model Comparison to Analytical Solution at Cross Section 263-267 (10/17/95 Dye Survey).

Despite the patchiness of the observed data, model predictions compared well to the observed data when the dispersion coefficient was set to 0.33 m^2/s. Correlation coefficients (r^2) of 0.7 and 0.8 were obtained between predicted and observed spread of the data for the two surveys.

The dispersion calibration was refined through model simulations that treated the dye injection as a "slug" loading rather than a continuous dye source. An analytical solution was developed using a nominal loading rate of 100 million gallons per day (MGD) at a concentration of 125 ug/L. Results were given as concentrations at rectangular grid points listed by an x-distance downstream and a y-distance across the stream. The origin point of the grid was taken to be the upstream center of segment 253, consistent with the dye surveys' loading point of approximately river mile 472.8, near the Ohio shore. Average concentrations were computed for three cross-sections, including segments 253-257, 258-262, and 263-267. Averages were computed by interpolating grid points to a finer grid, then calculating area-weighted averages for each segment.

Concentration profiles from the WASP5 model with dispersion coefficients ranging from 0.0 – 0.4 m^2/s were compared to the profile from the analytical solution for the two cross sections downstream of the loading cross section. The segment 263-267 cross section showed a better fit than the segment 258-262 cross section, which was expected because the cross section furthest downstream is presumably less affected by segment size impacts that predominate the simulation close to the discharge point. The sum of the absolute values of the segment concentration differences between the analytical solution and the WASP5 solution for the 263-267 cross section was used as the error measure. The best fit was determined to be when the dispersion coefficient is 0.30 m^2/s, as shown in Figure 4-8.

4.4.2.e PRELIMINARY MODEL APPLICATION

The WASP5 model was applied to the Ohio River for four wet weather events sampled in the fall of 1995. These events varied in hydrologic conditions, CSO loadings and environmental conditions. The parameters simulated were fecal coliform, dissolved oxygen, including ammonia nitrogen and carbonaceous biochemical oxygen demand as oxygen sinks, and the heavy metals copper, zinc and lead. Site-specific inputs were used in these runs where available.

Although the model was not fully calibrated, significant conclusions were made from these preliminary runs. Concentrations of the metals measured in the discharges were all below water quality criteria so all of the simulated in-river concentrations were within the acceptable range. This conclusion will not change, regardless of the water quality model calibration. Further modeling of heavy metals was therefore discontinued. High concentrations for fecal coliform and drops in dissolved oxygen concentration levels were predicted with these model runs, indicating that further evaluation of these parameters with a calibrated model was warranted.

4.4.3 CALIBRATION – MAY 2000 WET WEATHER EVENT

WASP5 water quality model simulations were conducted for four water quality surveys in 1995 and one in 2000. The WASP5 model was calibrated to the water quality survey conducted in May 2000 because this dataset included the greatest spatial and time extents. Water quality data, model inputs and calibration results (e.g., comparison of model simulated concentrations to observed data) are presented in this section. The WASP5 model was then validated using the water quality surveys from 1995 as described in section 4.4.4.

The approach to calibrating the model was to specify site-specific model inputs whenever possible, including loads, boundary concentration, flows, environmental conditions and to run the simulation. The model output was compared to observed data at specific points in time. Reproducing observed concentration differences between near shore and center channel areas and simulating the observed timing and location of peak concentrations were the primary calibration objectives. Matching the magnitude of observed concentrations was a secondary objective due to the uncertainty in loadings.

A separate calibration of the Licking River and Banklick Creek portion of the water quality model was done using data collected in 1995-96 for Sanitation District #1 and is detailed elsewhere (Limno-Tech, Inc., 1998).

4.4.3.a DATA

ORSANCO conducted a wet weather water quality survey from May 27, 2000 through May 31, 2000 in the study area to provide a dataset suitable for model calibration. The study area received approximately two inches of rain over the first two days of the survey. A gauge at the Cincinnati/Northern Kentucky Airport in Covington recorded 1.87 and 0.30 inches of rain on May 27 and May 28, respectively. A survey of 29 rain gages throughout the study area indicated that rainfall ranged from 0.12 to 2.48 inches on May 27 and from 0 to 0.53 inches on May 28, depending on the location of the gauge. The Ohio River flow was monitored at a station in Cincinnati and ranged from 100,000 cfs to 140,000 cfs during the survey. Flows at Cincinnati were corroborated using flow data from stations at Markland Dam and at Meldahl Lock and Dam. Tributary flows were also monitored and represent less than five percent of the Ohio River flow. Flow and rainfall data are shown in Figure 4-9.

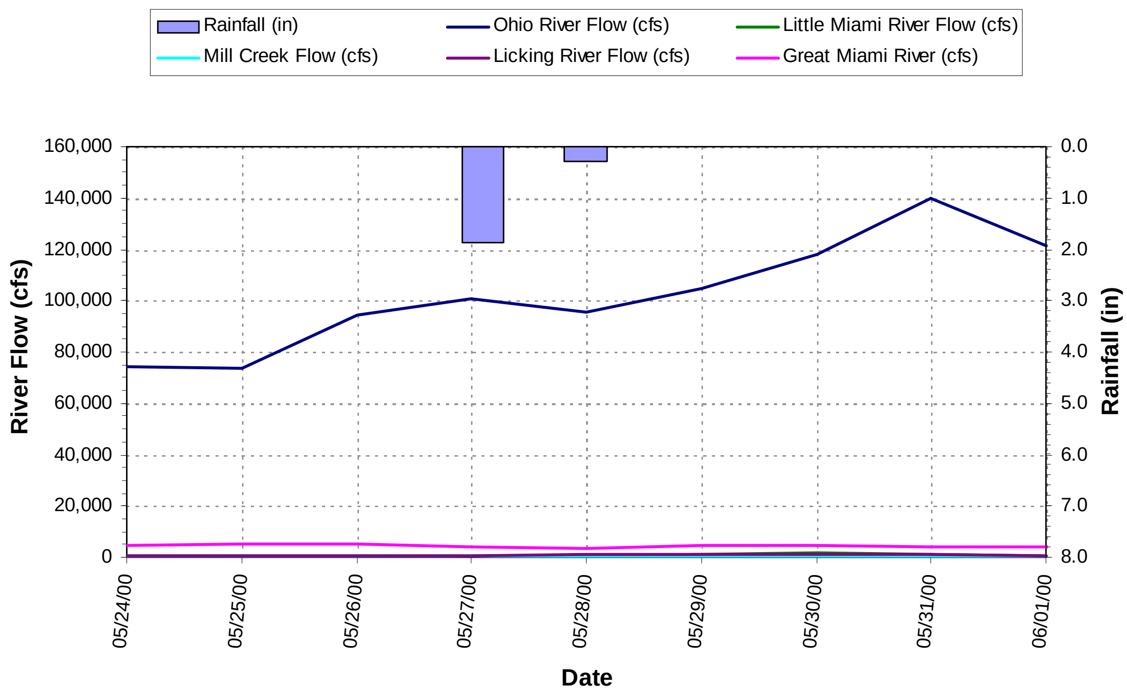


Figure 4-9. Rainfall and River Flow Data During May 2000 Wet Weather Event.

Water quality samples were collected from river mile 460, approximately corresponding to the upstream boundary of the WASP5 model to river mile 495 for the first two days of the survey (May 27-28, 2000). Sampling was extended down to Markland Dam at river mile 530, the downstream boundary of the water quality model, during the last three days to enable calibration of the fecal coliform decay (die-off) rate and to capture a dissolved oxygen concentration sag, if present, resulting from CSO loadings of oxygen-demanding constituents during wet weather. Samples also were collected near the mouths of the four primary tributaries in the study area--Little Miami River, Mill Creek, Great Miami River and Licking River--to assess pollutant loadings entering the Ohio from these sources. Table 4-1 presents the constituents that were included in the sampling survey for the Ohio River and the tributaries.

Table 4-1. Parameters Sampled During May 2000 Wet Weather Survey.

Parameter	Ohio River	Tributaries
Secchi Depth	✓	
Water Temperature	✓	✓
pH	✓	✓
Dissolved Oxygen	✓	✓
Conductivity	✓	✓
Ammonia-Nitrogen	✓	✓
5-Day Carbonaceous Biochemical Oxygen Demand	✓	✓
Chlorophyll a	✓	
Eschericha coliform	✓	✓
Fecal coliform	✓	✓
Hardness as CaCO3	✓	✓
Nitrate-Nitrite Nitrogen	✓	✓
ortho-Phosphate	✓	
Total Kjeldahl Nitrogen	✓	✓
Total Phosphorus	✓	✓
Total Suspended Solids	✓	✓

Results of surveys for the two primary constituents of concern, fecal coliform and dissolved oxygen, are presented in Figures 4-10 through 4-13. Water quality samples were collected at five points across each sampling transect to track near shore effects from the CSO loads during the first two days of the storm, when the CSOs were most active. Figures 4-10a-b show fecal coliform concentrations for samples from the left bank, center channel and right bank by river mile for each day of the survey. Note that left and right are designated based on an orientation looking downstream. From these figures, peak concentrations at all three locations occur near river mile 480, just downstream of Dry Creek on the Kentucky side and Mill Creek on the Ohio side, with bank concentrations generally slightly higher than center channel concentrations.

Figure 4-11 shows how center channel fecal coliform concentration varies at selected locations over time. In general, peak concentrations occur on May 27, the first day of the storm, and range from 1,000 to 10,000 #/100 mL. By the end of the survey, concentrations generally decline by at least an order of magnitude to less than 100 #/100 mL. Near-shore fecal coliform concentrations were measured on the first two days of the survey and thus, time trends could not be developed for these sections of the river.

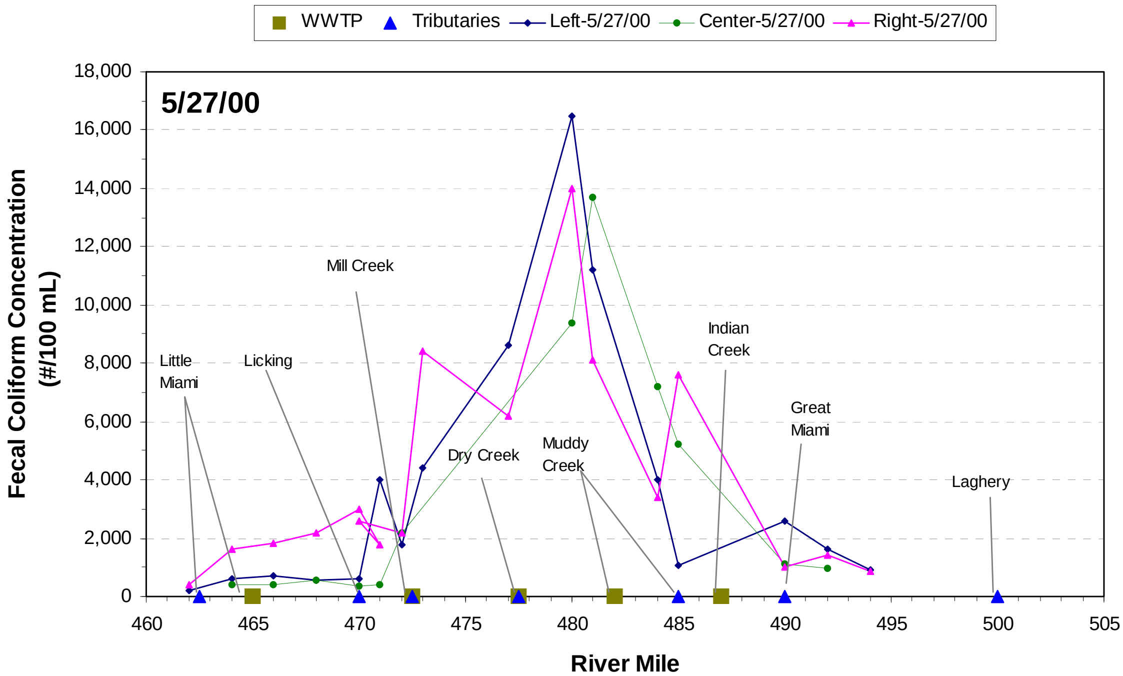
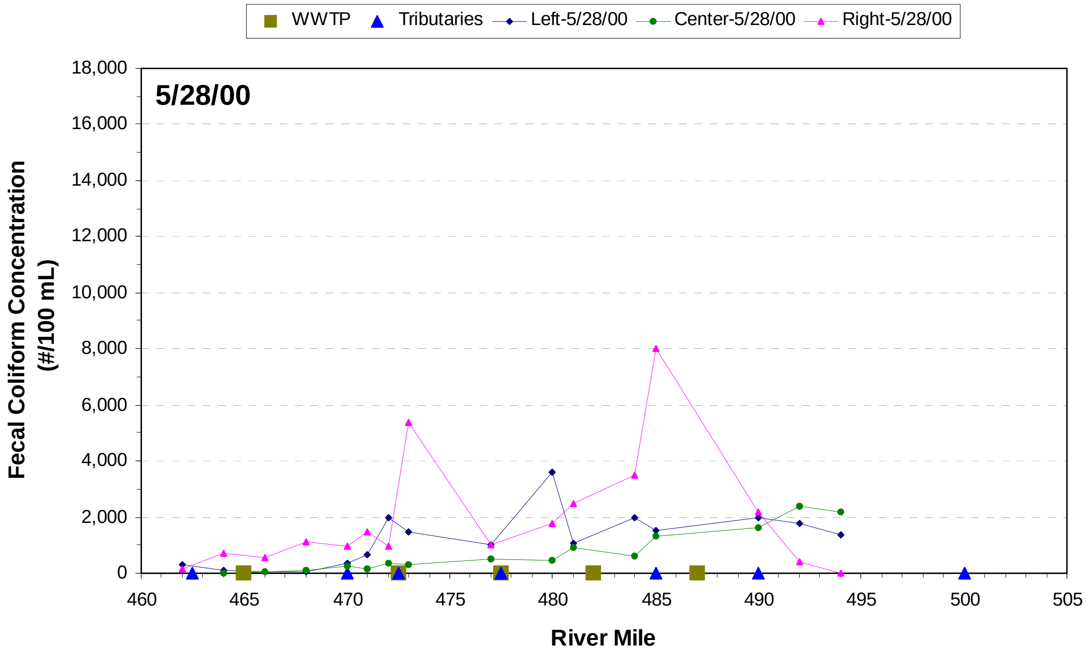


Figure 4-10 a. Ohio River Fecal Coliform Concentration Profile – 5/27/00.



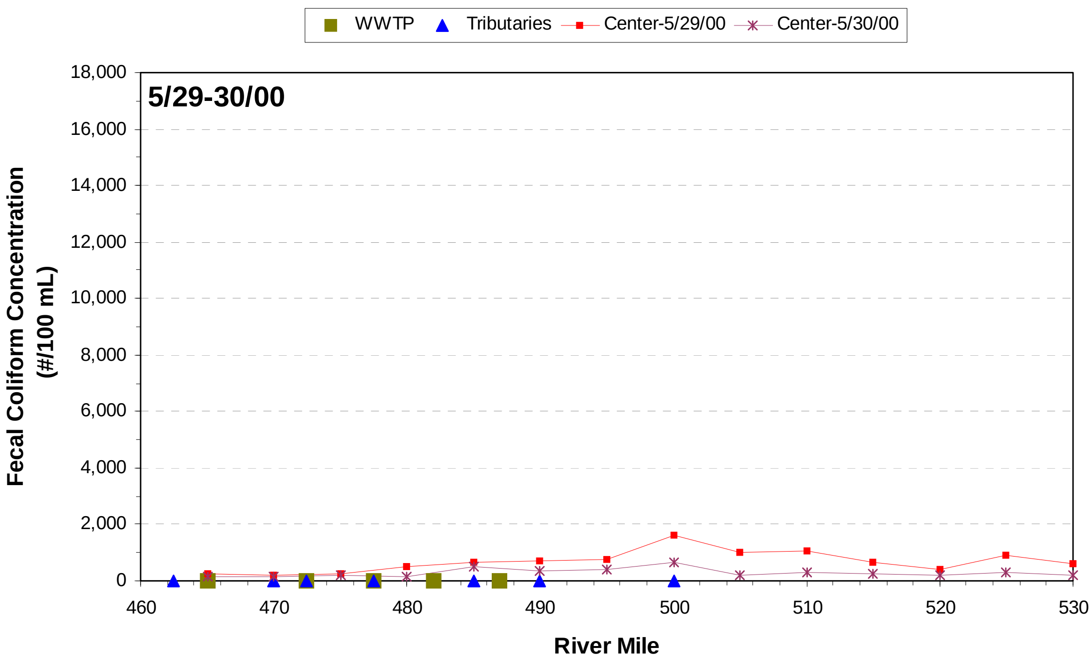


Figure 4-10 b. Ohio River Fecal Coliform Concentration Profile – 5/28/00-5/30/01.

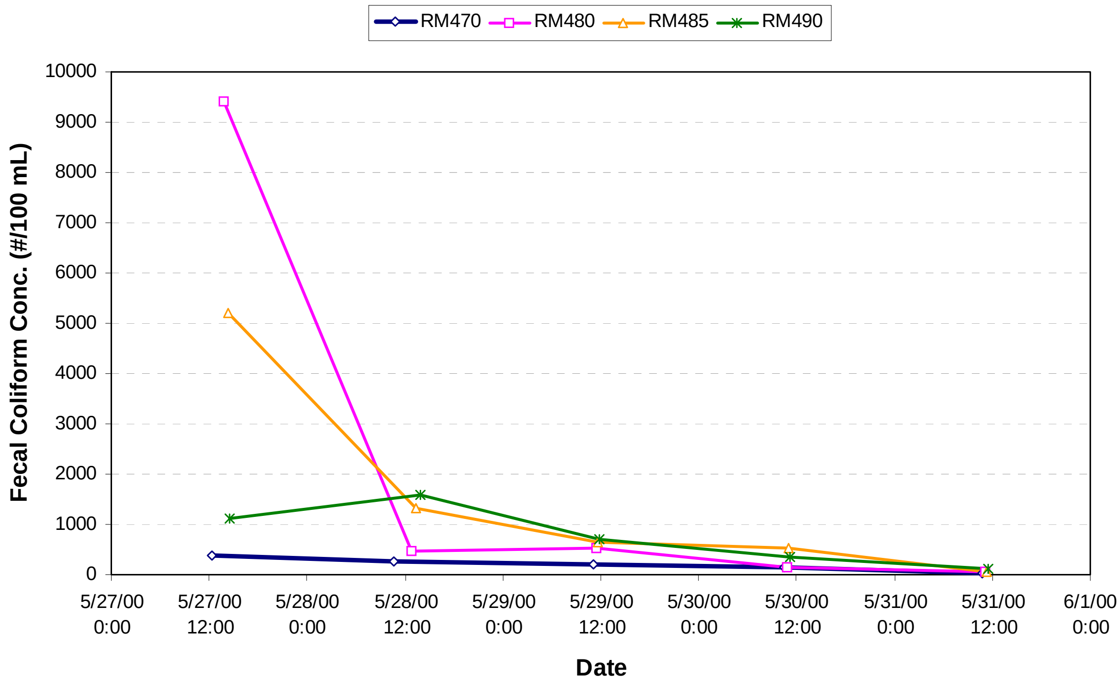


Figure 4-11. Ohio River Fecal Coliform Concentration Data at Selected Locations.

Figure 4-12 shows tributary fecal coliform results for the four main tributaries in the study area. The tributaries were sampled at three points across each transect and are shown on the figures. The tributary hydrograph is superimposed, showing that the peak concentration and peak flow are out of phase. Peak flow usually occurs after the storm, reflecting runoff upstream of the study watershed. Peak concentrations occurred on the first day of the storm and averaged between 32,000 #/100 mL in the Licking River and Little Miami River to approximately 1,000,000 #/100 mL in Mill Creek.

Figure 4-13 shows how dissolved oxygen concentration varies at selected locations over time. As this figure illustrates, dissolved oxygen concentrations do not change very much over the survey, a preliminary indication that CSO loadings of oxygen-demanding constituents do not adversely affect dissolved oxygen concentrations.

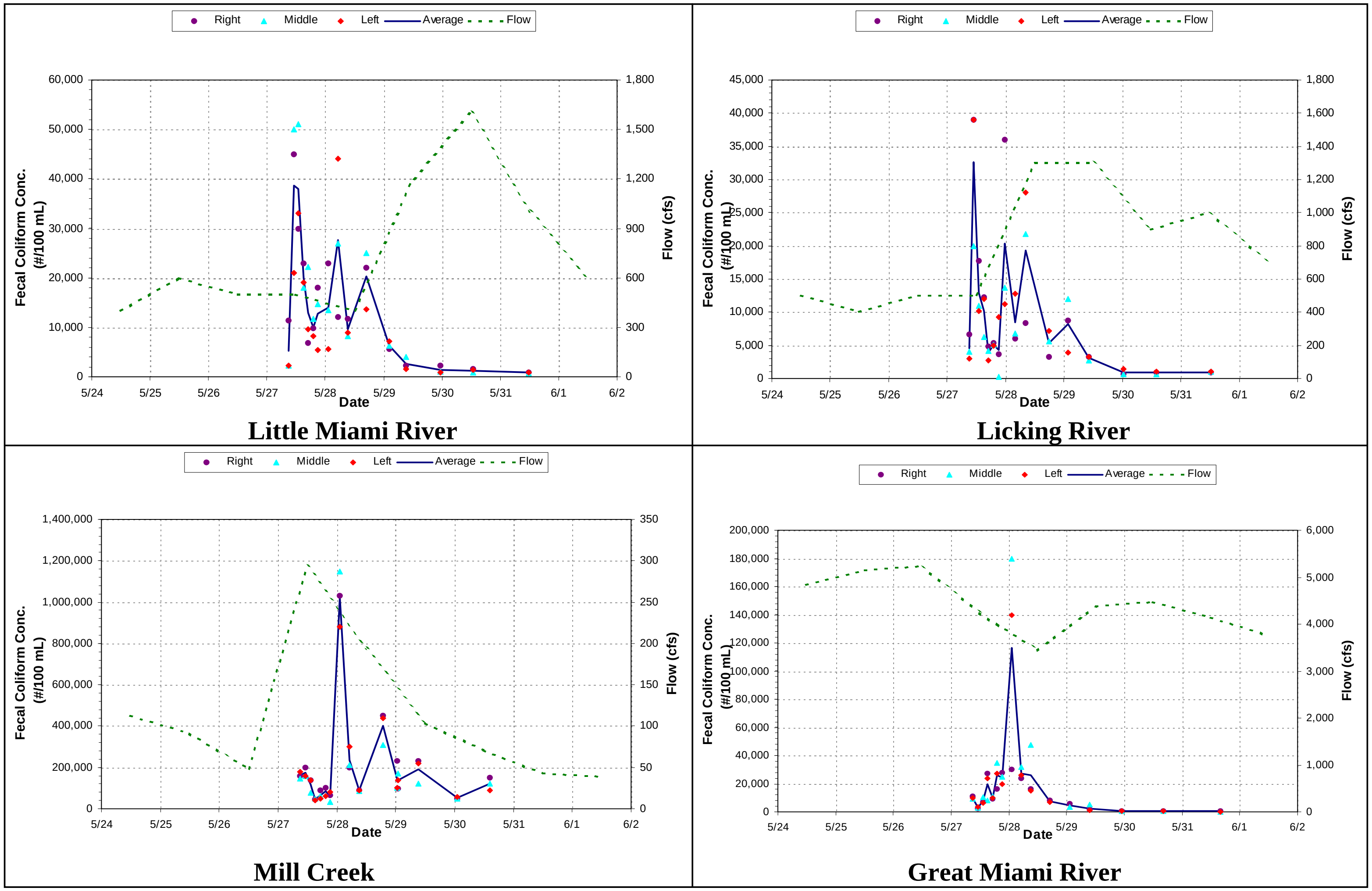


Figure 4-12. Tributary Fecal Coliform Concentration Profiles – 5/27/00 – 5/31/00.

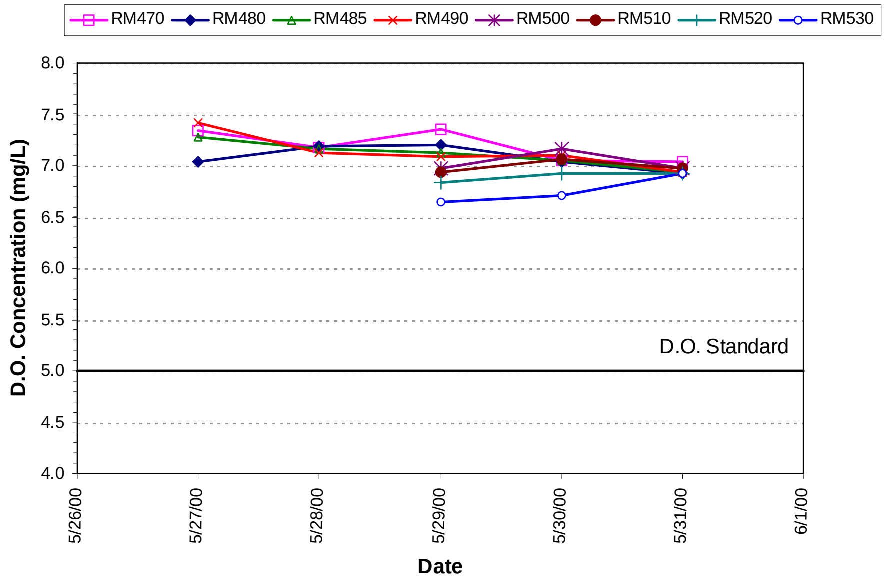


Figure 4-13. Ohio River Dissolved Oxygen Concentration Data at Selected Locations.

4.4.3.b MODEL INPUTS

The WASP5 model simulates pollutant mass in each model segment as the result of transport processes, external loadings and transformation processes. It requires user-specified inputs of calculation time steps and duration, environmental conditions, boundary conditions, pollutant inputs and choices of kinetic processes, rates and coefficients. This section describes model inputs for the transport and transformation processes. Due to their complexity, loadings are discussed in the next section.

Transport Process Inputs

Transport processes modeled with the WASP5 model include advection, dispersion, diffusion and boundary exchanges. For advection, the flow measured at the Cincinnati gage (see Figure 4-9) was used and routed downstream using the linkage described in Section 4.4.2.c. Because the total tributary flow was less than five percent of the upstream Ohio River flow, tributaries were not included in the model calibration. Dispersion was simulated using the segment areas determined from the hydrodynamic water quality model linkage (Section 4.4.2.c) and with the site-specific dispersion coefficient determined from the dye survey calibrations described in section 4.4.2.d.

Boundary exchanges at the upstream and downstream ends of the model were based on concentrations observed during the water quality survey. These are summarized in Table 4-2.

Table 4-2. Upstream and Downstream Boundary Conditions.

Constituent	Segment #'s	Concentration (mg/L)*	Notes on Data Source
Upstream Conditions			
Ammonia	1-5	0.04	Concentration from May 31, 2000 survey, RM 460. Indicative of Dry Weather Conditions.
$CBOD_5$[1]	1-5	0	Concentration from May 31, 2000 survey, RM 460. Indicative of Dry Weather Conditions.
$CBOD_5$[2]	1-5	0	Concentration from May 31, 2000 survey, RM 460. Indicative of Dry Weather Conditions.
Chlorophyl a	1-5	0.001166	Concentration from May 31, 2000 survey, RM 460. Indicative of Dry Weather Conditions.
Dissolved Oxygen	1-5	7.09	Concentration from May 31, 2000 survey, RM 460. Indicative of Dry Weather Conditions.
Fecal Coliform	1-5	60-300	Concentration from Measured Data on 5/27 - 6/1 are used
Nitrate	1-5	0.88	Concentration from May 31, 2000 survey, RM 460. Indicative of Dry Weather Conditions.
Organic Nitrogen (TKN)	1-5	0.25	Concentration from May 31, 2000 survey, RM 460. Indicative of Dry Weather Conditions.
Downstream Conditions			
Ammonia	469	0.05	Concentration from May 31, 2000 survey, RM 530. Indicative of Dry Weather Conditions.
$CBOD_5$[1]	469	0	Concentration from May 31, 2000 survey, RM 530. Indicative of Dry Weather Conditions.
$CBOD_5$[2]	469	0	Concentration from May 31, 2000 survey, RM 530. Indicative of Dry Weather Conditions.
Chlorophyl a	469	0.001444	Concentration from May 31, 2000 survey, RM 530. Indicative of Dry Weather Conditions.
Dissolved Oxygen	469	6.93	Concentration from May 31, 2000 survey, RM 530. Indicative of Dry Weather Conditions.
Fecal Coliform	469	120	Concentration from May 31, 2000 survey, RM 530. Indicative of Dry Weather Conditions.
Nitrate	469	0.94	Concentration from May 31, 2000 survey, RM 530. Indicative of Dry Weather Conditions.
Organic Nitrogen (TKN)	469	0.35	Concentration from May 31, 2000 survey, RM 530. Indicative of Dry Weather Conditions.

* Except for Fecal Coliform, which is reported as CFU/100 mL and CFU/day.

[1] indicates $CBOD_5$ from sources other than CSOs

[2] indicates $CBOD_5$ from CSOs

Transformation Process Inputs
Since the water quality modeling was focused primarily on fecal coliform impacts, the primary transformation process in the WASP5 model was fecal coliform die-off. The water quality model was calibrated using a first-order decay rate of 1.0 day^{-1}. Model sensitivity to the decay rate was evaluated as described in Section 5.4.3.e.

The fecal coliform die-off rate is temperature dependent. The other primary constituent of concern, dissolved oxygen, is highly impacted by water temperature. Water temperature is a factor in the level of dissolved oxygen saturation, reaeration rates, and kinetic process coefficients for oxygen-demanding pollutants. Water temperatures measured during the May 2000 survey ranged between 22 ^{o}C and 23^{o}C. A constant value of 22^{o}C was input into the WASP5 model for the model calibration.

Kinetic coefficients for oxygen-demanding constituents and fecal coliform are summarized in Table 4-3.

Table 4-3. Summary of WASP5 Kinetic Coefficients and Constants.

Constant	Calibration Value	Source	Literature Range	Units
FECAL COLIFORM				
Fecal coliform die-off rate at 20^{o}C	1.00	2	0.192-3.12	1/day
Temperature coefficient	1.08	2		
DISSOLVED OXYGEN				
Reaeration rate at 20^{o}C	0.1 based on 2 ft/d and 20 ft. avg. depth			
Deoxygenation rate ($CBOD_2$ decay) at 20^{o}C	0.2	1	0.16$\pm$0.05	1/day
temperature coefficient	1.07	2		
1/2 saturation constant for O_2 limitation	0.5	2		mg/L
Deoxygenation rate ($CBOD_1$ decay) at 20^{o}C	0.2	3	0.3-0.4	1/day
temperature coefficient	1.07	2		
1/2 saturation constant for O_2 limitation	0.5	2		mg/L
NITROGEN				
Organic nitrogen mineralization rate at 20^{o}C	0.16	1		1/day
temperature coefficient	1.07	1		
Nitrification rate	0.13	1	0.09-0.13	1/day
temperature coefficient	1.07	1		
1/2 saturation constant	0.5	1		mg/L
LOADING CONVERSION AND SETTLING				
CSO $CBOD_u/CBOD_5$ ratio	2	3	1.2-3.2	
Background $CBOD_u/CBOD_5$ ratio	1.5	3	1.2-3.2	
Organic matter settling rate (CSO CBOD and organic nitrogen)	1.0	2	0.04-1.8	m/day

fraction dissolved $CBOD_1$	0.85			
fraction dissolved organic nitrogen	0.85			

Sources:
1. U.S. EPA, 1985
2. U.S. EPA, 1993
3. Thomann & Mueller, 1987.

4.4.3.c LOADS

External loadings of pollutants to the Ohio River include point sources draining directly to the river, tributary loadings which may include CSO loads and loads resulting from drainage directly into the river. Point sources include CSOs and wastewater treatment plant (WWTP) effluents. External loads were developed using the following approach:

- CSO loads draining directly to the Ohio River were estimated using the XCG/Woolpert sewer model outputs and applying event mean concentrations,
- Tributary loads were estimated using survey data collected at the mouths of the tribuataries during the May 2000 event,
- WWTP effluents were estimated using either sewer model output or available data,
- Direct drainage loads for Ohio side loads were estimated using the sewer model.

CSO Loadings

XCG and Woolpert developed sewer models of the Cincinnati and Northern Kentucky Sanitation District #1 collection systems, respectively. Woolpert uses a preliminary, uncalibrated version of a collection system model for the Sanitation District. The Sanitation District has been collecting extensive flow-monitoring data in the collection system and is in the process of developing a detailed HydroWorks model of their system.

The XCG and Woolpert models were used to estimate CSO loadings directly to the Ohio River during the May 2000 event. CSO loading locations from the sewer models are summarized in Table 5-4. These models were used to estimate volume of overflow from each CSO in hourly increments.

Table 4-4. Summary of CSO and SWMM Model Description.

Receiving Water	Bank	KPDES#/ Ohio ID #	Description	SWMM Model	SWMM_ID	WASP SEG	River Mile
Ohio River	S	SGPS	Silver Grove Pump Station	Woolpert	L002SGPS	20	460.84
Ohio River	S	HHPS	Highland Heights Pump Station	Woolpert	L005HHPS	30	461.60
Ohio River	S	11	Government Sewer	Woolpert	L020001	50	462.93
Ohio River	S	13	Manor Lane	Woolpert	L034044	50	462.93
Ohio River	N	9000	Direct Stormwater Drainage	XCG-Duck/Little	ohiostm	51	463.5

Receiving Water	Bank	KPDES#/ Ohio ID #	Description	SWMM Model	SWMM_ID	WASP SEG	River Mile
				Miami			
Ohio River	N	1000	Little Miami River	XCG-Duck/Little Miami	lmiami6	56	463.5
Ohio River	S	14	Burnet Ridge	Woolpert	L034034	60	463.64
Ohio River	S	12	Tower Hill Road	Woolpert	L034009	70	464.46
Ohio River	N	5000	Little Miami WWTP-Bypass 2	XCG-Duck/Little Miami	1239	71	465.1
Ohio River	N	5000	Little Miami WWTP-Bypass 1	XCG-Duck/Little Miami	1249	71	465.1
Ohio River	N	5000	Little Miami WWTP-Bypass 3	XCG-Duck/Little Miami	1250	71	465.1
Ohio River	N	5000	Little Miami WWTP-Treated	XCG-Duck/Little Miami	wwtp	71	465.1
Ohio River	S	15	Elsmar Street	Woolpert	L035003	80	465.24
Ohio River	N	468	Humbert & Congress Avenue Regulato	XCG-Duck/Little Miami	252	81	466
Ohio River	N	469	Delta & Eastern Avenue Regulator	XCG-Duck/Little Miami	257	81	466
Ohio River	N	467A	Humbert & Delta Avenue Connection	XCG-Duck/Little Miami	282	81	466
Ohio River	N	467	Humbert & Delta Avenue Regulator	XCG-Duck/Little Miami	4672	81	466
Ohio River	S	OH-OF	SSO (bypass)	Woolpert	L036018	85	465.65
Ohio River	N	657	Corbin	XCG-Duck/Little Miami	291	91	466.6
Ohio River	N	459	Bayou St. 120 West D.D.	XCG-Mill	459-ovf	96	467.1
Ohio	N	460	Bayou St. 100 West D.D.	XCG-Mill	460-ovf	96	467.1

Receiving Water	Bank	KPDES#/ Ohio ID #	Description	SWMM Model	SWMM_ID	WASP SEG	River Mile
River							
Ohio River	N	457A	Colins St. West Regulator	XCG-Mill	457a-ovf	101	467.5
Ohio River	N	457	Colins St. West D.D.	XCG-Mill	457-ovf	101	467.5
Ohio River	N	458	Colins St. West Regulator	XCG-Mill	458-ovf	101	467.5
Ohio River	S	17	Main Street	Woolpert	L057030	105	467.22
Ohio River	N	456	Hazen St. D.D.	XCG-Mill	456-ovf	106	467.9
Ohio River	N	454	Litherbury St. D.D.	XCG-Mill	454-ovf	111	468.4
Ohio River	N	455	Walden St. D.D.	XCG-Mill	455-ovf	111	468.2
Ohio River	S	16	McKinney Street	Woolpert	L057011	115	468.03
Ohio River	N	453A	Collard St. Regulator	XCG-Mill	453a-ovf	116	468.7
Ohio River	N	453	Collard St. East D.D.	XCG-Mill	453-ovf	116	468.7
Ohio River	S	18	Foote Avenue	Woolpert	L060002	120	468.48
Ohio River	S	19	Ward Avenue	Woolpert	L060016	120	468.48
Ohio River	S	20	Washington Avenue	Woolpert	L061006	120	468.48
Ohio River	S	21	Taylor Avenue	Woolpert	L061029	120	468.48
Ohio River	N	452	Parsons St. D.D.	XCG-Mill	452-ovf	121	469.1
Ohio River	S	22	Lafayette Avenue	Woolpert	L062015	125	468.84
Ohio River	S	23	Patchen Street	Woolpert	L062031	125	468.84
Ohio River	N	451	Sawyer Point East D.D.	XCG-Mill	451-ovf	126	469.4
Ohio River	S	BELL-OF	SSO (elevated OF into CR near Bellevue)	Woolpert	L053083	130	469.14
Ohio River	S	25	Geiger Avenue	Woolpert	L065041	130	469.14
Ohio	S	26	Taylor Bottoms	Woolpert	L065084	130	469.14

Receiving Water	Bank	KPDES#/ Ohio ID #	Description	SWMM Model	SWMM_ID	WASP SEG	River Mile
River							
Ohio River	N	461	Eggleston & 4th D.D.	XCG-Mill	461-ovf	131	469.6
Ohio River	N	463	Eggleston & 3rd D.D.	XCG-Mill	463-ovf	131	469.6
Ohio River	N	464	Eggleston & 3rd C. D.D.	XCG-Mill	464-ovf	131	469.6
Ohio River	N	465	Eggleston & 3rd D.D.	XCG-Mill	465-ovf	131	469.6
Ohio River	N	466	Eggleson & P.R. Way D.D.	XCG-Mill	466-OVF	131	469.6
Ohio River	N	468	468-o	XCG-Mill	468-O	131	466
Ohio River	S	83	Riverside Drive	Woolpert	L063001	135	469.45
Ohio River	S	24	Interceptor Overflow	Woolpert	L064001	135	469.45
Ohio River	S	24	Washington Ave Chmbr	Woolpert	L064084	135	469.45
Ohio River	N		314-o	XCG-Mill	314-O	136	469.9
Ohio River	N	445	Riverfront Stadium Regulator	XCG-Mill	445-ovf	136	470
Ohio River	N	447	Riverfront Colliseum Regulator	XCG-Mill	447-ovf	136	470
Ohio River	N	449	Pike St. D.D.	XCG-Mill	449-ovf	136	469.9
Ohio River	N	450	Butler St. D.D.	XCG-Mill	450-ovf	136	469.8
Ohio River	S	28	Saratoga Street	Woolpert	L077006	140	469.73
Ohio River	S	31	Columbia St. Chamber	Woolpert	L079015	140	469.73
Ohio River	S	61	Garrard Street	Woolpert	L144156	217	470.07
Ohio River	N	442	Vine St. Regulator	XCG-Mill	4420ovf	218	470.6
Ohio River	S	56	2nd St. @ Russell St. (and Wash. St)	Woolpert	L144002	222	470.51
Ohio River	S	58	Madison Avenue (and 2nd St)	Woolpert	L144072	222	470.51
Ohio River	S	59	Scott Street	Woolpert	L144100	222	470.51

Receiving Water	Bank	KPDES#/ Ohio ID #	Description	SWMM Model	SWMM_ID	WASP SEG	River Mile
Ohio River	S	60	Greenup Street	Woolpert	L144121	222	470.51
Ohio River	N	437	Smith St. Regulator	XCG-Mill	437-ovf	223	471.2
Ohio River	N	438	Central Ave. West G.	XCG-Mill	438-ovf	223	471
Ohio River	S	62	Philadelphia Street	Woolpert	L147003	227	470.92
Ohio River	S	63	Bakewell Street	Woolpert	L147032	227	470.92
Ohio River	S	63	Main Street	Woolpert	L147052	227	470.92
Ohio River	S	63	Johnson Street	Woolpert	L147072	227	470.92
Ohio River	S	30	Willow Run (and #49 and 7 others)	Woolpert	L148WROF	227	470.92
Ohio River	N	436	Gest & Front Regulator	XCG-Mill	436-ovf	228	471.6
Ohio River	S	64	Swain Court	Woolpert	L149015	232	471.30
Ohio River	S	65	Parkway @ Highway	Woolpert	L149027	232	471.30
Ohio River	N	435	Baymiller St. Regulator	XCG-Mill	435-ovf	233	471.8
Ohio River	N	433	Carr St. Regulator	XCG-Mill	433-ovf	238	472.1
Ohio River	N	434	Carr & Front D.D.	XCG-Mill	434-O	238	472.1
Ohio River	S	66	Altamont Street	Woolpert	L150009	242	471.95
Ohio River	N	430	Gest St. West 2-A D.D.	XCG-Mill	430-ovf	243	472.4
Ohio River	N	431	McLean St. D.D.	XCG-Mill	431-ovf	243	472.4
Ohio River	N	432	9th St & McLean D.D.	XCG-Mill	432-O	243	472.4
Ohio River	N	489	7th & McLean D.D.	XCG-Mill	489-O	243	472.4
Ohio River	N		1-ovf	XCG-Mill	1-OVF	248	472.6
Ohio River	N	426A	Evans & River Rd. #1 D.	XCG-Mill	426A-O	248	472.6
Ohio	N	426B	Evans & River Rd. # 2 D.	XCG-Mill	426B-o	248	472.6

Receiving Water	Bank	KPDES#/ Ohio ID #	Description	SWMM Model	SWMM_ID	WASP SEG	River Mile
River							
Ohio River	N	427	Perin & Evans D.D.	XCG-Mill	427-OVF	248	472.6
Ohio River	N	428	South St. Regulator	XCG-Mill	428-OVF	248	472.6
Ohio River	N	429	Gest St. East D.D.	XCG-Mill	429-o	248	472.6
Ohio River	N	2000	Mill Creek	XCG-Mill	mill cree	248	472.5
Ohio River	S	72	Ash Street	Woolpert	L171098	252	472.45
Ohio River	N	6000	Mill Creek WWTP-Untreated (Bypass)	XCG-Mill	MILL	253	472.7
Ohio River	N	6000	Mill Creek WWTP-Treated (Bypass)	XCG-Mill	TREAT	253	472.7
Ohio River	S	70	Butler Street	Woolpert	L171068	257	472.69
Ohio River	S	71	Carneal Street	Woolpert	L171084	257	472.69
Ohio River	N	423	Mt. Hope Ave. Regulator	XCG-Mill	423-OVF	258	473.2
Ohio River	N	424	River Rd. at State D.D.	XCG-Mill	424-ovf	258	473
Ohio River	N	425	State Ave. D.D.	XCG-Mill	425-ovf	258	473
Ohio River	S	68	Adela Street	Woolpert	L171003	262	472.92
Ohio River	S	69	Kenner Street	Woolpert	L171054	262	472.92
Ohio River	N	422	Mt. Echo Rd Regulator	XCG-Mill	422-OVF	263	473.5
Ohio River	S	73	Lagoon Street	Woolpert	L172005	267	473.39
Ohio River	S	75	Pleasant Street	Woolpert	L173029	267	473.39
Ohio River	N	417	Bold Face #3 D.D.	XCG-Mill	417-OVF	268	474.4
Ohio River	N	418	River Road A.D.D.	XCG-Mill	418-OVF	268	474.4
Ohio River	N	419	Bold Face Sr. D.D.	XCG-Mill	419-OVF	268	474.4
Ohio River	N	420	Delhi Ave. D.D.	XCG-Mill	420-OVF	268	474.1

Receiving Water	Bank	KPDES#/ Ohio ID #	Description	SWMM Model	SWMM_ID	WASP SEG	River Mile
Ohio River	N	421	River Road & Delhi D.D.	XCG-Mill	421-OVF	268	474.1
Ohio River	S	74	Rohman Street	Woolpert	L173008	272	473.96
Ohio River	S	OF	Bromley Pump Station OF	Woolpert	L173BROF	272	473.96
Ohio River	S	BRPS	Bromley Pump Station	Woolpert	L173BRPS	272	473.96
Ohio River	N	416	Idaho	XCG-Muddy	416-OVF	273	474.6
Ohio River	N	415	Fithian	XCG-Muddy	415-OVF	278	475
Ohio River	N	413	Tyler	XCG-Muddy	413-OVF	283	475.8
Ohio River	N	414	McGinnis	XCG-Muddy	414-OVF	283	475.8
Ohio River	N	412	Colfax	XCG-Muddy	412-OVF	296	476.9
Ohio River	N	411	Anderson Ferry	XCG-Muddy	411-OVF	306	477.9
Ohio River	N	410	Feinmore	XCG-Muddy	410-OVF	311	478.8
Ohio River	N	223	Foley	XCG-Muddy	223-OVF	316	479.4
Ohio River	N	654	Stille	XCG-Muddy	654-OVF	316	479.4
Ohio River	N	408	Wochner	XCG-Muddy	408-OVF	321	480
Ohio River	N	541	East of Bender	XCG-Muddy	541-OVF	331	480.8
Ohio River	N	3000	Rapid Run Creek	XCG-Muddy	rapid	331	480.8
Ohio River	N	406	Belmore	XCG-Muddy	406-OVF	336	481.6
Ohio River	N	7000	Muddy Creek WWTP-Treated	XCG-Muddy	treated	336	481.4
Ohio River	N	7000	Muddy Creek WWTP-Untreated	XCG-Muddy	untreated	336	481.4
Ohio River	N	404	Invanhoe	XCG-Muddy	404-OVF	341	482.1
Ohio River	N	405	Revere	XCG-Muddy	405-OVF	341	482

Receiving Water	Bank	KPDES#/ Ohio ID #	Description	SWMM Model	SWMM_ID	WASP SEG	River Mile
Ohio River	N	402	Topinabee	XCG-Muddy	402-OVF	351	483.5
Ohio River	N	403	Elco	XCG-Muddy	403-OVF	351	483.2
Ohio River	N	401	Muddy Creek Pump Station	XCG-Muddy	401-OVF	356	484
Ohio River	N	4000	Muddy Creek	XCG-Muddy	muddy	356	484.1

An event mean concentration (EMC) was applied to the hourly overflow volumes to estimate a corresponding loading time series. Event mean concentrations developed as part of the Northern Kentucky water quality assessment conducted in 1998 were applied to Ohio River CSOs. EMCs are summarized by parameter and collection system model in Table 4-5.

Table 4-5. Event Mean Concentrations for Simulated Parameters.

Model	Model Output	Fecal coliform (#/100 mL)	CBOD5 (mg/L)	Ammonia (mg/L)	Organic Nitrogen (mg/L)
Woolpert	All	875,000	21.83	1.93	5.21
XCG	All		21.83	1.93	5.21
XCG	Stormwater	53,000			
	CSO	1,000,000			

Daily CSO load magnitude and duration are summarized in Table 4-6 and Appendix C. Because there are uncertainties associated with both the timing and magnitude of the sewer loads, sensitivity runs were conducted with the WASP5 model to CSO loads, described in Section 4.4.3.e.

Tributary Loadings
Loadings at the mouth of each tributary were estimated using survey data collected by ORSANCO during the May 2000 event. Flow and fecal coliform concentration data were combined to develop a loading time series for the Little Miami, Mill Creek, Muddy Creek, Licking and Great Miami rivers. The loading time series were input in two-hour increments on the first day of the storm, four-hour increments on the second day of the storm and twelve-hour increments on the remaining survey days. Tributary load magnitude and durations are also included in Table 4-6 and Appendix C.

WWTP Loadings
Loadings from the three wastewater treatment plants in the Cincinnati metropolitan area, the Little Miami WWTP, the Mill Creek WWTP, and the Muddy Creek WWTP, were estimated using the XCG collection system model output. Loadings from the Indian Creek WWTP, near

the Ohio River, were neglected because it is a minor load contributor and is not part of the XCG model. Loadings from the primary wastewater treatment plant serving the Northern Kentucky metropolitan area, the Dry Creek WWTP, were estimated using plant data of flow and concentration from May 2000.

Table 4-6. Combined Sewer Overflow Fecal Coliform Loadings.

KPDES#/ Ohio ID #	Description	Total Overflow Volume (MG)	Average Overflow Rate (cfs)	Maximum Overflow Rate (cfs)	Duration (hours)	Total Fecal Coliform Load (#)	Total Fecal Coliform Load (#) 5/27-29/00
SGPS	Silver Grove Pump Station	0	0	0	0	0	0
HHPS	Highland Heights Pump Station-Overflow#1	0.155	2.941	5.178	2	5.25E+12	5.25E+12
HHPS	Highland Heights Pump Station-Overflow#2	3.483	1.690	23.087	78	1.18E+14	1.11E+14
11	Government Sewer	0.315	3.977	7.974	3	1.06E+13	1.06E+13
12	Tower Hill Road	0.378	1.100	3.967	13	1.28E+13	1.28E+13
14	Burnet Ridge	0.531	5.028	9.231	4	1.79E+13	1.79E+13
13	Manor Lane	0.541	2.274	11.849	9	1.83E+13	1.83E+13
15	Elsmar Street	0.136	1.289	4.481	4	4.60E+12	4.60E+12
OH-OF	SSO (bypass)	3.477	1.645	8.259	80	1.17E+14	1.08E+14
BELL-OF	SSO (elevated OF into CR near Bellevue)	1.723	5.930	11.235	11	5.82E+13	5.82E+13
16	McKinney Street	16.247	55.911	431.559	11	5.49E+14	5.49E+14
17	Main Street	8.008	21.652	189.175	14	2.70E+14	2.70E+14
18	Foote Avenue	0.769	0.157	15.680	186	2.60E+13	2.42E+13
19	Ward Avenue	4.213	0.853	90.280	187	1.42E+14	1.37E+14
20	Washington Avenue	1.196	5.657	32.386	8	4.04E+13	4.04E+13
21	Taylor Avenue	1.661	6.289	45.424	10	5.61E+13	5.61E+13
22	Lafayette Avenue	0.619	4.684	17.366	5	2.09E+13	2.09E+13
23	Patchen Street	1.311	7.091	28.062	7	4.43E+13	4.43E+13
83	Riverside Drive	2.26E-06	8.56E-05	8.56E-05	1	7.64E+07	7.64E+07
24	Interceptor Overflow	49.511	9.761	76.241	192	1.67E+15	9.97E+14
24	Washington Ave Chmbr	3.571	16.895	90.195	8	1.21E+14	1.21E+14
25	Geiger Avenue	7.879	1.754	40.289	170	2.66E+14	2.61E+14
26	Taylor Bottoms	0.716	4.520	11.563	6	2.42E+13	2.42E+13
28	Saratoga Street	1.339	5.068	26.881	10	4.52E+13	4.52E+13
31	Columbia St. Chamber	2.274	14.349	57.626	6	7.68E+13	7.68E+13
56	2nd St. @ Russell St. (and Wash. St)	1.299	7.025	29.888	7	4.39E+13	4.39E+13
58	Madison Avenue (and 2nd St)	0.761	4.114	16.248	7	2.57E+13	2.57E+13
59	Scott Street	0.244	3.077	7.210	3	8.23E+12	8.23E+12
60	Greenup Street	0.474	4.485	11.784	4	1.60E+13	1.60E+13
61	Garrard Street	0.374	2.359	8.071	6	1.26E+13	1.26E+13
62	Philadelphia Street	0.571	5.402	14.131	4	1.93E+13	1.93E+13
63	Bakewell Street	0.285	2.694	7.576	4	9.61E+12	9.61E+12
63	Main Street	1.759	9.514	42.329	7	5.94E+13	5.94E+13

63	Johnson Street	0.288	1.557	6.208	7	9.72E+12	9.72E+12
30	Willow Run (and #49 and 7 others)	34.131	6.946	415.073	186	1.15E+15	9.41E+14
64	Swain Court	0.030	0.568	0.732	2	1.01E+12	1.01E+12
65	Parkway @ Highway	2.151	10.177	38.665	8	7.26E+13	7.26E+13
66	Altamont Street	3.154	14.923	60.405	8	1.06E+14	1.06E+14
68	Adela Street	0	0	0	0	0	0
69	Kenner Street	0.295	2.788	7.494	4	9.95E+12	9.95E+12
70	Butler Street	0.303	2.297	6.610	5	1.02E+13	1.02E+13
71	Carneal Street	0.662	3.582	13.789	7	2.24E+13	2.24E+13
72	Ash Street	0.387	3.660	8.376	4	1.31E+13	1.31E+13
73	Lagoon Street	1.288	6.964	24.699	7	4.35E+13	4.35E+13
74	Rohman Street	1.104	5.968	21.308	7	3.73E+13	3.73E+13
75	Pleasant Street	0.623	2.622	11.412	9	2.10E+13	2.10E+13
BRPS	Bromley Pump Station	0	0	0	0	0	0
	1-ovf	0	0	0	0	0	0
	314-o	0	0	0	0	0	0
417	Bold Face #3 D.D.	0.320	1.212	8.403	10	1.24E+13	1.24E+13
418	River Road A.D.D.	0.009	0.172	0.321	2	3.51E+11	3.51E+11
419	Bold Face Sr. D.D.	7.235	15.215	86.583	18	2.82E+14	2.82E+14
420	Delhi Ave. D.D.	0	0	0	0	0	0
421	River Road & Delhi D.D.	0	0	0	0	0	0
422	Mt. Echo Rd Regulator	2.970	2.742	52.362	41	1.18E+14	1.18E+14
423	Mt. Hope Ave. Regulator	1.968	1.817	33.633	41	7.89E+13	7.89E+13
424	River Rd. at State D.D.	0.067	2.530	2.530	1	2.59E+12	2.59E+12
425	State Ave. D.D.	0.317	1.090	7.884	11	1.26E+13	1.26E+13
426A	Evans & River Rd. #1 D.	0.001	0.021	0.042	2	4.37E+10	4.37E+10
426B	Evans & River Rd. # 2 D.	0	0	0	0	0	0
427	Perin & Evans D.D.	0	0	0	0	0	0
428	South St. Regulator	1.127	2.844	24.710	15	4.35E+13	4.35E+13
429	Gest St. East D.D.	0.057	1.074	2.147	2	2.19E+12	2.19E+12
430	Gest St. West 2-A D.D.	0.056	0.033	1.638	64	1.68E+12	1.68E+12
431	McLean St. D.D.	1.561	19.696	29.221	3	6.05E+13	6.05E+13
432	9th St & McLean D.D.	0.001	0.024	0.024	1	2.57E+10	2.57E+10
433	Carr St. Regulator	0.033	0.252	1.059	5	1.29E+12	1.29E+12
434	Carr & Front D.D.	0	0	0	0	0	0
435	Baymiller St. Regulator	0	0	0	0	0	0
436	Gest & Front Regulator	0.072	0.340	1.981	8	2.86E+12	2.86E+12
437	Smith St. Regulator	0.053	0.221	1.412	9	2.06E+12	2.06E+12
438	Central Ave. West G.	0.010	0.187	0.375	2	3.97E+11	3.97E+11
442	Vine St. Regulator	0	0	0	0	0	0
445	Riverfront Stadium Regulator	0.061	0.768	2.118	3	2.37E+12	2.37E+12
447	Riverfront Colliseum Regulator	0.004	0.133	0.133	1	1.39E+11	1.39E+11
449	Pike St. D.D.	0.004	0.076	0.153	2	1.56E+11	1.56E+11
450	Butler St. D.D.	0.009	0.166	0.332	2	3.56E+11	3.56E+11
451	Sawyer Point East D.D.	0	0	0	0	0	0
452	Parsons St. D.D.	0.191	2.412	6.246	3	7.37E+12	7.37E+12
453A	Collard St. Regulator	0.231	2.186	7.129	4	9.06E+12	9.06E+12

453	Collard St. East D.D.	0.163	1.028	5.079	6	6.29E+12	6.29E+12
454	Litherbury St. D.D.	0.361	3.416	11.473	4	1.40E+13	1.40E+13
455	Walden St. D.D.	0.210	1.588	6.589	5	8.10E+12	8.10E+12
456	Hazen St. D.D.	0.094	0.712	2.902	5	3.63E+12	3.63E+12
457A	Colins St. West Regulator	0.005	0.091	0.182	2	1.87E+11	1.87E+11
457	Colins St. West D.D.	0	0	0	0	0	0
458	Colins St. West Regulator	0.942	1.982	18.434	18	3.67E+13	3.67E+13
459	Bayou St. 120 West D.D.	0.075	0.203	1.765	14	2.90E+12	2.90E+12
460	Bayou St. 100 West D.D.	0.747	2.572	18.042	11	2.92E+13	2.92E+13
461	Eggleston & 4th D.D.	0.027	0.016	0.020	64	1.70E+10	1.70E+10
463	Eggleston & 3rd D.D.	0	0	0	0	0.00E+00	0.00E+00
464	Eggleston & 3rd C. D.D.	0.021	0.788	0.788	1	8.10E+11	8.10E+11
465	Eggleston & 3rd D.D.	0	0	0	0	0	0
466	Eggleson & P.R. Way D.D.	0.00242	0.092	0.092	1	9.35E+10	9.35E+10
468	468-o	0.00243	0.092	0.092	1	9.75E+10	9.75E+10
489	7th & McLean D.D.	0	0	0	0	0	0
2000	Mill Creek	230.028	128.052	1003.108	68	2.15E+15	2.15E+15
223	Foley	0.833	3.153	20.886	10	3.22E+13	3.22E+13
401	Muddy Creek Pump Station	7.756	12.765	76.483	23	3.02E+14	3.02E+14
402	Topinabee	0.287	1.553	8.413	7	1.11E+13	1.11E+13
403	Elco	0.107	1.349	3.530	3	4.13E+12	4.13E+12
404	Invanhoe	0.892	3.069	21.866	11	3.44E+13	3.44E+13
405	Revere	0.359	1.942	9.904	7	1.39E+13	1.39E+13
406	Belmore	0.662	2.784	16.473	9	2.57E+13	2.57E+13
408	Wochner	0.387	2.927	11.767	5	1.50E+13	1.50E+13
410	Feinmore	0.191	1.444	6.060	5	7.37E+12	7.37E+12
411	Anderson Ferry	1.593	5.024	38.536	12	6.16E+13	6.16E+13
412	Colfax	0.193	0.812	5.668	9	7.45E+12	7.45E+12
413	Tyler	0.431	3.263	12.551	5	1.67E+13	1.67E+13
414	McGinnis	0.048	0.611	1.667	3	1.87E+12	1.87E+12
415	Fithian	0.692	3.273	19.513	8	2.67E+13	2.67E+13
416	Idaho	0.589	2.788	15.787	8	2.29E+13	2.29E+13
541	East of Bender	0.012	0.450	0.450	1	4.60E+11	4.60E+11
654	Stille	0.158	1.197	4.834	5	6.17E+12	6.17E+12
4000	Muddy Creek	8.730	5.007	152.378	66	3.02E+14	3.02E+14
3000	Rapid Run Creek	5.445	3.123	104.919	66	1.91E+14	1.91E+14
7000	Muddy Creek WWTP-Treated	13.052	7.969	27.848	62	5.03E+14	5.03E+14
7000	Muddy Creek WWTP-Untreated	1.894	11.951	27.358	6	7.28E+13	7.28E+13
6000	Mill Creek WWTP-Untreated (Bypass)	0	0	0	0	0	0
6000	Mill Creek WWTP-Treated (Bypass)	96.389	53.658	356.922	68	3.43E+15	3.43E+15
468	Humbert & Congress Avenue Regulato	0.367	2.780	11.374	5	1.42E+13	1.42E+13
469	Delta & Eastern Avenue Regulator	5.027	10.571	70.796	18	1.98E+14	1.98E+14
467A	Humbert & Delta Avenue Connection	0.000441	0.008	0.017	2	1.49E+10	1.49E+10
657	Corbin	0	0	0	0	0	0
5000	Little Miami WWTP-Bypass 2	5.959	45.113	103.939	5	2.41E+14	2.41E+14
5000	Little Miami WWTP-Bypass 1	6.984	10.575	41.379	25	1.46E+13	1.46E+13
5000	Little Miami WWTP-Bypass 3	0	0	0	0	0	0

467	Humbert & Delta Avenue Regulator	0.284	2.688	9.158	4	1.10E+13	1.10E+13
1000	Little Miami River	308.082	174.062	1115.872	67	1.21E+15	1.21E+15
9000	Direct Stormwater Drainage	23.451	20.176	408.892	44	4.80E+13	4.80E+13
5000	Little Miami WWTP-Treated	127.041	67.733	113.744	71	2.61E+14	2.61E+14

Loading Summary

Although upstream flow dominates the volume of water entering the study area during the May 2000 wet weather event, as shown in Figure 4-14, elevated fecal coliform concentrations observed in the river during wet weather are largely the result of tributary and CSO loads draining directly into the Ohio River.

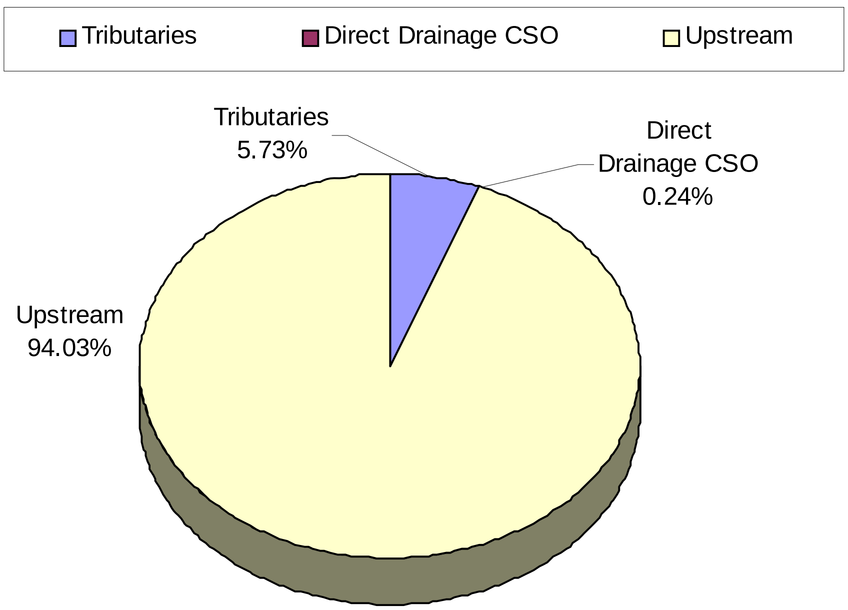


Figure 4-14. Comparison of Volume (MG) by Source during 5/27-29/00 Event.

Table 4-7 illustrates the relative contribution of each external and internal loading source: CSOs draining directly to the Ohio River, tributaries and loads originating upstream of the study area. A comparison of fecal coliform loads from these loading sources indicates that tributaries, which contain CSO loadings, are the dominant loading source on the first two days of the storm, 5/27/01 –5/28/01. The following two days, CSOs draining directly to the Ohio River dominated the loads, although they were diminished by two orders of magnitude. Finally, the wet weather effects from this storm ended five days after the start of the storm and upstream loads dominated. Figure 4-15 shows the relative contribution of fecal load by source for each day of the storm.

Table 4-7. Summary of Fecal Coliform Loadings by Source.

Source	Volume (MG)	Total Coliform Load 5/27-29/00 (#)	Fecal Coliform Load on 5/27/00 (first day of storm)	Fecal Coliform Load on 5/28/00 (second day of storm)	Fecal Coliform Load on 5/29/00 (no rain but still storm flow)	Fecal Coliform Load on 5/30/00 (non-storm conditions)	Fecal Coliform Load on 5/31/00 (non-storm conditions)
Tributaries in CSO area[1]	3,741.9	1.213E+17	5.449E+16	5.501E+16	1.181E+16	5.603E+15	1.078E+15
Direct Drainage CSO	489.1	1.107E+16	8.327E+15	9.454E+16	8.916E+16	2.379E+14	2.141E+14
Upstream	189,357.7	2.031E+15	1.120E+15	1.418E+14	7.692E+14	3.744E+14	2.052E+14
Great Miami River[2]	7,790.8	1.234E+17	5.374E+16	6.248E+16	7.187E+15	9.280E+14	8.470E+14

[1] Includes Little Miami River, Mill Creek, Muddy Creek and the Licking River

[2] The Great Miami River is downstream of the Greater Cincinnati Metropolitan Area's CSOs.

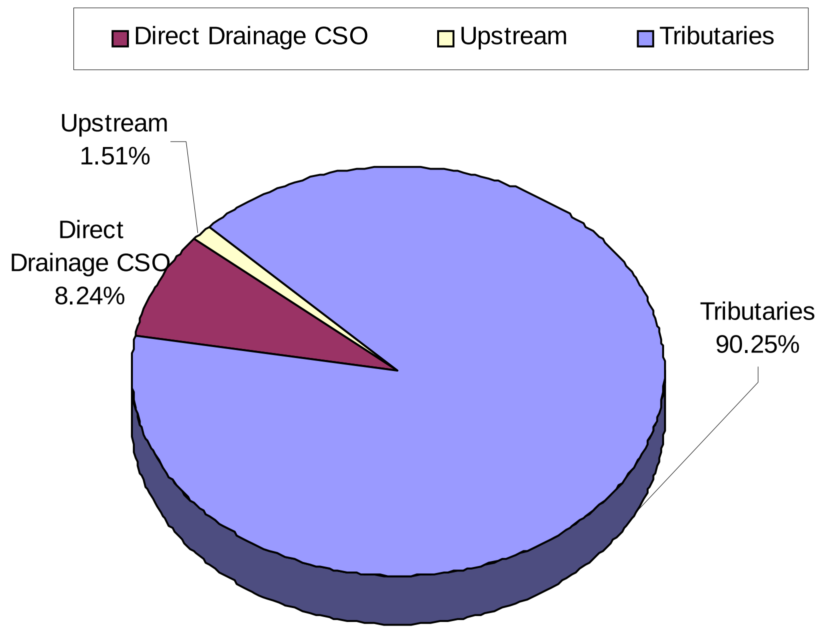


Figure 4-15. Comparison of Fecal Load (Total #) by Source during 5/27-29/00 Event

4.4.3.d RESULTS

This section presents the results of the WASP5 model calibration to the May 2000 survey conditions. Calibration results are presented in both spatial and temporal formats. The longitudinal river fecal coliform and dissolved oxygen concentration profiles along each bank and in the center channel during the survey period show the overall pattern observed and its comparison with the predicted levels. The temporal comparison displays the predictions over time at a particular location from the water quality model and the observed data.

Fecal Coliform
The model calibration to fecal coliform indicates that CSOs in the greater Cincinnati and Northern Kentucky metropolitan areas have an impact on water quality in the Ohio River. The greatest impacts were predicted to occur near the mouths of the major tributaries. Elevated concentrations resulting from the storm were predicted in the model domain for three days, through May 29. Upstream loads resulted in concentrations greater than the state standard of 200 #/100 mL for an additional two days. Concentrations generally returned to levels below the standard by 5/31/00. Maximum concentrations predicted for each day of the model simulation are provided in Appendix D.

The inputs used in the WASP5 water quality model reproduced the observations from the May 2000 event fairly well. The model reasonably reproduced the differences in concentration observed in near shore model segments compared to center channel model segments, as shown in Figures 4-16a-c. Given the uncertainty in the timing and magnitude of loadings, the model also produced reasonable estimates of the location of peak concentrations in near shore and center channel segments, as indicated in Figure 4-15. Comparison of the timing of model simulated concentrations to observed data at selected locations, as shown in Figure 4-17a-c, also shows good reproducibility with respect to capturing the timing and magnitude of observed maximum fecal coliform concentrations in the center channel and both near shore areas.

Simple statistical comparisons indicated that the model was well calibrated to the survey data from the May 2000 event. A comparison of observed and simulated daily geometric mean concentrations indicated a good correlation between the model and the survey data, as shown in Figure 4-18a. Further, a regression of the geometric means of the observed concentration data and corresponding simulated concentration showed a good correlation with an r^2 value of 0.90, as shown in Figure 4-18b.

Dissolved Oxygen
The overall spatial and temporal dissolved oxygen patterns in the Ohio River were captured well by the model for the wet weather event as shown in Figures 4-19a-b. The model confirmed observations from the water quality survey, namely that combined sewer overflows did not impact dissolved oxygen concentrations in the Ohio River. Concentrations ranged by less than one mg/L over the duration of the simulation and were well above the applicable water quality standards of daily average concentration of 5 mg/L and single measurement concentration of 4 mg/L. Inspection of model results at downstream locations indicated that there was not a significant dissolved oxygen sag resulting from this wet weather event.

4.4.3.e SENSITIVITIES

Selection of model inputs can have a significant influence on water quality model concentration predictions. The model's sensitivity to two inputs was tested with additional simulations of the May 2000 event. Selection of the fecal coliform decay rate was evaluated by rerunning the simulation using three other decay rates: 0 day^{-1}, 2 day^{-1}, and 4 day^{-1}. Model simulated concentrations using these decay rates were compared to observed data, as shown in Figure 4-20. Emphasis was given to matching observed data at the most downstream stations at river miles 500, 510, 520 and 530. Model predicted concentrations that most closely matched observed data at these downstream stations were simulated using a decay rate of 1 day^{-1}, which was the value used in the calibration.

A second sensitivity was performed to evaluate the uncertainty in the CSO and tributary loadings. The loads were varied by $\pm$ 50%. Results are shown in Figure 4-21 for the first two days for the storm in the near shore and center channel areas. Increasing the loads improved predictions in some areas, such as along the right bank (Ohio side). However, decreasing the loads improved predictions in other areas, such as the upstream left bank (Kentucky side) on the first day of the storm. In general, the loads used in the calibration resulted in the best overall model predictions of in-river concentrations at all locations.

4.4.4 VALIDATION – 1995 WET WEATHER EVENTS

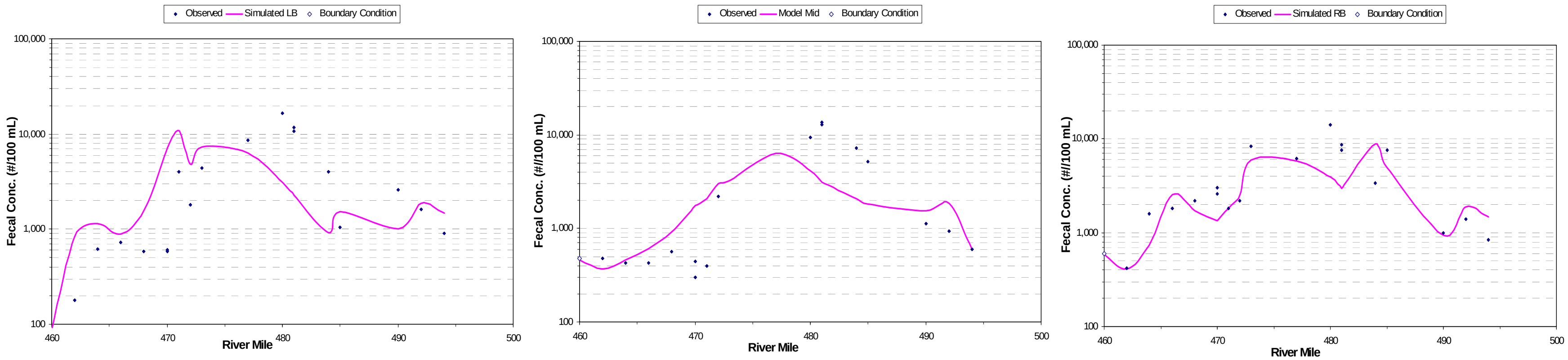
The WASP5 model was validated by simulating four wet weather surveys from 1995. Details of each of these wet weather events are summarized in Table 4-8. Because the calibration confirmed previous analyses that dissolved oxygen concentration impacts were negligible, fecal coliform was the only parameter or state variable modeled in the validation runs. The model inputs that were changed from the calibration were storm-specific inputs, including upstream flow, upstream and downstream boundary concentrations, and external fecal coliform loads.

Table 4-8. Summary of 1995 Survey Conditions.

Event	Start Day	End Day	Duration (days)	Flow[1] (cfs)	Rainfall[2] (in)
1	9/7/1995	9/11/1995	3	17,300	0.63
2	9/15/1995	9/19/1995	3	41,100	0.23
3	10/3/1995	10/7/1995	4	17,300	2.91
4	11/11/1995	11/15/1995	4	67,900	1.00

[1] Flow measured at Cincinnati
[2] Rainfall from Covington Airport Gage

Model simulated results were compared to observed data collected for the two storms representing minimum and maximum storm conditions from 9/8/95 and 11/11/95, respectively, in Figure 4-22 and Figure 4-23. Model simulations for each storm compared reasonably well to the collected survey data.

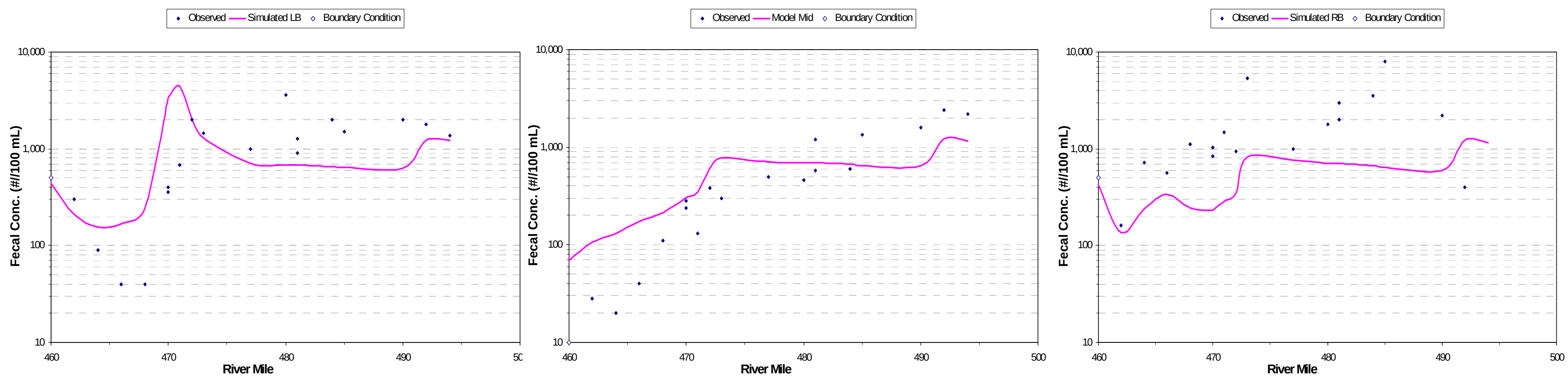


South (Left) Bank

Center (Middle) Channel

North (Right) Bank

Figure 4-16. a Simulated and Observed Fecal Coliform Concentrations Along the South (Left) Bank, Center (Middle) Channel and North (Right) Bank of the Ohio River on 5/27/00

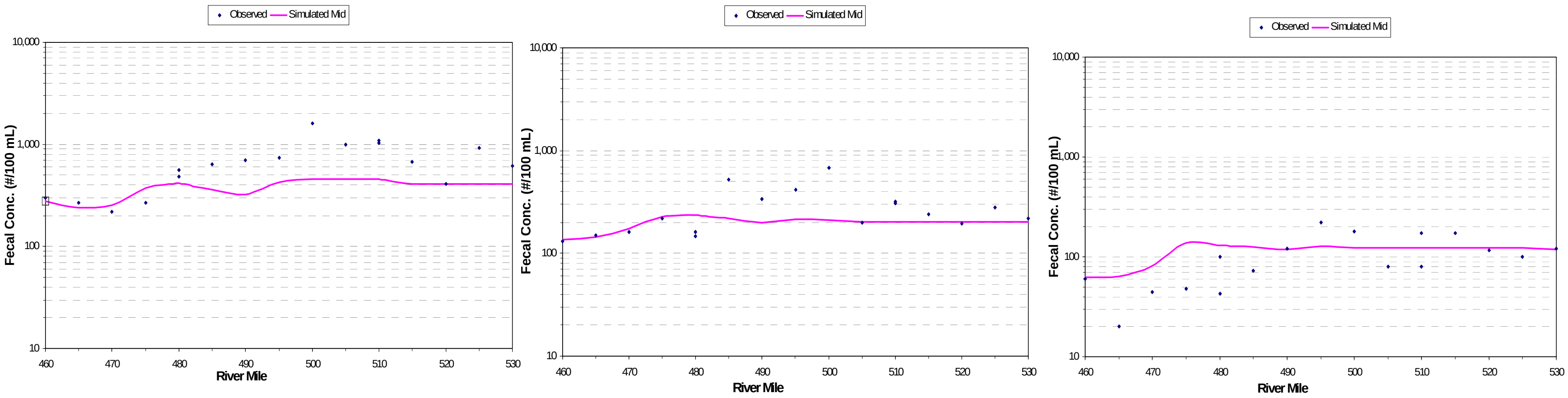


South (Left) Bank

Center (Middle) Channel

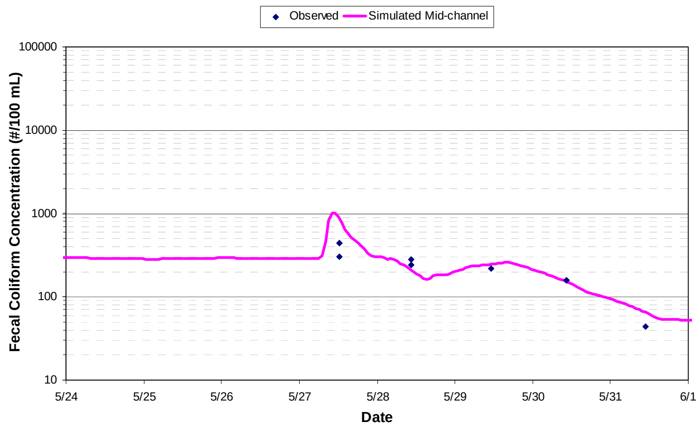
North (Right) Bank

Figure 4-16. b Simulated and Observed Fecal Coliform Concentrations Along the South (Left) Bank, Center (Middle) Channel, and North (Right) Bank of the Ohio River on 5/28/00.

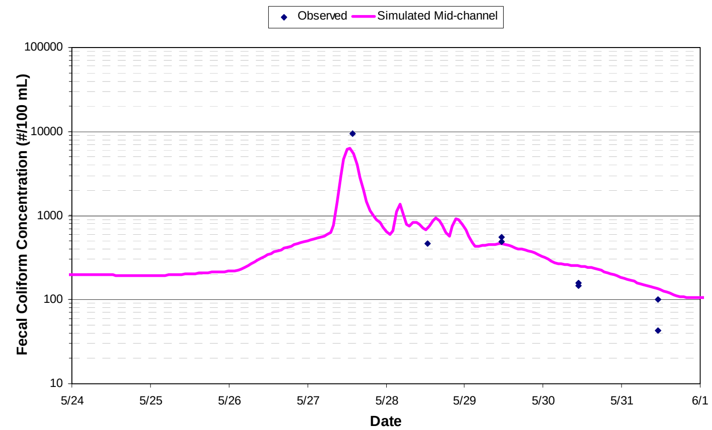


5/29/00 **5/30/00** **5/31/00**

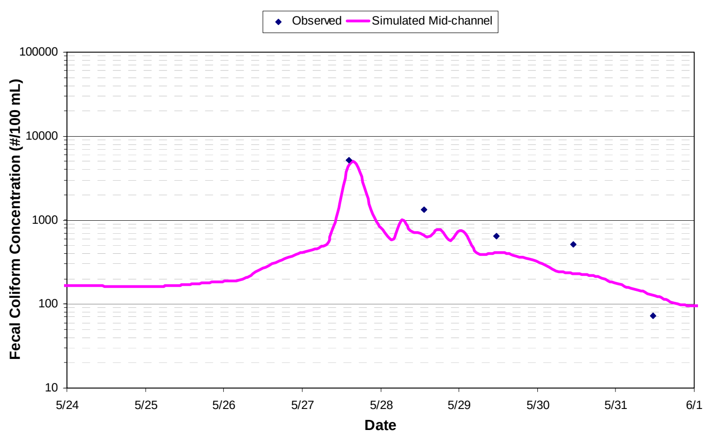
Figure 4-16. c Simulated and Observed Fecal Coliform Concentrations Near Center (Middle) Channel of Ohio River on 5/29/00-5/31/00.



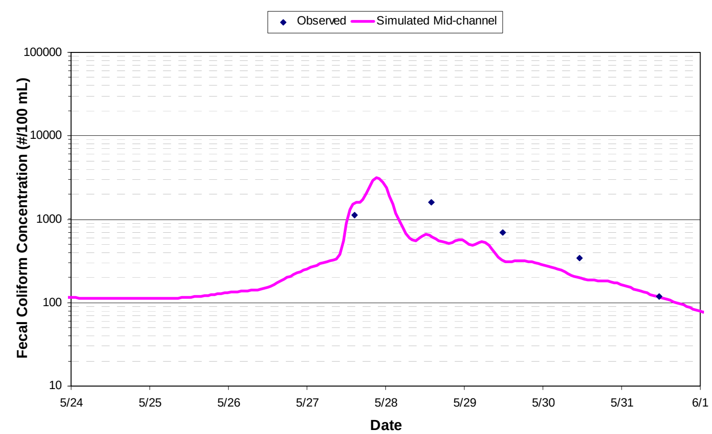
River Mile 470-*Licking River Confluence*



River Mile 480-*Dry Creek Confluence*



River Mile 485-*Downstream of CSO and WWTP Sources*



River Mile 490-*Great Miami Confluence*

Figure 4-17 a. Comparison of Simulated and Observed Center Channel Fecal Coliform Concentrations at Selected Locations.

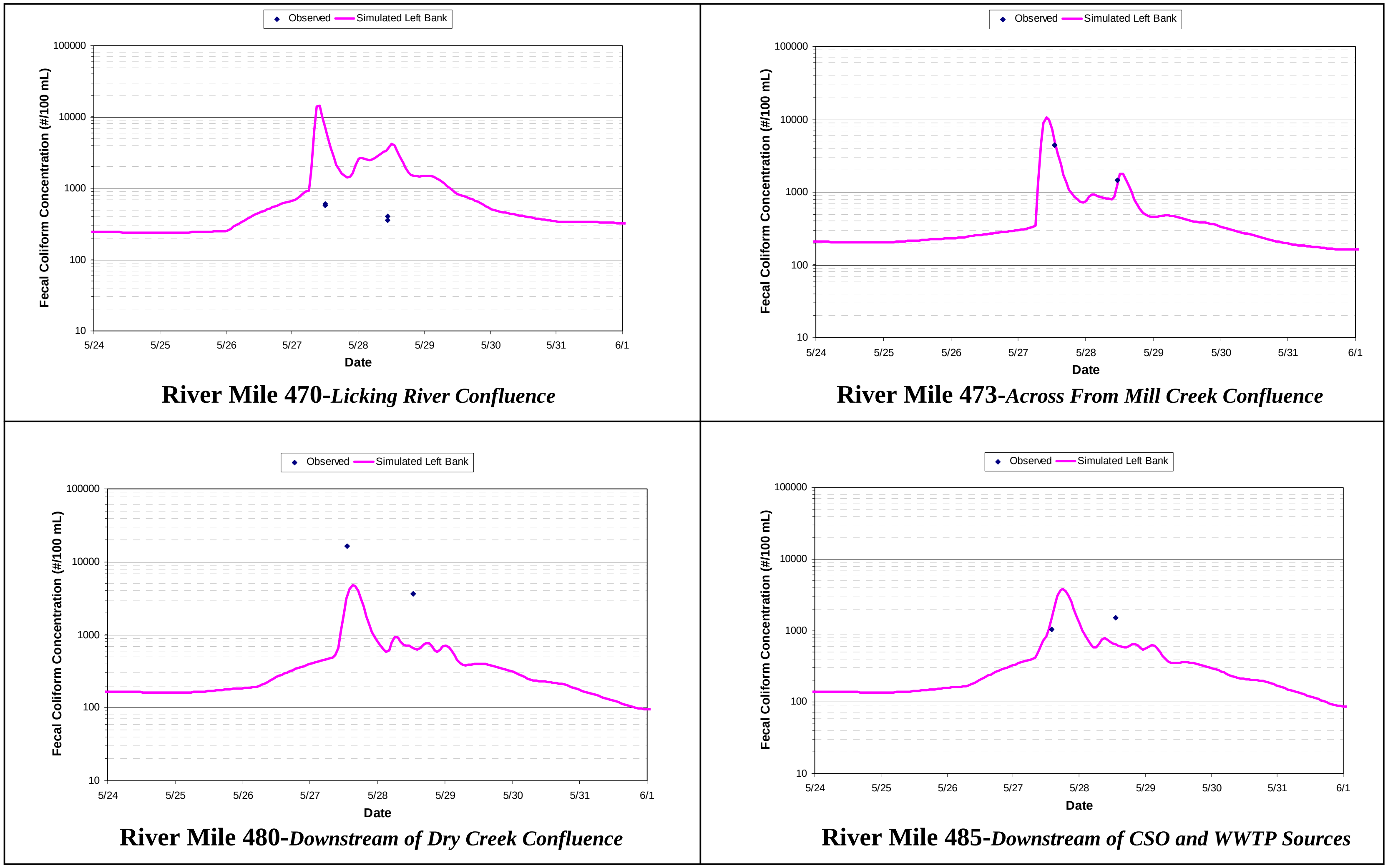
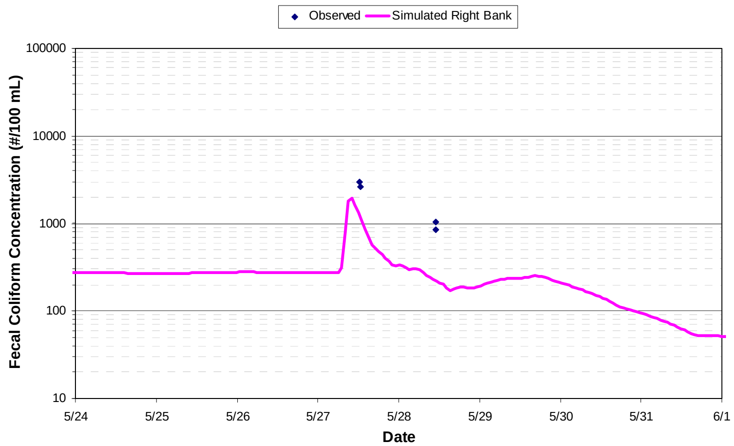
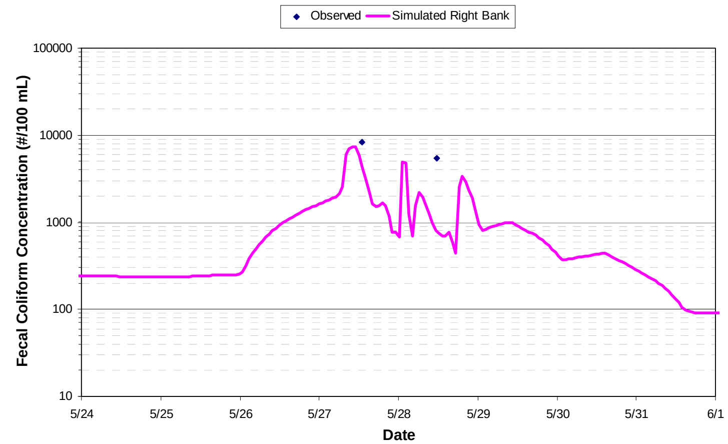


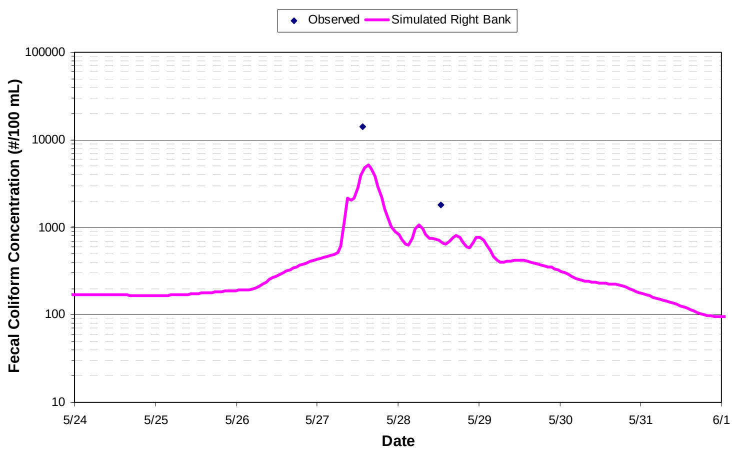
Figure 4-17 b. Comparison of Simulated and Observed South (Left) Bank Fecal Coliform Concentration at Selected Locations.



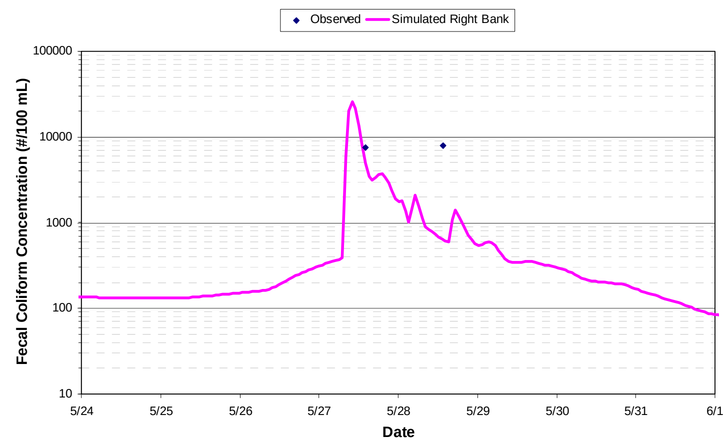
River Mile 470-*Across from Licking River Confluence*



River Mile 473-*Mill Creek Confluence*

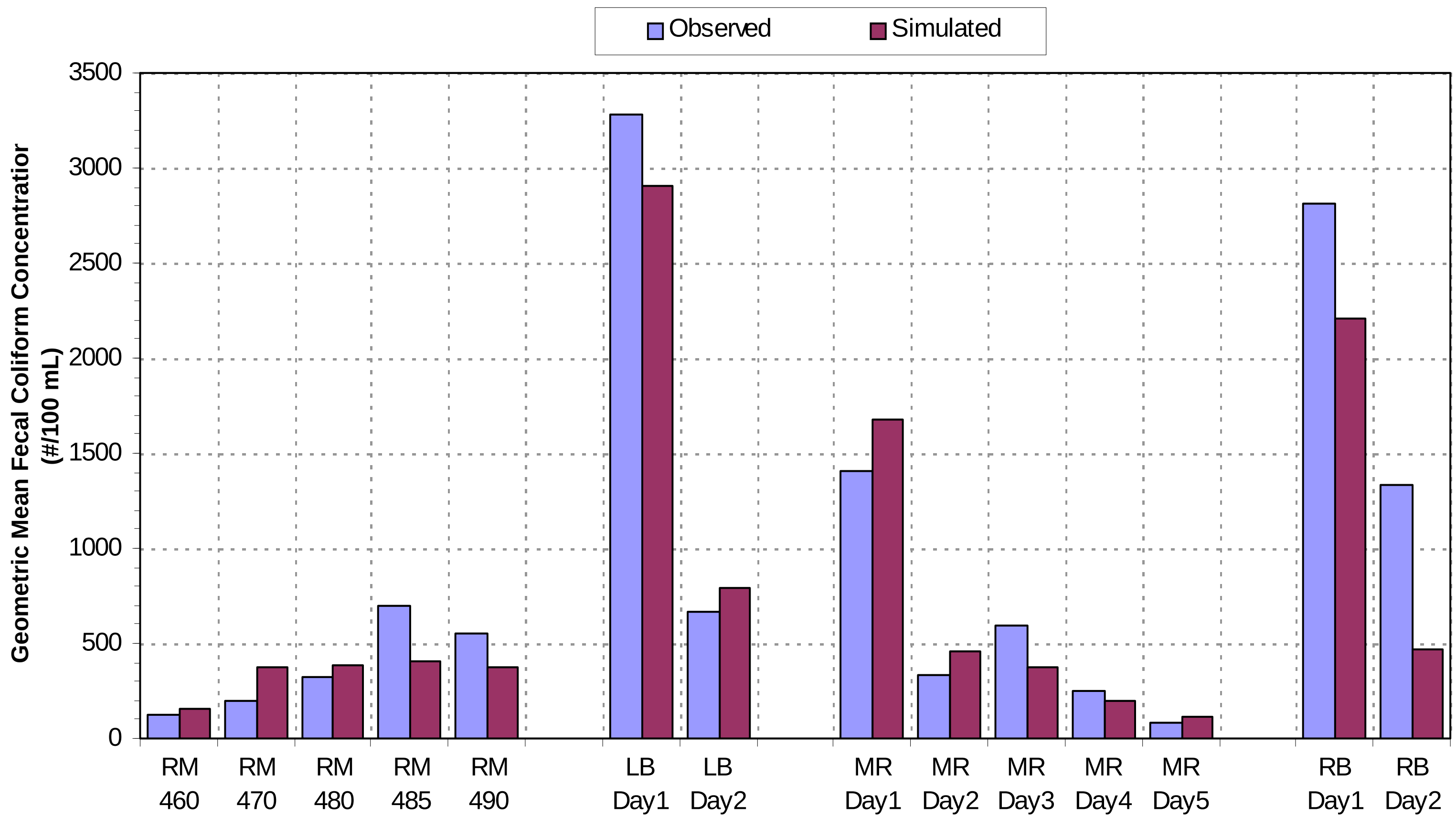


River Mile 480-*Upstream of Muddy Creek Confluence*



River Mile 485-*Downstream of CSO and WWTP Sources*

Figure 4-17 c. Comparison of Simulated and Observed North (Right) Bank Fecal Coliform Concentration at Selected Locations.



Key:	RM=River Mile	LB=Left Bank	MR=Middle of River	RB=Right Bank

Figure 4-18 a. Comparison of Simulated and Observed Geometric Mean Fecal Coliform Concentrations at Various River Locations.

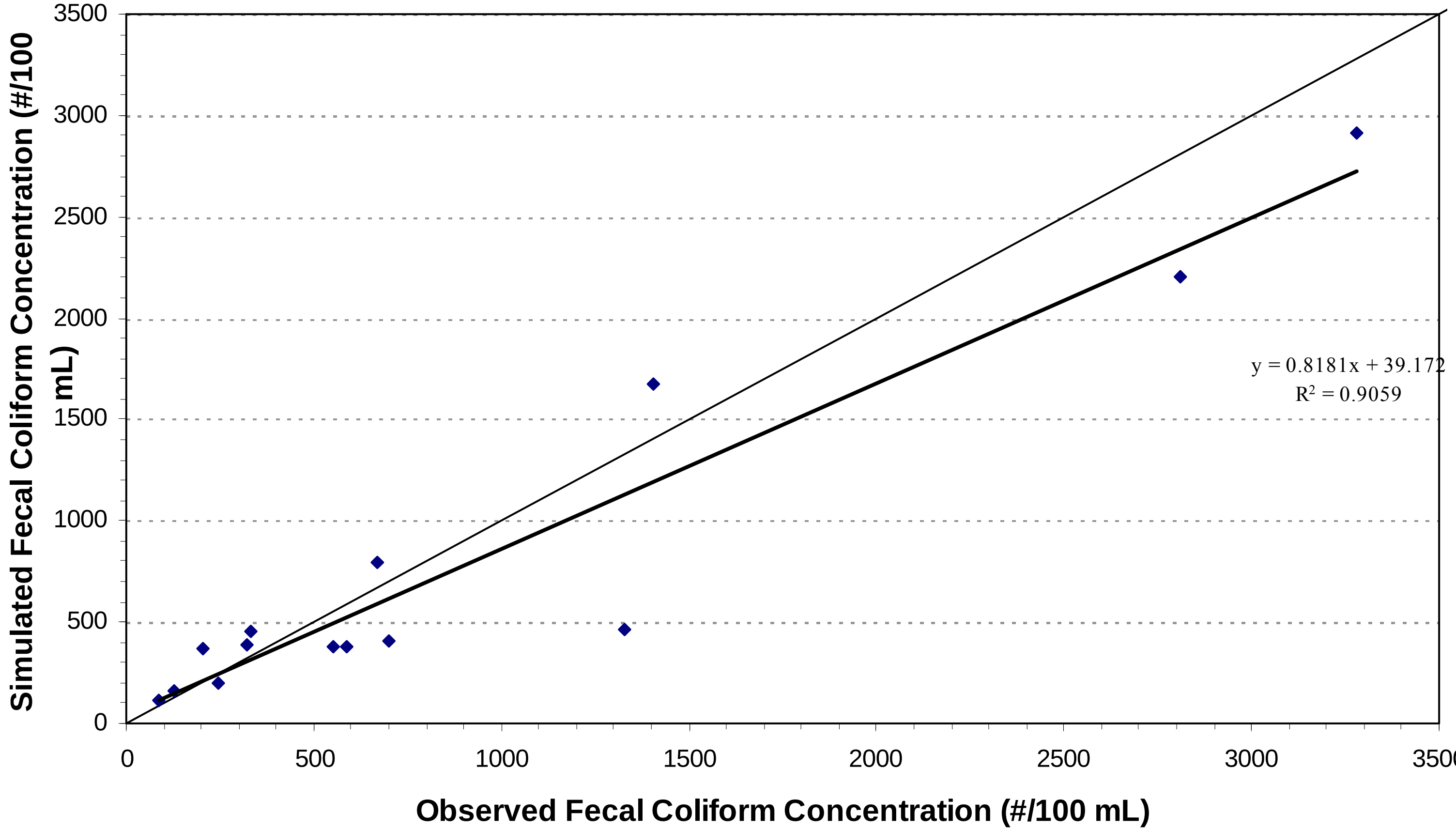


Figure 4-18 b. Regression of Observed and Simulated Geometric Mean Fecal Coliform Concentrations.

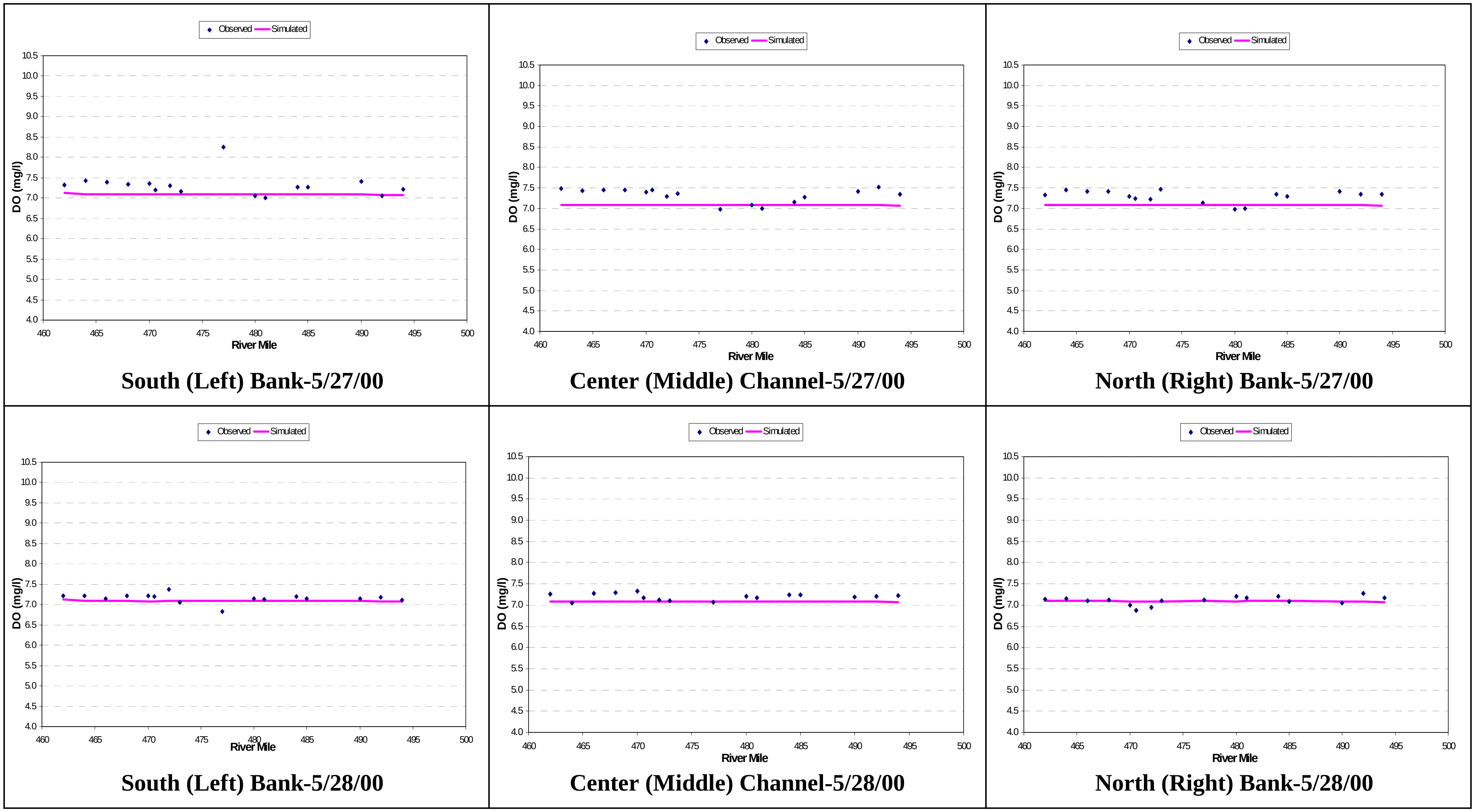
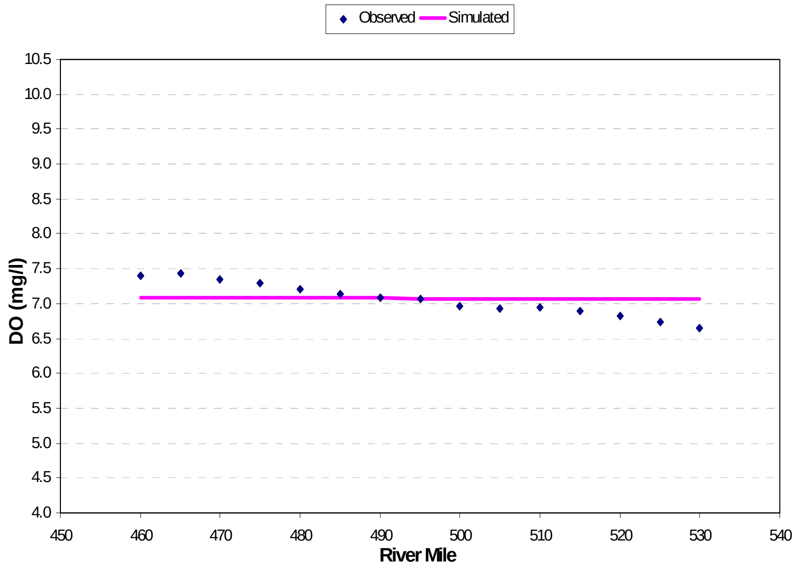
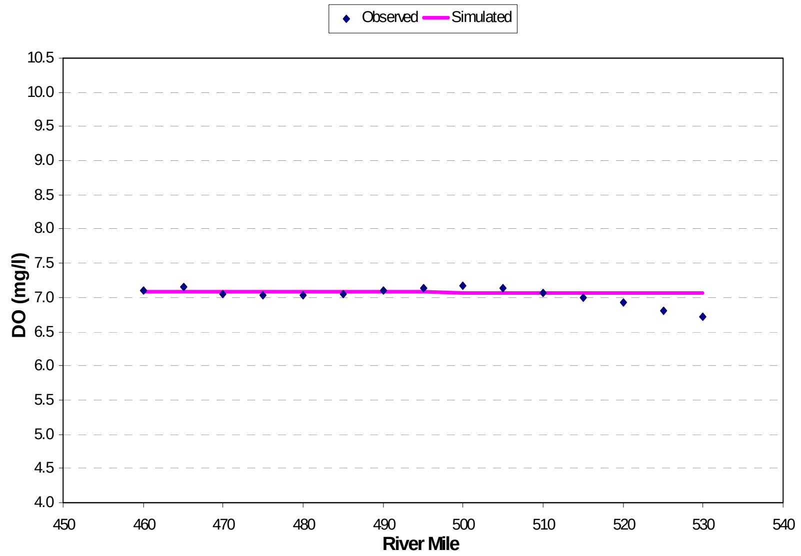


Figure 4-19 a. Simulated and Observed Dissolved Oxygen Concentrations Along South (Left) Bank, Near Center (Middle) Channel, and North (Right) Bank of Ohio River on 5/27/00-5/28/00.



5/29/00



5/30/00

Figure 4-19 b. Simulated and Observed Dissolved Oxygen Concentrations Near Center Channel of Ohio River on 5/29/00-5/30/00.

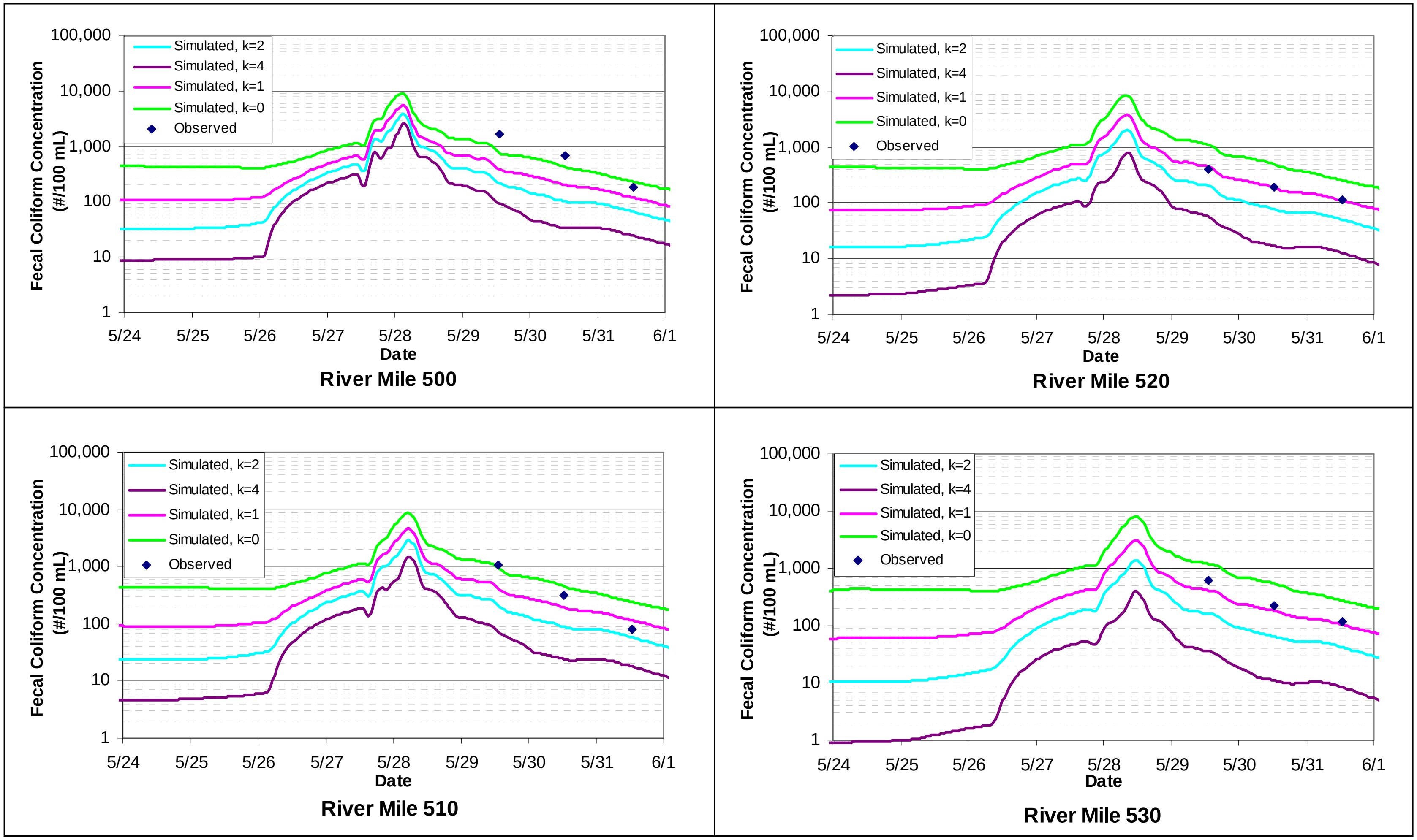


Figure 4-20. Model Sensitivity to Fecal Coliform Decay Rate at Downstream Ohio River Locations.

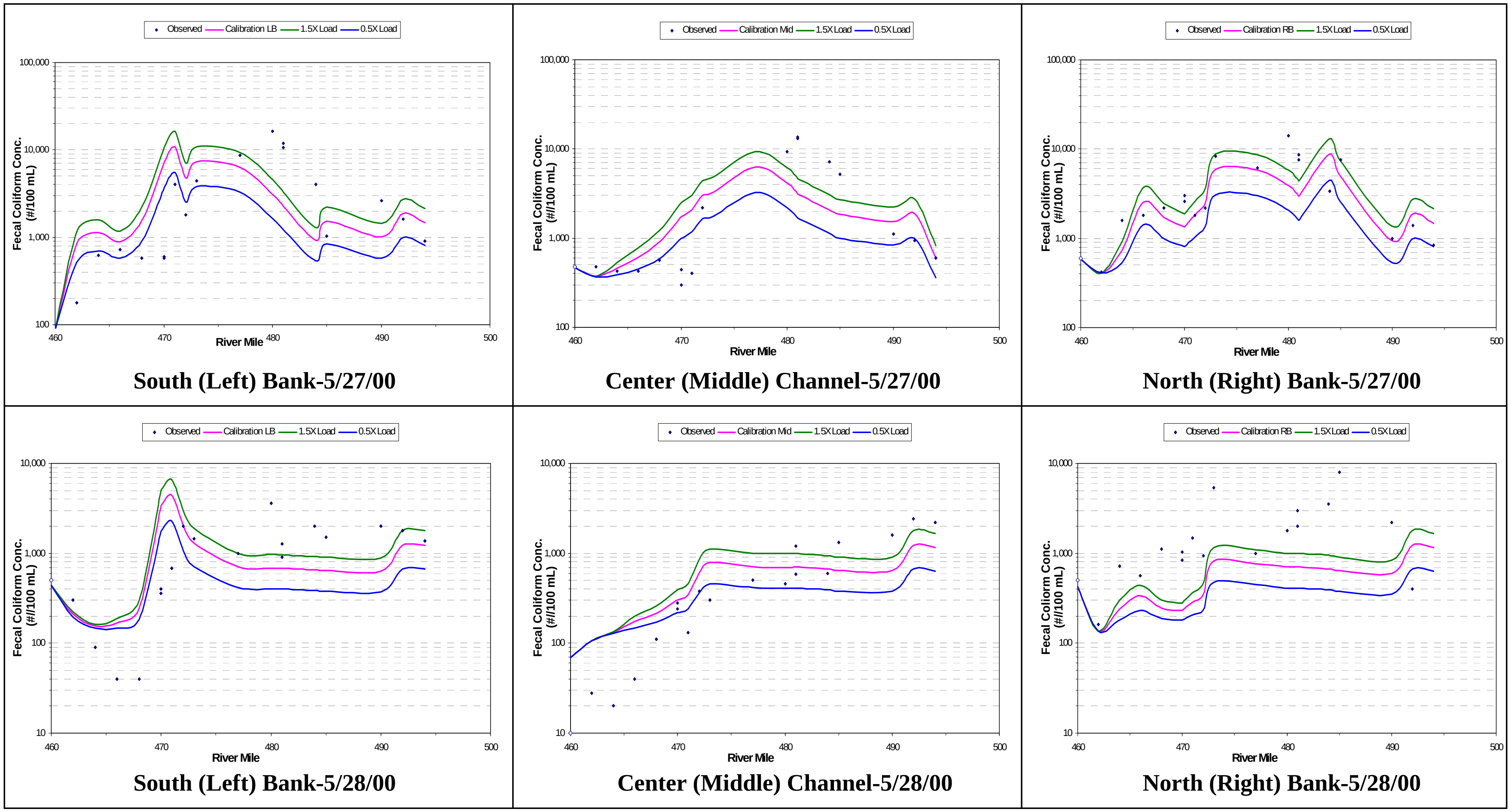


Figure 4-21. Model Sensitivity to Fecal Coliform Loads Along the South (Left) Bank, Near Center (Middle) Channel, and North (Right) Bank of the Ohio River on 5/27/00 and 5/28/00.

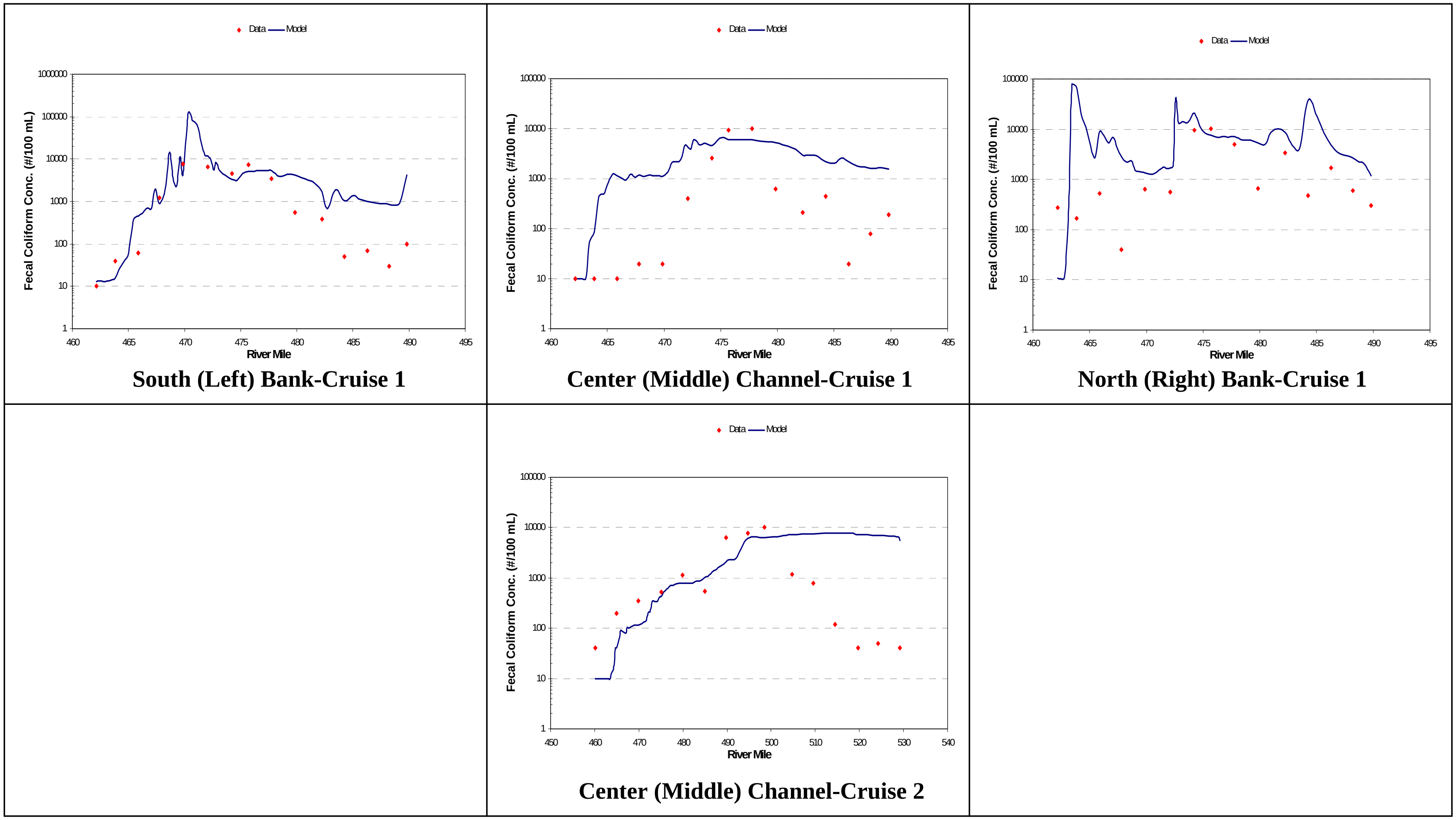


Figure 4-22. Wet Weather Event #4 (11/11/95) Observed vs. Simulated Fecal Coliform Concentrations.

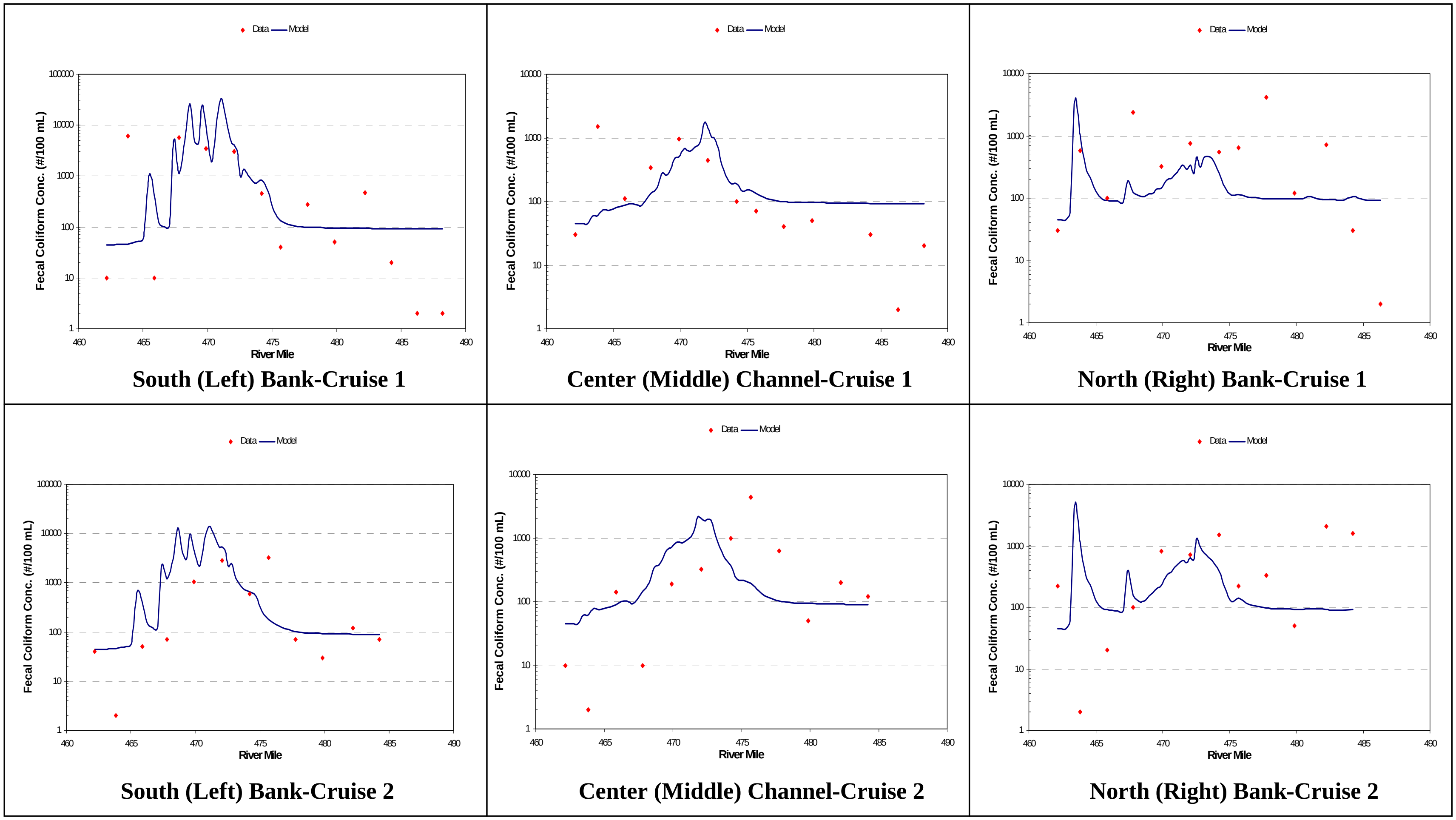


Figure 4-23. Wet Weather Event #1 (9/8/95) Simulated vs. Observed Fecal Coliform Concentrations.

5. WATER QUALITY MODEL APPLICATION – TYPICAL YEAR

5.1 INTRODUCTION

The model calibration and validations, described in sections 4.4.3 and 4.4.4 in the previous chapter, indicated that loads originating from CSOs significantly increase bacteria concentrations in the Ohio River in the vicinity of the Cincinnati metropolitan area. Maximum concentrations of fecal coliform in the Ohio River increased by one to three orders of magnitude during the storm events, when CSO loads are discharging to the river, as compared to pre-storm conditions. For the calibration wet weather event (2000 survey), the Ohio River fecal coliform concentrations did not return to pre-storm conditions until five days after the storm. Further, the water quality modeling indicated that dissolved oxygen and heavy metal concentrations in the Ohio River are not adversely impacted by CSO discharges.

Use of a calibrated and validated water quality model allows further investigation of the impact of CSOs on Ohio River water quality under a range of environmental and CSO conditions. By applying the model to a variety of storm and environmental conditions, it may be possible to assess the extent to which CSOs impact water quality for a range of conditions. Model simulations that incorporate a measure of CSO control (reduction in CSO volume or fecal coliform concentration) are an efficient way to evaluate the effectiveness of the controls in reducing the impacts on water quality in the receiving waters.

This chapter describes the application of the Ohio River water quality model over a year with typical hydrometeorological conditions (i.e. a "typical" year) for several screening-level CSO reduction scenarios. Use of the model in this application utilizes the advantages that a calibrated water quality model offers. Five hypothetical reduction scenarios were evaluated in this application: no reduction (current conditions), 100% reduction (all CSOs eliminated) and three scenarios in between these extremes, 25%, 50% and 75% reduction. The year 1971 was selected for use as the "typical" year. The collection system and water quality models were applied for conditions encountered over this year. Results from the five scenarios are compared to each other and to applicable state water quality standards.

Section 5.2 describes the "typical" year and the reduction scenarios used in the model application. Section 5.3 describes the water quality model inputs, including boundary concentrations and flows, environmental conditions and external loadings from CSO and other sources. Results from the water quality model are presented in Section 5.4. Section 5.5 presents conclusions and Section 5.6 presents recommendations for further study.

5.2 "TYPICAL" YEAR APPLICATION

This section presents information regarding the development and rationale for selecting a "typical" year as a further application of the water quality model as well as details on the CSO reduction scenarios selected for simulation. First, the value of using the models to simulate a "typical" year is presented in Section 5.2.1. The process by which the year 1971 was selected as a representative "typical" year is presented in Section 5.2.2. The CSO reduction scenarios are detailed further in Section 5.2.3.

5.2.1 Basis for Modeling a Typical Year

A "typical" year for water quality modeling is one where important environmental conditions are representative of what frequently occur in the study area. Modeling using "typical" year conditions is a useful tool for several reasons:

- Simulated water quality reflects the range of conditions that typically occur;
- Reduction scenario effectiveness is based on conditions that typically occur and are not distorted by extreme environmental conditions; and
- The "typical" year provides an equitable framework with which to compare reduction scenarios.

For the reasons listed above, a "typical" year is chosen based on analysis of records of flow, rainfall, and environmental characteristics in the study area.

5.2.2 Selection of Typical Year

The impacts of untreated CSO discharges on receiving water quality largely depend on four factors: the time of year, the total amount of rain, the maximum rainfall intensity, and the upstream flow rate of the receiving waters. The year 1971 was found to be typical for all four factors. Time of year is important because the recreation season occurs from May through October (when people are most likely exposed to bacteria from body contact). Rainfall determines the magnitude and duration of the CSO discharges. The upstream receiving water flow rate affects the magnitude of the upstream pollutant loads, serves to flush pollutants out of the rivers and also provides dilution of the landside pollutant loadings. The evaluation of these factors is described below.

5.2.2.a Rainfall

Five candidate years were identified by ORSANCO as having "typical" rainfall (LTI, 1996) for the Greater Cincinnati area. The year 1971 was selected as the "typical" year based on analysis of 46 years (1950 to 1996) of hourly precipitation records for the Northern Kentucky International Airport. This analysis showed that:

- Total yearly precipitation for 1971 was 41 inches from 79 discrete storms (a storm is defined as greater than 0.10 inches of rainfall with at least 6 hours of dry period between). For the historic period, the average total yearly precipitation is 40 inches from 81 storms.
- The maximum total rainfall for an event during the summer of 1971 was 1.59 inches (occurring on September 20, 1971). Only 1.6% of the historic storms exceeded this total precipitation. The maximum intensity during 1971 was 1.00 inches per hour (occurring on July 28, 1971). Less than 1% of the summer storms over the entire period of record exceeded this maximum intensity.

Table 5-1 provides the rainfall statistics for the Greater Cincinnati/Northern Kentucky International Airport for 1950-1996. Figure 5-1 shows the rainfall frequency distribution for the historical and 1971 rainfall events. The distribution of 1971 storms is very close to the historical distribution of storms. This distribution indicates that approximately 75 percent of the rainfall events had 0.5 inches or less of precipitation. The significance of this is explained further in Section 5.4.2.d.

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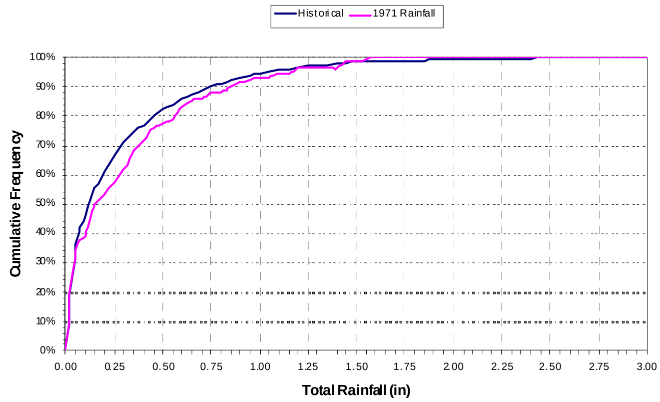

Figure 5-1. Rainfall Cumulative Frequency Distribution (Greater Cincinnati/Northern Kentucky International Airport (WBAN #93814), 1950-1996).

The events were further characterized using the CSO overflow results from the collection system models (presented in Section 5.3.3). The definition of a storm was expanded to include the requirement that there was no CSO discharge for at least three hours prior to the start of rain. Eighty-six discrete events were identified for 1971, with 65 having a total rainfall of at least 0.1 inches. Details regarding the characteristics of the storm events for 1971 are presented in Appendix E.

Table 5-1. Summary of Rainfall Statistics for Greater Cincinnati/Northern Kentucky International Airport (1950-1996).

	Low Year	Typical Year (1971)	High Year	Average
Total annual rainfall (inches)	28" (1963)	41"	58" (1990)	40"
Number of annual storms	56 (1963)	79	103 (1973)	81
Maximum total rain for a storm (inches)	1.32" (4/4/81)	1.59" (9/20/71)*	5.21" (3/9/64)	2.47"
Maximum intensity for a storm (in/hr)	0.74" /hr (8/3/72)	1.0" /hr (7/28/71)**	2.58" /hr (7/5/53)	1.20" /hr
Number of summer storms	24 (1963)	39 (1971)	49 (1962,1990)	40
Maximum total rain (summer storm)	0.92" (6/12/52)	1.59" (9/20/71)	4.3" (10/20/85)	2.29"
Maximum intensity (summer storm)	0.54"/hr (8/6/64)	1.0"/hr (7/28/71)	2.58"/hr (7/5/53)	1.19"/hr

Notes:

* Less than 1.6% of all historic storms exceeded the typical year's maximum total rainfall.

** Less than 1% of the historic storms exceeded the typical year's maximum intensity.

Summer defined as May 1 through October 31. Storm defined as total precipitation for an event >0.1" with at least 6 hours between events (note: total precipitation <0.1" will cause CSOs to discharge, but the volume of overflow is much less than the volume of overflow resulting from a storm event).

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5.2.2.b River Flows

Flow characteristics of the Ohio River at Cincinnati (USGS Gage #03255000), Meldahl Dam (from U.S. Army Corps of Engineers records), and the Licking River (Catawba, KY USGS Gage #03253500) were analyzed to determine if 1971 was a "typical" year.

To determine if 1971 was typical for upstream flows, LTI examined historical records of flow (1928-1996) for the Ohio River. Twenty-eight years of daily mean discharge measurements for the Licking River at Catawba (USGS gage # 03253500) were also evaluated to determine "typical" flow in the Licking River, a major tributary to the Ohio River. The year 1971 was confirmed as being "typical" based on the following comparisons:

- Flows for the Ohio River at Cincinnati (USGS Gage #03255000) and Meldahl Dam (from U.S. Army Corps of Engineers records) for 1971 were examined and found to be comparable to historical monthly average conditions.
- The average annual flow for the Licking River in 1971 was 4,084 cfs, which is 97% of the historical average annual flow of 4,191 cfs.

Although the entire year was modeled, total daily rainfall and upstream flow conditions are provided for May through October 1971 in Figure 5-2 for the Ohio River. The most stringent bacterial standards are applicable during this summer period.

Based on the analyses of the Ohio and Licking River flow characteristics, 1971 flow data were used as upstream boundary conditions and for tributary input to the Ohio River water quality model. Additional detail regarding model input is located in section 5.3.3.

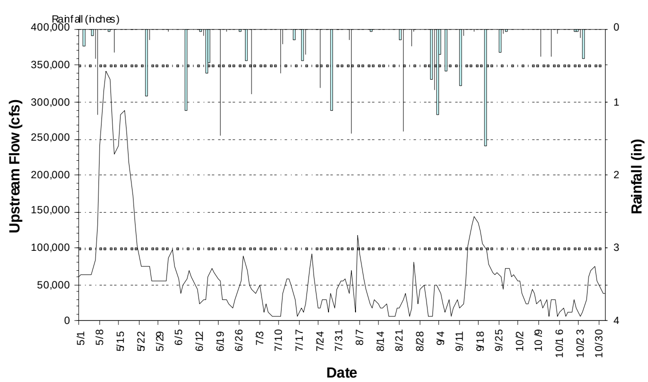

Figure 5-2. 1971 Summer Season Ohio River Upstream Flow Hydrograph and Rainfall
(Hydrograph based on USGS gage #03255000 at Cincinnati, Rainfall taken from gage at Greater Cincinnati/Northern Kentucky International Airport (WBAN #93814)).

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5.2.3 Reduction Scenario Selection

Five hypothetical scenarios were examined using the Ohio River water quality model. The scenarios are screening level analyses that show the impact of five broad levels of CSO reduction. The five scenarios are

1. Baseline (0% or no additional reduction);
2. 25% reduction;
3. 50% reduction;
4. 75% reduction; and
5. 100% reduction.

The "baseline" scenario represents the current discharges from the combined sewer systems (without sanitary sewer overflows), tributary loads, and treated waste water discharges. The "reduction" scenarios (25%, 50%, 75%, and 100%) represent hypothetical situations where all CSO discharges have been treated or eliminated to the degree specified, and other contributions (upstream, non-point sources) remain unchanged from the "baseline" scenario. The 100% reduction scenario represents the complete elimination of CSO, which would illustrate the maximum benefit from CSO reduction. The five levels of reduction were chosen to give additional insight into how CSOs affect water quality in the Ohio River. More detailed simulations that consider sewer system design and operation could be completed for each sewer district as a tool in developing a long-term control plan.

5.3 WATER QUALITY MODEL

The "typical" year model was used to evaluate the effects of potential CSO reduction scenarios on Ohio River water quality. The "typical" year scenarios were simulated with the same water quality model used for the calibration and verification events (described in detail in section 4.6). Boundary conditions, environmental conditions, CSO loads, and tributary loads were expanded to include an entire year as described in this section. The physical representation of the river system and environmental kinetic rates were not changed. Fecal coliform was the only constituent simulated for the "typical" year because the modeling and data analysis indicated that other parameters, including heavy metals and dissolved oxygen, in the Ohio River were not adversely affected by combined sewer overflows.

Conditions affecting the receiving water concentrations vary over an extended time-period, such as the "typical" year. These conditions include upstream and downstream concentrations (i.e. boundary conditions); environmental conditions such as water temperature, air temperature and wind speed; and flows and loads of chemical constituents from CSOs and from other sources such as upstream, non-point and wastewater treatment plants (WWTP). These conditions were estimated for the typical year and were incorporated into the model.

Section 5.3.1 describes the upstream boundary concentration development for the Ohio River. Section 5.3.2 describes the data sources of environmental conditions used in the model. Section 5.3.3 and Section 5.3.4 describe the development of flows and loads, respectively, used in the model. Results from the model simulations of each reduction scenario are presented in a separate section of this chapter, Section 5.4.

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Note that although the Licking River and Banklick Creek portions of the water quality model were included in this application, detailed descriptions of the primary model inputs are provided elsewhere (LTI, 2000). Fecal coliform loads from CSOs discharging into the Licking River and Banklick Creek, however, were updated with this application and are described in Sections 5.3.3 and Sections 5.3.4.

5.3.1 "Typical" Year Boundary Concentrations

The model requires upstream and downstream boundary conditions for fecal coliform. The "wet" and "dry" boundary concentrations for the Ohio River were averaged from available data, primarily collected in 1995, 1999 and 2000 between Ohio River mile 460 and 462. This area is near the model's upstream boundary and above all CSOs in the study area.

The boundary conditions are summarized in Table 5-2. The terms "wet" and "dry" refer to storm (e.g. high flow) and non-storm (e.g. base flow) upstream conditions, respectively. The daily mean flow record at the USGS gage in Cincinnati (Gage #03255000) was analyzed to determine storm flow events. These events were identified using a program that designates days as either storm or base flow days, depending on the rate of change between two consecutive days and other statistics (MWCOG, 1998). This distinction is needed to account for upstream sources that contribute a larger pollutant load during wet weather.

The available fecal coliform data were classified as being collected on either a "wet" or "dry" day, based on the hydrograph characterization, and averaged. The results of this process were fecal coliform boundary concentrations for "wet" days and for "dry" days, 121 #/100 mL and 41 #/100mL, respectively.

Table 5-2. Boundary Conditions for Dry and Wet Weather for the "Typical" Year (1971).

Boundary Location	River Mile	Fecal Coliform (#/100 ml)	
		Dry	Wet
Upstream Ohio River	460.0	41	121
Upstream Banklick Creek[1]	3.75	600	6,000
Upstream Licking River[1]	5.125	200	600
Downstream Ohio River	530.0	41	121

[1]Source: LTI, 2000. *Water Quality Assessment of Banklick Creek and the Lower Licking River for a "Typical" Year*.

5.3.2 Environmental Conditions

The environmental conditions included in the model are water temperature, wind speed, and air temperature. Since the fecal coliform decay rate is temperature controlled, fecal coliform concentrations are water temperature dependent.

The monthly average water temperatures from the Ohio River Fact Book, published by ORSANCO, were used for the Ohio River. This monthly average is based on data collected from 1961-1986. The Licking River and Banklick Creek monthly average temperature were estimated using data collected by LTI and Kentucky Division of Water

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(KDOW) from 1991 to 1996 (LTI, 2000). Water temperature model inputs for the Ohio River are summarized in Table 5-3. A daily time series was used in the model by applying the monthly average temperature on the 15th day of each month and allowing the water quality model to interpolate between these inputs.

Recorded values of daily wind speed and air temperature during 1971 at the Cincinnati/Northern Kentucky Airport (station #93814) were used as model inputs. These were input into the model as a daily time series.

Table 5-3. Monthly Water Temperature Values Applied in the Ohio River Water Quality Model.

Month	Ohio River Temperature (°C)
January	2.9
February	3.3
March	6.9
April	12.0
May	17.7
June	23.4
July	26.6
August	26.9
September	24.7
October	18.8
November	12.2
December	5.9

5.3.3 Flow Inputs

There are four source types of flows entering the Ohio River that were utilized in the "typical" year model application. These include the flow in the Ohio River entering the model domain, flows from major tributaries in the Cincinnati metropolitan area, combined sewer overflows, and flows from the four primary wastewater treatment plants (WWTPs) in the Cincinnati area. The tributary, CSO and WWTP flows are very small compared to the upstream Ohio River flow, as shown in Figure 5-3, and were used only for loading calculations. Each flow source is described in the following sub-sections.

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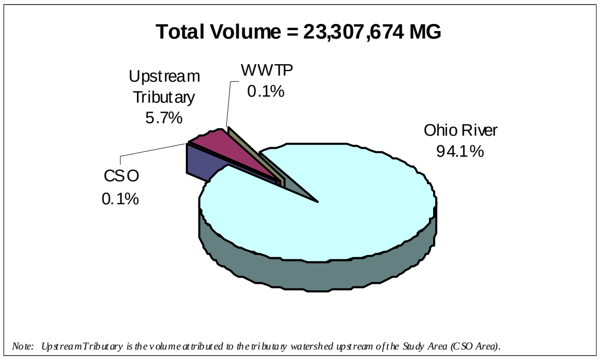

Figure 5-3. Annual Flow Distribution in the Ohio River CSO Study Area (Great Miami River not included).

5.3.3.a Upstream Flow

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The records for the USGS gage at Cincinnati (gage #03255000) provided a daily average flow for each day in 1971. Although this gage is just within the study area, tributary inflows in the modeled system are less than 7% of the total flow, so this gage adequately represents upstream flow entering the model domain at river mile 460. The daily average flow was input into the water quality model at noon on each model day. The water quality model interpolated between these inputs to reproduce the hydrograph shown in Figure 5-2.

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5.3.3.b Tributary Flows

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There are four major and three minor tributaries in the study area (based on fecal coliform loading to the Ohio River). The major tributaries are the Little Miami River, Mill Creek and the Great Miami River on the Ohio side and the Licking River on the Kentucky side of the Ohio River. The two minor tributaries are Muddy Creek and Rapid Run on the Ohio side. Banklick Creek is the final minor tributary included in the modeling and is tributary to the Licking River whereas all of the others are Ohio River tributaries. Other tributaries in the study area do not have a notable impact on water quality and were neglected.

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Generally, the tributary flows in the CSO study area are very small relative to the upstream Ohio River flow, representing approximately 6% of the total flow, as shown in Figure 5-3 (note that the Great Miami River, which is downstream of the CSO area, would not influence water quality in the CSO vicinity and was neglected from the figure). Consequently, the tributary flows were used solely to compute fecal coliform loadings, as described in Section 5.3.4.c and were not input into the WASP water quality model during this application (except the Licking River and Banklick Creek which are part of

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the model framework). This also provides a conservative approach to estimating the water quality impacts from CSOs.

The flows were separated into CSO and non-CSO components. The CSO loads were reduced by the appropriate percent reduction in each model scenario while the non-CSO loads were kept the same in each model scenario.

Tributary flow input sources are also summarized in Table 5-4. A brief description of each tributary's features affecting flow and loading inputs are given below:

Table 5-4. Tributary Flow and Load Input Data Sources.

Tributary Name	State	Ohio River Mile Confluence[1]	CSO Flow?	Non-CSO Flow?	Upstream Flow Source[2,3]	Frequency of Input into Water Quality Model[4]	Upstream Fecal Coliform Concentration (#/100 mL)[5,6,7]	
							Base	Storm
Little Miami River	Ohio	463.5	Yes	Yes	XCG SWMM Model[2]	Hourly	3,40[5]	3,40[5]
Mill Creek	Ohio	472.5	Yes	Yes	XCG SWMM Model[2]	Hourly	7,43[5]	7,43[5]
Rapid Run	Ohio	480.8	Yes	No	XCG SWMM Model[2]	Hourly	--	--
Muddy Creek	Ohio	484.1	Yes	No	XCG SWMM Model[2]	Hourly	--	--
Great Miami River	Ohio	491.1	No	Yes	USGS Gages (#03274000-Hamilton, Oh; #03276500-Whitewater River at Brookville, In)[3]	Daily	160[6]	1,850[6]
Licking River	Kentucky	470.2	Yes	Yes	Non-CSO Flow:USGS Gage (#03253500)[3]	Daily[4]	200[7]	600[7]
Banklick Creek	Kentucky	5.25	Yes	Yes	Woolpert SWMM Model[2]	Daily[4]	600[7]	6,000[7]

[1] Banklick Creek confluence is with the Licking River.
[2] Stream flow estimated using USEPA SWMM with 1971 precipitation data from Northern Kentucky International Airport.
[3] USGS stream flow data increased to account for watershed area below gage.
[4] CSO overflow and loads were input into WASP as an hourly time series.
[5] XCG applied this concentration based on Year 2 report data-see ORSANCO, 1997 for details.
[6] Geometric mean of available data collected at the mouth between 1994 to 2000.
[7] See LTI, 2000 for details.

Little Miami River and *Mill Creek*:

- Watersheds have both upstream and study area components (described in Chapter 3).
- Hourly CSO and non-CSO flows at the mouth were generated by XCG using the Stormwater Management Model (SWMM). Non-CSO flow included both flow upstream of the study area and stormwater draining directly into each tributary within the study area.

Muddy Creek and *Rapid Run*:

- Watersheds are entirely within the study area (described in Chapter 3).
- Hourly CSO and non-CSO flows at the mouths of each tributary were generated by XCG using SWMM. Non-CSO flow included stormwater draining directly into each tributary.

Great Miami River:

- Watershed is outside the combined sewer area of the Cincinnati Metropolitan Sewer District, and therefore not modeled by XCG.
- Daily average flows for 1971 were available for each main branch of the river; gage #0327400 on the Great Miami at Hamilton, Ohio and gage #03276500 on the Whitewater River at Brookville, Indiana. The flows from these two gages represent approximately 87% of the drainage area. The flow at the mouth of the Great Miami River was calculated by applying a drainage area ratio of 1.15 to the sum of the gaged flows.

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Licking River and *Banklick Creek*:

- Watersheds have both upstream and study area components. The lower 5.25 miles of the Licking River and lower 3.875 miles of Banklick Creek are included in WASP water quality model (described in Chapter 4; LTI, 1998; and LTI, 2000).
- The upstream boundary flow of the Licking River at river mile 5.25 was developed using daily average flows measured at the USGS gage in Catawba, Kentucky (gage #03252500) and applying a drainage area ratio (LTI, 2000).
- Upstream Banklick Creek flow at river mile 3.875 was modeled by Woolpert using a SWMM model. Model output was averaged to daily values for input into the WASP model (LTI, 2000).
- CSO flows discharging into the Licking River and Banklick Creek were also modeled by Woolpert (see Chapter 3) and input into the WASP water quality model as an hourly time series.

5.3.3.c CSO Flows

Overflows from Cincinnati and the Kentucky Sanitation District No. 1 combined sewers were modeled by XCG and Woolpert, respectively, using SWMM models. This modeling is described in detail in Chapter 3. Generally, the CSOs were actively discharging only during storm events and for a relatively short duration, although there were a couple of exceptions to this characterization. Appendix E contains a summary of the characteristics for the CSOs discharging directly into the Ohio River for the "typical" year.

Appendix C contains summary statistics for each event for the CSOs discharging directly to the Ohio River, including the overflow volume, maximum flow rate and duration of overflow for each event in the "typical" year. CSO discharges to tributaries are summed and results at the mouth of each tributary are also included in Appendix C.

5.3.3.d Wastewater Treatment Plant (WWTP) Flows

There are four primary municipal wastewater treatment plants in the study area: the Little Miami WWTP; the Mill Creek WWTP; the Muddy Creek WWTP; and the Dry Creek WWTP. The flows for each WWTP were estimated using Discharge Monitoring Reports (DMR) from each facility from 1996 to 2001. The average daily flow reported for each month of the five years was averaged to estimate a typical daily flow for each month of the year. The 5-year average daily flow was used to compute WWTP loads as described in Section 5.3.4.d.

5.3.4 Fecal Coliform Loads

Fecal coliform enters the Ohio River primarily through CSOs that discharge directly to the Ohio River and to several tributaries. Additional delivery paths are diffuse runoff not collected by a combined sewer; portions of tributary watersheds upstream of the study area; sources upstream of the Ohio River model boundary; and municipal treatment plants (WWTPs). Each of these sources contributes fecal coliform loads to the Ohio River. The approach used to estimate fecal coliform loadings was similar to that used in

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the calibration (section 4.4.3), which was to multiply the flow from each source by a representative concentration. Loadings are detailed in sections 5.3.4.a to 5.3.4.d.

Since the purpose of this demonstration project is to study the impacts of CSOs on the Ohio River, loads were classified as either being from a CSO in the study area, from sources outside of the study area via a tributary, and from sources outside the study area via the Ohio River. Figure 5-4 shows the relative contribution of each fecal coliform source input to the water quality model. "KY CSO" loads represent those discharging from the southern bank of the Ohio River, the Licking River and Banklick Creek. "OH CSO" loads represent those discharging from the North bank of the Ohio River, to the Little Miami River, Mill Creek, Muddy Creek, and Rapid Run. "Tributary" loads represent the upstream load from all tributaries. WWTP load represents the load due to treated effluent discharged to the Ohio River from area treatment plants. Finally, the upstream load is that from the Ohio River upstream of the study area. The loadings in this figure were computed as described in sections 5.3.4.a to 5.3.4.d.

This figure indicates that CSOs discharging from the Ohio side of the river contribute the largest portion of fecal coliform loads to the study area, followed by upstream sources delivered to the Ohio River via tributaries, and then by CSOs discharging from the Kentucky side. Treated POTW effluent and upstream sources on the Ohio River contribute a small portion of the total load. The CSO loads are largely a function of the choice of the chosen event mean concentration (EMC) and are subject to significant uncertainty.

The following sections discuss the relative contribution of each, how they were estimated, and how they were applied to the Ohio River water quality model.

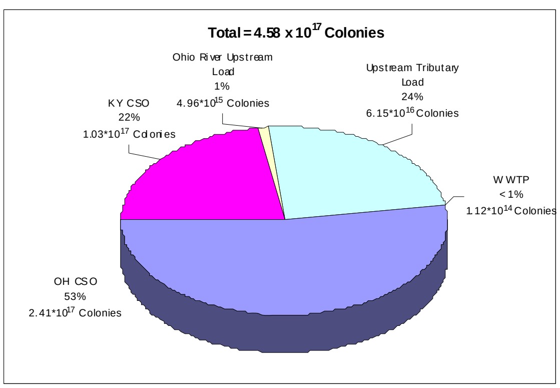

Figure 5-4. Fecal Coliform 1971 Annual Loads in the Ohio River Study Area (includes all tributaries).

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5.3.4.a Upstream Loads

The fecal coliform load in the Ohio River upstream of the model domain was computed within the WASP water quality model as the product of the in-stream Ohio River flow (see Section 5.3.3.a) and fecal coliform upstream boundary concentration (see Section 5.3.1). This load was a very small fraction of the overall load in the study area, as shown in Figure 5-4, largely as a result of the low "wet" and "dry" boundary concentrations, 121 and 41 #/100 ml, respectively, that were applied.

The upstream loads from the Licking River and Banklick Creek were also computed within the WASP water quality model as the product of the flow at each upstream boundary and the boundary concentration. This is described in more detail in the LTI report "Water Quality Assessment of Banklick Creek and the Lower Licking River for a "Typical" Year" (LTI, 2000).

5.3.4.b Combined Sewer Overflow Loads

Overflows from Cincinnati and Northern Kentucky combined sewer collection systems were modeled by XCG and Woolpert, respectively, using SWMM models. CSOs discharging directly into the Ohio River as well as CSOs discharging to tributaries within the study area were included in the XCG and Woolpert models. This modeling is described in detail in Chapter 3. Appendix E contains a summary of each CSO's characteristics for the CSOs discharging directly into the Ohio River.

LTI applied a system-wide event mean concentration of 875,000 #/100ml for fecal coliform to each Northern Kentucky CSO overflow volume. This concentration is representative of the model's calibration to the 1995-1996 water quality monitoring data (see Section 4.4.3). The CSO flow rate and event mean concentrations were combined and entered into the water quality model as an hourly pollutant load.

XCG applied an event mean concentration of 53,000 #/100 ml to the stormwater portion of CSO discharge and 1,000,000 #/100 ml to the sewage portion of the CSO discharge. XCG provided an hourly pollutant load time series for each of the Cincinnati CSOs draining directly into the Ohio River. XCG also provided an hourly pollutant load time series at the mouth of each tributary that included the sum of all of the CSO loadings discharging into that tributary.

Appendix E contains summary statistics for the CSOs discharging directly into the Ohio River, including total load and maximum loading rate, for each event in the typical year. CSO loads from the tributaries are summed and results at the mouth of each tributary are also included in Appendix E.

5.3.4.c Tributary Loads

The Ohio River receives fecal coliform loads from six significant tributaries. Three of these tributaries (Little Miami River, Licking River, and Mill Creek) carry a combination of CSO and upstream loads to the Ohio River. Two (Muddy Creek and Rapid Run) receive CSO discharges and have negligible dry weather flows, and the Great Miami River has no CSOs discharging to it.

With the exception of the Licking River and Banklick Creek, which were explicitly modeled with the WASP water quality model, the loads at the mouths of each tributary

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were separated into CSO and non-CSO components. The CSO load represents the sum of the load from all of the CSOs discharging into receiving waters within a tributary's watershed. These loads were estimated using the event mean concentrations specified in Section 5.3.4.b by XCG. Non-CSO loads are primarily loadings originating upstream of the study area. A tributary-specific event mean concentration, developed during the second year of the project, was applied to this flow to generate the non-CSO loading. Table 5-4 includes the upstream tributary loading inputs. CSO and non-CSO loads from each tributary were put into the WASP water quality model as an hourly time series.

The non-CSO loadings for the Licking River and Banklick Creek are described in Section 5.3.4.a. The CSO loadings are described in Section 5.3.4.b.

5.3.4.d Wastewater Treatment Plant (WWTP) Loads

The four wastewater treatment plants in the study area, Dry Creek, Mill Creek, Muddy Creek and the Little Miami WWTPs, typically disinfect their primary effluent and bypasses before discharging into the Ohio River. Because actual data were not available for this application, LTI assumed that all of the flow from each WWTP received disinfection. The last five years (1996-2001) of monthly Discharge Monitoring Reports (DMR) were used to determine an appropriate effluent concentration for each facility. The average daily concentration reported for each month of the five years was averaged to estimate a typical daily average concentration for each month. This 5-year average daily concentration was combined with the 5-year average daily flow described in Section 5.3.3.d to compute loads for each month of the simulation. The load was held constant within the WASP water quality model for each day of the month. The average daily flows and concentrations for each WWTP are summarized in Table 5-5.

Table 5-5. Municipal Wastewater Treatment Plant Average Flows and Fecal Coliform Concentrations.

	Average Flow (cfs)[1]				Average Concentration (#/100 mL)[2]			
Month	Little Miami WWTP	Mill Creek WWTP[3]	Muddy Creek WWTP	Dry Creek WWTP	Little Miami WWTP	Mill Creek WWTP	Muddy Creek WWTP	Dry Creek WWTP
January	28.5	127.7	14.7	34.7	20	93	134	25
February	27.2	127.6	16.0	36.2	29	20	312	15
March	30.3	137.0	14.4	36.5	33	10	240	11
April	34.6	120.5	14.8	35.9	23	34	99	14
May	31.6	122.1	15.3	33.9	20	38	121	18
June	34.1	140.1	14.0	36.1	34	144	87	92
July	22.9	87.0	11.6	31.1	41	18	97	56
August	19.2	81.1	11.7	30.5	18	13	26	44
September	29.5	100.3	11.8	29.8	14	9	154	19
October	24.2	55.9	11.0	28.8	21	15	71	19
November	23.1	71.0	23.7	29.7	16	16	34	11
December	30.8	119.4	12.8	32.7	17	41	104	14

[1] Average daily flow is the 5-year average based on monthly DMR reports compiled from the Permit Compliance System (PCS) database from 1996 to 2001 for each facility.

[2] Average daily concentration is the 5-year average based on monthly DMR reports compiled from the Permit Compliance System (PCS) database from 1996 to 2001 for each facility.

[3] High January 1996 value replaced in averaging with January 1995 value.

5.3.4.e Loading Analysis Results

The largest fecal coliform load delivered to the Ohio River by a tributary is transported by Mill Creek. The load in Mill Creek accounts for 22% of the total load in the Ohio River. Over the course of a year, 96% of the fecal coliform transported by Mill Creek is from CSOs and only 4% is from upstream sources. Approximately half of the load delivered by Little Miami River is from CSOs and half from upstream sources. This

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tributary accounts for 15% of the total load in the Ohio River. Seventy-five percent of the Licking Rivers load is from CSOs and 25% is from upstream sources. This tributary accounts for 17% of the total load in the Ohio River. Figure 5-5 shows the CSO and upstream load contributions of each tributary containing both sources and are summarized in Table 5-6.

Figure 5-6 re-presents the analyses in Figures 5-4 and 5-5. The magnitude of each tributary loading relative to other sources reaching the Ohio River is shown in this figure. These tributary loadings are further broken down into CSO and Upstream components as indicated in the figure (and illustrated in Figure 5-5). Mill Creek and CSOs from Cincinnati discharging directly into the Ohio River are the largest sources, 22.3% and 22.5%, respectively, of the total load in the Ohio River. The remaining tributaries, Little Miami River, the Licking River and the Great Miami River, all contribute more than 10% of the total load. Sanitation District No. 1 CSOs discharging directly into the Ohio River comprise only 8.3 % of the total load.

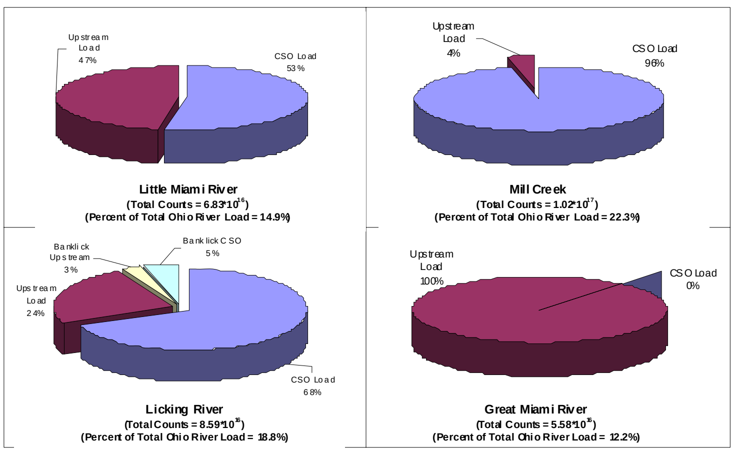

Figure 5-5. Fecal Coliform 1971 Annual Load Distribution of Major Tributaries in the Ohio River Study Area.

There is a great deal of uncertainty associated with these loading estimates as conditions can vary significantly from storm to storm. Load distributions by source from actual storms may be quite different from those shown in Figures 5-4 to 5-6. Upstream boundary concentrations are a function of rainfall throughout the watershed, including some precipitation events that may occur only in areas upstream of the Cincinnati area. CSO data show great variability in fecal coliform concentration during overflows. CSO concentrations are also affected by antecedent conditions, which vary from event to event. Additional CSO and stormwater water quality data may reduce the uncertainty associated with the CSO loadings and would, therefore, increase confidence in results from the model.

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Table 5-6. Distribution of Annual Tributary Fecal Coliform Loadings.

Tributary	CSO Load (#)	Upstream Load (#)	Total Load (#)	Percent of Ohio River Load
Little Miami River	3.63E+16	3.2E+16	6.87E+16	15.0%
Licking River	5.86E+16	2.1E+16	7.94E+16	17.3%
Mill Creek	1.02E+17	3.9E+15	1.06E+17	23.2%
Banklick Creek	4.25E+15	2.2E+15	6.42E+15	1.4%
Rapid Run	1.02E+16	--	1.02E+16	2.2%
Muddy Creek	1.52E+16	--	1.52E+16	3.3%

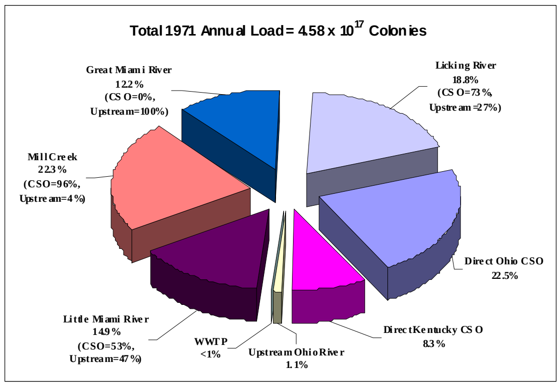

Figure 5-6. Fecal Coliform 1971 Annual Load Distribution by Source in the Ohio River Study Area.

5.4 MODEL APPLICATION RESULTS

Five simulations of the "typical" year were conducted using the WASP water quality model. Each simulation represented a different level of CSO reduction by reducing the fecal coliform load attributable to CSOs by the specified reduction level while keeping all other model loads and inputs unchanged from simulation to simulation. Hourly model output of fecal coliform concentration in each water quality model segment were analyzed and results are presented in this section. Section 5.4.1 presents a summary of the principal findings, which are described in more detail in Section 5.4.2.

5.4.1 Summary

The approach used to evaluate the model results for the five reduction scenarios conducted as part of this study consisted of four steps:

1. Compare the predicted daily average concentration from the model in each segment to applicable state water quality standards (see Section 5.4.2.a).
2. Determine the areas in the Ohio River most impacted by (responsive to) wet weather effects by evaluating peak (maximum) concentrations and by comparing

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the predicted hourly concentration in each model segment to a concentration threshold of 400 #/100 ml, which provides a worst-case (i.e. is more conservative) scenario for exceedances (see Section 5.4.2.b).

3. Determine the effectiveness of reduction scenarios in reducing peak concentrations and durations of high concentrations during events by considering the entire year as a whole and by closely examining a few representative events spanning the range of conditions over the "typical" year, including a dry period, a light storm, an average storm and a heavy storm (see Section 5.4.2.c).
4. Evaluate the relationship between storm conditions (total rainfall, intensity, duration) and resulting water quality (see Section 5.4.2.d).

The key results from the "typical" year modeling are summarized below:

- CSO reduction improves water quality in some, though not all, areas of the Ohio River near Cincinnati, as Figure 5-7 illustrates.
- Less than two percent of the Ohio River study area violates the drinking water standard (2,000 #/100 ml monthly geometric mean concentration), applied over the winter (November-April) in any month as shown in Table 5-7.
- During the recreational season (May through October), the 400 #/100 ml state water quality standard is exceeded over a greater area of the Ohio River and is thus, more stringent than the geometric mean water quality standard as a comparison of Tables 5-7 and 5-8 illustrate.
- The highest concentrations in the Ohio River are observed near the mouths of tributaries which have both CSO and upstream/diffuse (NPS) loads (Licking River, Little Miami, and Mill Creek) as Figure 5-8 illustrates. Major tributaries are indicated on the figure and correspond to the locations of maximum concentration.
- CSO reduction is more effective at reducing the duration that concentrations exceed 400 #/100 ml in the recreational season than in reducing maximum concentrations as shown in Figures 5-8 and 5-9.
- The type of rainfall influences how effective specific levels of CSO reduction are, as shown in Figure 5-10. Events with greater than 0.5" of rain do not show marked changes in water quality, as measured by the area of the river exceeding 400 #/100 ml. At the low end of storm intensity, storms with less than 0.1" of total rainfall also do not show differences in water quality either. Between these two rainfalls, there is a correlation between CSO reduction and improvement in water quality (as measured by area exceeding 400#/100 ml and duration of that exceedance). This is also demonstrated in Figure 5-11 for the evaluation of four representative periods in the "typical" year.
- Concentrations greater than 400 #/100 ml are predicted in some areas during dry weather as shown in Figure 5-11 and Figure 5-12.

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These results indicate that reducing the magnitude of CSO load or extending the existing load over a longer duration would reduce concentrations simulated in the river and potentially improve compliance with the "instantaneous" (single sample maximum) water quality standard of 400 #/100 ml. Further, evaluation of CSO reduction on the basis of controlling a volume of rainfall may be an alternative screening level control approach to investigate.

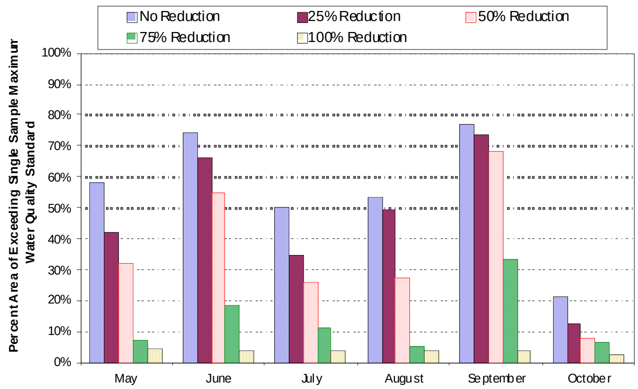

Figure 5-7. Percent of River Area Exceeding Single Sample Maximum ("Instantanous") Water Quality Standard.

Note: The area corresponding to model segments which exceeded the water quality standard for each month were summed, then divided by the total area of the river in the Study Area to determine the Percent Area indicated on the y-axis.

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Table 5-7. Percent of Study Area Predicted to Exceed the Ohio River Geometric Mean Water Quality Standard.[1,2,3]

Month	No Reduction	25% Reduction	50% Reduction	75% Reduction	100% Reduction
Jan[1]	0.5%	0.4%	0.4%	0.4%	0.0%
Feb[1]	0.6%	0.6%	0.6%	0.6%	0.5%
Mar[1]	0.5%	0.5%	0.4%	0.4%	0.4%
Apr[1]	0.5%	0.5%	0.5%	0.4%	0.4%
May[2]	5.8%	4.9%	4.8%	4.5%	3.6%
Jun[2]	6.9%	5.2%	4.9%	4.4%	2.1%
Jul[2]	7.0%	6.3%	5.2%	4.7%	3.0%
Aug[2]	4.8%	4.6%	4.3%	4.3%	2.2%
Sep[2]	26.0%	16.4%	10.6%	7.3%	3.4%
Oct[2]	4.9%	4.7%	4.5%	4.2%	1.9%
Nov[1]	1.9%	1.7%	0.9%	0.5%	0.4%
Dec[1]	0.6%	0.5%	0.4%	0.4%	0.4%

1 Water Quality Standard is the Drinking Water Standard: Monthly Geometric Mean Concentration Standard not to exceed 2,000 #/100 ml.

2 Water Quality Standard is Full Body Contact Standard: Monthly Geometric Mean Concentration Standard not to exceed 200 #/100 ml.

3 Monthly geometric mean concentration was calculated from daily average model results for each segment. The area corresponding to model segments which did not meet the criteria defined in footnotes 1 and 2 were summed, then divided by the total area of the river in the Study Area to determine the Percent Area of Exceedence.

Table 5-8. Percent of Study Area with Concentrations Predicted to Exceed the Ohio River Single Sample Maximum ("Instantaneous") Water Quality Standard.[1,2]

Month	No Reduction	25% Reduction	50% Reduction	75% Reduction	100% Reduction
May	58.4%	42.3%	32.2%	7.2%	4.1%
Jun	74.4%	66.5%	54.6%	18.4%	3.5%
Jul	50.4%	34.6%	25.6%	10.9%	3.8%
Aug	53.4%	49.6%	27.5%	5.0%	3.6%
Sep	77.0%	73.7%	68.4%	33.4%	4.0%
Oct	21.3%	12.5%	8.2%	6.0%	2.5%

1 Single Sample Maximum ("Instantaneous") Water Quality Standard is 400 #/100 ml in less than 10% of all samples in a month.

2 The daily average concentration from the model was calculated for each segment and evaluated on a monthly basis. The area corresponding to model segments which did not meet the criteria defined in footnote 1 were summed, then divided by the total area of the river in the Study Area to determine the Percent Area of Exceedence.

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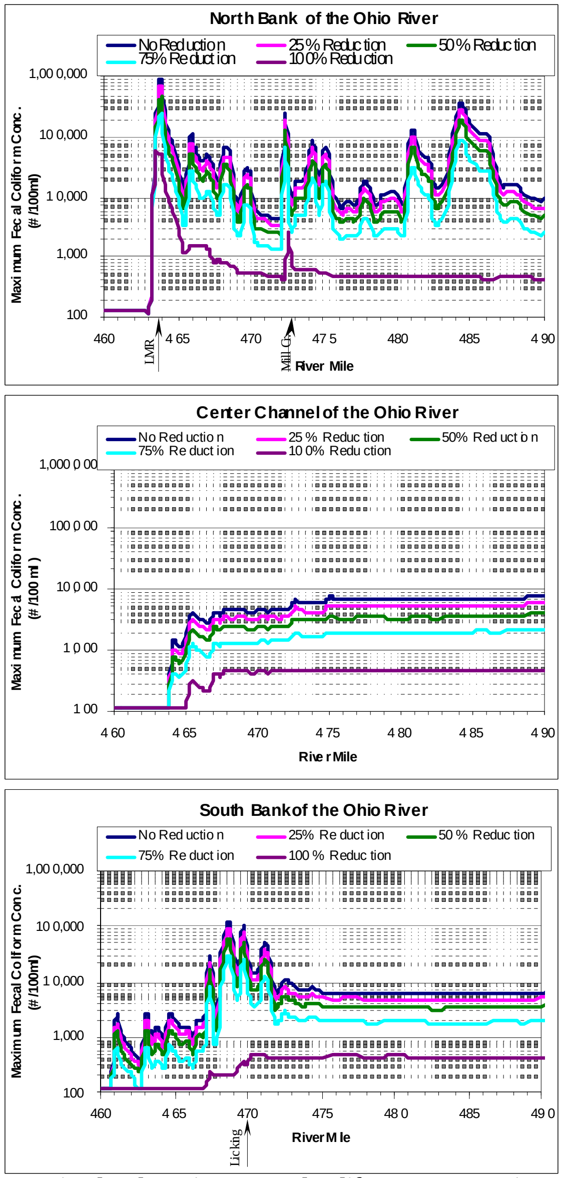

Figure 5-8. Simulated Maximum Fecal Coliform Concentration Along North Bank, Center Channel and South Bank During 1971 Recreational Season (May through October).

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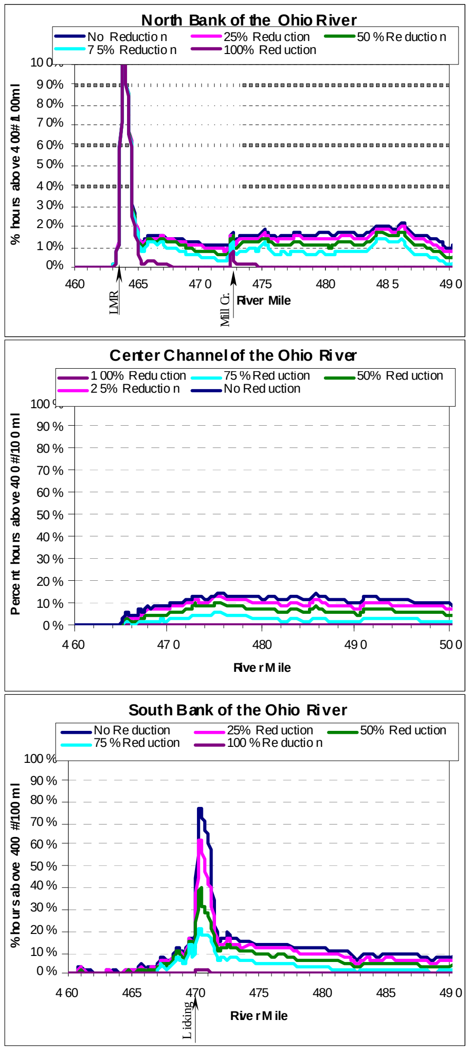

Figure 5-9. Percent Duration of Simulated Concentration Greater than 400#/100 mL Along North Bank, Center Channel and South Bank of Ohio River During 1971 Recreational Season (May through October).

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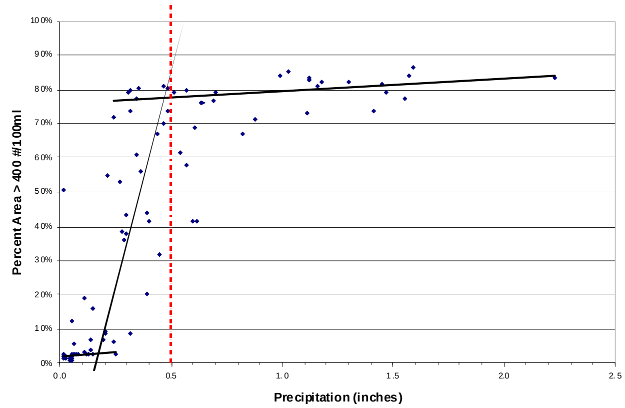
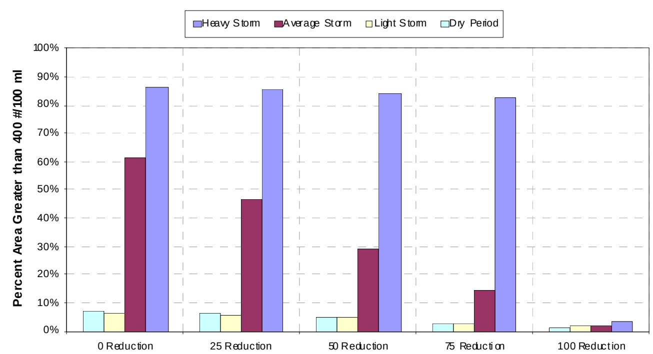


Figure 5-10. Precipitation Volume vs. Percent Study Area > 400 #/100 ml for the No CSO Reduction (Baseline) Scenario. (Note: Percent study area is based on annual results.)



Heavy Storm: total rainfall = 1.59 in; max intensity = 0.50 in/hr.
Average Storm: total rainfall = 0.54 in; max intensity = 0.14 in/hr.
Light Storm: total rainfall = 0.24 in; max intensity = 0.09 in/hr.
Dry Period: No rainfall.

Figure 5-11. Percent of River Area Greater Than 400 #/100 ml During Example Event Periods.

Note: The area corresponding to model segments in which concentrations greater than 400 #/100 ml were observed were summed, then divided by the total area of the river in the Study Area to determine the Percent Area indicated on the y-axis.

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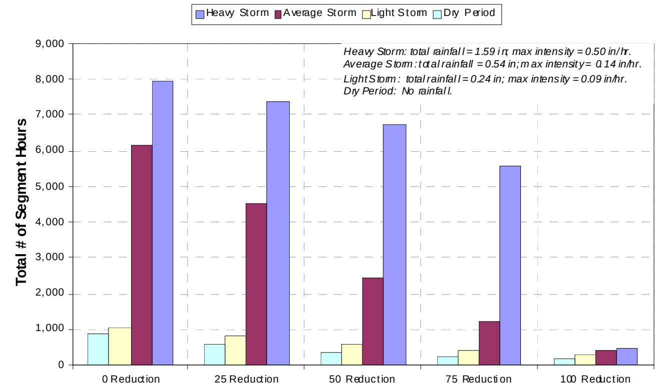

Figure 5-12. Total Hours of Segment Concentration Greater than 400 #/100 ml During Example Event Periods.

Note on y-axis label: Segment Hour = Σ(number of hours greater than 400 #/100 ml) for each 2-D water quality model segment.

5.4.2 Discussion of Results

As stated in the summary in Section 5.4.1, the approach to evaluating the model results for the five "typical" year simulations was to progressively evaluate results from general to more detailed. The evaluation of model results can be separated into four categories, which are presented in the following sub-sections: Section 5.4.2.a presents the comparison of each model simulation's results to state water quality standards, Section 5.4.2.b evaluates the most responsive (sensitive) areas in the river to wet weather effects, Section 5.4.2.c presents results for specific periods within the critical recreation season that span the range of environmental conditions, and finally, Section 5.4.2.d presents an analysis of the relationship between water quality and storm event characteristics.

5.4.2.a Comparison to State Water Quality Standards

ORSANCO has published the following fecal coliform Pollution Control Standards for discharges to the Ohio River (ORSANCO, 2000):

> "*Maximum allowable level of fecal coliform bacteria for use as a source of public water supply – for the months of November through April, content shall not exceed 2,000/100 mL as a monthly geometric mean based on not less than five samples per month.*
>
> *Maximum allowable level of fecal coliform bacteria for contact recreation—for the months of May through October, content shall not exceed 200/100 mL as a monthly geometric mean based on not less than five samples per month; nor exceed 400/100 mL in more than 10 percent of all samples taken during the month."*

The recreational, or summer, season has two applicable standards, a geometric mean standard of 200 #/100 ml and a single sample maximum ("instantaneous") standard of

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400 #/100 ml for which 10% of the values can exceed before the standard is violated. The winter, or non-recreational, season has only a drinking water geometric mean standard, which is an order of magnitude higher than the summer season standard, at 2,000#/100 ml.

To compare the model results to state water quality standards, the hourly model output for each model segment was averaged to determine a daily concentration. Each month was evaluated against the appropriate standard(s) using the daily average concentration. The geometric mean, and percent of days exceeding 400#/100ml are included in Table 5-7. The areas of the segments that violated the standard were summed, then normalized to the total area of the river in the study area to compute a percent area of violations. This process was repeated for each of the reduction scenario simulations.

Results are tabulated in Table 5-7 for the geometric mean standard and Table 5-8 for the single sample maximum standard for each of the reduction scenarios for each month of the year. As Table 5-7 indicates, very little area of the Ohio River violates the summer or winter geometric mean concentration water quality standard. Whereas typical compliance is evaluated on the basis of five samples collected over a month-long time period, the model results are evaluated on the basis of a daily concentration for each day within the month, nominally 30 days.

More area in the Ohio River violates the single sample maximum water quality standard for the model results for the months of May through October (Table 5-8). This result is consistent with typical bacteria impacts on water quality resulting from CSO overflows. CSO overflows are associated with storm (rainfall) events that cause combined sewers to overflow for a relatively short duration but with very high, untreated fecal coliform concentrations. This behavior results in "spikes" in fecal coliform concentration in the receiving waters that are well above the state-specified criteria.

Variations in the area of the river that violates the 400 #/100 ml standard from month to month are largely due to the number of storms and the total rainfall. More storms, such as in the month of June (when nine storms occurred), increase the frequency of "spike" concentrations. Higher amounts of rainfall, such as in the month of September, when the largest storm event occurred, tend to increase the duration of high concentrations in the river due to prolonged CSO overflow. Both conditions (i.e. more frequent storms and larger storms) will increase the likelihood that ten percent of the daily concentrations will exceed 400 #/100 ml.

However, CSO reduction does reduce the area that violates the single sample maximum standard as shown in Figure 5-7. The month with the greatest number of violations, September, shows a 20-fold reduction in the area that violates 400 #/100ml when complete CSO reduction is implemented. The greatest change seems to be between 50% and 75% reduction, with a 51% to 82% reduction in the area that violates. October is an exception to this observation. There is a 42% reduction in area of violation between the Baseline and 25% reduction whereas there's only a 26% reduction between the 50% and 75% reduction scenarios.

The primary conclusion from this comparison is that the single sample maximum standard is the more critical standard in the recreation season as it has more violations than the geometric mean standard. Reductions that can reduce either the magnitude or duration of high concentrations will improve compliance with this standard. Other

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To simplify the analysis of model results, each month of model results was evaluated rather than doing a rolling 30-day average analysis.

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conclusions are that water quality is not a major problem in the non-recreational season nor is a large portion of the study area impacted by the geometric mean standard during the recreation season. As the evaluation of peak concentrations presented in the next section will show, violations of the standards can occur in near-shore and channel areas. However, violations are much more likely to occur in near-shore segments. This is also supported by the examination of example periods presented in Section 5.4.2.c.

5.4.2.b Sensitive Areas in the River

Sensitive areas in the river, defined as areas that have the greatest change in simulated concentration from dry to wet periods, were identified by evaluating the hourly model output from each scenario for locations of maximum concentration and by how long specific locations exceeded a threshold concentration of 400 #/100 ml. This threshold was chosen to mimic the more restrictive state water quality standard (i.e. 10% of samples greater then 400 #/100 ml) identified in the previous analysis. Use of hourly model concentration outputs rather than daily average concentrations approximates an upper bound in maximum concentration and duration that might reasonably be captured in an extensive sampling program.

The process for evaluating maximum concentration and duration of exceedance greater than 400 #/100 ml was straightforward. The highest concentration in each segment for each reduction scenario's output was plotted as the maximum concentration in Figure 5-8. This represents the peak concentration that is predicted to be found in the river throughout the entire year. The duration of exceedance figures were completed for the months of May through October, when the single sample maximum water quality criteria of 400 #/100 ml is in effect. To calculate the percent of time that concentration exceeded 400 #/100 ml, the hours that the concentration was greater than 400 #/100 ml in each segment were counted, then divided by the total number of hours from May through October to generate a percentage for comparing reduction scenarios, as shown in Figure 5-9.

Results are presented for near shore and center channel segments to permit evaluation of lateral variation in peak concentrations and duration of exceedances. The near-shore areas have concentrations that are typically at least an order of magnitude higher than simulated in the center channel. Not surprisingly, given the magnitude of the concentrations in the near-shore segments, the duration of these high concentrations is longer for the near-shore segments than in the center channel.

On the Ohio shoreline (bank), maximum concentrations for the baseline scenario generally range between 5,000 #/100 ml to 100,000 #/100 ml. Near the confluence of the Little Miami River, the maximum concentration is closer to 1,000,000 #/100 ml, reflecting the large load and high concentration of fecal coliform delivered by the tributary. Another area of high concentration occurs near river mile 473, the confluence with Mill Creek. As discussed in Section 5.3.4.d, both of these tributaries contribute a significant load to the Ohio, approximately 15% and 22% respectively. The Kentucky shoreline (bank) shows a similar pattern, with concentrations in the baseline scenario ranging between 2,000 #/100 ml and 100,000 #/100 ml. The highest concentration occurs near river mile 470, the confluence with the Licking River, which contributes approximately 17% of the load to the Ohio River in the study area. In the center channel, maximum concentrations never exceed 10,000 # /100 ml. This is likely due to two

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possible factors: first, the hydrodynamics in the river cause point source loads entering the river on the shoreline to become well mixed over a larger area as they are transported both downstream and across the river and second, the larger segment volumes in the center channel segments offer some dilution capacity.

Comparison of the five reduction scenarios plotted on Figure 5-8 indicates that increasing CSO reduction progressively reduces peak concentrations. The separation in maximum concentrations is greatest between the 75% and 100% (no CSO) reduction scenarios. This trend is consistent across the river from north bank to center to south bank. The 100% reduction very clearly illustrates locations in the Ohio River that are receiving non-CSO loads such as loads upstream of the study area from tributaries.

The duration of time in the summer that each segment's concentration exceeds 400 #/100 ml shown in Figure 5-9 shows more clearly that the segments in the Ohio River receiving tributary loads are the most sensitive to CSO loadings. On the north bank, the longest durations of exceedances are associated with river mile 463.5, where the Little Miami River enters, and with river mile 473, where Mill Creek enters the river. These areas remain the most responsive to wet weather loadings for all of the reduction scenarios, although the duration of exceedance is reduced with increasing CSO reduction. Areas outside of the tributary confluences generally have durations of exceedance between 10% and 20% for both near-shore and center channel segments.

In general, these hypothetical CSO reduction scenarios indicate that CSO reduction is most effective at reducing peak concentrations in areas that receive CSO loadings only, as the south bank near-shore area between river miles 461 and 467 illustrate in Figure 5-8. When CSOs are completely eliminated (100% reduction scenario), the concentration in this area is approximately the same as the upstream boundary concentration. However, it should be noted that the 100% CSO reduction scenario eliminates both stormwater and sanitary components of CSO and doesn't simulate effects of separating the combined sewers. The reduction scenarios appear to uniformly reduce the duration of exceedances along the length of the river, regardless of the loading sources.

5.4.2.c Example Event Comparison

Four example periods during the "typical" year simulation were analyzed in detail to evaluate the effects of varying environmental conditions on water quality and effectiveness of CSO reduction. These periods are listed below and summarized in Table 5-9:

1. Dry period: August 16-21, no rainfall;
2. Light storm: August 25-26, total rainfall = 0.24 inches, maximum intensity = 0.09 in/hr;
3. Average storm: October 23-24, total rainfall = 0.54 inches, maximum intensity = 0.14 in/hr; and
4. Heavy storm: September 20, total rainfall = 1.59 inches, maximum intensity = 0.5 in/hr.

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Table 5-9. Example Period Characteristics.

Event Description	Event Start Time	Event End Time	Rainfall Start Time	Total Rainfall (in)	Maximum Intensity (in/hr)	Duration of Rainfall (hrs)	Upstream Ohio Flow at start of storm (cfs)
Dry	8/16/1971	8/21/1971		0	0	0	24,000
Light Storm	8/25/1971	8/26/1971	8/25/1971 16:00	0.24	0.09	7	18,000
Average Storm	10/23/1971	10/24/1971	10/23/1971 21:00	0.54	0.14	12	6,000
Heavy Storm	9/20/1971	9/20/1971	9/20/1971 4:00	1.59	0.5	6	99,400

Example periods were sought during the critical recreational season months of May through October. Periods where upstream flow was less than or equal to median flow were also desired. This minimizes the dilution effects of upstream flow and presumably maximizing the effective impact of CSO loads and, therefore, the benefits of CSO reduction would be maximized. Each period was evaluated for approximately 6 days (144 hours) to fully capture the storm effects on water quality. Analysis of area and duration of exceedance of the 400 #/100 ml threshold concentration was performed using the same methods described in Section 5.4.2.b. Results are presented in Figure 5-11 and Figure 5-12.

Figure 5-10 displays the fraction of the total river area (percent area) that is greater than the 400 #/100 ml concentration threshold during the four example periods by reduction scenario. Several observations can be made from this figure. First, the area of exceedance is greatest for all of the reduction scenarios for the heaviest storm, followed by the average storm, then light and dry periods. Second, the effectiveness of the reduction scenario in reducing the area of the river that exceeds the criteria varies from storm to storm. The heavy storm shows very little difference in percent area of exceedance between reduction scenarios, staying between 80% and 90% area of the area impacted, until the 100% reduction scenario where CSOs are completely eliminated and the percent of impacted area is reduced to less than 10%. Likewise, the light storm and dry period have small areas of exceedance that do not change significantly between reduction scenarios. The average storm shows a linear relationship between the fraction of area with exceedance and level of reduction. This observation is explored in more detail in Section 5.4.2.d. Finally, during the dry period selected, there is a small portion of the area that exceeds the 400 #/100 ml concentration threshold, primarily in areas that receive tributary inflows, such as the confluence of the Licking River. Areas in the Ohio River during the selected dry period with concentrations greater than 400 #/100 ml may be a result of extended CSO overflows from an event prior to the dry period.

Figure 5-12 presents the total number of segment hours that concentrations for each storm exceeded 400 #/100 ml. This value is computed as the sum of each hour that each model segment's concentration exceeded 400 #/100 ml. Comparing absolute values is more meaningful than comparing percentages because each storm duration and effects are different. This figure illustrates many of the same trends observed in Figure 5-11. The greatest number of hours of exceedance is associated with the heaviest storm for all of the reduction scenarios, followed by the average storm and so on. Although the relationship between the level of reduction and number of hours of exceedance appears to be more correlated in this figure, the heaviest storm still has the most dramatic reduction in exceedance between the 75% and 100% reduction scenarios. The relationship between reduction level and number of hours of exceedance seems to be more linearly related for

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the other periods. For example, in the average storm, a 50% reduction in CSO loads reduces duration by approximately 50%.

Appendix F presents temporal plots for each reduction scenario at representative or key locations, including the upstream and downstream CSO area boundaries, segments receiving both CSO and tributary loadings, as well as a presumably well-mixed downstream center-channel segment. The start of the storm is indicated on these plots to provide a reference point for evaluating the response time of the Ohio River system to loadings from the storm. In general, even for the heaviest storm, most of the load is transported downstream within the first two days. The system returns to pre-storm conditions no later than the fourth day after the storm begins. These observations hold true regardless of the level of CSO reduction. Schematic grid figures indicating maximum concentrations by model segment are also presented in the appendix.

5.4.2.d Relationship Between Event and Exceedance

Although the discussion presented in Section 5.4.2.c. was limited to three events (and one dry period), there appeared to be a relationship between the area of the river exceeding 400 #/100 ml and the event characteristics. This analysis was expanded for all 86 events in the "typical" year and the relationship between the total rainfall and percent area of exceedance for the baseline scenario is presented in Figure 5-10. This figure reinforces the observations made for the three events examined in Section 5.4.2.c. The area of exceedance does not significantly increase for storms with total rainfall greater than 0.5 inches, as illustrated by the relatively flat trend line in this area of the plot. The trend is also relatively flat for the area of the graph where total rainfall is less than 0.1 inches. Between these two storm rainfalls, the relationship between total rainfall and area of exceedance is much better correlated. This suggests that there may be significant benefits associated with controlling the first 0.5 inches of an event. Rainfalls up to 0.5 inches represent approximately 77% percent of the "typical" year rainfall distribution (and approximately 82% of the historical rainfall distribution), as shown in Figure 5-1.

Similar correlations between area of exceedance with rainfall intensity and rainfall duration were also examined for the baseline scenario. The results were too scattered to observe a correlation between either of these variables and area of exceedance.

5.5 CONCLUSIONS

The ultimate success of CSO control is compliance of receiving waters with applicable water quality standards. Control of bacteria is especially important during the recreational season, from May through October for the Ohio River, because people are using the river and are more likely to come into contact with water that may pose a health risk. It is impossible to monitor conditions in the river at every moment and at every location to protect human health during the recreation season. A water quality model of the system can supplement monitoring programs by filling in the gaps in space and time that monitoring cannot cover. Thus, water quality models can be used as a predictive tool for assessing when conditions in the river are safe for designated uses, given a specific rainfall event. Applying the model in a "typical" year simulation can indicate the range of environmental and storm conditions that trigger violations of water quality standards and thus, require CSO reduction. The use of a water quality model can be expanded to assess the effectiveness of a proposed control scenario. Application of the water quality

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model in the Cincinnati Wet Weather Demonstration Project over a "typical" year using five screening level CSO reduction scenarios have provided additional insights into this study area. These conclusions are that:

1. CSO reduction can improve water quality with respect to bacteria concentration, though complete reduction of CSO will not eliminate water quality violations in some parts of the study area.
2. CSO reduction is more effective at reducing durations of high concentrations in the Ohio River rather than reducing peak concentrations, though both occur.
3. The area of the river that exceeds a concentration of 400 #/100 ml increases proportionally between 0.1 inches and 0.5 inches of rainfall, but for rainfalls greater than 0.5 inches, the area of the river with high concentrations does not increase as dramatically.

5.6 RECOMMENDATIONS

This project evaluated screening level CSO reduction scenarios. The models developed as part of this project can be used as tools for conducting more rigorous simulations of the study area. Use of the sewer and water quality models with more detailed CSO reduction scenarios will provide more insight into the system behavior.

Recommendations for additional scenarios include evaluating control up to a specified volume of rainfall rather than targeting a volume of overflow. Secondly, continued sampling of combined sewer overflows and stormwater will provide better constraints on the CSO loading estimates used in the water quality model. Similarly, continued sampling of stormwater will provide better constraints on the potential effectiveness of control alternatives, such as sewer separation scenarios.

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Metropolitan Washington Council of Governments, October 1987. "Potomac River Fall-Line Loadings Dynamics, January 1983-April 1987-Based on Chain Bridge Automated Storm Event Monitor." Washington, D.C.¶
Ohio EPA, 1997. State of Ohio Water Quality Standards, Chapter 3745-1 of the Administrative Code, Part 3745-1-32.¶

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The type of rainfall influences how effective specific levels of CSO control are, as shown in Figure 7-8. Control of CSO from events where storms >0.5” of rain do not show marked improvement in water quality until between 75 and 100% control. At the low end of storm intensity, storms with less than 0.1” of total rainfall, water quality in the Ohio River does not improve significantly with increased CSO control. Between these two rainfalls, there is a correlation between CSO control and improvement in water quality (as measured by area exceeding 400#/100 ml and duration of that exceedance). This is also demonstrated in Figure 7-9 for the evaluation of four representative periods in the “typical” year;

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(note to myself: use the word “violation” exclusively in discussion of the water quality standard comparison and use the word “exceedence” when talking about comparing model results to the 400#/100 ml threshold. Mixing terms may implicitly suggest that the 400#/100 ml threshold has the same weight as the published standards-want to avoid implying that)

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(Full citation to put in references section: Ohio EPA, 1997. State of Ohio Water Quality Standards, Chapter 3745-1 of the Administrative Code, Part 3745-1-32)

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For the months of May to October, the maximum allowable level (either MPN or MF count) shall not exceed two hundred per one hundred ml as a monthly geometric mean based on not less than five samples per month; nor exceed four hundred per one hundred ml in more than ten per cent of all samples taken during the month. For the months of November to April, the maximum allowable level (either MPN or MF count) shall not exceed two thousand per one hundred ml as a geometric mean based on not less than five samples per month."

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instantaneous

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control

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instantaneous

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Page 166: [28] Deleted tnaperala 11/26/2001 3:50:00 PM

the

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s

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(note: 9 storms in June, 10 in September)

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when the largest storm event occurred *(note: 5.18 inches in June, 6.56 inches in September)*

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and seasonal decreased upstream flows

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(although higher rainfalls would increase flow and flush upstream stuff out faster too so I could just be talking out of my ass here-think about this and see if data can support these statements).

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instantaneous

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worst

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for

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improvement

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the

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comparing the baseline conditions to

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Control

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November 29, 2001November 27, 2001November 26, 2001

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The peak concentration occurred in the summer for all of the model segments *(need to check if this is true-perhaps Troy can limit query to summer months and rerun and replot-it would simplify explanation to say that both were examined during critical summer period. should be true based on storm distribution)*.

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(and the small volume of the near-shore segment receiving the load-include this?)

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November 29, 2001November 27, 2001November 26, 2001

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Comparison of the control scenarios for the south bank near-shore area between river miles 461 and 467 in Figure 7-6 is a good illustration of the effectiveness of control, especially complete control (100% control simulation).

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November 29, 2001November 27, 2001November 26, 2001

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so

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would be minimized

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control

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effects of differences in CSO control

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(this may be a B.S. statement, haven't thought through completely)

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7.5

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7

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exceeds

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exceedence

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n’t

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very much

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somewhat linear

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exceedence

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control

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7.5

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segments

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segment 217,

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which receives the Licking River inflow

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7-10

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method of presentation was preferred over computing a percent duration because storm durations vary so the normalization factor would not be consistent.

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in this case.

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control

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data

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as

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these

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exceedence

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ANCE FOR RAINFALLS >0.5" WITH UPSTREAM FLOW TO SEE IF THERE'S A CORRELATION THERE

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; MAGNITUDE AND/OR DURATION OF CSO OVERFLOW VS. AREA OF EXCEED

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ANCE (I WOULD THINK THERE WOULD BE A RELATIONSHIP THERE BUT MAYBE THAT'S OBVIOUS AND DOESN'T NEED EXPLICIT DISCUSSION)

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; REPEATING THE CORRELATION BETWEEN AREA OF EXCEED

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ance and total rainfall for the control scenario that's closest to the percent of the distribution that 0.5" storms represent

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usually evaluated on the basis of

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control

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November 29, 2001November 27, 2001November 26, 2001

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Misc. Text and figures that might be useful

Table 2 provides details regarding how upstream and tributary flows were estimated for the typical year modeling.

Table 2: Upstream flow and tributary flow estimation.

River	***Flow Estimation Technique***
Ohio River near Cincinnati (upstream boundary)	USGS Gage 0325000[a]
Licking River	USGS Gage 0323500[b]
Banklick Creek	SWMM Model[c]
Little Miami River	SWMM Model[c]
Mill Creek	SWMM Model[c]
Great Miami River	USGS Gages 03274000 and 03276500 [b]

Notes:

[a] USGS stream flow data used without modification.

[b] USGS stream flow data increased to account for watershed area below gage.

[c] Stream flow estimated using USEPA SWMM with 1971 precipitation data from Northern Kentucky International Airport.[1]

6. 0 APPLICATION OF STUDY FRAMEWORK TO OTHER LARGE RIVER SITES

6.1 INTRODUCTION

One of the primary objectives of this study was to develop a framework for the evaluation of wet weather water quality problems and control measures that can be readily transferred to other large river communities. This chapter presents this framework as a description of the factors considered in developing the methodology used in this study, the sequence of tasks conducted using the methodology and how communities at other large river sites can apply this methodology.

This chapter is divided into three parts. Section 6.2 describes the unique characteristics of large rivers as they relate to wet weather water quality assessments. The actual methodology is described in Section 6.3, containing separate discussions on Study Objectives; Monitoring Plans; Model Development; and Model Application. The text of these sections provides guidance for other communities in applying this framework to their specific location. Section 6.4 summarizes the material presented in this chapter.

6.2 LARGE RIVER CHARACTERISTICS

The Ohio River is one of the "Great Rivers" of the United States and is an appropriate site for conducting a demonstration case study of wet weather impacts and controls on large rivers. The River's water quality and beneficial uses (contact recreational use) have been impaired largely due to bacteria levels resulting from urban wet weather pollution. More than 1,400 combined sewer overflows are located in cities along the Ohio River main stem, representing approximately ten percent of the national total. Land use in the Ohio River watershed ranges from forests, having very little imperviousness, to largely impervious urban areas.

While the necessity of studying and, ultimately, improving water quality in large rivers is demonstrated by the current conditions in the Ohio River, efforts to do so can be complicated by several factors unique to large rivers. These include having multiple community and multi-state regulatory jurisdiction, large watershed areas and the physical characteristics of the river itself. Acknowledging and understanding the uniqueness of large rivers is a key to conducting a successful study. These factors are described in detail using examples from this project.

6.2.1 Multiple Jurisdictions

Large rivers often serve as interstate boundaries and thus, can span state, EPA regional and municipal boundaries. Consequently, there may be several significant stakeholders that have potentially diverse objectives, stemming from legal or political concerns or from competing agency/organizational missions. Studies of large rivers will likely need to address these differences to ensure the completion of the project. The success of a proposed study in achieving stakeholder buy-in under such conditions is greatly improved by building consensus up front in the project planning stage. Oversight of the project at a national or regional level also provides a means for reducing conflicts that may result from competing agendas.

This wet weather demonstration project focused on a 70-mile section of the Ohio River, from river mile 460 downstream to river mile 530. From an environmental regulatory perspective, the study area falls within the jurisdiction of three states (Ohio, Indiana, and Kentucky), two U.S. EPA Regions (Regions IV and V), and a regional authority (ORSANCO). Major urban areas within the study area include the cities of Cincinnati, Ohio, Covington, Kentucky and Newport, Kentucky. Stakeholders providing funding for the project included U.S. EPA Office of Wastewater Management; Metropolitan Sewer District of Greater Cincinnati; Sanitation District No. 1 of Northern Kentucky; and Cincinnati Water Works.

6.2.2 Large Watershed Area

The Ohio River and similar large rivers have very large drainage basins, which can complicate many aspects of wet weather assessments. The drainage area for the entire Ohio River is over 200,000 square miles (ORSANCO, Ohio River Fact Book). In the Cincinnati project study area, there are three major tributaries (the Great Miami, the Little Miami and the Licking River) that flow into the Ohio River. The combined area of these tributary watersheds is over 10,000 square miles. In addition, there are several smaller tributaries in the study area, such as Mill Creek, that also contribute to the drainage area of the Ohio River in the vicinity of the project.

Large watershed areas complicate the assessment of "wet weather" impacts on large rivers in several ways. First, the precipitation is rarely uniformly distributed throughout a large area; second, large watersheds can have large lag times between the onset of wet weather and the occurrence of water quality problems; and third, larger watersheds have more variety in land use and population and thus, have a large number of potential pollutant sources that are very diverse in their discharge characteristics (types of pollutants, magnitude of pollutant loadings, volume released). The implications of each of these factors on interpreting wet weather impacts on water quality in large rivers are discussed in detail below.

Wet weather water quality assessments are most readily conducted when relatively uniform precipitation occurs across the watershed. The precipitation falling over a large watershed area can vary by large amounts. As an example, for the May 2000 event, which was used to calibrate the receiving water model, rainfall on the day of the storm (5/24/00) was measured at 18 gages located throughout the watershed. Measured rainfall amounts from these gages ranged from 0.12 inches to 2.48 inches. Such variations can significantly change the amount of nonpoint source runoff and collection system modeled overflow volumes predicted for an area. For example, there may be enough precipitation in one portion of the watershed to trigger a CSO event and another portion of the watershed may receive insufficient precipitation to cause any wet weather loadings to the river. Assessing what is truly a "wet weather impact" on water quality in large rivers is certainly challenging under these common conditions.

Determining the relative proportion of each source loading's contribution to the river is also difficult when the precipitation is not uniformly distributed. Sources in areas with heavy precipitation will contribute more loading to the river and will be incorrectly emphasized as major sources of impairment if the varying rainfall pattern is not accounted for. Setting up an extensive rainfall gage network (discussed in Section 6.3.2) will permit good understanding of the rainfall pattern and, when incorporated into the collection system modeling, will reduce uncertainty in model predictions. Another approach used in this study was to have the collection system modelers use the same rainfall record (average rainfall) throughout the watershed to model their collection systems when simulating the control scenarios presented in Chapter 5.

The second characteristic of large watershed areas that complicates wet weather assessments is the large variation in time response between the occurrence of a wet weather event and the presence of water quality issues. Using Cincinnati as an example, wet weather loads generated in the downtown area will show up in the Ohio River immediately; wet weather loads generated near the headwaters of Mill Creek or the Licking River may take hours to days to arrive in the Ohio; while wet weather loads generated in watersheds upstream of the study area on the Ohio may take days to weeks to show up in Cincinnati. This range of response times causes two problems. First, it is not possible to capture all of the wet weather water quality impacts in a large river with short duration sampling events. Depending on when the sampling is conducted, the river water quality may be responding to only a small subset of the total number of wet weather sources that contribute to it. Second, wet weather sources that have long travel times before reaching the study area are subject to large amounts of transformation that must be considered in the analysis

The final characteristic of large watershed areas that complicates assessment of wet weather impacts on large rivers is the large number of diverse sources. Sources of pollutant loadings include point (CSO, SSO, industrial permittees and WWTPs) and nonpoint sources. In the Cincinnati project area, there are approximately 335 CSOs, 40 industrial permittees and five municipal wastewater treatment plants. Nonpoint sources include basins upstream of the study area, stormwater runoff from areas with separated sewers, and runoff from non-urban land uses, such as agriculture. Pollutant loadings from all of these source types must be incorporated into the study to obtain a reasonable estimate of the relative magnitude of each source's contribution to the loads in the river.

The process of acquiring information on the variety of sources in a watershed(s) can be very challenging. First, the sources need to be identified and located within the study area. Second, representative loadings from each source need to be quantified. Review of available data or targeting the monitoring program (described in section 6.3.2) to fill in data gaps can provide this information. A time series of pollutant loadings from each source needs to be incorporated into the model of the study area. Ideally, this would reflect travel time and potential losses of contaminants that occur before the source load reaches the river. Finally, a method for estimating these loadings in the absence of data may be necessary as well.

6.2.3 Physical Characteristics of Large Rivers

The physical characteristics of large rivers themselves warrant special consideration when developing a study of their water quality. Large rivers require logistical monitoring considerations, such as safety consideration for high flow sampling and potentially large travel times between sampling stations. These are discussed in detail in Section 6.3.2.b. The physical dimensions of large rivers (width, depth, length) increase the likelihood that spatial gradients may be important. A primary ramification of this characteristic is the potential need for a more sophisticated, multi-dimensional water quality model that can account for spatial variations in flow and concentration. Using Cincinnati as an example, sampling data showed periods of high fecal coliform concentrations along one shore of the Ohio River and not the other, depending upon local rainfall patterns. Use of a laterally-averaged water quality model common for smaller rivers would underestimate peak river concentrations by providing only an average shore-to-shore concentration. The presence of these lateral gradients necessitated the use of a two-dimensional model that could describe these variations.

Large rivers often have many diverse areas. These include sensitive areas and distinctive physical features. Examples of sensitive areas include wildlife habitat and recreation areas. Protecting these areas by improving water quality is very often one of the objectives of water quality studies. Examples of distinctive physical features include dams and large islands. These features often complicate the understanding of flow and pollutant transport in the river itself.

6.3 METHODOLOGY

The methodology that was applied in this study was developed specifically for large rivers. The unique characteristics of large rivers required special consideration in setting project objectives and developing a series of tasks that would meet these objectives. This section presents the methodology in chronological order, beginning with setting detailed study objectives, monitoring (collecting data), model development, and finally, model application for the control scenarios. This chronology is recommended for use at other large river sites.

Details regarding the application of this methodology in Cincinnati are presented in Chapters 2-5. However, this section discusses key elements of the methodology design. The lessons learned and insights gained from the application of this plan are presented as guidance to aid others in successfully transferring this methodology to other large river sites.

6.3.1 Detailed Study Objectives

Setting appropriate study objectives is a key component of wet weather impact studies, especially for large river systems. These projects are typically initiated with a limited number of broad objectives. The broad objectives for this study were:

- Provide an assessment of wet weather water quality impacts and potential controls addressing these impacts on the Ohio River near Cincinnati

- Document the approach taken so that it can serve as a template for other large river wet weather assessments.

These broad objectives must be fleshed out with more specific detail during the initial stages of the project to establish the scope and schedule needed to complete the study. Objectives can be classified into two categories: management objectives and technical considerations. In complicated large river sites, both types of objectives need to be established early in the project process.

Specification of detailed objectives for large river studies is also important to achieve consensus for the potentially large number of diverse stakeholders common to large rivers. For this project, ORSANCO conducted a series of meetings with the project team and the project Technical Advisory Committee (TAC) to detail specific project objectives prior to completion of the work plan. The TAC was comprised of representatives of Cincinnati MSD, Sanitation District No. 1, Cincinnati Water Works, U.S. EPA Office of Research and Development, and the University of Cincinnati. The specific management and technical objectives that resulted from these meeting are described below. The TAC also met on a routine basis throughout the duration of the project to provide clarifying guidance on project objectives as questions arose during the project.

6.3.1.a Management Objectives

Management objectives include determining what the project products will be, taking into account resource availability and site-specific characteristics, such as those presented in Section 6.2. In the Cincinnati project, these more detailed objectives included: 1) determining the extent and severity of wet weather water quality impacts on the Ohio River; 2) identifying the causes (pollutants) and sources of impairment and estimating their relative contribution of loadings; 3) evaluating the resulting improvements in water quality from screening-level CSO control scenarios.

Wet weather water quality “impacts” were initially defined as any pollutant that caused (or could be expected to cause) violation of existing water quality standards in the Ohio River. This definition was expanded to include consideration of *Cryptosporidium* and *Giardia*, which were of particular concern to Cincinnati Water Works.

Another required management objective corresponded to defining the specific boundaries of the study domain. From a management perspective, it was necessary to specify the portion of the entire watershed that would be considered for pollutant loading controls. This domain was defined as the Cincinnati metropolitan area. The spatial domain of the water quality analysis was defined as the maximum downstream extent of water quality impacts. Converting this management objective into a specific area is a technical issue discussed below, as it requires analysis of the water quality data to define this extent.

Resource availability also needs to be considered as a check on whether the objectives are realistic. Management objectives will typically result in a desire for a high degree of model detail and reliability, although available resources are generally insufficient to provide the degree of reliability desired by management. Resource availability includes an assessment of the available data, time, level of effort and staff expertise. This project experience indicates that there is a geometric increase in resource needs relative to smaller systems. For example, water quality samples will need to be collected at multiple locations across the width of the river, as well as multiple downstream locations. Acquiring the resources needed to characterize a complicated large river system can be expensive and time-consuming, and must be factored into the objectives-setting process.

6.3.1.b Technical Objectives

Certain technical aspects of project objectives must also be defined before the project can proceed. Technical objectives related to this project included setting the spatial and temporal dimensions of the analysis, and finalizing the constituents of concern to be considered in the project.

The spatial considerations include both the length of the river section and the degree of spatial detail to be provided. Analysis of available water quality data showed strong lateral gradients in the direct vicinity of the Cincinnati metropolitan area, with concentrations becoming laterally well-mixed in the portions of the river downstream of the City. For this reason, a two-dimensional approach, which considered lateral (i.e. side to side) and longitudinal (i.e. upstream-downstream) changes in water quality, was implemented from the upstream study boundary down to below Cincinnati at the confluence of the Great Miami River. The upstream boundary of the study area was determined by ensuring that the boundary was upstream of all known or anticipated sources in the urban areas. Locations of historical data collection were also factored into determining the upstream boundary. In this study, the upstream boundary was set to river mile 460 because it was upstream of the most upstream urban source (at river mile 461) and corresponded to a location where ORSANCO and other agencies (Cincinnati Water Works) had monitored water quality in the past.

Downstream of this point, a one-dimensional approach was used that only considered changes in concentration in a longitudinal direction. This approach was selected because the resources required to apply a two-dimensional approach over the entire study domain were excessive, and little additional benefit would be gained by describing lateral variability downstream of the urbanized areas. Screening level modeling was conducted to determine how far downstream on the Ohio River the study would need to extend to consider all potential water quality impacts. The downstream boundary was ultimately selected as Markland Dam, approximately 50 miles downstream of Cincinnati.

The temporal domain includes the length of time that water quality in the river will be evaluated. For the Cincinnati project, the water quality was evaluated on an event basis for the purposes of calibrating and validating the receiving water model, then applied over a “typical” year for the control scenario comparison.

Finally, the constituents of concern should initially include all parameters that have historically shown violations of local water quality. The list of constituents can be refined as the project work progresses. In Cincinnati, the initial list of constituents included metals, dissolved oxygen and bacteria. *Cryptosporidium* and *giardia*, constituents of concern to Cincinnati Water Works, a key stakeholder, were also included in the list of parameters. Monitoring done during the first year of the project indicated that wet weather sources were not contributing enough metals loadings to adversely affect the water quality in the river. Similarly, monitoring also indicated that dissolved oxygen violations were not occurring during wet weather, which was confirmed by the calibration of the receiving water model. Ultimately fecal coliform was the only constituent identified as impairing water quality during wet weather and was the only constituent modeled for the control scenarios.

6.3.2 Monitoring Plan

The purpose of the monitoring plan was to collect data with sufficient spatial and temporal detail to provide a better understanding of the system and to provide complete datasets for developing reasonably constrained models of the system. The data collected during the monitoring was fed forward into the system models to meet several of the objectives presented in Section 6.3.1.a - determining the extent and severity of wet weather water quality impacts and identifying the causes and sources of impairment and quantifying their relative contribution to in-stream loadings.

The monitoring plan was designed to provide targeted information for all of the models used to characterize the study area (land side or collection system, receiving water hydrodynamic and water quality models) as described in Chapter 2. This is an extremely important aspect of the monitoring design. A monitoring plan that doesn't consider the system model's needs will result in models that are less well constrained in their specification of site-specific inputs and in their comparisons to observed data. Ultimately, poorly constrained models are less useful as planning tools (discussed in Section 6.3.4.a) and do not meet the project objectives. Meetings between the monitoring plan developers and model developers to discuss the modeling data needs and their incorporation into the monitoring plan should be part of the monitoring plan development to facilitate this aspect of the framework design.

The monitoring plan design attempted to address "what, where, when, why, who and how" questions of the data collection effort. The answer to the "why" question, summarized in the previous paragraph, drives the answers to the remaining questions, which are addressed in the remaining sections through discussion of the following aspects of the sampling plan: sampling considerations, field logistics and laboratory selection.

6.3.2.a Sampling Considerations

To address the technical considerations raised as part of the study objectives (see Section 6.3.1), the sampling plan considered the constituents to sample and analyze, the sampling locations, the monitoring frequency and the number of events. This section addresses the "what, where and when" questions of the plan's design.

<u>Constituents to Sample</u>

Having identified constituents of concern during the planning stages of the project makes defining this part of the sampling plan fairly straightforward. This study initially collected samples for metals, dissolved oxygen, CBOD, nutrient, chlorophyll *a* and bacteria analyses. Results from the first year of monitoring in Cincinnati demonstrated that wet weather sources of metals were not responsible water quality standard violations, so metals were dropped from consideration in subsequent years. The ability to adapt the sampling plan based on interim results is especially important in large river systems, due to the large number of (potentially unnecessary) samples that could be collected.

If the river hydraulics are not well understood, then one or more dye surveys should be conducted in addition to sampling for water quality parameters. Two dye surveys, conducted at high and low flow, provided a better understanding about the lateral mixing variations in the Ohio River for this study. The surveys provided a calibration and validation dataset for the dispersion coefficients used in the water quality model (see Section 4.4.2.d) to describe the lateral and longitudinal mixing of water quality constituents as they are transported downstream. This provided a level of confidence in the water quality model's ability to successfully route constituents downstream in a manner consistent with the true routing of the flow in the river.

Sampling Locations

In large river sites, all dimensions of the river, lateral, longitudinal and depth, should be considered when determining sample locations, as concentrations of particular constituents can vary significantly in each of these dimensions. In this study, surface samples were collected at each of three locations across the river for each river mile that was sampled. Longitudinally, samples were spaced approximately every two miles in the urban area (RM 460 – RM 490) and approximately every five miles further downstream (RM 490 – RM 530). Decreasing the longitudinal frequency in the downstream section was deemed appropriate in this study because loads that enter upstream would be well mixed further downstream. Only a single sample was collected at each downstream location for the same reason.

To address the data needs of the collection system/landside models, tributary and point source (such as CSO outfalls) water quality samples were collected. For this study, CSO outfalls were selected for sampling so that all types of land use in the CSO service areas were represented. Note that in this study, the CSO portion of the sampling plan was unsuccessful and did not produce useable data. The modeling proceeded by using data from other studies and literature values, but this added uncertainty to the model simulations.

Samples were also taken at the mouths of all significant tributaries (in terms of loading to the river) to provide a cumulative loading estimate from CSOs and other sources discharging to each of the tributaries. Initially tributary samples were collected in the center of the stream transect. However, pollutant loads enter many of the sampled tributaries near their confluences with the Ohio and spatial gradients were observed in water quality. The sampling plan was revised so that three samples were collected across the transect of each tributary sampling location. Measurements of flow rate or overflow volume are also desirable at these sites for modeling purposes.

Sample Frequency and Duration

The third sampling consideration is to determine how frequently and for how long each location should be sampled during each event. This is important for large river systems, because the large spatial scale of the system can result in much longer duration wet weather events than for smaller systems. Ideally, the frequency should be high enough that temporal variations in water quality in the river and tributaries can be defined while still surveying the spatial extent needed. However, the analytical requirements (sample size, preservative, filtered vs. unfiltered) should also be reviewed prior to initiating sampling to ensure that there is sufficient space on the boat or vehicle and an appropriate number of coolers and bottles to gather samples for all of the desired constituents.

The duration of sampling depends on the type of event. For dry weather sampling (discussed below), a single round of samples are sufficient. For wet weather events (discussed below), the entire event duration needs to be sampled. In addition, because wet weather in-stream effects often persist longer than precipitation events, sampling should continue until wet weather water quality impacts have subsided. For the Ohio River, a simple nomograph was developed that indicated how long wet weather impacts would be observed in the study area, based upon observed river stage. For most events, sampling was required at least two to three days after the rainfall had ended. The duration of sampling during wet weather is largely dependent on the size of the storm and the in-stream flow conditions. Wet weather event sampling ranged from one to two days to five days in this study.

<u>Number of Events</u>

The final sampling consideration is the number of events to sample. The number of events needs to be high enough that there is at least one calibration and validation dataset. Since large rivers experience a wide range of flows, even under wet weather conditions, sampling more wet weather events is preferred to ensure that the receiving water model's performance over the range of conditions can be confirmed with data. More sampling events are typically needed for larger systems, as the large watershed size makes it less likely than any given precipitation event will provide sufficient rainfall to generate wet weather impacts across the watershed. It is often common to have to conduct multiple events, each of which contains sufficient precipitation over a portion of the watershed, in order to provide equivalent data from a single watershed-wide precipitation event.

In addition to wet weather events, sampling during dry weather is also a necessary component of the monitoring program. Dry weather surveys provide baseline information on water quality free from wet weather-related influences. Dry weather surveys should include both main stem and tributary stations. A range of dry weather conditions should also be sampled. In this study, three dry weather and six wet weather surveys were conducted.

6.3.2.b Field Logistics

Field logistics deal with the "how" question of the monitoring plan and the "who" question of sample collection. Since wet weather event sampling is much more complicated than dry weather sampling, this section will deal exclusively with the logistics of wet weather sampling. Many of the considerations are applicable to dry weather sampling too.

The complexity of large river sites requires extensive up front planning of sample collection, timing and crew coordination. Poorly planned or executed logistics can undermine the intent of a sampling program by providing incomplete datasets for characterizing the system and for the models. Logistics for large river site sampling plans should consider the following complexities: the large area requiring sampling at a relatively high frequency, safety considerations, and dealing with inconsistent rainfall patterns. Ultimately, each of these components in the logistics is factored into a “Go/No go” decision on whether to sample an event.

Spatial Coverage

As part of the sampling considerations, main stem, tributary and source (CSO) samples are desired for a complete dataset. Each location is sampled very intensely early in the event, and then the frequency decreases as the event passes through the system. To accommodate the spatial coverage and frequency of sampling desired, multiple crews and sets of equipment are needed.

Because large rivers are generally not wadable, sampling at these locations will need to be done by boat. If the pollutant loadings entering the river span a long stretch of the river, more than one boat and crew may be necessary to timely capture water quality impacts with the sample collections. Likewise, if there are physical features, such as dams or large sandbars, that inhibit expeditious boat travel down the river, a second crew and boat may be necessary to collect the samples at the necessary locations and frequency. Sampling tributaries is less problematic since they can usually be done from bridges or by wading.

The crew and equipment needs for wet weather surveys involving large rivers often exceed any single organization’s sampling capacity. Often a successful sampling program involves coordination with local stakeholders or consultants with sampling expertise. For example, using local utility personnel to sample CSO outfalls is a way to free up resources to handle other components of the sampling plan. Another example is to utilize a laboratory courier to transport samples to the laboratory, thus freeing up one field crew member to continue sampling activities.

Separating the sampling into phases is another technique that has resulted in successful sampling programs. In this study, the wet weather monitoring was split into three phases. In Phase 1, “snapshots” of water quality conditions were determined by conducting rounds of cross-sectional sampling in the main stem using a boat during a wet weather event. Samples were collected once or twice per day on the mainstem for the duration of the event. The frequency of sampling rounds on the tributaries was initially every 2 hours, and then decreased to every 12 or 24 hours once the storm had ended. In Phase 2, “snap shots” of water quality in the tributaries and CSOs during and after wet weather events were measured by collecting samples from bridges (tributaries) or in the outfalls (CSOs) at a similar frequency as the main stem samples. In Phase 3, a longitudinal profile of the physical parameters (temperature, pH, dissolved oxygen, conductivity) of the upper one-foot of water in the main stem was sampled by boat over the 70-mile extent using a flow-through system that recorded information at 20-second increments. Separating the sampling program into these phases also aided in managing the crews and ensuring that samples were collected at the right locations and right frequencies.

Safety Considerations

Safety considerations, which are important for any wet weather monitoring, are elevated for large rivers. Sampling in a large river like the Ohio from a boat deck during wet weather can be extremely dangerous. Large rivers have much more total energy (velocity, elevation and pressure heads) at higher flows than smaller rivers. Large objects that can damage boats, like uprooted trees, will float in large rivers but not in smaller rivers. In this study, ORSANCO suspended sampling once the river reached a certain stage because of the increased risk of large debris being washed down the river.

Care should be taken prior to initiating sampling that all safety considerations have been made and implemented. This includes basics such as having enough life preservers on board to alerting the Coast Guard that sampling is occurring during wet weather. Finally, safety should never be compromised in order to complete a wet weather sampling. If the weather deteriorates or a sampling crew determines that conditions are unsafe to continue, sampling should be suspended immediately. A decision whether to terminate the event sampling entirely will need to be made by the project manager (usually in consultation with other project team members and sampling crews). If this occurs, a notification system should be in place so that all crews can be advised to suspend their sampling as well.

Inconsistent Rainfall

Inconsistent rainfall was identified in section 6.2.2 as one of the unique problems facing studies of large river sites. An ideal wet weather event has significant rain across the watershed sufficient to cause impacts (through the overflow of CSOs and large runoff volume from nonpoint sources). Usually a minimum of 0.1 inches of rainfall is required to trigger a "wet weather" event. However, at least 1.0 inches of rainfall or more is desired. Since rainfall rarely falls in a uniform rate across a watershed, a study could linger indefinitely while waiting for the "perfect" event to occur. A compromise approach that may meet the objectives of the plan is to initiate sampling if a 'significant' rainfall (i.e. at least 0.1 inches) is occurring throughout the watershed, even if volumes of rainfall vary within the watershed. Having a network of rainfall gages distributed throughout the watershed is extremely valuable in providing this information. Having each gage monitored by someone, preferably located near the gage, that is not involved in the water quality sampling is a useful way to conserve sampling resources.

"Go/No Go" Decision

A critical decision for any wet weather study is whether to initiate sampling based upon a given rainfall forecast. The project manager ultimately makes the "go/no go" regarding the initiation of sampling of a wet weather event. Large river site characteristics (large watershed area to cover, uneven precipitation, in-stream conditions) make this decision difficult. Usually experience is the best teacher in making these decisions. However, in the absence of experience, the likelihood of a correct "go/no go" call increases when all resources are utilized in making the decision. This includes consulting with project team members, sampling crews and the laboratory, and evaluating conditions across the watershed. All of the logistical factors described above should be included in the manager's decision. In addition, the readiness of the crew, equipment and laboratory should also be considered. Since wet weather event sampling typically lasts beyond the rainfall duration, some insight into the weather forecast should also be a factor in deciding whether to start sampling. For example, if rain is forecasted for the next three days and with increasing intensity, continued sampling may be unsafe or the wet weather effects in the river will be prolonged, leading to more sample collection and more expense.

6.3.2.c Laboratory Selection

One of the most important decisions in the monitoring program is the selection of the laboratory to perform the analyses on the samples collected. The choice is not a trivial matter since the laboratory provides the numbers (results) that are used by the project team in meeting the sampling program objectives. Thus, the laboratory is the other key “who” in the monitoring program. Large rivers provide unique challenges for laboratory selection in terms of the large quantities of samples being generated during a given event.

Laboratory selection should be based on the laboratory’s ability to: perform the analyses using standard methods and within their QA/QC guidelines, handle large influx of samples over a short period of time, meet holding times for short hold time parameters such as bacteria, provide results within a reasonable amount of time and cost. It is important that these factors be included along with cost in selecting a laboratory. Short-term savings may result in long-term project costs when using an inexpensive but poor quality laboratory that produces large amounts of unusable data.

Usually a local lab is selected because of the method requirements for holding time of some key wet weather constituents, such as bacteria and CBOD. A single laboratory should perform all of the analyses of a particular parameter to avoid uncertainty associated with comparing and interpreting results for the same parameter from two different laboratories. Adhering to this concept will result in a large number of samples being delivered to the laboratory periodically throughout a wet weather event sampling. This study produced approximately 500 fecal coliform samples over a five-day period at the peak of the sampling program. Another advantage of a single laboratory is that it simplifies the sample drop-off procedure, reducing the potential for broken samples during transport or having the wrong bottles dropped off at the wrong laboratory.

Often laboratory results are qualified and potentially unusable when hold times or other QA/QC requirements are not met. These QA/QC failures can be minimized by including the laboratory in a “Go/No Go” decision and by informing them when sampling starts and when they can expect to receive samples. This will allow them time to align their resources to meet the project demands.

Results can also be unusable if the results are outside the range of the analytical procedure, either through over- or underdilution of the sample prior to analysis. In this study, results for the CSO samples were not useable. It is recommended that the chain-of-custodies and labels on sampling bottles clearly indicate which samples are CSO samples, as these require special handling in the laboratory. Pollutant concentrations in CSO outfall samples can range over several orders of magnitude and are significantly higher in concentration than receiving water samples. The laboratory should be cautioned that extra measures are probably necessary to ensure no cross-contamination occurs during the analysis and that several dilutions are likely needed to ensure a result within the analytical range.

Finally, laboratories often offer other services that will make the wet weather sampling easier. One example is the ability of the laboratory to provide couriers to pick up the samples in the field, saving the project manager from devoting precious field resources to transporting samples to the lab. Also, laboratories sometimes sub-contract analyses that they can't or don't perform. It's reasonable to expect the laboratory to handle all aspects of sub-contracting analyses, but this should be clarified before sampling commences, preferably before the contract with the laboratory is signed.

6.3.3 Model Development

In this study, the complexity of the large river site and the project objectives required site characterization beyond the information that the monitoring data provided. This would likely be true at other large river sites where this framework was adapted. It would be cost-prohibitive to collect sufficient data with the monitoring plan to thoroughly characterize the system's response to wet weather impacts. This amount of data would include landside data measurements of overflow volume and constituent concentration from each source and water quality measurements at much more tightly spaced locations in the river at higher frequency (on the order of minutes or hours). Given the impracticality of these data requirements, landside/collection system and receiving water models are used to fill in the gaps between sampling locations and collection times.

Models offer other advantages in that they provide a method to link land side loadings to their impact on in-stream water quality and they have the ability to forecast changes in water quality conditions in response to alternative pollutant loading rates or environmental conditions. Models are also an effective way to integrate the large number of diverse sources that are typically encountered in large river sites (as discussed in Section 6.2.2) into an analysis of the entire system. They also have the ability to simulate observed lag times within the model domain that are common in large river sites. Having established the benefit of using models in these studies, this section presents how to select appropriate models, the information necessary to develop them, and how to calibrate and validate them.

6.3.3.a Model Selection

Primary emphasis in identifying and selecting models for use in a study is usually given to the study objectives and types of available data. The site-specific characteristics, both in-stream and landside, must also be merged into the model selection process. Consideration of these objectives and factors will aid in determining the level of sophistication needed in the receiving water and landside/collection system models.

A range of models, from simple to complex, are available for modeling watersheds and/or collection systems. Factors to consider include the variety of point and nonpoint sources and the watershed area to model. Management objectives to consider include, for example, the level of specificity in separating loadings given the available information. In this study, SSO information was very limited so modeling these releases with a landside model was not practical. Finally, the landside/collection system models need to be compatible with the receiving water quality model. An example of incompatible models is a receiving water quality model that requires hourly load inputs and a landside/collection system model with daily load output.

Generally CSO communities on both sides of the large river under study will need to be characterized with a model if the objective of the study is to evaluate wet weather impacts on receiving water quality. This may require more than one model, as was the case in this study, where separate SWMM models were developed for the portions of the Cincinnati combined sewer collection system and the Northern Kentucky combined sewer collection system. Selection of a model to simulate surface runoff from watersheds depends on the size and number of watersheds to model and availability of site-specific inputs for the model.

Site characteristics also influence the selection of the receiving water hydrodynamic and water quality models. Large rivers, as described in Section 6.2.3, have unique physical characteristics, including a wide range of flows and velocities and significant spatial variations of velocities and pollutant concentrations in potentially all three dimensions of the river. To properly capture these characteristics of a large river, it's likely that both a hydrodynamic and a water quality model of the river will be needed. Hydrodynamic models describe the movement of water within a river system while water quality models describe the transport, chemical transformations and degradations of pollutants within the river. Although a variety of hydrodynamic and water quality models, ranging from simple to complex, are available to model large rivers, the particular models selected will need to have the ability to reproduce the spatial and temporal variations in water and pollutant movement. In this study, RMA-2V (USACE, 1997) and WASP5 (USEPA, 1993) were selected as the hydrodynamic and water quality models (see section 5.2 for details), respectively. An analysis of the project objectives (and constraints) and site-specific characteristics should be done at each site to select appropriate models.

An important consideration in model selection for large rivers with multiple jurisdictions is whether the model is part of the public domain or is privately supported. Generally, public domain models are created by government agencies, like the EPA or USGS. Examples of public domain models are WASP and SWMM, which were used in this study. The primary advantage of these models is that they are openly available and can be accessed by anyone. This arrangement is advantageous to large river studies where there are multiple agencies and other stakeholders that may be potential users of the models because it eliminates many of the distribution issues associated with private domain models. Private domain models are copyright protected and proprietary issues will likely have to be addressed before these models can be distributed to stakeholder agencies or groups. Public domain models can be readily distributed to local agencies or other parties interested in using the models for more detailed simulations or with scenarios that are outside the scope of the study.

6.3.3.b Model Setup

Once the models are selected, they need to be developed for the study area. This includes structuring the models to be consistent with project objectives and available data, incorporating site-specific data into the models, and developing additional tools to facilitate meeting project objectives and linking the models efficiently.

Initial set up decisions include the level of temporal and spatial definition within the model. These definitions in the models should be fine enough to allow for meaningful comparisons to data collected in the monitoring program (which are used to calibrate the model). In this study, for example, the Ohio River water quality model was composed of rows of segments where each row contained five segments across and each segment averaged 0.4 miles in length (see Section 4.4.2.b). However, structuring a model too finely may cause operational inefficiencies in the form of long run or processing times.

Site-specific model inputs are also part of the model development. In addition to utilizing data collected from the monitoring program, site-specific data from other sources should be utilized if available. Groups or agencies that may have site-specific data include the United States Geological Survey (USGS), United States Environmental Protection Agency (USEPA), United States Army Corps of Engineers (USACE), National Oceanic and Atmospheric Administration (NOAA), regional agencies (such as ORSANCO for the Ohio River) and local groups (Departments of Health, universities). Examples of site-specific data used in model development for this study include pipe dimensions, imperviousness of catchment areas and slopes for collection system models and river bathymetry and channel slope for receiving water hydrodynamic and water quality models.

Because large sites like this are complex and require several models, an aspect of the model development may include making modifications to the model code to reflect site-specific or project objectives. The types of models used at a site are interconnected. For example, the landside model provides load inputs to the receiving water quality model. Likewise the flow movement output from the hydrodynamic model is translated into the water quality model. Often tools to directly link these models are unavailable and may need to be developed at this stage in the framework.

6.3.3.c Model Calibration and Validation

Taking the models through a calibration and validation process increases confidence in the models selected and developed for use at a site. This process will demonstrate the models' robustness in being applied under, or ability to reasonably simulate, conditions for which there are no data available, such as investigating alternative loading scenarios. The calibration and validation approach are not significantly different for large river sites as compared to other sites. However, the priority of calibration and validation endpoints should reflect the uniqueness of large rivers.

The calibration and validation procedures are fairly straightforward and are made easier in this framework by designing the monitoring plan to provide datasets for use in calibrating and validating the models. The approach to calibrating a model is to specify site-specific inputs whenever possible for a selected event and to run the model. The model output is compared to observed data at specific points in time and if deemed acceptable, the process is repeated with one or more different datasets to validate the model.

The monitoring plan is designed to provide several complete wet weather datasets for use in evaluating the models' performance. Determining which of these events to use to calibrate the models should be based on an assessment of the most complete dataset (for the purposes of all of the models), as this will provide the most rigorous evaluation of model performance. Another criterion to consider is the number of potential wet weather sources discharging pollutant loadings to the river. An event that has more active sources is preferred to an event with fewer sources, because this type of event will have more impacts on water quality and will provide better feedback on the accuracy of the model's formulations in capturing these water quality impacts.

As much site-specific and event-specific data should be input into the model for calibrating. This reduces uncertainty in the model inputs and better constrains the models by having fewer inputs to vary, thereby also reducing uncertainty in the model outputs. An example of a site-specific event input for the collection system models used in this study includes rainfall amounts. Examples of site-specific inputs for the hydrodynamic model used in this study include downstream stage (water surface elevation) and upstream flow. Examples of site-specific inputs for the water quality model include loads, boundary concentrations, flows, and environmental conditions.

The strategy for determining the "goodness of fit" of a model's simulation of an event to measured data should account for the distinctive features of large river sites. For the receiving water quality model, reproducing observed concentration gradients between near shore and center channel areas and simulating the observed timing and location of peak concentrations were prioritized over matching the magnitude of observed concentrations. The calibration targets for the collection system modeling were simulating peak flow rates and total volume of each catchment area. The hydrodynamic model's targets were in-stream velocity measurements made during the dye surveys.

The purpose of validating the model is to demonstrate that the model formulations produce reasonable results for a different set of model inputs. Thus, the best test of a calibrated model's formulations is to run it with a set of inputs that represent much different conditions in the system than the inputs that were used to calibrate it. Because large river sites have a wide range of flow and environmental conditions, validating the models to several other wet weather events surveyed as part of the monitoring plan is recommended.

6.3.4 Model Application

The calibrated and validated models developed in the previous section can be used to further investigate the impact of wet weather sources on water quality under a range of environmental and future source loading conditions. By applying the models to a variety of storm and environmental conditions, it may be possible to assess the extent to which wet weather sources impact water quality for a range of conditions. The models can then be used to forecast improvements in water quality resulting from various levels of source controls. Alternatively, the models can be used to investigate the applicability of stream-designated uses during wet weather. The methodology framework developed for this project is sufficiently generalized to allow application of the models for a range of scenarios, which are discussed in the following sections.

6.3.4.a Multi-jurisdictional Considerations

As described in Section 6.2.1, large river sites often span multiple federal, state and local jurisdictions. The modeling framework was designed to reflect the multi-jurisdictional nature of these sites by developing a suite of tools that can be used to investigate future conditions using broad assumptions or with more detailed analyses.

Broad scenarios would typically be of interest to project stakeholders at the federal or regional level. These scenarios are not very detailed and involve large-scale (watershed, study area) changes to the system and the resulting change (improvement) in water quality in the river and are more general and investigative in nature. The scenarios simulated in this study (see Chapter 6) are examples of broad scenarios. The CSOs in both Cincinnati and Northern Kentucky were uniformly reduced by a specified percentage (25, 50, 75 and 100% control) without regard to the practicality of implementing these scenarios.

However, the calibrated models developed under this framework also allow local communities to have tools for evaluating more detailed analyses. These scenarios would probably incorporate regulatory, political and cost considerations into the simulations of future conditions. An example of this type of application is the use of these models by the Sanitation District No.1 to evaluate detailed CSO control scenarios under consideration for their Long Term Control Plan.

6.3.4.b Environmental Considerations

Despite the intentions of the monitoring program to measure in-stream water quality for a range of flow and storm conditions, it is impossible, given the resource constraints, to monitor all of the possible combinations of these two parameters. Thus, these calibrated models can be used to evaluate a range of environmental conditions. In addition to storm and flow conditions, other environmental factors of interest include temperature, which often affects kinetic rates in transformation reactions, and wind speed, which influences stream dissolved oxygen concentrations.

Applying the models over a range of environmental conditions will permit a more complete characterization of the system under both dry and wet weather conditions. Trends and correlations may become apparent when simulating a range of conditions. For example, Section 5.4.2.d presents evidence in this study of a relationship between precipitation volume and resulting water quality when the rainfall amount is between 0.1 inches and 0.5 inches.

Seasonal variations may be of interest in areas where different water quality standards are applicable during different times of the year, as was the case in Cincinnati. The model applications may indicate that certain times of the year are more sensitive to wet weather events than others, either because of compliance with water quality standards or because of the seasonal effects on loads (ex. solids loadings from agricultural lands are likely higher in spring, when the fields are plowed but without vegetation, than in the fall, when the fields well vegetated).

Several approaches have been used to apply the models over a range of environmental conditions. One approach is the one used in this study, which was to model a “typical” year. A year (1971 in this study) that had rainfall and in-stream flows that approximated the historically observed ranges in rainfall and flows was selected for simulation as a “typical” year (see Section 5.2). The advantage that this approach offers is that it is uses conditions that have actually occurred in the area. The disadvantage is that historical records may not reflect future conditions, particularly as impervious areas increase through land development and as meteorological patterns change.

Another approach to consider is to develop synthetic hyetographs and hydrographs for the study area that are of particular interest to the user and to simulate those conditions with the models. An example would be using the models to simulate a 100-year precipitation event for a range of environmental conditions (flow and temperature) that would simulate conditions in each season. This approach offers the advantage of simulating worst-case scenarios and may be better able to reflect future conditions. However, disadvantages in the design storm approach are that these conditions have never been observed and their likelihood of actually occurring is unknown (though can be predicted statistically). Also, the design hyetographs and hydrographs at the project study scale would probably need to be developed, if not already available, and this would probably require more resources than using the "typical" year approach.

6.3.4.c Designated Uses Considerations

Large river sites often have many designated uses. The designated uses are maintained through compliance with water quality standards. The EPA, through the National CSO Policy, has recognized that current water quality standards may not be appropriate for wet weather conditions (EPA, 2001). The National Academy of Sciences has also reached the same conclusion (NRC, 2001). Changing the designated uses of a stream is one method of reviewing and changing water quality standards to better reflect reasonable expectations of stream uses during wet weather.

The models developed using this framework can be used as tools for conducting a use attainability analysis (UAA). This type of application of the models can evaluate not only how long a designated use is impaired for a given wet weather condition but also several options for revising water quality standards associated with a designated use, such as: whether adopting a seasonal use is appropriate, if incorporating a high-flow threshold into the water quality standard is appropriate and whether a variance should be issued for designated use during wet weather.

6.3.4.d Model Results

Understanding the model results is critical in large river sites, which are subject to all of the complicating factors described in Section 6.2 and thus, confound model results. For example, large river sites tend to have uneven rainfall patterns and multiple contributing jurisdictions. If these rainfall patterns are faithfully input into the model, the display of the model results for any given event could potentially show misleading results, making the area that received the heaviest rainfall look like the primary cause of all water quality impacts in the river. Under differing rainfall distribution, other areas of the watershed would appear to be the primary cause. If the purposes of the modeling include determining relative magnitude of sources and using the models to identify areas to target source control, care should be taken in specifying model inputs when applying the model for various control scenarios to ensure that the model results will yield useful information.

Presenting the model results in a simple yet meaningful manner is one of the challenges of studies, particularly large river sites, which span large areas and will usually require a two-dimensional model. In this study, the model output was generated every hour for each of the 470 model segments. Each "typical" year simulation generated over four million outputs from the receiving water model. Distilling these outputs into a series of simple diagrams that illustrate key findings from the simulations is necessary to successfully convey the results to a wide audience. This can be accomplished by simplifying the temporal display of results, the spatial display of results or both.

In this study, the goal was to present "typical" year results for the entire river. Since each model segment surface area varies, model results for each segment were normalized to their relative proportion of the model's area. Temporal simplifications were made by averaging hourly results into daily averages for each segment and by presenting model results on a total annual and recreation season basis (see section 5.4.2.a).

Although not done in this study, a spatial display can be simplified by focusing presentation of results to a few known sensitive areas (examples described in Section 6.2.3) in the study area. As presented in Section 5.4.2.b, model results can be used to identify areas that are particularly responsive to wet weather. This is one option to simplify the results on a spatial scale.

Presenting the range of system response to the range of storm events in a "typical" year simulation was also challenging. In this study, results were presented for a few storms representing the range of storm conditions (see Section 5.4.2.c). Statistical analyses (see Section 5.4.2.d) that explore relationships between rainfall and system response are another option for presenting this information in a simplified manner.

Other challenges in presenting model results for the "typical" year simulations included identifying which Water Quality Standards were appropriate for comparison to predicted concentrations and determining what averaging period of model results was appropriate for this comparison. These problems are common to many wet weather planning studies, where water quality standards (written in terms of an assumed discrete sampling frequency) do not readily translate to a continuous simulation model result. For example, ORSANCO's Pollution Control Standards include a monthly geometric mean concentration standard of 200 #/100 ml for fecal coliform based on no less than five samples per month. Samples are collected as grab samples. Selecting an hourly model result would be most similar to reproducing the grab sample process but determining which hour of model results to compare to the standard presented a challenge. Sampling is done on only five days of the month yet during the model application, model results were produced for every day of the simulation, which spanned twelve months. Determining how many days of model output for each month to compare to the water quality standard was another issue that required resolution. For this study, hourly model outputs for each day of simulation were averaged to estimate a daily average concentration. The monthly geometric mean concentration was computed for the daily average concentrations from the model for each month and compared to the water quality standard to determine exceedances. This approach allowed the maximum amount of model output to be utilized in the comparison to water quality standards while avoiding an unbearable computational burden that could result from evaluating different combinations of model output.

Similarly, ORSANCO has a single sample maximum concentration standard for fecal coliform of 400 #/100 ml based on no less than five samples per month. Determining a suitable approach to compare model results to this standard presented many of the same challenges as the monthly geometric mean standard comparison. For this study, hourly concentrations from each model segment were compared to the single sample maximum concentration standard and any day where at least one hour exceeded the standard was counted as an exceedance for that segment. This approach provided a reasonable upper bound estimate on the number of exceedances of this water quality standard.

In this study, a new issue with the receiving water quality model was identified during the model application step. One model segment, at the mouth of the Little Miami River, was problematic in that it appeared to always exceed the single sample maximum concentration standard of 400 #/100 ml. Further investigation indicated that this model segment had the smallest volume of any of the segments in the receiving water quality model. Because the segment volumes were not changed during the simulation and tributary inflows were not included in the model simulations, the load (pollutant mass) from the Little Miami River entering this model segment was sufficiently high to cause the predicted concentration (mass/volume) to exceed 400 #/100 ml at every time step. Consequently, predicted results from this segment were not included in the analysis of exceedances of water quality standards.

6.4 SUMMARY

The study framework developed for this project was designed to be easily transferable to other large river sites. This framework accounts for the unique characteristics of large rivers that complicate wet weather study, including their multiple regulatory jurisdictional nature, their large watersheds that typically have variable rainfall and large numbers of diverse sources, and the physical characteristics of the river itself, which usually requires careful planning for the monitoring phase of the study and a two-dimensional model to characterize the lateral and longitudinal gradients in the river.

The methodology consists of four discrete steps: setting objectives, developing a monitoring plan, developing models of the study area, and applying the models under alternative scenarios. Because large river sites are complex systems, each step must be carefully planned and executed. However, each of these steps cannot occur in a vacuum; consideration of the other pieces of the framework is necessary to get the most value out of the study and ensure its overall success for all of the stakeholders. This chapter presents the framework components, aspects of their interdependency and the factors unique to large rivers that will enable the reader to successfully apply it at another large river site.

6.5 REFERENCES

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7.0 LESSONS LEARNED

7.1 Wet Weather Tracking

The project had a defined wet weather condition necessary to conduct a water quality survey. This was necessary to ensure that CSOs were discharging during a sampling event. Tracking weather for the desired storm event can be time consuming, and requires a substantial employee commitment on a 24-hour basis. Holidays can also present a problem, particularly with laboratories and contract samplers that sometimes are not available during these times. Additionally, stream conditions may be non-representative due to such things as heavier boat traffic, fireworks celebrations, etc.

Twenty-four hour internet access to weather forecasts at work and home is essential to effectively track weather conditions for sampling event initiation. A regular dialogue with local meteorologists can also prove to be valuable.

7.2 Mobilization Logistics

Numerous field crews and laboratories were involved in the sampling events, all requiring 24-hour notification of a sampling event. Recent popular use of wireless phones and economical pagers significantly eased this task. Practice runs also helped smooth the process.

7.3 False Starts

The wet weather monitoring program was designed to begin sampling just prior to the beginning of a storm event. However, a minimum, uniform coverage of rainfall over a majority of the study area was required over a six hour period to validate the sampling event. As a result, the project had a few false starts, where sampling was initiated, but enough rain did not occur, and the monitoring event was ultimately cancelled.

Budgets and schedules need to be developed that anticipate and account for false starts.

7.4 Project Schedule & Budget

The project schedule and budget must account for uncooperative weather, which ultimately adds time and costs that are difficult to estimate. This project experienced two years of delays due to weather. During one year, the rainfall requirement for initiating a wet weather sampling event never occurred. During another year, a sampling event was conducted for a large, intense storm that occurred after an unusually long, dry period. Because it was such an unusual occurrence, the model could not be adjusted to replicate the data. Such weather-related delays added substantial unanticipated time and unbudgeted costs to the project.

7.5 Use of the Flow-Through System

The flow-through system allowed for collection of surface water samples and measurement of physical parameters from a moving boat. This system proved to be an efficient way to collect samples and measure physical parameters over lengthy river reaches of 70 miles in a relatively short timeframe of two to three hours. This type of sampling is contingent upon having a well mixed river. A concern with the system was decontamination between sampling events. However, data was collected to support the assumption that the system could be decontaminated effectively. Data was also collected to support the assumption that physical parameter measurements were not significantly altered by the system.

7.6 Tributary Sampling

Several sampling frequencies and durations were attempted during the project. The following scheme was the most effective at defining the “pollutograph” for bacteria from tributaries:

1st 12 Hours:	Sample collected every two hours.
2nd 12 Hours:	Sample collected every four hours.
Next 24 Hours:	Sample collected every eight hours.
3rd 24 Hours:	Sample collected mid-day.
4th 24 Hours:	Sample collected mid-day.
5th 24 Hours:	Sample collected mid-day.

7.7 Sampling Equipment Cleaning

At the beginning of the study, elaborate “decontamination” procedures (acid or methanol rinses, Alconox/Liquinox wash, followed by clean water rinses) were put in place to clean the sampling equipment between sites). However, sporadic contaminated blanks would appear from lab results. After performing side-by-side test, it was confirmed that the wash products were never completely removed by the rinse procedure.

Subsequently, a new procedure was established for stainless steel equipment using only a “triple deionized water” rinse followed by a river rinse between sampling sites. This procedure has been tested and verified to remove the parameters of concern (primarily bacteria) and minimize cross-contamination.

7.8 Bacteria 24 Hour Hold Time

Standard Methods specifies a six hour holding time for bacteria sample analyses. This can be a difficult time constraint, particularly involving surveys having a large number of samples to analyze. ORSANCO consulted with US EPA and also conducted a study to evaluate the differences in analytical results for fecal coliform for triplicate river samples with holding times of 6, 15 and 24 hours. Results of the study indicate that a 24-hour hold time for fecal coliform samples is sufficient considering the purposes of this project. It was also the opinion of US EPA national experts that a 24-hour hold time would be adequate for this project. Therefore, a 24-hour hold time was used for fecal coliform and E. coli samples. Results of the comparative study can be found in Appendix H.

7.9 Bacteria Dilutions and Colony Count Reporting

A major difficulty encountered with the analytical program was use of appropriate dilutions in the analyses of fecal coliform and E. coli samples, especially those collected on tributaries due to high bacteria densities. Laboratory dilutions used during the early sampling events resulted in some the samples being reported as "too numerous to count." Numeric values were necessary in order to calibrate and/or verify the water quality model. Therefore, the contract laboratory utilized a "pre-dilution" method which allowed for bacteria counts in the millions CFU/100mL range. Additionally, ORSANCO developed a procedure for determining bacteria concentrations from samples with various dilution density counts that further enhances the procedures defined in Standard Methods. This procedure was developed with national experts from the US EPA's Briedenbach Research Center. The calculation procedure is included in Appendix I. This methodology is useful for obtaining the best numeric results for samples in which the density counts do not occur within Standard Methods' "ideal range" of 20 to 60 counts.

7.10 Blending Study

In 1999, concern was raised over the high bacteria densities present in the tributaries during wet weather events and whether is would be appropriate to homogenize samples, utilizing a laboratory blender, before filtration according to Standard Methods. This concern was raised by experts from US EPA's Briedenbach Center and based on a CSO study that was conducted in the eastern U.S. This US EPA study showed that particulate matter interfered with bacteria counts. In an effort to address this concern, duplicate samples were collected and analyzed by the membrane filtration method, one blended and the other not. Results indicate, for samples with turbidities as high as 260 NTU, that blending does not enhance recovery of fecal coliform. Therefore, it was concluded that blending fecal coliform samples was not necessary. Results of the study are provided in Appendix H.

7.11 Laboratory QA/QC & Oversight

Laboratory QA/QC and oversight by project management was a major issue which caused significant delays in this project. A number of issues arose here which are discussed below in brief:

- Sample Capacity – It is critical to ascertain whether a lab can handle a large volume of bacteria samples usually necessary to complete a wet weather survey of a large river setting. A laboratory that can proficiently handle tens of bacteria analyses concurrently might be completely incapable of handling hundreds of samples. A pre-survey audit of the lab should be conducted to determine that appropriate and correct equipment is available and in good condition to handle the proposed volume of samples.

- Lab Audits – It pays to audit the lab during the analyses of survey samples. A number of serious deficiencies were identified by an audit conducted during one of the wet weather surveys that identified invalid data and resulted in discarding laboratory results from the entire sampling event.

- Pink Growth – Incorrect incubation temperatures (lower than specified by Standard Methods) in the laboratory caused a pink overgrowth on the membrane filter plates. This pink overgrowth was identified as E. cloaca*e* which caused erroneous fecal coliform and E. coli results. The occurrence of this phenomenon was repeated by national experts from US EPA's Breidenbach research laboratory. They concluded that the pink colony overgrowth problem could be reduced or eliminated with proper incubation temperatures.

- Review of Laboratory Bench Sheets – Review of laboratory Bench sheets which show the bacteria counts for each of the individual sample dilutions can assist in identifying lab problems.

- Blanks – Field and method blanks add substantial analytical costs to a survey but are critical in proving that the data are valid or to identify problems. This is important to all types of analyses, but even more so for bacteria analyses which tend to have a lesser degree of accuracy and precision.

8.0 SPECIAL STUDIES

8.1 WATER SUPPLY CONCERNS – *CRYPTOSPORIDIUM* AND *GIARDIA*

8.1.1 STUDY OBJECTIVE

The objective of this portion of the study was to evaluate the potential impacts and sources of wet weather pollution, particularly *Cryptosporidium* and *Giardia*, on Ohio River water quality as it relates to drinking water utilities.

8.1.2 BACKGROUND

From a public health position, the water supply industry is concerned about the presence of *Cryptosporidium*, *Giardia* and viruses in source waters. Urban wet weather sources, including wastewater treatment plants, combined sewer overflows, and other nonpoint pollution sources are demonstrated mechanisms of entry for these organisms into surface waters. It is therefore appropriate for an investigation of the water quality impacts of wet weather to consider potential sources of these microorganisms.

National Primary Drinking Water Regulations are legally enforced standards that apply to public water systems. Primary standards protect public health by limiting the levels of contaminants in drinking water. According to these regulations *Cryptosporidium* and *Giardia lamblia* have a zero maximum contaminant level goal.

Drinking water utilities serving the Cincinnati/Northern Kentucky area obtain water from three locations along the Ohio River. The nearest combined sewer overflows that could potentially impact water suppliers in the study area are located approximately 50 miles upstream and therefore logistically difficult to sample because of mobilization and travel time. However, other demonstrated sources of pathogens within the study area include publicly owned treatment works effluent and runoff from various land uses.

The sampling program for this study focused on a number of wastewater treatment plants in the study area. The sampling program included both in stream and source sampling. In stream sampling involved bracketing (upstream and downstream sampling) discharge points in order to evaluate the relative impact of an individual discharge on Ohio River in stream concentrations.

Additionally, wet weather sampling was conducted on a combined sewer overflow and a publicly owned treatment works influent at roughly the same time to determine if a correlation exists between the concentrations of pathogens in a publicly owned treatment works influent and a combined sewer overflow discharge. Attempts were made to characterize the impacts of dry weather collection system bypasses, which result from high river stages. In stream sampling was not feasible under high stage conditions so river intakes above and below a known bypass point were used to bracket the discharge. The City of Cincinnati Water Works also conducts an intensive sampling program of raw and finished drinking water.

8.1.3 SAMPLE COLLECTION AND ANALYTICAL METHODS

The sampling program consisted of three water quality scenarios at eight locations throughout the Greater Cincinnati area. Surveys were conducted during dry weather and wet weather events in 1996 and 1997. The eight locations were as follows:

-Beckjord Power Plant at Ohio River Mile 453.0
-Clermont County Nine Mile Wastewater Treatment Plant at Nine Mile Creek Mile 0.18
-Cincinnati Water Works Main Plant at Ohio River Mile 462.8
-Mill Creek Wastewater Treatment Plant at Ohio River Mile 472.5
-Upstream of Mill Creek at Ohio River Mile 470.5
-Mill Creek at Mile Creek Mile 2.90
-Downstream of Mill Creek at Ohio River Mile 472.8
-Miami Fort Power Plant at Ohio River Mile 490.3

Raw Ohio River water was sampled at the Beckjord Power Plant, Cincinnati Water Works Main Plant and Miami Fort Power Plant. Finished plant effluent before chlorination was sampled at the Nine Mile Plant. All sampling was initiated by ORSANCO. Timing for sample collection was determined based on Ohio River flow conditions and was specified by ORSANCO upon event initiation. Field crews were responsible for: (1) sampling the four locations for *Cryptosporidium*, *Giardia* and viruses according to U.S. EPA's <u>Information Collection Requirements Rule – Protozoa and Enteric Virus Sample Collection Procedures</u> (June 1995), (2) collection of water samples at the four locations for the analyses of physical parameters, organics and metals and (3) shipment of all samples to an independent laboratory within four hours of collection for laboratory analyses.

The sample collection method for *Cryptosporidium* and *Giardia* was taken specifically from the U.S. EPA-approved Information Collection Requirements Rule (ICR). The field crews filtered exactly 100 liters (26.4 gallons) of sample through the yarn wound filter. The filters were then bagged (including the remaining water in the filter housing), sealed, placed on ice and shipped overnight to the laboratory.

The test method for *Cryptosporidium* and *Giardia* is specified in the ICR. This test method describes the detection and enumeration of *Giardia* cysts and *Cryptosporidium* oocysts in ground, surface and finished waters by a fluorescent antibody procedure. Results obtained by this method should be interpreted with extreme caution. The recovery efficiency of this method can be affected by high turbidity, as well as turbidities less than 1 nephelometric turbidity units (NTU). Failure to detect organisms of interest and/or a low detection limit does not ensure that the water tested is pathogen free.

The analytical method used for *Cryptosporidium* and *Giardia* generates both presumed and confirmed results. Presumed results represent the detection of a microorganism that resembles the structure of the appropriate microorganism that is being analyzed. Confirmed results represent further analysis confirming the microorganism has the same internal structure as the microorganism that is being analyzed. For purposes of this project, presumed results were used because this data is a good indicator of the presence of pathogens. Lack of confirmed results does not necessarily indicate the absence of the pathogen.

Along with the *Cryptosporidium* and *Giardia* analyses, chemical parameters were collected and analyzed. Table 8-1 lists these parameters. All data from this component of the study can be found in Appendix J.

Table 8-1. Chemical Parameters Collected

Parameter
Total Suspended Solids
Total Dissolved Solids
Turbidity
Total Organic Carbon
Sulfite
Hardness
Phosphate
Chloride
Chlorine, Demand
Nitrate-Nitrite
Total Coliform
Fecal Coliform
E. coli
Heterotrophic Plate Count

8.1.4 MONITORING SCENARIO #1

Scenario #1 was a survey that investigated longitudinal changes in pathogens under both wet and dry conditions. The sampling locations shown in Figure 8-1 were Miami Fort Power Plant, the City of Cincinnati Water Works and Beckjord Power Plant on the Ohio River. Nine Mile Wastewater Treatment Plant and a site on the Mill Creek were used as sampling locations on Ohio River tributaries. Six events were completed under scenario #1, two wet (see Figure 8-2) and four dry events (see Figure 8-3).

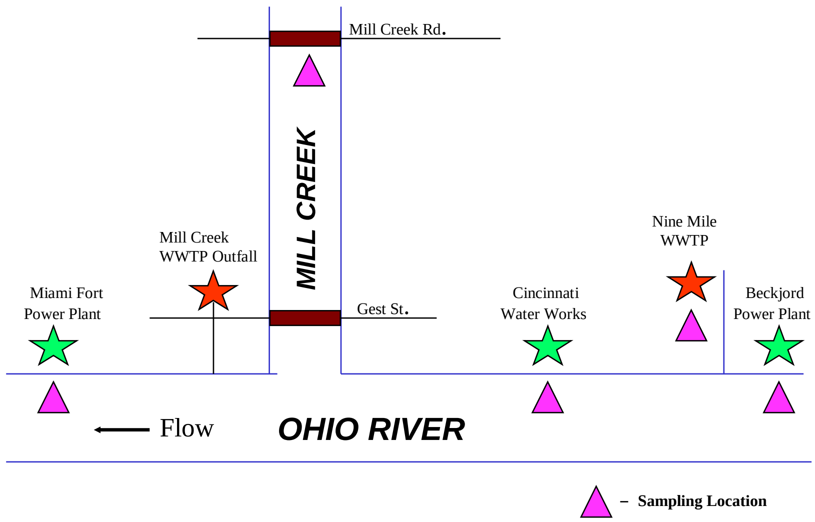
Both events one and four were completed under wet weather conditions. Event one took place July 8-9, 1996 with 0.63 inches of rain and a river stage of 26.6 feet. At the Beckjord Plant both *Cryptosporidium* oocysts and *Giardia* cysts were presumed to be present. Only *Giardia* cysts were presumed at Cincinnati Water Works and Miami Fort Power Plant. Event four was also a wet event with rain measuring 1.36 inches. The event took place on December 17, 1996 while the river stage was 37.5 feet. During this event *Giardia* cysts were presumed at each location. *Cryptosporidium* oocysts were presumed at every location except Nine Mile Wastewater Treatment Plant. *Giardia* cysts were confirmed at the Miami Fort Power Plant.

Events two, three, five and six were dry weather events. During event two (August 6-7, 1996), *Giardia* cysts were presumed at Beckjord, Nine Mile and Miami Fort. Cincinnati Water Works and Nine Mile had confirmed *Giardia* cysts. *Giardia* cysts were presumed at every site during event three which occurred October 8-9, 1996. Event five, which occurred March 12, 1997, presumed *Giardia* cysts at each site and *Cryptosporidium* oocysts were presumed at Beckjord and Nine Mile. The last dry weather event in scenario #1 took place March 20, 1997. During event six, *Giardia* cysts were presumed at every location except Miami Fort.

Results:

- *Giardia* was seen frequently in the Ohio River.
- *Cryptosporidium* was seen less frequently in the Ohio River.
- *Giardia* concentrations were occasionally above 10,000 cysts/100 mL.
- *Giardia* and *Cryptosporidium* occurrences do not appear to correlate with rainfall.

Figure 8-1. Scenario #1 – Longitudinal *Cryptosporidium/Giardia* Survey



54

Figure 8-2. Wet Weather Demonstration Study
Total Number of Pathogens
Scenario 1 - Wet Weather Events

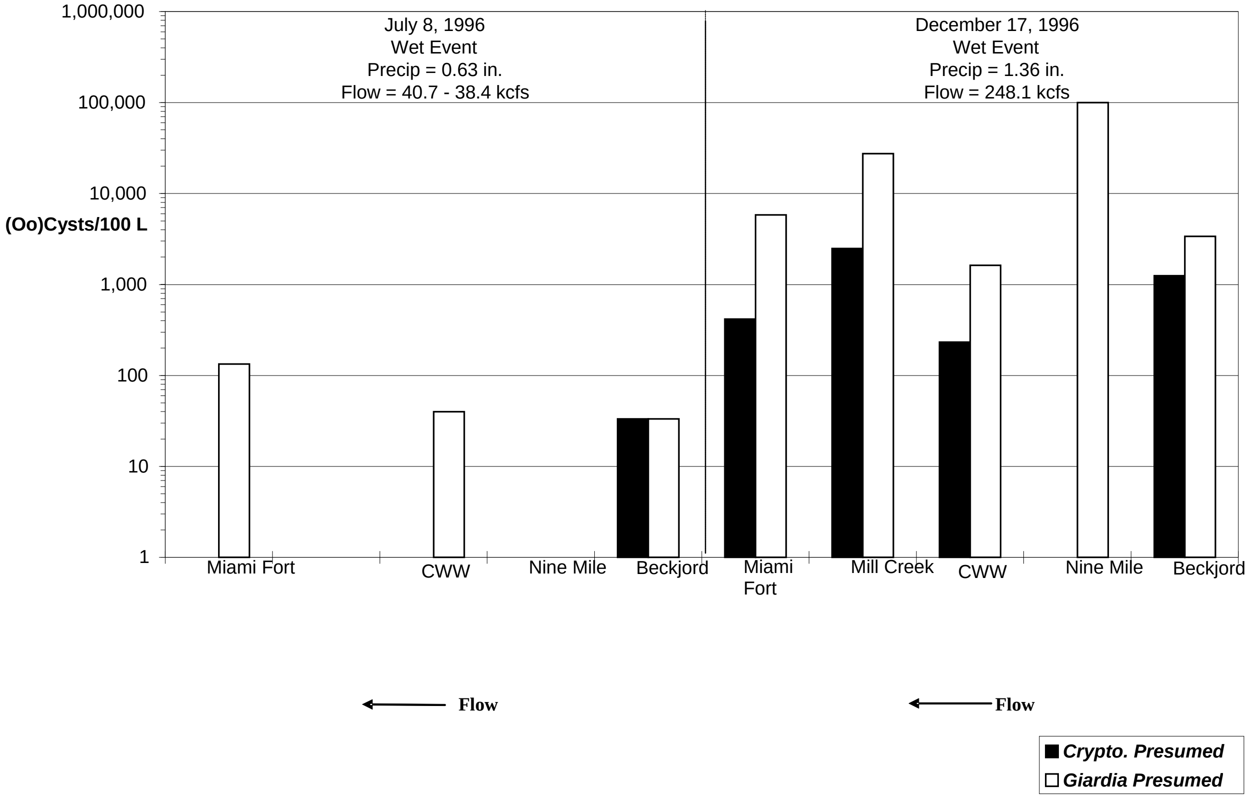
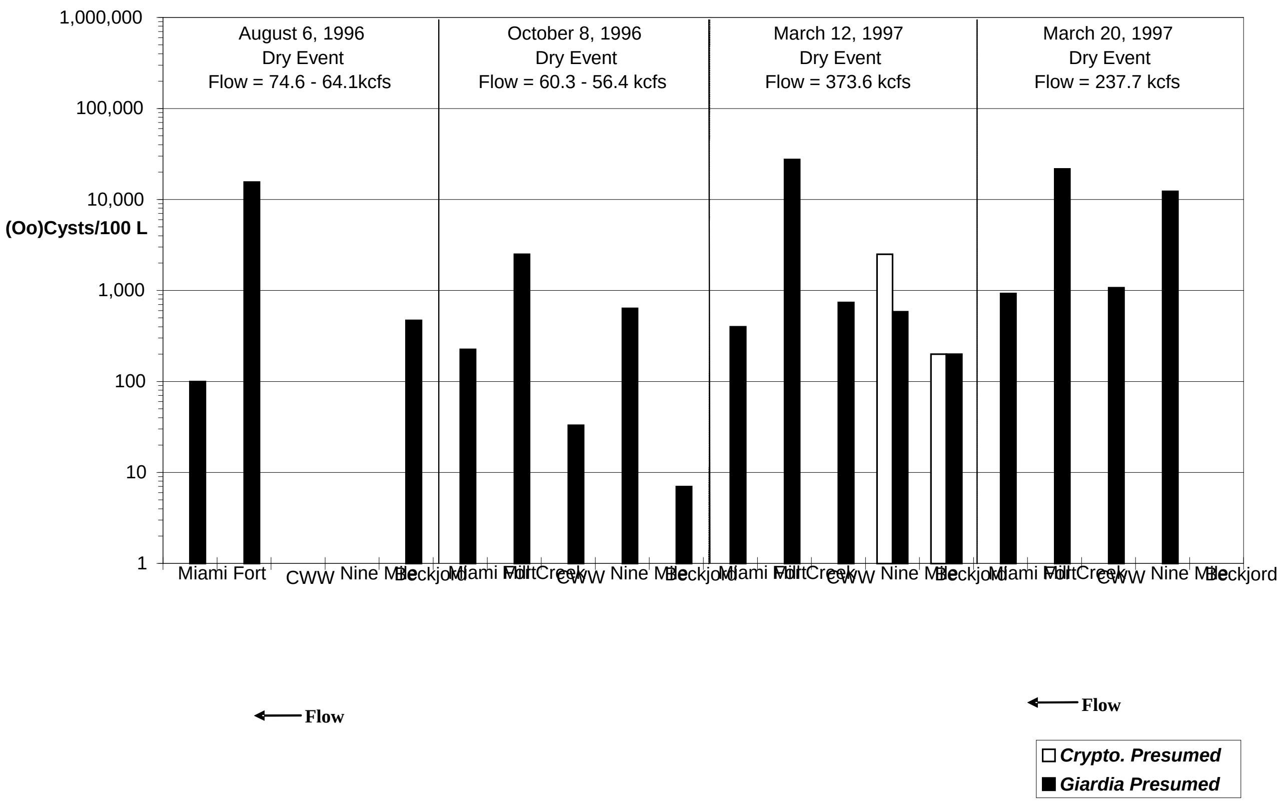


Figure 8-3. Wet Weather Demonstration Study
Total Number of Pathogens
Scenario 1 - Dry Weather Events



8.1.5 MONITORING SCENARIO #2

Scenario #2 focused on the impacts of Mill Creek and Mill Creek Wastewater Treatment Plant on the Ohio River during both wet and dry events. The sampling locations for this scenario as shown in Figure 8-4 were Miami Fort Power Plant, Mill Creek Wastewater Treatment Plant (both from the influent and effluent), Mill Creek and a site upstream of Mill Creek.

Events seven and eight were dry events conducted in this scenario (see Figure 8-5). During event seven, which took place May 12, 1997, *Giardia* cysts were presumed at all locations. C*ryptosporidium* oocysts were presumed at all locations except Mill Creek Wastewater Treatment Plant influent. *Cryptosporidium* oocysts were confirmed at the site upstream of Mill Creek, while *Giardia* cysts were confirmed at the Mill Creek Wastewater Treatment plant effluent. *Giardia* cysts were presumed during event eight at Mill Creek, Mill Creek Wastewarer Treatment Plant (WWTP) influent and at the downstream diffuser.

Events nine and ten were wet weather events sampled in this scenario (see Figure 8-6). Event nine was conducted May 29, 1997 with 0.32 inches of rain. *Cryptosporidium* oocysts were presumed at the sites upstream and downstream of Mill Creek. *Giardia* cysts were presumed at the site upstream and downstream of Mill Creek, Mill Creek and Miami Fort locations. On June 17, 1997 event ten was completed with 0.99 inches of rain. *Cryptosporidium* oocysts were presumed at the sites upstream and downstream Mill Creek, Mill Creek and Mill Creek Wastewater Treatment Plant effluent. At the Mill Creek, Mill Creek Wastewater Treatment Plant effluent, downstream of Mill Creek site and Miami Fort locations, *Giardia* cysts were presumed.

Results:

- Ohio River *Giardia* levels downstream of Mill Creek were somewhat higher than the upstream site.
- There was no significant difference on Mill Creek during wet and dry conditions.
- *Giardia* levels were typically around 1,000 cysts/100 mL on Mill Creek.

Figure 8-4. Scenario #2 - Dry & Wet Weather Samples

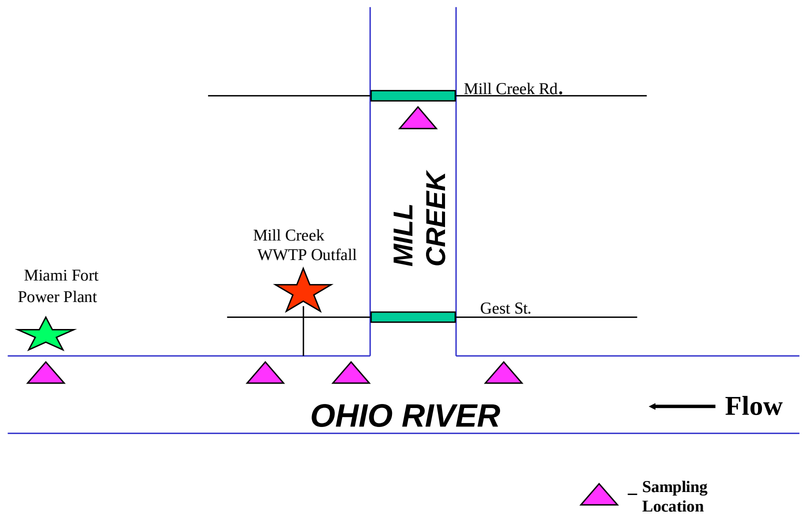


Figure 8-5. Wet Weather Demonstration Study
Total Number of Pathogens
Scenario 2 - Dry Weather Events

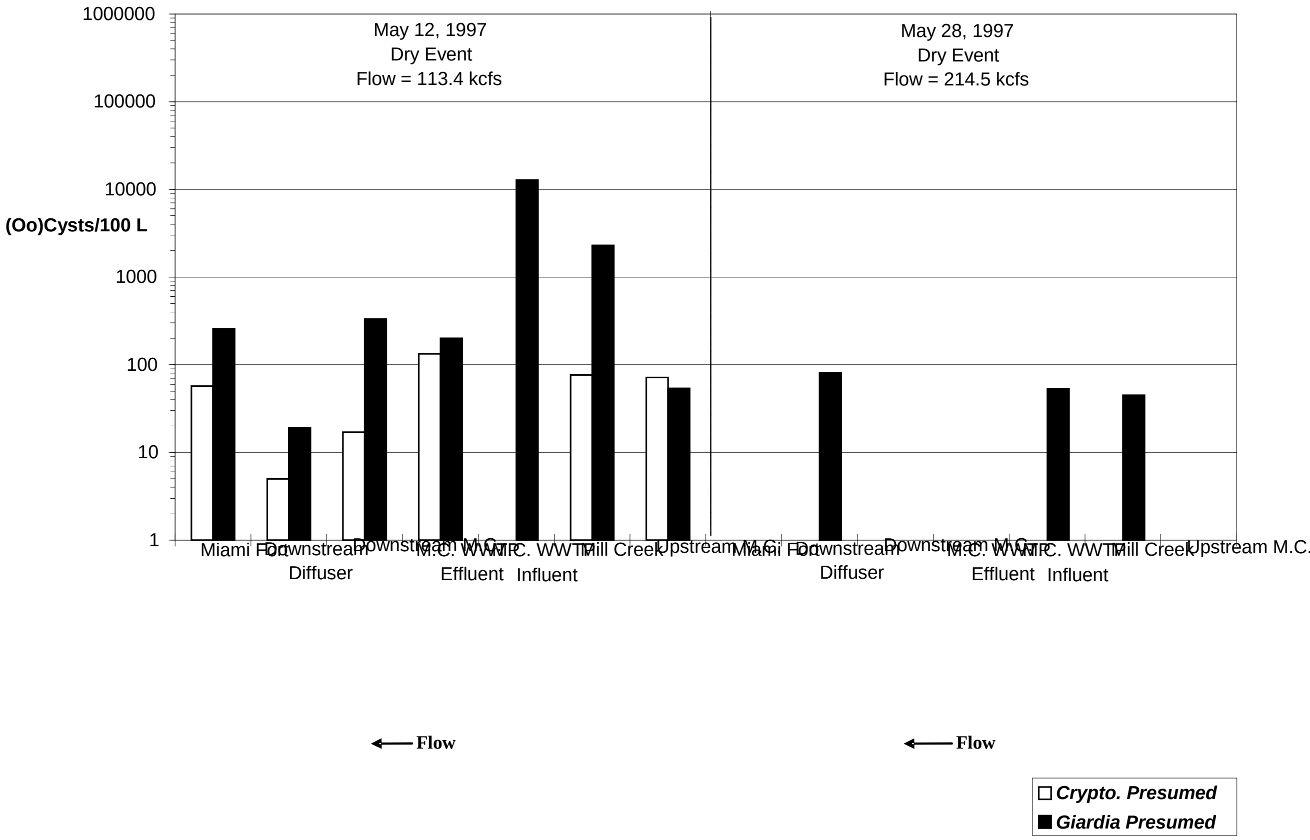
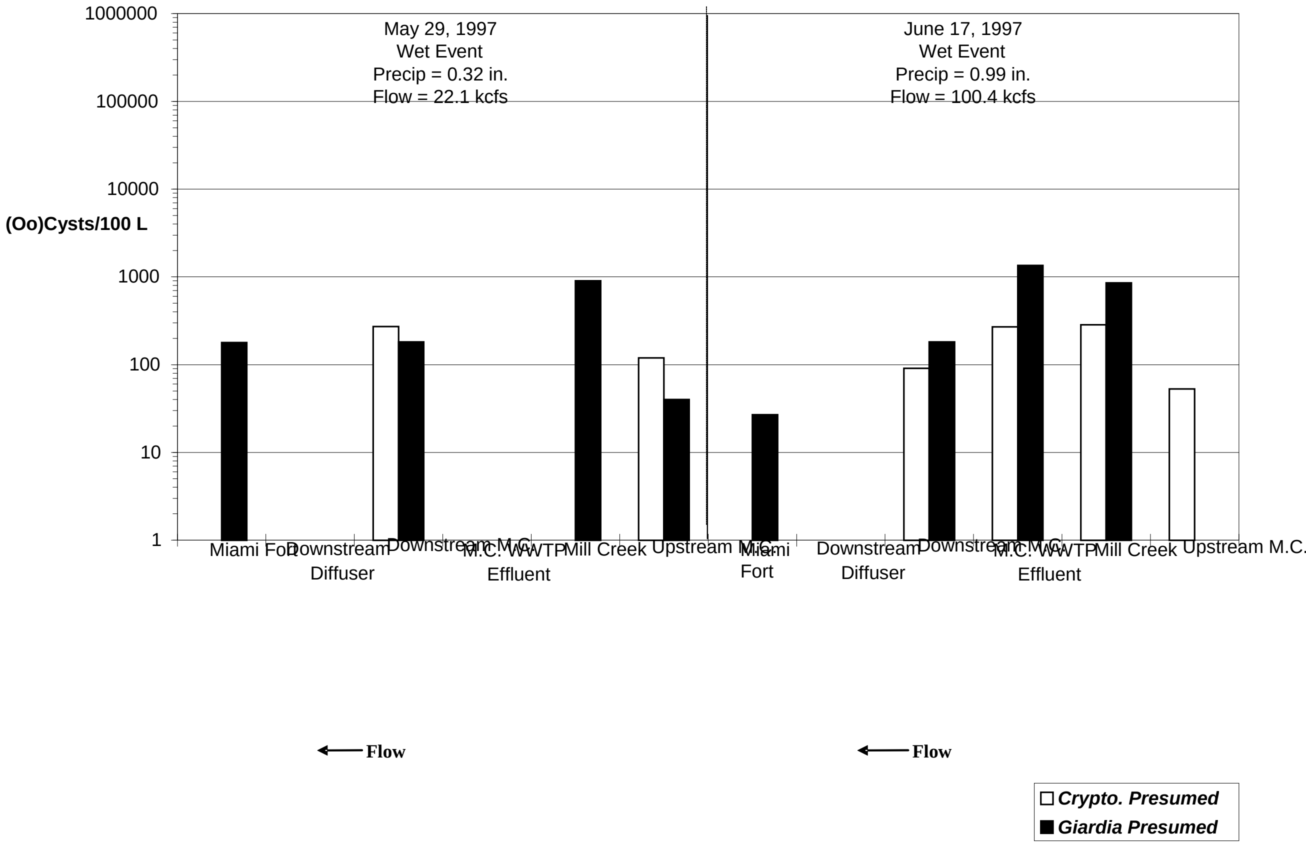


Figure 8-6. Wet Weather Demonstration Study
Total Number of Pathogens
Scenario 2 - Wet Weather Events



8.1.6 MONITORING SCENARIO #3

The objective of scenario #3 was to examine the pathogen removal efficiency of the Mill Creek WWTP. Samples were collected from Mill Creek WWTP as shown in Figure 8-7. Influent and effluent sampling were timed to coincide with evaluation of the same drop of water.

Events 11 and 12 were dry weather events while events 13 and 14 were wet weather events (see Figure 8-8). Event 11 showed both presumed *Cryptosporidium* oocysts and *Giardia* cysts in the influent. Presumed *Giardia* cysts were present in both the influent and effluent in event 12, with the effluent showing a higher level than the effluent. Event 13 had 2.99 inches of rain, while event 14 had an accumulated rainfall amount of 2.11 inches. *Giardia* cysts were presumed in event 13 at both the influent and the effluent. Again, the influent possessed a higher level of cysts than the effluent. During event 14 both *Cryptosporidium* oocysts and *Giardia* were presumed in the influent of the wastewater treatment plant.

Results:

- Mill Creek WWTP influent levels of *Giardia* were higher during wet events.
- *Giardia* was seen frequently in both the influent and the effluent.
- *Giardia* effluent levels were lower than the influent, suggesting that some level of removal occurred.
- *Cryptosporidium* was not seen in the effluent.

Figure 8-7. Scenario #3 - Removal Efficiency

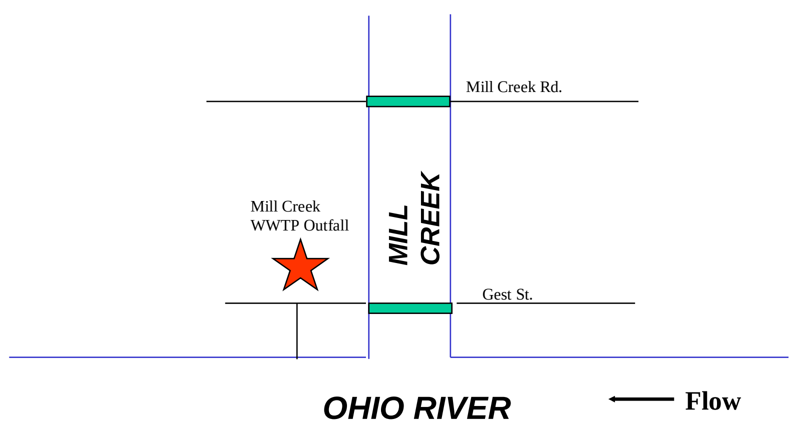
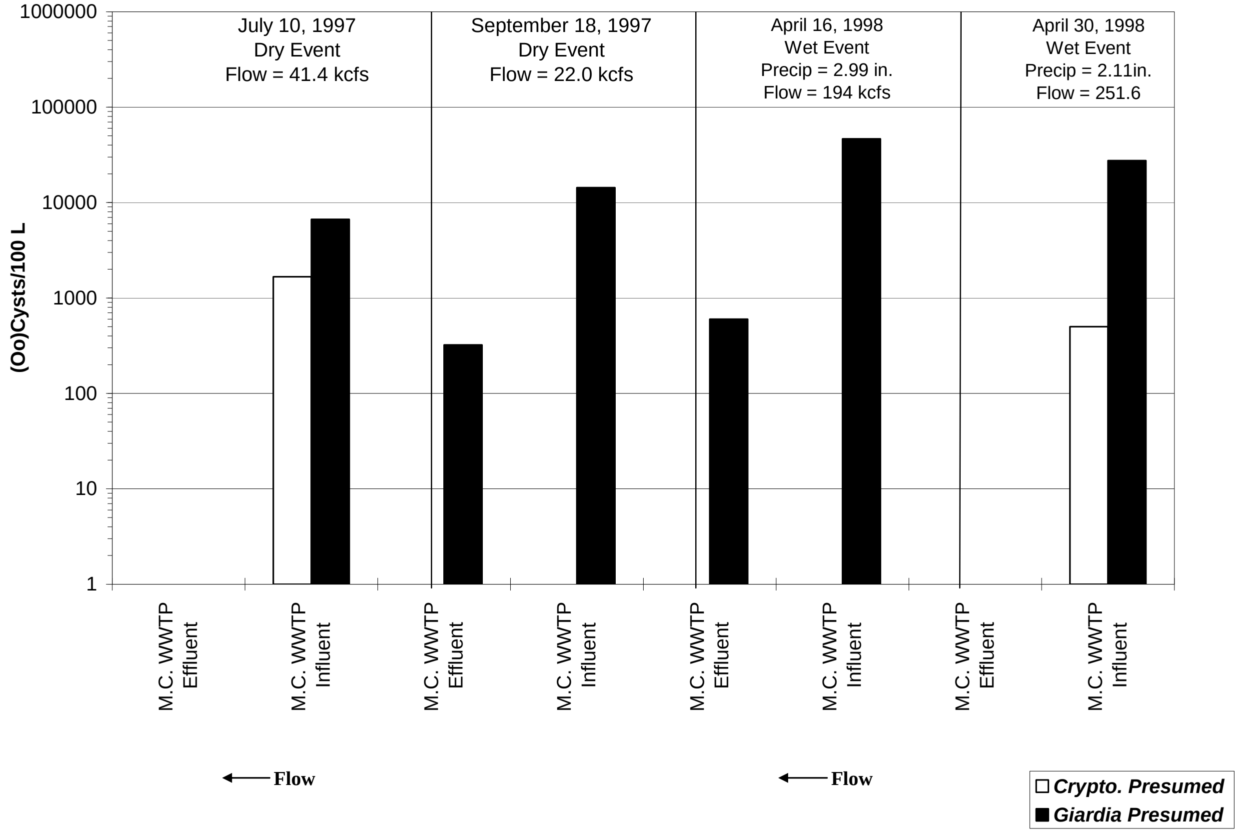


Figure 8-8. Wet Weather Demonstration Study
Total Number of Pathogens
Scenario 3 - Removal Efficiency



8.1.7 OVERALL CONCLUSIONS

- Utilization of presumed data was necessary to make evaluations because there are almost no confirmed detections of *Cryptosporidium* or *Giardia*.
- There were no consistent correlations differences between the occurrence of *Giardia* and *Cryptosporidium* and rainfall events.
- Based on the observations from the presumed results, *Giardia* was commonly detected in the Ohio River.
- *Cryptosporidium* was detected less frequently and at lower levels than *Giardia* in the Ohio River.
- Mill Creek Wastewater Treatment Plant:
    - *Giardia* levels were lower in the effluent than the influent, suggesting some level of removal.
    - There were no signs of *Cryptosporidium* in the effluent.
- Presumed *Giardia* concentrations were seen as high as 100,000 cysts/100 mL at the Nine Mile Wastewater Treatment Plant effluent.
- Presumed *Cryptosporium* results were seen as high as 2,000 oocysts/100 mL at both the Nine Mile Wastewater Treatment Plant effluent and Mill Creek.
- Both *Giardia* and *Cryptosporidium* were compared to many of the chemical parameters to look for correlations with the pathogens. After reviewing the comparisons there does not seem to be a relationship between the pathogens and the chemical parameters (such as TSS, turbidity, fecal coliform and *E. coli*).

8.2 EVALUATION OF WET WEATHER SOURCES OF POLLUTION ON LARGE RIVERS UTILIZING BIOLOGICAL COMMUNITIES

8.2.1 INTRODUCTION

The primary objective of the study's biological component was to utilize existing methods of biological sampling to determine the effects of wet weather pollution on the biological communities of a large river. To achieve this goal, both fish and macroinvertebrate populations were sampled. Surveys were conducted in a segment of the Markland Pool--Ohio River mile points (ORMP) 462 to 492.

The scope of work for this study included a fish population assessment and the collection of macroinvertebrate samples on the Ohio River at designated locations in Markland Pool. Fish population surveys were conducted in three rounds of sampling at 21 sites. Macroinvertebrate samples were collected in four rounds of sampling, each round consisting of an eight-week colonization period. Objectives of this biological monitoring were to: (1) provide upstream background data; (2) examine the effects of major identifiable pollutant inputs (clusters of combined sewer overflows, sanitary sewer overflows, wastewater treatment plants, and tributaries) within the Greater Cincinnati/Northern Kentucky urban area; and (3) investigate the level of downstream recovery relative to upstream conditions within the confines of the study area.

8.2.2 SAMPLING METHODS

8.2.2.a FISH POPULATION ASSESSMENT

The fish population assessment conducted for this component consisted of sampling 21 sites during rounds one and three, and 23 sites during round two (Table 8-2). Sites were chosen to produce optimum coverage for the study area. The surveys focused on sampling similar habitat areas (mud/gravel substrate) to reduce environmental variability as much as possible.

The fish population assessment was conducted in cooperation with the Ohio Environmental Protection Agency (Ohio EPA). Sampling was conducted from September 18 - 26, 1995 (round one), August 13 - 29, 1996 (round two), and October 7 - November 6, 1996 (round three). Sites were approximately 500 meters in length, and were sampled at night to optimize catch abundance and diversity (Ohio EPA, 1987). Fish collected were counted, measured and identified to the lowest practical taxonomic level on site. All minnows and questionable identifications were preserved on site and later identified by Ohio EPA staff.

TABLE 8-2. Electrofishing Sites

Station ID	*ORMP & Bank **	*Station ID*	*ORMP & Bank **
E-1	459.0 RDB	E-13	472.8 RDB
E-2	463.0 LDB	E-14	473.6 RDB
E-3	463.3 LDB	E-15	476.5 LDB
E-4	464.0 LDB	E-16	478.7 LDB
E-5	466.6 LDB	E-17	480.7 RDB
E-6	467.5 RDB	E-18	483.0 RDB
E-7	468.2 RDB	E-19	486.0 LDB
E-8	469.0 RDB	E-20	487.2 RDB
E-9	469.4 RDB	E-21	488.2 RDB
E-10	469.3 LDB	E-22	489.8 RDB
E-11	471.5 LDB	E-23	491.3 RDB
E-12	472.1 LDB		

* Bank refers to the descending bank or the relative position of the bank as seen while traveling downstream. LDB is the left descending bank (Kentucky side) and RDB is the right descending bank (Ohio/Indiana side).

8.2.2.b MACROINVERTEBRATE SAMPLING

Macroinvertebrate samples were obtained using Hester-Dendy artificial substrate multi-plate sampler units. Sampler units consisted of five individual samplers/sampler unit. Each unit of five was anchored to a cement block at the sampling site to stabilize and submerge the unit. Macroinvertebrate sampling consisted of three distinct phases:

Phase one established 16 macroinvertebrate “longitudinal” sampling stations consisting of one Hester-Dendy sampling unit per station within the study area (Table 8-3). Sites between ORMP 462 and 492 were sampled at regular intervals (approximately two miles) for four rounds, each round lasting eight weeks.

Phase two established three macroinvertebrate “cluster” sampling stations consisting of five Hester-Dendy sampling units per station (Table 8-3). Four rounds of sampling were also conducted at these sites, each round lasting eight weeks. The objective was to identify the extent of natural variability in macroinvertebrate populations within the study area.

Phase three isolated the near-field effects of individual CSOs within the study area. In the first year of sampling (1995) individual sampling units were placed above and below each of three CSO discharges. In the second year, the number of sites was expanded to six. Dye tests were used to determine the location of the sampling sites (Table 8-3). Each CSO was monitored for overflow frequency and duration. Sites were sampled for a total of three rounds, each round lasting eight weeks. The objective was to determine if overflows produce a measurable near-field impact on macroinvertebrate populations below the outfall.

The colonization period for macroinvertebrate samples was eight weeks. Sampling was conducted July 12 - September 5, 1995 (round one), August 31 - October 26, 1995 (round two), July 9 - August 29, 1996 (round three), and August 27 - October 16, 1996 (round four). Recovery rates of the sampler units were as follows: round one-27 of 34 (79.4%); round two-20 of 38 (52.6%); round three-37 of 44 (84.1%); and round four-41 of 44 (93.2%). Table 7-3 also lists the specific units recovered for each round. Once retrieved, the individual plates from each sampler unit were processed in the field and the resulting composite of organisms stored in a preservative for shipment. Composites were sent to an independent laboratory, where they were counted and identified to the lowest practical taxonomic level.

TABLE 8-3. Macroinvertebrate Sites

Phase One - Longitudinal Sites

Station ID	*ORMP & Bank **	*Round One*	*Round Two*	*Round Three*	*Round Four*
L-1	462.25 LDB	X	X	X	X
L-2	464.1 LDB	X	X	X	X
L-3	466.0 LDB	X	X	X	X
L-4	467.9 LDB		X		X
L-5	469.75 LDB	X	X	X	
L-6	472.1 LDB	X		X	X
L-7	474.0 RDB	X	X	X	X
L-8 A	476.0 LDB		N/P	N/P	N/P
L-8 B	475.9 RDB			X	X
L-9	478.1 RDB			X	X
L-10	480.0 LDB	X		X	X
L-11 A	481.9 RDB		N/P	N/P	N/P
L-11 B	482.0 RDB	X		X	X
L-12	483.9 RDB			X	X
L-13	485.9 LDB	X		X	X
L-14	488.0 LDB			X	X
L-15	490.0 LDB	X		X	X
L-16 A	491.9 LDB	X	X	X	X
L-16 B	491.9 LDB	X	X	X	X

Phase Two - Cluster Sites

Station ID	*ORMP & Bank **	*Round One*	*Round Two*	*Round Three*	*Round Four*
C-1	462.25 LDB	X	X	X	X
C-2	474.0 RDB	X	X	X	X
C-3	490.0 LDB	X		X	X

Phase Three - CSO sites

Station ID	*ORMP & Bank **	*Round One*	*Round Two*	*Round Three*	*Round Four*
O-1 A	467.15 RDB	N/P		X	X
O-1 B	467.20 RDB	N/P		X	X
O-2 A	471.6 RDB	N/P	N/P	X	X
O-2 B	471.65 RDB	N/P	N/P	X	X
O-3 A	472.0 LDB	N/P	X	X	X
O-3 B	472.25 LDB	N/P	X		X
O-4 A	472.3 RDB	N/P	N/P	X	X
O-4 B	472.35 RDB	N/P	N/P	X	
O-5A	475.8 RDB	N/P	N/P	X	X
O-5 B	475.85 RDB	N/P	N/P		
O-6 A	481.9 RDB	N/P	N/P	X	X
O-6 B	481.9 RDB	N/P	N/P		X

X - Indicates retrieval of macroinvertebrate sampler unit, blanks indicate sampler units which were not recovered.
N/P - Indicates sampler unit was Not Placed

Field measurable water quality parameters were collected at each site at the time of placement and retrieval of sampler units. Temperature, pH, dissolved oxygen and conductivity were recorded using a Hydrolab Model H-20 instrument. The Hydrolab instrument was pre- and post-calibrated to ensure the accuracy of data collected. The range of measurements is presented in Table 8-4 below.

TABLE 8-4. Range of Physical Parameters

Parameter	***Round One***	***Round Two***	***Round Three***	***Round Four***
Temperature (C)	27.83 - 31.93	16.89 - 31.33	26.82 - 28.87	18.05 - 28.28
pH	6.76 - 8.60	6.80 - 8.60	6.73 - 9.03	6.73 - 9.03
Dissolved Oxygen (mg/L)	6.77 - 12.38	6.73 - 12.38	6.69 - 8.98	7.46 - 9.61
Conductivity (umhos/cm)	290 - 443	290 - 596	253 - 432	253 - 550

Total precipitation was measured at gauges throughout the study area during rounds one through four, and is expressed in Table 8-5 as an average of all the gauges within the study area.

TABLE 8-5. Precipitation Summary

Parameter	***Round One***	***Round Two***	***Round Three***	***Round Four***
Total Precipitation (in)	6.84	6.24	4.52	6.38
Number of Storms	14	15	12	8
Avg. Precipitation/Storm (in)	0.49	0.42	0.38	0.80

Total flow from CSOs where sampler units were placed was monitored during rounds two through four (CSO samplers were not placed during round one). An example of the information collected at each of the sampling locations is expressed in Table 8-6.

TABLE 8-6. CSO at Site O-3

Parameter	***Round Two***	***Round Three***	***Round Four***
Total Flow (mgd)	1.60	0.84	1.42
Number of Overflows	11	8	8
Avg. Flow/Overflow (mgd)	0.15	0.11	0.18

8.2.3 DATA ASSESSMENT

8.2.3.a FISH POPULATION ASSESSMENT

Sites were evaluated with the help of Ohio EPA personnel who calculated an Index of Biotic Integrity (IBI) and a Modified Index of well being (MIwb). It should be noted that both indices were designed to evaluate fish populations in inland streams and waterways. Since an index designed and calibrated specifically to evaluate fish populations for a large river like the Ohio River has not been developed, the IBI and MIwb were utilized in their present form.

The IBI is a multi-metric approach to evaluating fish populations and was originally described by Karr (1981) for use in Illinois streams. Ohio EPA uses a modified version of the IBI which takes into account regional differences between the fish populations of Ohio and Illinois. It consists of 12 metrics which are compared to the value expected at a reference site and then rated either a 5 (value approximates), 3 (deviates somewhat from) or 1 (strongly deviates from the value expected). The maximum IBI score is 60 and the minimum score is 12. Metrics used by Ohio EPA are: total number of species, sunfish species, sucker species, intolerant species, round body suckers, simple lithophils, tolerant fishes, omnivores, top carnivores, insectivores, DELT anomalies (Deformities, Eroded fins, Lesions, and Tumors), and relative number minus tolerant species (Ohio EPA, 1987).

IBI values expected at a reference site for the study area (Interior Plateau Ecoregion) for an Ohio inland stream would have a mean value of 43, a standard deviation of 1.1, and a range of 32 - 52 (Ohio EPA, 1987). Results from the Ohio River samples collected in 1995 (round one) and those collected in 1996 (rounds two & three) are displayed in Table 8-7.

TABLE 8-7. Range of IBI Results

Parameter	***Round One***	***Round Two***	***Round Three***
Mean	42.95	36.00	36.40
Standard Deviation	3.91	2.09	1.60
Range	36 - 52	26 - 46	32 - 44

The MIwb is also a multi-metric approach to evaluating fish populations and was originally developed as the Index of well being (Iwb) by Gammon (1976) for use on the Wabash River in Indiana. The Iwb consists of four measures of fish communities: numbers of individuals, biomass, Shannon Diversity based on numbers, and Shannon Diversity based on weight. Ohio EPA modified the Iwb by eliminating any of 13 highly tolerant species, hybrids or exotic species from the numbers and biomass components of the Iwb, but not from the Shannon components (Ohio EPA, 1987). A minimum MIwb score is 0 and the maximum is 12.

MIwb values expected at a reference site for the study area (Interior Plateau Ecoregion) for an Ohio inland stream would have a mean value of 9.2, a standard deviation of 0.1, and a range of

8.5 - 10.2 (Ohio EPA, 1987). Results from the Ohio River samples collected in 1995 (round one) and those collected in 1996 (rounds two & three) are displayed in Table 8-8.

TABLE 8-8. Range of MIWB Results

Parameter	***Round One***	***Round Two***	***Round Three***
Mean	9.04	8.46	8.49
Standard Deviation	0.56	0.36	0.30
Range	8.80 - 9.90	6.90 - 9.70	7.20 - 9.60

8.2.3.b Macroinvertebrate Sampling

A total of 125 composite samples was collected over four rounds of sampling and was evaluated with the help of Ohio EPA staff. The following indices were calculated for each composite sample: total number of organisms, taxa richness, percent Dominant taxa, percent Chironomids, Chironomid richness, percent EPT (Ephemeroptera, Plecoptera, and Trichoptera), EPT richness, EPT/Chironomid ratio, Modified Hilsenhoff's Biotic Index, Community Loss Index, Jaccard Coefficient, Ohio EPA's Invertebrate Community Index (ICI) and various analyses associated with the Zebra Mussel population. It should be noted that these indices were designed to evaluate macroinvertebrate populations in inland streams and waterways and were used in the absence of an index specifically designed and calibrated to evaluate macroinvertebrate populations for a large river like the Ohio. Sites were compared statistically based on a mean value at each cluster location and standard deviation at a 95 percent confidence level. The expectations prior to the initiation of sampling was that the indices would reflect higher biological integrity at the upstream sites as compared to the sites within the urban area. In addition, it was expected that the downstream sites would display a recovery in the composition of the macroinvertebrate community that would more closely represent the upstream conditions. Similarly, the expectation was that indices would reflect higher biological integrity upstream of the CSO sites than immediately downstream. CSO site O-3 offered two years of results that are used in Figure 8-9 to represent all CSO locations studied.

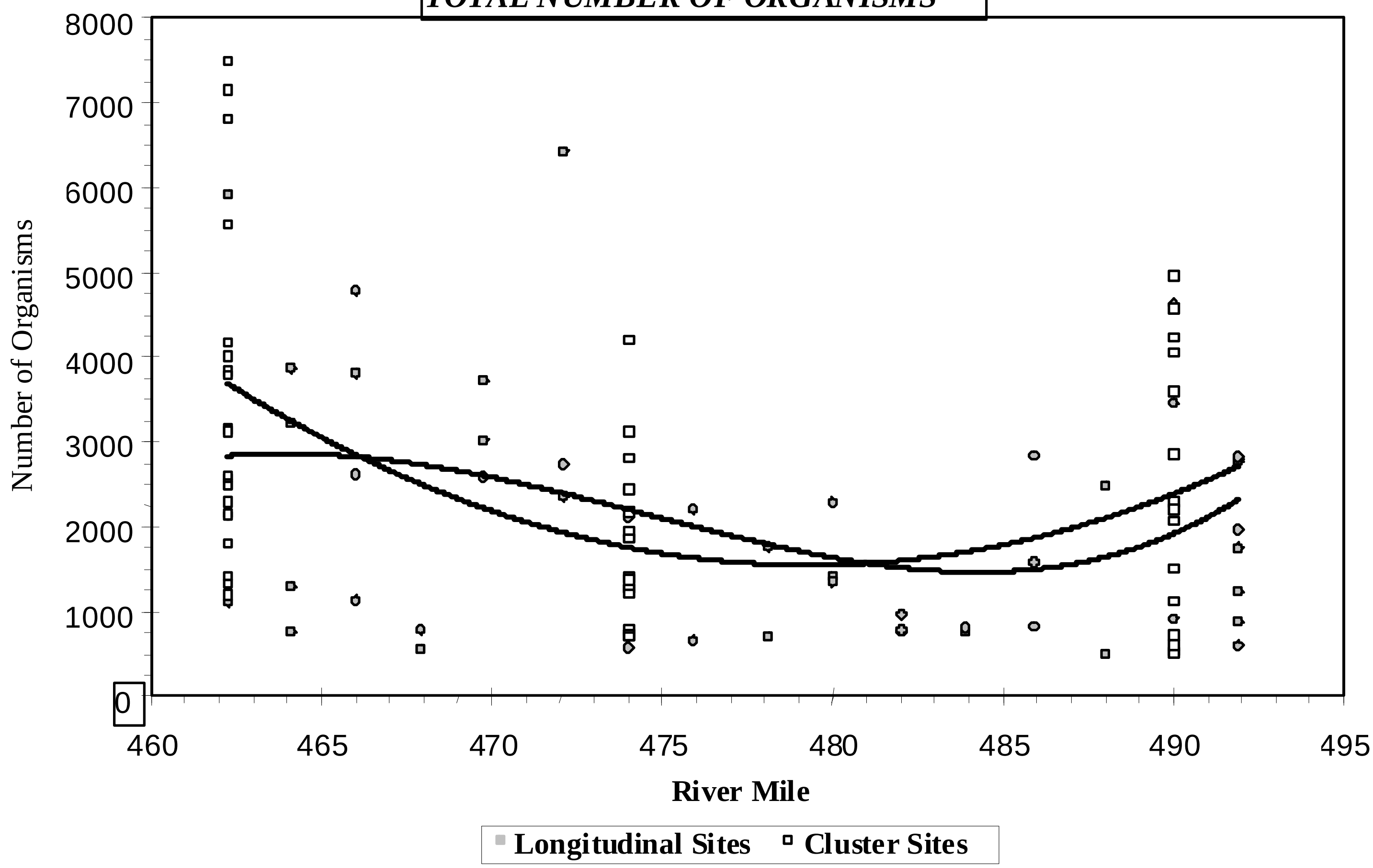
This index is simply a count of the organisms found in each macroinvertebrate sample. The expectation prior to sampling was that the total number of organisms would be highest at the upstream sites, show a decrease through the urban area and a recovery at the downstream sites. At the CSO sites, the expectation prior to sampling was that the total number of organisms upstream of the overflow would be higher than the number downstream. Results are as follows:

- Cluster and longitudinal site sampling resulted in the expected trend (Figure 8-9).
- The number of organisms above CSO O-3 was statistically the same as the number below the outfall during rounds two through four. This does not confirm the expectation prior to sampling.

FIGURE 8-9

1995 - 1996 MACROINVERTEBRATE RESULTS

TOTAL NUMBER OF ORGANISMS



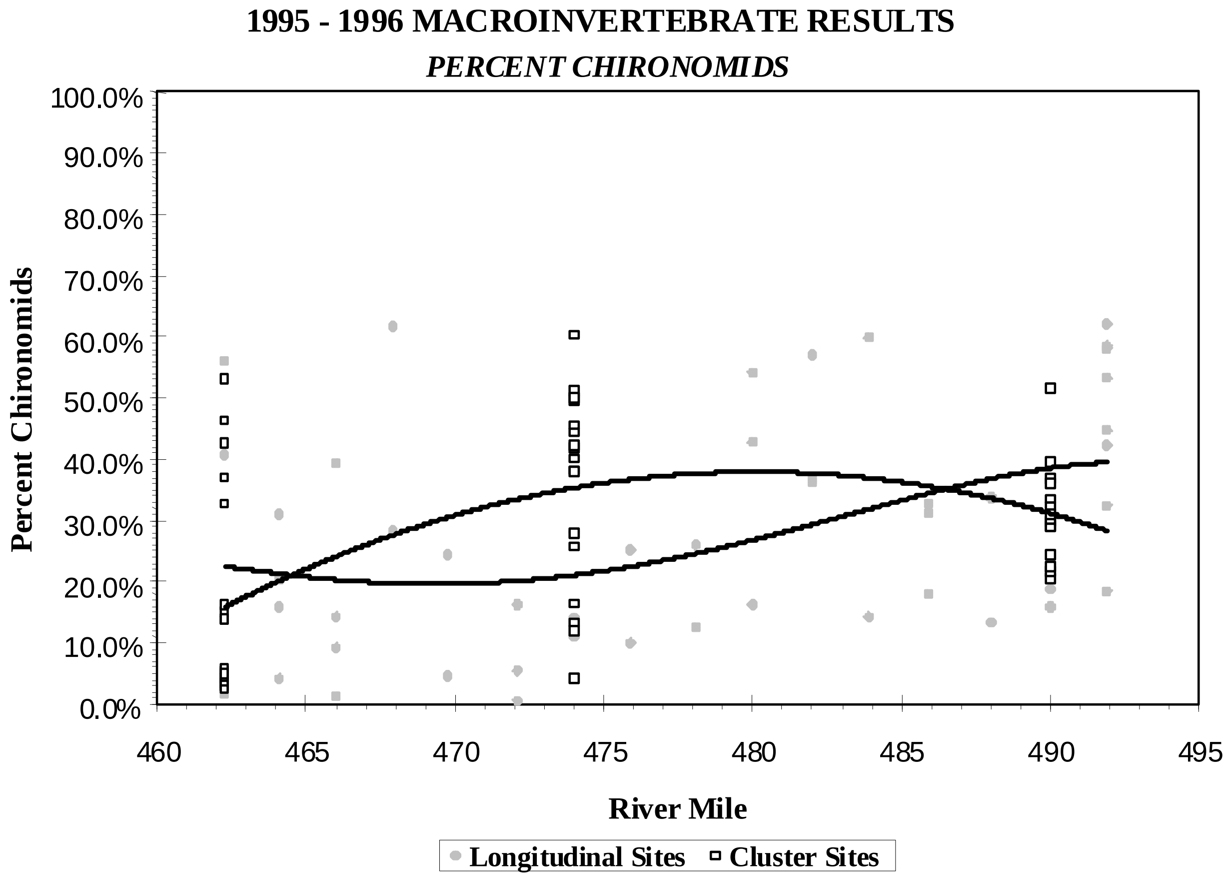
Taxa richness is simply a count of the taxa found in each macroinvertebrate sample. In this case, all roundworm taxa were counted as only one taxa per Ohio EPA protocol. The expectation prior to sampling was that the total number of taxa would be highest at the upstream sites, show a decrease through the urban area, and a recovery at the downstream sites. At the CSO sites the expectation prior to sampling was that the total number of taxa upstream of the overflow would be higher than the number downstream. Results are as follows:

- The number of taxa at cluster and longitudinal sites showed a steady, increasing trend throughout the study area that does not conform to expectation.
- The site O-3 CSO samplers recovered in rounds two through four either showed an increase in number of taxa from upstream to downstream of individual outfalls or remained statistically the same--opposite of the expectation. However, of the additional taxa below the outfall, the majority was of the family Chironomidae, generally considered to be pollution tolerant organisms.

Percent chironomids is a measure of the percentage of the Family Chironomidae (Midges) within the community found at each site. These organisms are generally tolerant of pollution and their numbers tend to increase in degraded conditions. The expectation prior to sampling was that the percentage of chironomids would be lowest at the upstream sites, show an increase through the urban area and decrease at the downstream sites. At the CSO sites, the expectation prior to sampling was that the percentage of chironomids upstream of the overflow would be lower than the percentage downstream. Results are as follows:

- The cluster site samples conformed to expectation, however the longitudinal site samples did not meet expectations (Figure 8-10).
- Of the site O-3 CSO samplers recovered in rounds two through four, the mean percent chironomids above the CSO was 36.84 and the percentage below the outfall was 51.66 (statistically significant) indicating the expected performance. This may suggest that a CSO can have a quantifiable effect upon near-field macroinvertebrate communities even on large rivers where tremendous dilution can occur.

FIGURE 8-10



Percent Ephemeroptera, Plecoptera and Trichoptera (EPT) index is a measure of the percentage of the Orders Ephemeroptera (Mayflies), Plecoptera (Stoneflies), and Trichoptera (Caddisflies) within the community found at each site. These organisms generally are considered pollution-sensitive species. The presence of EPT organisms at a site is generally an indicator of good water quality, since their sensitivity precludes them from inhabiting degraded areas. The expectation prior to sampling was that the percentage of EPT will be highest at the upstream sites, show a decrease through the urban area and a recovery at the downstream sites. At the

CSO sites the expectation prior to sampling was that the percentage of EPT upstream of the overflow would be higher than the percentage downstream. Results are as follows:

- The number of taxa at cluster and longitudinal sites showed a steady, increasing trend through the study area that did not conform to expectation.
- Of the site O-3 CSO samplers recovered in rounds two through four, mean percentage of EPT above the CSO was 23.42 and the percentage below was 12.35. Based on this information, the difference in the percentage of EPT was statistically significant and indicated the expected performance.

Hilsenhoff (1977) originally developed Hilsenhoff's Biotic Index (HBI) for use in Wisconsin streams. The original tolerance classifications were based on a numerical range of 0 to 5 and later modified by Hilsenhoff (1987) to use a 0 to 10 scale. However, similar results can be obtained using an index value of either 0 to 5 or 0 to 10, and adequate information is not available for several species that would allow use of the more definitive 0 to 10 tolerance range (U.S. EPA, 1990). Therefore, a 0 to 5 scale was chosen as modified by the Maryland Department of the Environment (1992). Higher index values indicate a more pollution tolerant macroinvertebrate community, and generally a lesser degree of water quality. A score of:

0 to 1.75	= excellent water quality
1.76 to 2.50	= good water quality
2.51 to 3.75	= fair water quality
3.76 to 4.00	= poor water quality
> 4.00	= serious water quality problems

The expectation prior to sampling was that the HBI score would be lowest at the upstream sites, show an increase through the urban area and a decrease at the downstream sites. At the CSO sites the expectation prior to sampling was that the HBI score upstream of the overflow would be lower than the score downstream. Results are as follows:

- Cluster and longitudinal site sampling resulted in the expected trend.
- Of the site O-3 CSO samplers recovered in rounds two through four, mean HBI score above the CSO was 3.33 and the mean below was 3.66 (statistically significant) indicating the expected performance.

The percent mussels index is a measure of the percentage of the Zebra Mussels (Dreissena polymorpha) and Asiatic Bivalves (Corbicula fulminea) within the community found at each site. Since the mussels were the largest contributors of organisms to the population in many samples, this index may also be considered the percentage of dominant taxa for those samples. These two mussel taxa are generally tolerant of pollution and their numbers tend to increase in degraded conditions. The expectation prior to sampling was that the percentage of mussels would be lowest at the upstream sites, show an increase through the urban area and decrease at the downstream sites. At the CSO sites, the expectation prior to sampling was that the percentage of mussels upstream of the overflow would be lower than the percentage downstream. Results are as follows:

- Cluster and longitudinal sites displayed the opposite of the expected trend with high numbers upstream, lower numbers through the urban area and increasing numbers at downstream sites.
- At the site O-3 CSO samplers recovered in rounds two through four, the percentage of mussels above the CSO was 18.63 and the percentage below the outfall was 0.86. This

seems to confirm that these mussels may be more sensitive to urban influences than originally expected.

8.2.4 DISCUSSION AND CONCLUSIONS

The indices used to evaluate the fish population assessment and the macroinvertebrate collections conducted in 1995 and 1996 were designed to evaluate inland streams as opposed to a large river like the Ohio River. Given this, the results of these analyses must be viewed with a certain amount of caution. ORSANCO is aware that any attempt to evaluate water quality conditions using biological populations on the Ohio River must be conducted with new indices designed for, or existing indices calibrated for, the special conditions that exist on large rivers (i.e., large amounts of flow, transient sediments, etc.). However, biological populations have been valuable assessment tools for smaller streams, and may prove to be of similar value on large rivers in the future. In the interim, biological results from this project did show some interesting results using available methods of evaluation.

8.2.4.a FISH POPULATION ASSESSMENT

In general, for the fish population assessed during this study, neither of the two indices was able to demonstrate any consistent, statistically reasonable difference between the upstream sites, the urban sites and the downstream sites. It is important to note that the standard deviation for both the IBI and MIwb was rather high. As sampling efforts continue both river-wide and in the study area, and as the sample size becomes more robust, the standard deviation should be compressed for both of the indices. It is quite possible that the urban wet weather sources do not have an adverse impact on Ohio River fish communities in the Cincinnati area.

8.2.4.b MACROINVERTEBRATE SAMPLING

In rounds one through four, several indices performed as expected. In particular, total number of organisms, percent chironomids, Hilsenhoff's Biotic Index, and percent mussels showed clear statistically significant results over the study area. As with the fish population indices, it is clear that a larger, more robust sample size is important to compress the standard deviations for many indices.

Of the CSO samples recovered in Rounds Two through Four, several indices performed as expected. In particular, percent Chironomids, percent EPT, EPT/Chironomid ratio, Hilsenhoff's Biotic Index and the Invertebrate Community Index showed clear statistically significant differences in the makeup of the macroinvertebrate populations above and directly below particular CSOs. Future sampling efforts should focus on sampling at a variety of outfalls and at different seasons. There is evidence that, at least at these sites, CSOs have a quantifiable impact on the near-field populations of organisms irrespective of the unique qualities that large rivers, like the Ohio River, possess. Once these impacts are defined, efforts could be focused on examining the length of the impact in terms of distance downstream.

LITERATURE CITED

Ohio Environmental Protection Agency, 1987. Biological Criteria for the Protection of Aquatic Life: Volume II: Users Manual for Biological Field Assessment of Ohio Surface Waters. Division of Water Quality Monitoring and Assessment, Surface Water Section, Columbus, Ohio.

United States Environmental Protection Agency, 1990. Macroinvertebrate Field and Laboratory Methods for Evaluating the Biological Integrity of Surface Waters. Office of Research and Development, Washington, D.C. EPA/600/4-90/030

United States Environmental Protection Agency, 1993. Fish Field and Laboratory Methods for Evaluating the Biological Integrity of Surface Waters. Office of Research and Development, Washington, D.C. EPA/600/R-92/111

9.0 SUMMARY

This section summarizes results and conclusions from individual chapters of this report and contains several items not discussed elsewhere.

9.1 DEVELOPMENT OF A TRANSFERRABLE FRAMEWORK

A primary objective of this study was to develop a tool or framework for the evaluation of wet weather impacts and controls on large rivers. This project in its entirety is the essence of such a framework. Chapter 7 presents an overview of the application of the study framework. This framework is in the process of being transferred successfully to evaluate wet weather impacts in the Louisville area of the Ohio River. The framework in summary includes:

1) Monitoring to identify pollutants of concern, calibrate/validate water quality river models, and estimate boundary conditions.
2) Landside modeling to estimate wet weather loads to surface waters. In this case, SWMM was used for both the Cincinnati and Northern Kentucky sides of the river.
3) River water quality modeling to predict water quality conditions during periods not monitored and to evaluate resulting water quality from various pollution abatement scenarios. WASP was used to model Ohio River water quality.
4) Execution of the model for typical conditions and various control scenarios.

9.2 POLLUTANTS OF CONCERN

Based on water quality studies and historical data, bacteria was determined to be the only cause of impairment from wet weather. A large number of parameters were monitored, as noted in Chapter 2, in order to reach this conclusion. Dissolved oxygen was heavily scrutinized, including an evaluation of historical data in order to determine that DO is not a wet weather concern for the Cincinnati area. This conclusion should not be construed to apply to other urban areas. Each urban area should be considered to be unique, with problems particular to the area being evaluated. For instance, in the Wheeling, West Virginia area, ORSANCO is evaluating dissolved metals as a wet weather concern from acid mine drainage, whereas acid mine drainage would not be considered in the Louisville, Kentucky area.

9.3 ESTIMATION OF TRIBUTARY NONPOINT SOURCE BACTERIA LOADS

In addition to estimating bacteria loads from CSOs in each of the major tributary watersheds using the SWMM models, nonpoint source bacteria loads from tributaries upstream of the CSO catchment areas were also estimated for a typical year. Estimation of these tributary upstream bacteria loads was done daily for the typical year by applying an estimated mean bacteria concentration to a daily flow value in order to determine a load. This was done for the Little Miami River, Licking River, Mill Creek and Great Miami River. However, no good bacteria data was available for any of the tributaries upon which to make a good estimate of bacteria concentrations. It would have been beneficial to have long term, routine monitoring of the tributary upstream catchment areas, as well as at their confluence with the Ohio River to facilitate more accurate estimates of bacteria loads coming from non-CSO sources.

9.4 OBSERVATIONS FROM WET AND DRY WEATHER WATER QUALITY SURVEYS

- Ohio River bacteria concentrations exceed levels for the protection of human health from contact recreation, at times even during dry weather.
- Ohio River bacteria concentrations in the Greater Cincinnati area tend to be very high during the first two days after a storm event, then decline rapidly. During the 1999 and 2000 wet weather water quality surveys, maximum Ohio River bacteria concentrations were two orders of magnitude greater than the level for the protection of human health from contact recreation.
- Of the major tributaries within the study area, the Mill Creek has the highest bacteria concentrations after a storm event, generally an order of magnitude higher than the other tributaries. The Little Miami and Licking rivers tend to have similar concentrations, while the Great Miami River tends to have the lowest bacteria concentrations. These observations are consistent with the numbers of CSOs within each drainage area.
- The highest concentrations in the Ohio River occur immediately downstream of the major tributary confluences.
- It was estimated from the modeling exercise that the Great Miami River contributes approximately 12 percent of the total annual fecal coliform load to the Ohio River within the study area. This load seems high relative to the other sources since there are no CSOs discharging to the Greta Miami River within the study area. Additional investigation is warranted to identify the cause(s) and source(s) of fecal coliform in the Great Miami River.

9.5 LAND-SIDE LOADING ESTIMATES

XP-SWMM models were set up and executed separately for the Cincinnati and Northern Kentucky CSO systems. These models were used to estimate flows from CSOs. Then event mean concentrations (for fecal coliform) are applied to flow values to calculate fecal coliform loads. While a minimal amount of CSO outfall water quality monitoring was conducted, additional bacteria data from CSO outfalls would have been useful for estimating event mean concentrations.

9.6 RIVER WATER QUALITY MODEL

- The river model is comprised of the RMA-2V hydrodynamic model to simulate flow and the WASP5 model to simulate pollutant transport and fate. The purpose of these models is to predict water quality conditions for specific storm events as well as "typical conditions," and to evaluate the resulting effects on Ohio River water quality from various pollutant reduction strategies.

- The WASP5 water quality model was calibrated to the May 2000 wet weather event and validated with 1995 wet weather survey data. Validations on two separate 1995 storm events of 0.63 inches and 1.0 inches indicated better agreement with the moderate (0.63 inches rain) rain event.

9.7 MODEL APPLICATION

- The models were executed for the typical year in terms of rainfall--determined to be 1971. Selected model results are available in an animator included with this report on CD.

- A cumulative mass balance on the total flow within the study area during the typical year 1971 resulted in relative contributions to the total flow from the following source categories:

Ohio River In-Flow	93.4 %
Non-CSO Tributary Flow	6.2 %
CSO Flow	0.2 %
WWTP Flow	0.1%

- A cumulative mass balance on total annual fecal coliform load for a "typical" year (1971) was estimated from the models. Relative contributions from the various sources are presented below and are subject to error:

Mill Creek Loads	22 %
Direct CSO Loads - Ohio-side	22 %
Licking River Loads	19 %
Little Miami River Loads	15 %
Great Miami River Loads	12 %
Direct CSO Loads – Kentucky-side	8 %
Upstream Ohio River Loads	1 %
WWTP Loads	<1 %

- Based on the above figures generated from modeling results, CSOs and SSOs collectively contribute approximately 75 percent of the total fecal coliform load to the Ohio River within the study area. The upstream Ohio River and WWTP loads are almost negligible, while the non-CSO loads from tributaries within the study area account for 24 percent of the load. These estimates, based on modeling results, are subject to error.

- Ohio River bacteria levels are worst immediately downstream of the confluence with the major tributaries.

- Along the center channel of the Ohio River, representing a well-mixed scenario, the Ohio River exceeds the contact recreation criterion approximately 15 percent of the time (during the recreation season). This figure is based on modeling results and is subject to error.

- Bacteria concentrations tend to be higher and persist longer along the banks of the river than the center channel. This may be due to mixing characteristics or because the vast majority of the load originates from the banks of the river.

9.8 CSO REDUCTION SCENARIOS

- The model was executed for the typical year with CSO reduction scenarios of 25, 50, 75 and 100 percent. Heavy, moderate and light magnitude storms, as well as a dry period, were evaluated for improved river water quality based on the various CSO load reduction scenarios.

- The greatest benefits to river water quality improvement occur for an "average storm," defined as 0.54 inches rain total and maximum rainfall intensity of 0.14 inches per hour. For heavy storms, 100 percent reductions in CSO load contributions are necessary to affect significant river water quality improvements.

- Along the center channel of the Ohio River, the contact recreation criteria were exceeded approximately five percent of the time, even with 100 percent control of CSO loads, while it exceeded the criteria approximately 15 percent. These estimates are based on modeling results and are subject to error.

9.9 *CRYPTOSPORIDIUM* AND *GIARDIA*

- A special study of *Cryptosporidium* and *Giardia* was undertaken to evaluate potential impacts on water utilities and sources. The analytical method generates "presumed" and "confirmed" data. "Presumed" data is always much higher than "confirmed" data and was used for the purposes of this report. Very few "confirmed" data were observed for either *Cryptosporidium* or *Giardia*.

- Giardia is observed much more frequently in the Ohio River than *Cryptosporidium*.

- There are no significant differences in levels of *Crypotosporidium* and *Giardia* between wet and dry periods.

- *Giardia* levels were lower in the Mill Creek WWTP effluent than in the influent. There was no *Cryptosporidium* observed in the Mill Creek WWTP effluent.

- No correlations were found to exist between *Giardia* and *Cryptosporidium*, and a selected set of other pollutants investigated including several bacteria indicators.

9.10 BIOLOGICAL STUDY

A biological component of the project was undertaken to evaluate whether or not biological monitoring would provide an effective means of identifying wet weather impacts. Both fish and macroinvertebrate monitoring were conducted. While results were somewhat inconclusive, certain characteristics of the macroinvertebrate sampling data tended to respond to wet weather impacts, while fish communities did not appear to be impacted.

9.11 SURVEY DATA

Relevant project data is included with this report on CD. It is provided with GIS-based analysis tools in a system called RPO DataView. This portion of the project was completed by the Rouge River Project.

9.12 LESSONS LEARNED

A number of important lessons were learned during this project and are detailed in Chapter 6. Many involved laboratory QA/QC oversight since large numbers of bacteria samples (one hundred or more) tend to be difficult for laboratories to handle. Another important lesson learned was that delays caused by uncooperative weather must be anticipated and accounted for in project budgets and schedules.

Appendix A

RPO Users Guide

RPO DataView Reference Guide

Version 2.1

SECTION 1 - INTRODUCTION

"It is not the facts that we can put our fingers on that concern us but the sum of these facts; it is not the data we want but the essence of the data."

John Cheever

RPO DataView has been designed as a data exploration tool which combines tabular data viewing, data plotting, summary statistics and spatial display in one easy to use package. In addition, RPO DataView allows for non-numeric data association (linking of graphics, photos and text files) to sites and provides for the creation of ASCII text files for transferring data to other software programs.

System Requirements

- IBM compatible 486 or higher
- CD drive
- Monitor capable of 800x600 resolution
- Mouse or compatible pointing device
- 32 megabytes or more of memory
- Microsoft Windows 95 or later

SECTION 2 - RPO DATAVIEW VERSION HISTORY

RPO DataView Version 1.2 Beta Changes:

- Able to select sites from map
- Able to create new data sets by combining and/or aggregating existing data sets.
- Added option to display flag codes and their descriptions.
- Added full parameter name look-up function.
- Added non-numeric data input procedures.
- Enabled multi-document associations with sites.
- Enabled DataView connection to ArcView 2.1 (currently being tested).
- Added legend to map.
- Added procedures to detect and attempt to repair corrupted database files.
- Added site photos for most rain and continuous water quality sites.
- Configured to run off a CD-ROM.

RPO DataView Version 1.3 Change:

- Resolved the inaccurate plotting of data collected at less than one hour intervals.

RPO DataView Version 2.0 Major Changes

- Added dynamic mapping utilizing ArcView shape files.
- Added ability to display geo-referenced images as “backdrops” for maps.
- Added functionality to export a map to a file or the Window’s clipboard.
- Added a data import wizard.
- Added frequency distribution calculation and display.
- Modified data plotting to allow graphing of data for multiple sites and multiple parameters.
- Added ability to “stack” plots.
- Added support for .jpg, .gif and .wmf files for non-numeric data display.
- Added support for transect, depth and event data.

RPO DataView Version 2.1 Major Changes

- Combined yearly data sets
- Modified combo box population routine to speed up item display
- Modified plot options to work with combined data sets

SECTION 3 – RPO DATAVIEW EXAMPLE DATA SET

Included with this set of data is a data set named Example Data. This data set was included to demonstrate the non-numeric data association capabilities (i.e. linking graphics, photographs and text documents of sites) of RPO DataView. To view this data:

1. Select Example Data as the data set.
2. Click the Map Sites button.
3. In the DataView Mapper window, click the camera icon on the tool bar.
4. Move the cursor over a site which will display a pop-up menu of document types.
5. Double click on the document type desired.
6. Click on the document desired.

The example data contains:

Site D2003581
- graphic: none
- text document: example memo
- photograph: site photo

Site L2003535
- graphic: field data sheet
- text document: none
- photograph: site photo

* Appearance of photographs will be degraded if a video mode utilizing less than 256 colors is used.

SECTION 4 – INSTALLATION AND STARTUP INSTRUCTIONS

4.1 – INSTALLATION INSTRUCTIONS

To install the RPO DataView application do the following:

1. Insert the RPO DataView CD in your CD drive.
2. From Window's Explorer, select **File** menu and choose **Run**.
3. In the command line box type **D:** (or whatever your CD drive letter is) **setup** and press **Enter**.
4. Follow the instructions on the screen.

4.2 STARTING THE APPLICATION AND LOADING DATA

To start RPO DataView, select DataView from the Windows' program list.

After the program is selected, the title screen shown below appears. Click the 'Begin' button to enter the application. Next, double-click the desired data set in the 'Data Set' list box.

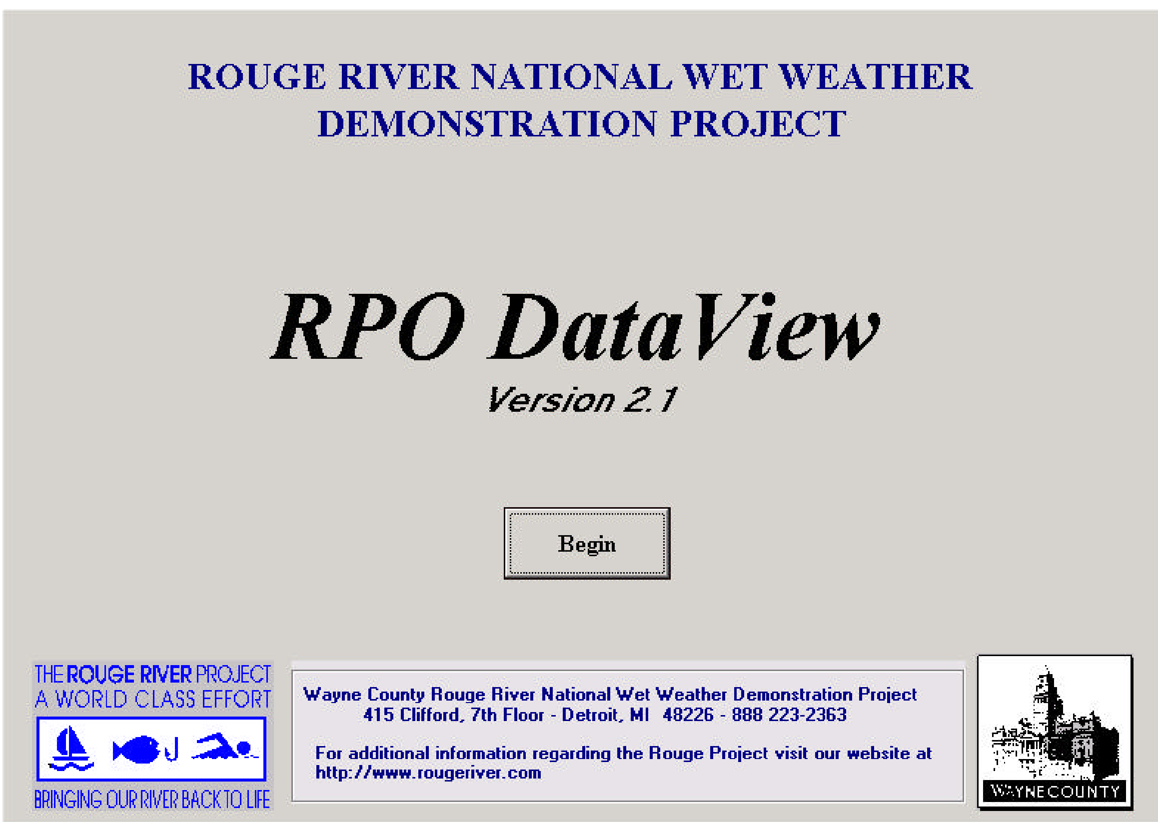


Figure 4.1: Initial Screen

4.2.1 Selecting Sites, Data and Parameters

Single items may be selected by clicking on the desired items in its list box. Multiple contiguous items may be selected by clicking the first item you want to select and dragging down to the last item you want to select or by clicking the first item you wish to select and then, while holding down the SHIFT key, click the last item you wish to select.

Multiple non-contiguous items may be selected by clicking on the items of interest while holding down the CTRL key. Sites may also be selected by clicking on the "Map Sites" button to display a map of the sites. Once displayed the sites can be selected by clicking on their respective dots. Clicking on a selected site will de-select it.

4.2.2 Descriptions of Data Sets, Sites and Parameters

Users may obtain a description of a data set, site or parameter by clicking on the desired item in its list box and pressing the "F1" key on the keyboard.

4.2.3 Removing Tables, Plots or Information Boxes

To remove a plot from the screen click anywhere in the plot. To remove a table or info box, click on the close button in the upper right corner of the window title bar.

SECTION 5 – MAIN WINDOW FUNCTIONS

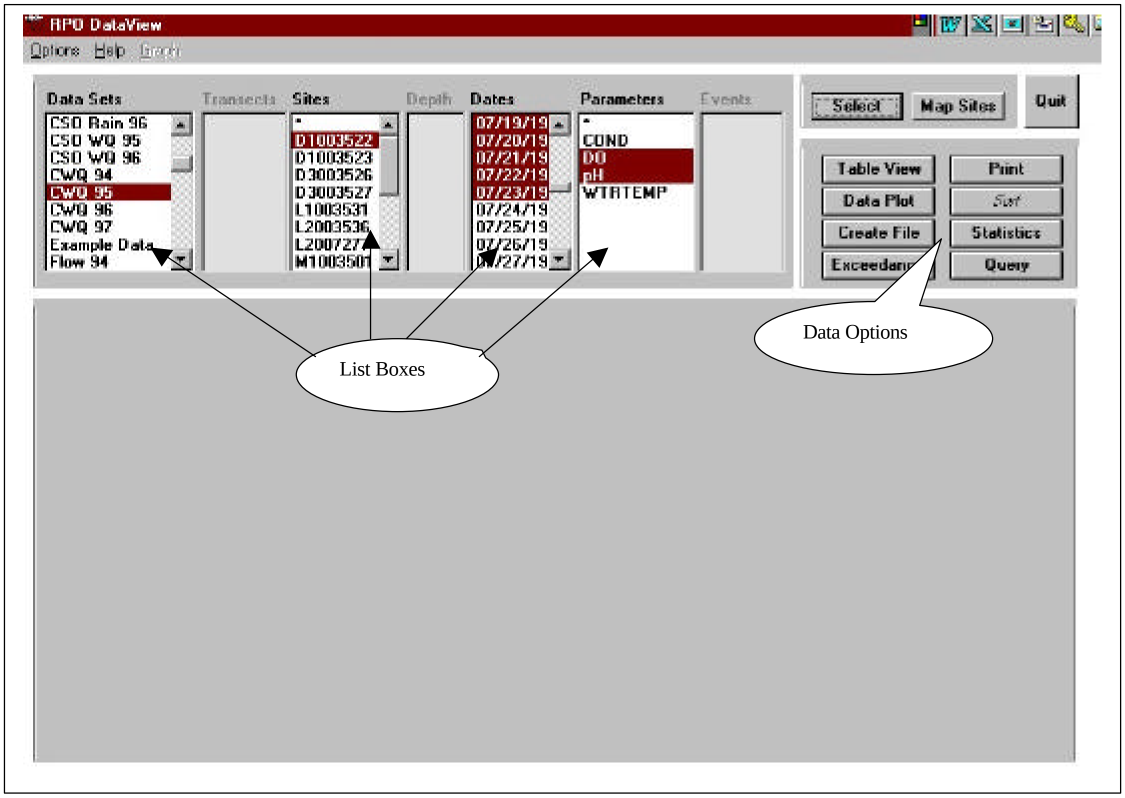
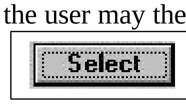


Figure 5.1: Main Window

The main window appears after the user clicks the ‘Begin’ button on the introduction page. The main window is where the user selects the data sets for analysis.

5.1 LIST BOXES AND SELECT

The ‘Data Sets’ list box shows all data sets available. The user selects a single data set by double clicking on an entry in the list box. Once a data set is selected the ‘Sites’ list box is populated with a list of sites available for the selected data set. The user may then select one or many sites. All sites may be selected by clicking on the “*” which appears at the top of the list box. Once sites are selected the user may then select dates and parameters. After all list boxes have selections the user clicks the select button to create a selection set.



A message indicating the number of records in the selection set is displayed briefly on the screen.

A flashing ‘Select’ button indicates changes have been made to the record selection criteria and the current record set no longer represents the selection criteria indicated by the highlighted items in the list boxes. To make the current record set representative of the selection criteria click the ‘Select’ button again.

The ‘Map Sites’ button

displays site locations on a map as colored circles: yellow circles represent selected sites (those highlighted in the Site list box) green circles represent unselected sites. The mapping functions are discussed in detail in section seven of this document.

The 'Quit' button exits the RPO DataView application.

- **DATA VIEW OPTIONS**

A set of data view option buttons is located at the upper right side of the screen. These buttons allow the user to view and manipulate the selected data set. The available data view buttons are shown below in figure 5.2

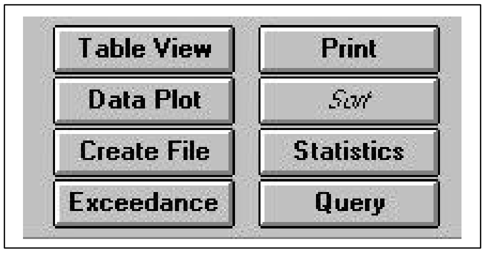


Figure 5.2: Data View Option Buttons

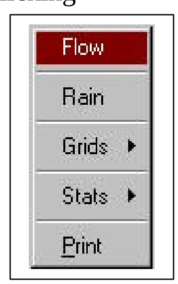
5.2.1 Table View

The 'Table View' button displays selected records in a table according to the option selected in the "OPTIONS" menu. Users may choose from either 'Cross Tabulated' or 'Record' view options. A table displayed in cross tabulated format has all parameters shown on one line with the data sorted by site, date, and time. Tables displayed in record format have each table row representing one database record. In addition to site, date, time and parameter value; units, detection limits and flags are also shown

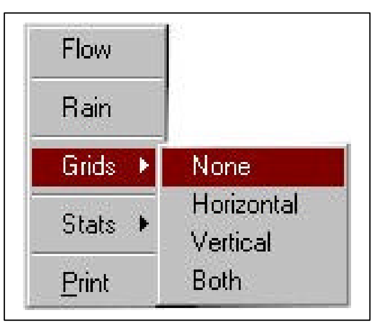
5.2.2 Data Plot

Users can create a plot of the selected data set by clicking on the 'Data Plot' button. Plots can be created for up to six stations with one parameter or two parameters for one station.

Changes to the look of the plot can be made using the data plot menu, accessed by right clicking anywhere on the data plot. The top menu option is 'Flow'. This option plots the flow for a selected station. When the user selects this option a list of stations appears. The user must select one station to be plotted.



The next option on the menu is 'Rain'. The user may plot the rainfall for a selected site. Once the user selects this menu option a list of sites appears on the screen. The user must select one site to plot.



The 'Grids' menu option allows the user to show grids; horizontal, vertical, both or neither. Select the menu option to display the desired grid. Select the 'None' option to turn off all grid lines.

The ‘Stats’ menu option allows the user to display a set of statistics on the graph. Marker lines are shown on the graph when the desired statistic is selected from the menu. The available statistics are shown below in figure 5.3.

To remove marker lines from the data plot select the ‘None’ menu option.

The ‘Print’ menu options allows the user to print out the data plot. This menu option sends a plot file to the user’s default printer.

Click anywhere on the data plot to remove the plot from the screen.

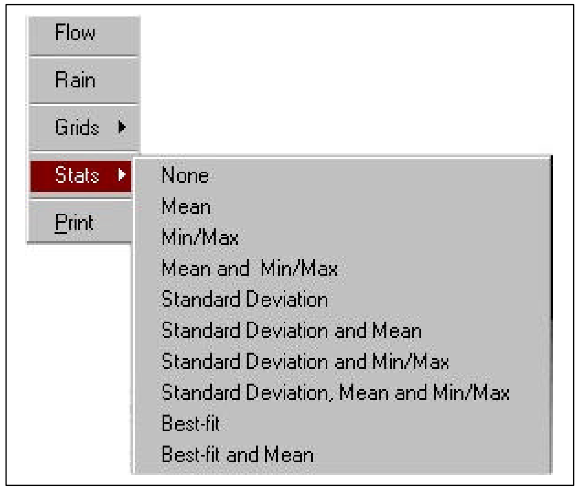


Figure 5.3: Stats Options

5.2.3 Create File

When the user clicks the ‘Create File’ button a dialog box appears. The user may then select the text output criteria. Figure 5.4 shows the text file output criteria dialog box. Set criteria by clicking on the radio button of the desired criteria.

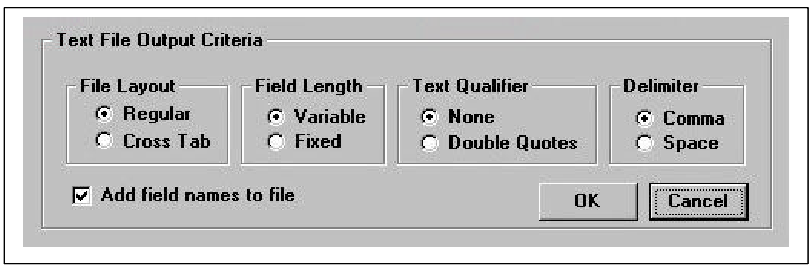


Figure 5.4: Text File Output Criteria

5.2.4 Exceedance

The ‘Exceedance’ button allows the user to view all selected sites where values exceed a set value. Upon clicking the ‘Exceedance’ button an exceedance window appears. Shown in Figure 5.5 at the right this window is where the user can set criteria for a given parameter. When the user clicks the ‘OK’ button on the window a list of all sites that exceed the criteria appear along with the number of times the value exceeds the criteria. The sites are shown on a map when the user clicks the ‘Map Sites’ button. Sites that exceed the criteria set are shown on the map in red. Clicking the Water Quality Criteria button displays various water quality criteria values (if they exist) for the selected parameter.

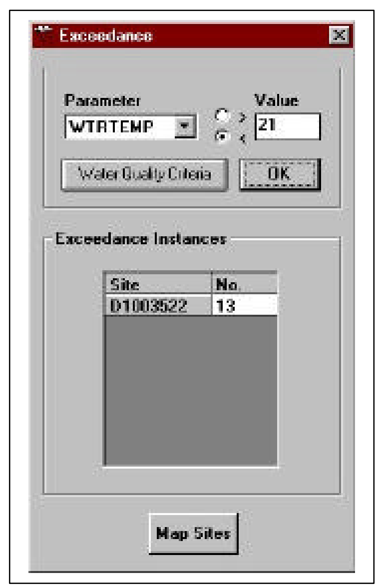


Figure 5.5: Exceedance Criteria

5.2.5 Print

The ‘Print’ button allows the user to print selected records to the default Window's printer. This option, when clicked, brings up a report form, from which the user may print. The form has three buttons at the top of the screen. The button on the right with the envelope icon is an export button. This is another way to export data to another program. The middle button is the print setup button. The user can select a printer and change the page size and orientation using this button. The leftmost button sends the selected records to the printer.

5.2.6 Sort

The ‘Sort’ button allows the user to do a three level sort using site, date/time, parameter or value as sort options. Sorts can be done in ascending or descending order. This button is available only when the table view option is set to ‘Record’. Setting the table view option is discussed in Section 6 of this document. A grayed out ‘Sort’ button indicates that this option is not available because the table option is set to ‘Cross tabulated’. Cross tabulated records are automatically sorted by site, date and time.

5.2.7 Statistics

Clicking the ‘Statistics’ button generates and displays basic statistics about the selected records including: average, min, max, count, sum, standard deviation and variance. Clicking the ‘Freq. Dist’. button in the upper left corner of the ‘Statistics’ window displays the ‘Frequency Distribution’ window.

5.2.8 Query

The ‘Query’ button brings up a query window that allows the user to create a subset of records from the current selection set. The query window is shown below in figure 5.6

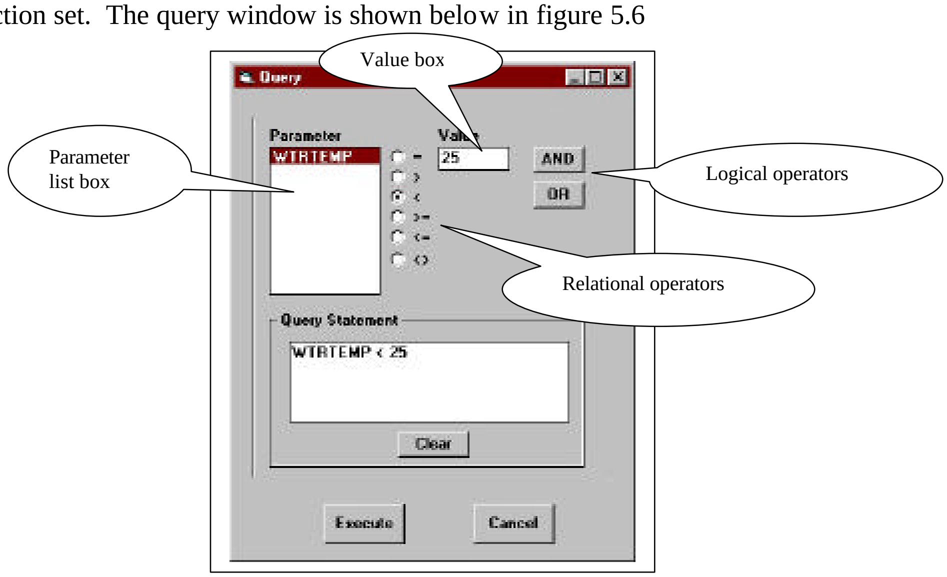


Figure 5.6: Query Window

User the query builder to create a selection set. First, select a parameter from the parameter list box and double click on it to place it onto the ‘Query Statement’ window. Next, select a relational operator from the relational operator list. Make sure the operator you select is placed in the query statement window. Then type a value into the value box and press the ‘ENTER’ key on the keyboard. This will place the value into the query statement window. For multiple parameters use the logical operator buttons to form the query statement. Finally, when the query statement is complete click the ‘Execute’ button.

Once the query is executed the Query Window disappears. A number of the data option buttons will be colored red on the main window. These buttons can be used to view the selected data set. To clear the selection set click the ‘Select’ button on the main interface.

SECTION 6 – OPTIONS MENU

The ‘Options’ menu allows the user to manipulate the data available to be viewed in the application. This menu is where a user may add or delete data sets, control the way the data is viewed, and add non-numeric data to the database. The ‘Options’ menu is shown to the right in Figure 6.1

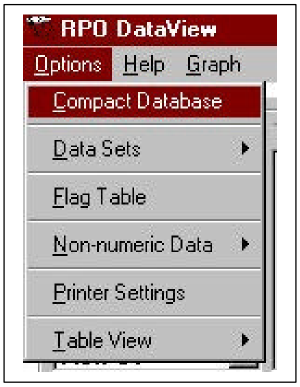


Figure 6.1: Options Menu

6.1 COMPACT DATABASE

The DataView application makes changes to the database during the course of normal operation. The ‘Compact Database’ option optimizes disk space and usually creates a smaller database file. Selection of this option from the menu can take 5 or more minutes.

6.2 DATA SETS

The ‘Data Set’ menu option allows the user to create or import data, edit, and delete data sets. There are three menu options listed under the ‘Data Sets’ option: Create, Delete/Edit, Import.

6.2.1 Create

The ‘Create’ option allows the user to create custom data sets from existing data sets. The new data sets are created by combining and/or sub-setting the available data sets and by selecting an aggregation interval. If daily aggregation is desired, the user may select to have the daily values calculated by summing or averaging. Figure 6.2 shows the ‘Create Data Sets’ dialog box. Buttons shown in pink indicate that a selection is required.

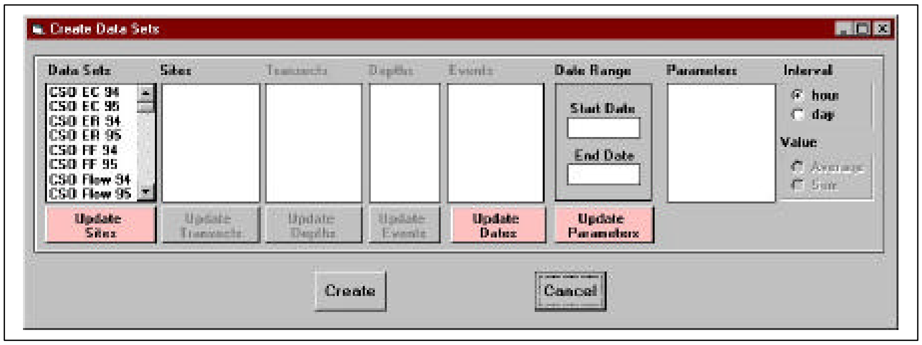


Figure 6.2: Create Data Sets

A custom data set may be created by following the steps listed below:

1. Select the desired data set(s) from the ‘Data Sets’ list and click the pink ‘Update Sites’ button.
2. Select the desired site(s) from the ‘Sites’ list and click the pink ‘Update Dates’ button.
3. The ‘Start Date’ and ‘End Date’ default to the minimum and maximum dates in the selected data set(s). If other dates are desired, enter them into the date boxes. Once the dates have been entered click the red ‘Update Parameters’ button.
4. Select a parameter(s) from the ‘Parameter’ list.
5. Select an interval with which to report the data, ‘hour’ or ‘day’.
6. If day is selected as the reporting interval, enter the type of value aggregation desired, ‘Average’ or ‘Sum’.
7. Click the ‘Create’ button to create the data set.

8. When prompted enter a name for the new data set (not to exceed 16 characters) and click the ‘OK’ button.
9. Once the data set has been created it must be registered with RPO DataView. When the Add Data Set window appears, enter a description for the data set and click ‘OK’. The data set is then automatically added to the data set list box and is available for use.

6.2.2 Delete/Edit

The ‘Delete/Edit’ option allows the user to edit information in the data set info table and to delete data sets from the database. Figure 6.3 shows the ‘Delete/Edit Data Set’ information dialog box.

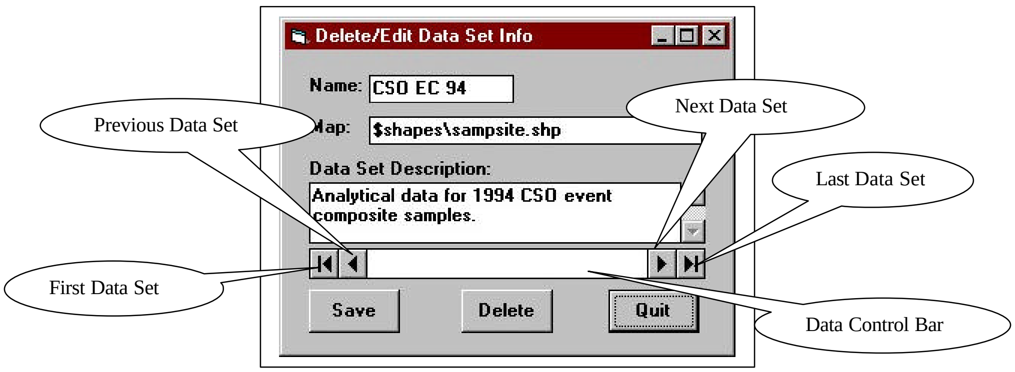


Figure 6.3: Delete/Edit Data Set Information

Users may edit or delete data sets by following the steps listed below**:**

1. Select the data set of interest using the data control bar to move through the data sets.
2. When the desired data set information is displayed, make appropriate changes to the ‘Data Set Description’ box.
3. Click the ‘Save’ button to save the changes.
4. Click the ‘Delete’ button to delete the data set listed.

NOTE: Only the Data Set Description should be changed by the user.

6.2.3 Import

The ‘Import’ option allows the user to import data into the application. Data may be in the following formats: Microsoft Access, dBase, Excel or comma delimited text. See *Appendix A – Data Import* for additional information on required file structure.

Data sets may be added to the application by following the steps listed below:

1. Select ‘Import’ from the ‘Data Sets’ menu under the ‘Options’ menu.
2. Identify the data source type by clicking in the dialog box that appears on the screen and click the ‘Next’ button.
3. Identify the data set.
4. Enter a name and description for the data set and associate a map file by clicking the ‘Browse’ button and identifying a shapefile which contains the mapped data.
5. Click the ‘Next’ button to move through the information screens. The application performs some preliminary data checking before attempting to import data. Figure 6.4 shows the error reporting screen, which indicates any errors found prior to import.
6. The final entry screen has a ‘Finish’ button. Click the ‘Finish’ button to complete the import process. Once the import process is complete the newly added data set appears in the list of data sets.

6.3 FLAG TABLE

The 'Flag Table' menu option allows the user to view descriptions of all data flags used in the database. Data flags are only visible when the table is displayed using the 'Record' view option. Table view options are discussed in section 6.6 of this document. The 'Print Flag Table' button prints the flag table to the default Windows's printer.

6.4 NON-NUMERIC DATA

The 'Non-numeric Data' menu option allows the user to associate text files, graphics and/or photographs with site locations. Text files must be in ASCII text format and their size is limited to that which can be accommodated by MS Windows Notepad. Graphics and photographs can be stored as .bmp, .jpg, .gif or .wmf formats and can be of any size.

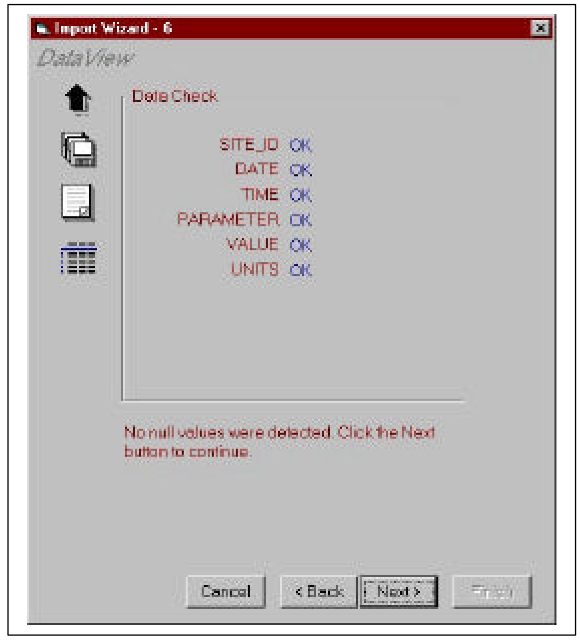


Figure 6.4: Data Check Screen

In order to add non-numeric data to the database the user must first copy the text, graphic and/or photograph files to be used into the \UDOCS directory which can be found under the directory in which RPO DataView was installed. Next, select the 'Non-numeric Data' menu option and click 'Add/Delete'option in the menu. This brings up the Non-numeric Data dialog box, shown below in Figure 6.5. Then click the 'Add' button.

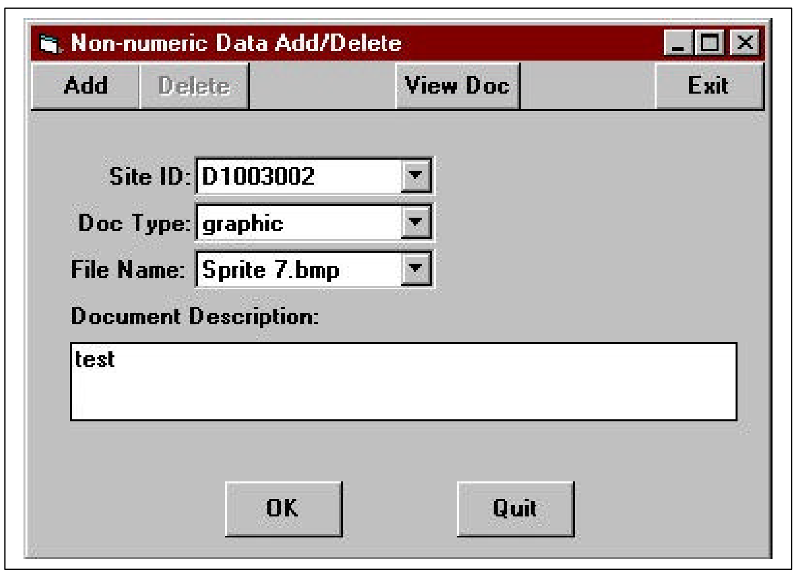


Figure 6.5: Non-numeric dialog box

Select the site from the site drop down box and then select the document type. Then select the specific file name and enter a description. Once the file is selected it may be viewed by clicking the 'View Doc' button. Finally, click the 'OK' button to associate the document with the site.

To delete a document, select the document and click the ‘Delete’ button. The ‘Delete’ button only removes the document association to the site in the database. ‘Delete’ does not delete the document file from the computer.

6.5 PRINTER SETTINGS

The ‘Printer Settings’ menu option opens a standard MS Windows printer properties dialog box. Users may change printer settings from this dialog box.

6.6 TABLE VIEW

The ‘Table View’ option determines how the records will be displayed when a table view is requested. The ‘Cross Tabulated’ option displays records in a spreadsheet-like format with each parameter in a separate column. Figure 6.6 shows an example of the ‘Cross Tabulated’ option. The ‘Record’ option displays the data as it is stored in the database, with each row representing a single parameter at a given site, date and time. In addition to the site, date, time, parameter and value information, the ‘Record’ format displays value units, detection limit, detection limit units, data flags, and if appropriate transect, depth, depth units and event data. Figure 6.7 shows the data displayed using the ‘Record’ option.

Site_ID	Date	Time	BOD5	CBOD
D1003522	6/13/94	11:19 AM	4.8	4.6
D1003522	6/13/94	3:01 PM	2.4	3.2
D1003522	6/13/94	6:04 PM	3.4	4.5
D1003522	6/13/94	8:06 PM	4.2	
D1003522	6/13/94	10:10 PM	2	2

Figure 6.6: Cross Tabulate Format

Site_ID	Date	Time	Parameter	Value	Units	DL	DL_Units	Flag
D1003522	6/13/94	11:19 AM	BOD5	4.8	MG/L	2	MG/L	NONE
D1003522	6/13/94	11:19 AM	CBOD	4.6	MG/L	2	MG/L	NONE
D1003522	6/13/94	3:01 PM	BOD5	2.4	MG/L	2	MG/L	NONE
D1003522	6/13/94	3:01 PM	CBOD	3.2	MG/L	2	MG/L	NONE
D1003522	6/13/94	6:04 PM	BOD5	3.4	MG/L	2	MG/L	NONE

Figure 6.7: Record Format

SECTION 7 – MAP SITES

The Map Sites component of the application allows users to locate sites geographically. Users can add layers to the basemap, change the legend, and display results of basic queries. Click on the 'Map Sites' button on the main window to display the map window. The mapping window displays sites in the current selection set of data.

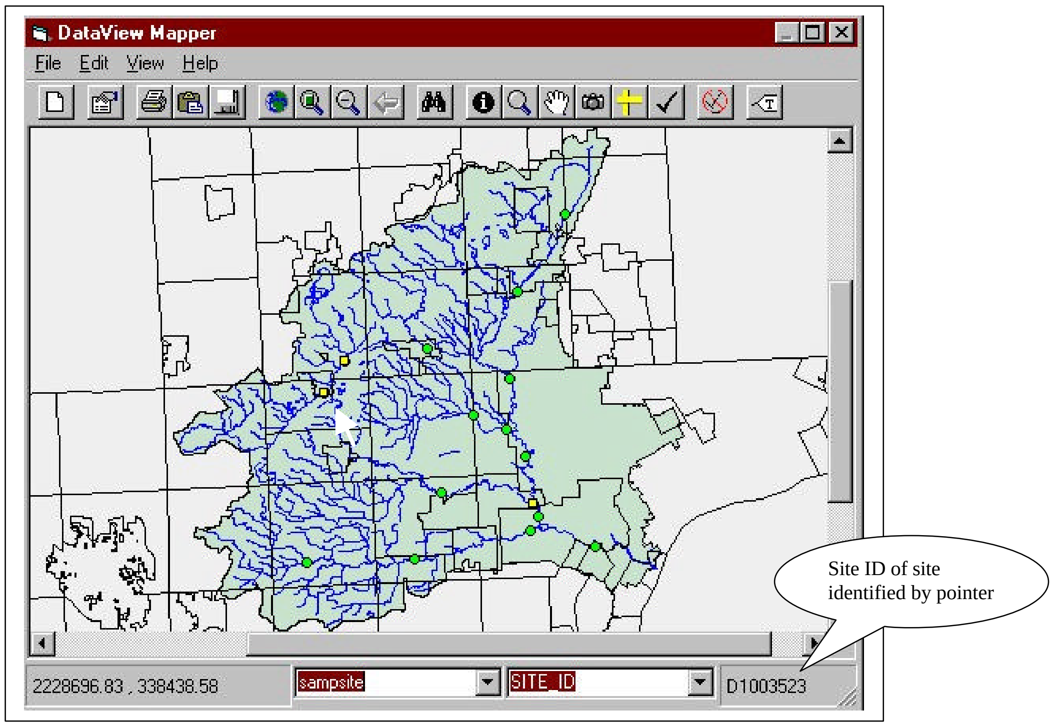


Figure 7.1: Map Display Window

Selected sites are displayed as yellow squares while other sites in the data set are represented by green circles.

The top of the map window contains drop down menus. Below the menus are tools and buttons. The bottom of the window contains x,y coordinates which change as the user moves the cursor around the screen. There are two drop down windows also located at the bottom of the window. The leftmost drop down box lists the data layers present in the display window. Make a layer active by selecting it from the drop down list. Once a layer is made active a field may be chosen from the second drop down list. The values in this field are then visible as the pointer passes over each feature on the map.

7.1 GRAPHICAL USER INTERFACE (GUI)

The button and tools located under the menu list at the top of the map window constitute the graphical user interface(GUI). Figure 7.2 shows the GUI.

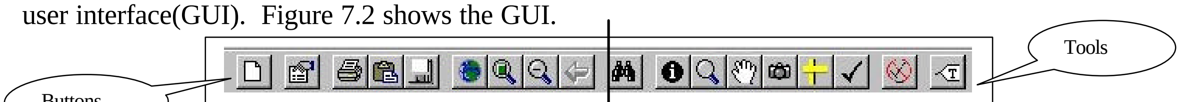


Figure 7.2: Map View GUI

The first nine icons from the left represent buttons while the remaining icons represent tools. Buttons are one-time actions; the user clicks a button and a process happens. Buttons are also shortcuts to menu items listed in the menus. Tools exist only on the interface as an icon; they are not accessible from the menus. Tools are also for multiple time uses. The user clicks a tool and then performs an action. The tool remains selected so that action may be performed repeatedly.

7.1.1. File Menu

The 'File' menu contains the functions associated with the map display. The 'Export Map' function allows the user to export the map to a Windows Metafile (WMF) or a .BMP file or to save it to the Window's clipboard
The 'New' menu option allows the user to add new layers of data to the current map or create an entirely new map. Clicking the 'Layer' menu item brings up a selection window through which a user may select additional map layers to add to the current map. Clicking the 'Map' menu option clears out the current map window. Users must then add layers to the new map.

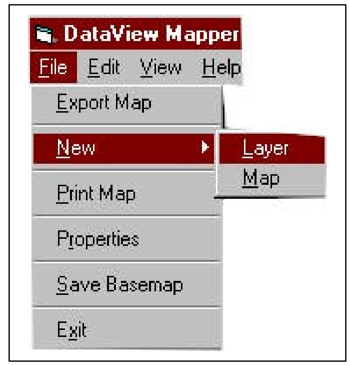


Figure 7.3: File Menu

Clicking the 'Print Map' button sends the map to the default Windows printer.

The 'Properties' menu item activates the 'Map Properties' dialog box. This dialog box is the layer control. Layer properties such as color, drawing order, fill patterns, and marker symbols are set from this dialog box. Figure 7.4 shows the 'Map Properties' dialog box.

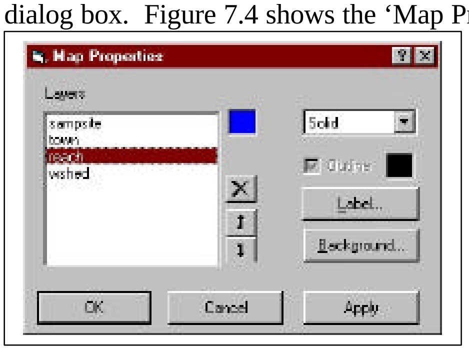


Figure 7.4: Map Properties Dialog Box

All layers present in the Map Window are listed in the list box at the right. The arrows in the center of the dialog window control the drawing order of the layers. Select a layer by clicking on it and then use the arrows to move the selected layer up or down. The 'X' button deletes the selected layer.

Colors and symbols may be changed by clicking on the color button or the symbol drop down list box. Only the color and symbol of the selected layer will be changed. Label height and font style can be set by clicking the 'Label' button. All changes to layer display are only applied to the map when the 'Apply' button is clicked.

The 'Save Basemap' button saves the current basemap.

7.2.2 Buttons

The buttons on the toolbar are shortcuts to the menu items. The first five buttons from the left are shortcuts to menu items listed in the 'File' me nu. Placing the cursor over a button will bring up tip text, text that describes the function of the button.

The next four buttons control the view extent. The view extent can also be adjusted using the 'View' menu options.

The 'Zoom to Extents' button zooms to the full extent of all map layers.

The 'Zoom to Layers' button zooms to the extent of the active layer. The active layer is listed in the drop down list at the bottom of the Map window.

The 'Zoom Out' button zooms out 2 times from the center of the display window.

The 'Zoom Previous' button zooms to the previous extent.

7.1.3 Tools

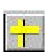
The remaining icons on the GUI are tools. Each tool is shown below and accompanied by a description of how to use the tool. The 'Find' tool is discussed later in Section 7.2 of this document.

The 'Identify' tool brings up the database record associated with the feature clicked. Click the tool then click a feature on the map.

The 'Zoom Box' tool allows the user to zoom in to a specified area in the map window. Click the tool and then draw a box around the area to zoom to.

The 'Pan' tool allows the user to move around the map window. Click the 'Pan' tool and then drag the map view window to move.

The 'Photo' tool allows the user to view graphics associated with a particular site. When the tool is active, moving the cursor over a site with associated graphics will cause a pop-up menu of graphic types to be displayed. Click on the type of graphic to view and then double click the document desired.



The 'Distance' tool allows the user to measure the distance between two points on the map window. Click the tool and then click the two points. A message box then appears on the screen displaying the distance, in feet, between the two points clicked.

The 'Select' tool can be used to add sites to the selection set by clicking on them.

The 'Clear Select' tool clears the site selection set.

The 'Label' tool allows the user to place labels on the Map window. The label tool labels the active layer, listed in the drop down list at the bottom left of the Map window. The field listed in the right drop-down window is the field used for labeling.

The 'Find' tool located on the toolbar brings up a query window. This window may also be accessed from the 'Edit' menu. Use the query window to select a particular site or sites that meet the search criteria entered in the query window. After executing a query the features that match your selection criteria will be selected.

Appendix A – Data Import

Data may be imported to DataView from a variety of file formats including:

- dBase
- Fox Pro
- Access
- Excel
- Delimited Text File

Regardless of the input file format used, each file must contain the following fields:

Field Name	Data Type	Description
SITE_ID*	Text	Sample location ID
TRANSECT	Text	Transect ID
DEPTH	Number	Depth value
DEPTHUNITS	Text	Units of depth value
EVENT	Text	Event type
DATE*	Date	Date of sample collection
TIME*	Time	Time of sample collection
PARAMETER*	Text	Parameter type
VALUE*	Number	Value of measurement
UNITS*	Text	Units of measurement
DL	Number	Detection limit of measurement
DL_UNITS	Text	Units of detection limit of measurement
FLAG	Text	Data flag
METHOD	Text	Sample analysis method
SAMPLETYPE	Text	Type of sample

Fields marked with * must be populated. Other fields may be left empty but they must be included.

Data Import Tips

<u>Excel</u>

- Make sure time field is formatted as time (1:20 pm) and date field is formatted as date (3/16/99)
- Select all data (Press shift end, shift right arrow, shift end, shift down arrow)
- Click name bar and name the selection “Importtemplate”
- Save changes

<u>Dbase</u>

Time should be entered in a text field.

<u>MS Access</u>

Name the table to be imported *ImportTemplate*

<u>Text</u>

Files should be comma delimited.

Appendix B

Evaluation of Wet Weather Impacts on Dissolved Oxygen in the Ohio River

Memorandum

TO: Jim Gibson

DATE: March 22, 2000
PROJECT: ORSA2

FROM: Hans Holmberg

COPIES: Dave Dilks

SUBJECT: Evaluation of Wet Weather impacts on Dissolved Oxygen in the Ohio River

Summary

This memorandum presents an evaluation of the relationship between rainfall in the Cincinnati/Northern Kentucky area and dissolved oxygen levels downstream at Markland Locks and Dam on the Ohio River. This evaluation was conducted to make a preliminary determination if wet weather loads to the Ohio River from the Cincinnati area have a significant impact on dissolved oxygen levels downstream.

Empirical relationships between rainfall in the Greater Cincinnati/Northern Kentucky area and the percent saturation of dissolved oxygen at Markland Locks and Dam were analyzed. This evaluation was based on six years of rainfall data and continuous dissolved oxygen measurements. Total daily rainfall was plotted versus percent saturation. Time lags were given consideration for the time it takes rainfall to result in CSO loads to the Ohio River, and travel time from the point where loads enter the river to the dissolved oxygen measurements at Markland Locks and Dam.

The results of the evaluation conducted by LTI showed no significant correlation between rainfall and dissolved oxygen saturation downstream in the Ohio River. This provides empirical evidence that wet weather loads from the Cincinnati/Northern Kentucky area do not significantly impact dissolved oxygen levels downstream. This conclusion will be tested by conducting sensitivity analyses using the water quality model. Also, final calibration/validation of the water quality model may be possible using available data and additional data to be collected in 2000.

Study Area

The study area for this evaluation includes the Ohio River from river mile 460, just upstream of the Little Miami River confluence, to Markland Locks and Dam at river mile 531. The reach of the river with CSOs under study extends from the Little Miami River confluence to the Great Miami River confluence around river mile 490.

Available Data

Data were collected for the months of May through October from 1994 through 1999. These data included total daily precipitation at the Greater Cincinnati/Northern Kentucky Airport, daily average dissolved oxygen concentration and water temperature at Markland Dam, and daily average flow and velocity at Cincinnati and Markland Dam.

Daily average percent saturation of dissolved oxygen at the Markland Dam was calculated based on the daily average of measured dissolved oxygen concentrations and water temperature. Percent saturation was used in order to evaluate dissolved oxygen independent of temperature effects on saturation.

Time Lag Considerations

Total daily precipitation on a given day was paired with the daily average percent saturation for the date that wet weather loads were expected to arrive at Markland Dam. The time lag was determined based on two factors. First, a time lag of twelve hours was assumed to account for the time it takes for CSOs to discharge from the beginning of a rainfall event. Second, the average of the velocities at Cincinnati and Markland Dam were used to estimate the time-of-travel for the wet weather load to reach Markland Dam. The time-of-travel was determined for three separate cases, depending on the point where the load was assumed to enter the river. These cases included the load entering the river at: the upstream end of the CSO reach at river mile 460; the middle of the CSO reach at river mile 475; and the end of the CSO reach at river mile 490. The time-of-travel ranged from 1 to 7 days, depending on the observed velocities and point where loads were assumed to enter the river. These three cases bracket the spatial range of potentially significant wet weather sources.

Results

Paired total daily precipitation and time-lagged percent saturation were plotted for all days with non-zero precipitation. The plots of percent saturation versus rainfall are presented below for each time-of-travel case, as Figures 1, 2, and 3. A linear regression was applied in each case. The results show that no significant correlation exists between rainfall and percent saturation for any of the cases, as represented by the very small values of the sample coefficient of determination (R^2). Also the slope of the fitted line is basically flat, meaning that no trend of decreasing percent saturation with increasing rainfall was observed. If wet weather loads significantly impact dissolved oxygen, a downward trend or negative slope would be expected in the plots of percent saturation versus rainfall. These results indicate that wet weather loads do not significantly impact dissolved oxygen levels at Markland Dam, as represented by percent saturation.

Rainfall versus percent saturation was also plotted only for days that the flow in the Ohio River was less than 20,000 cfs. This analysis would represent potentially worst case conditions for wet weather impacts on dissolved oxygen. The results are plotted for the three time-of-travel cases in Figures 4, 5, and 6. These results also indicate that wet weather loads do not significantly impact dissolved oxygen levels.

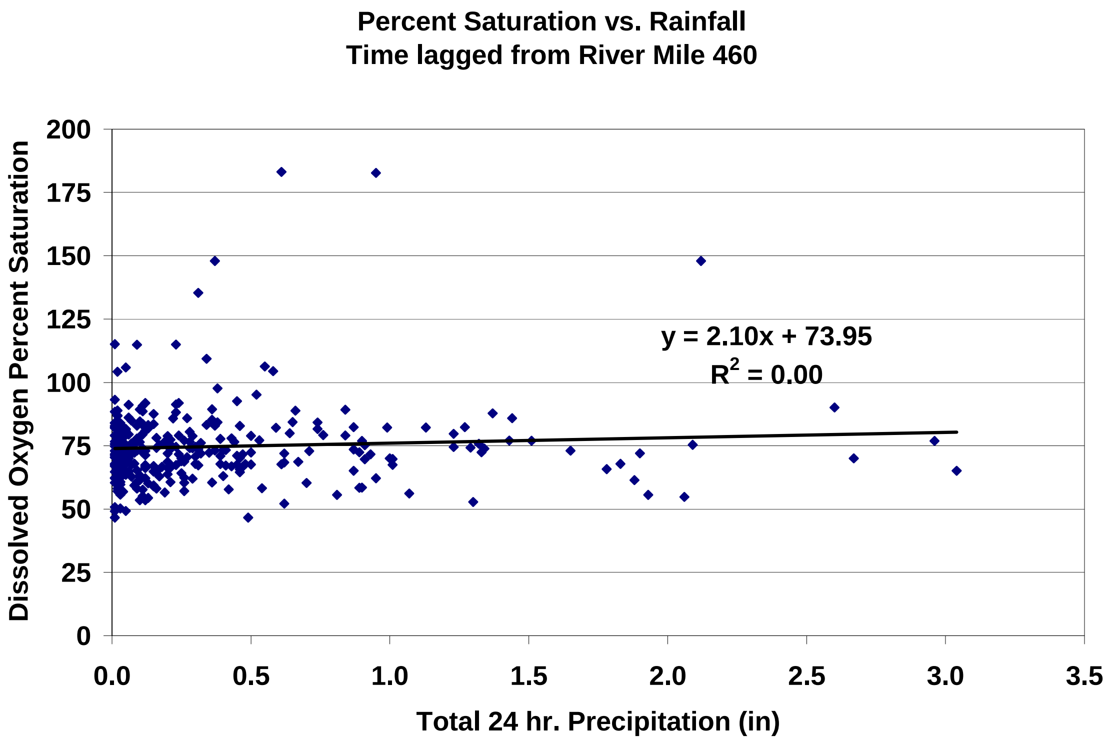


Figure 1.

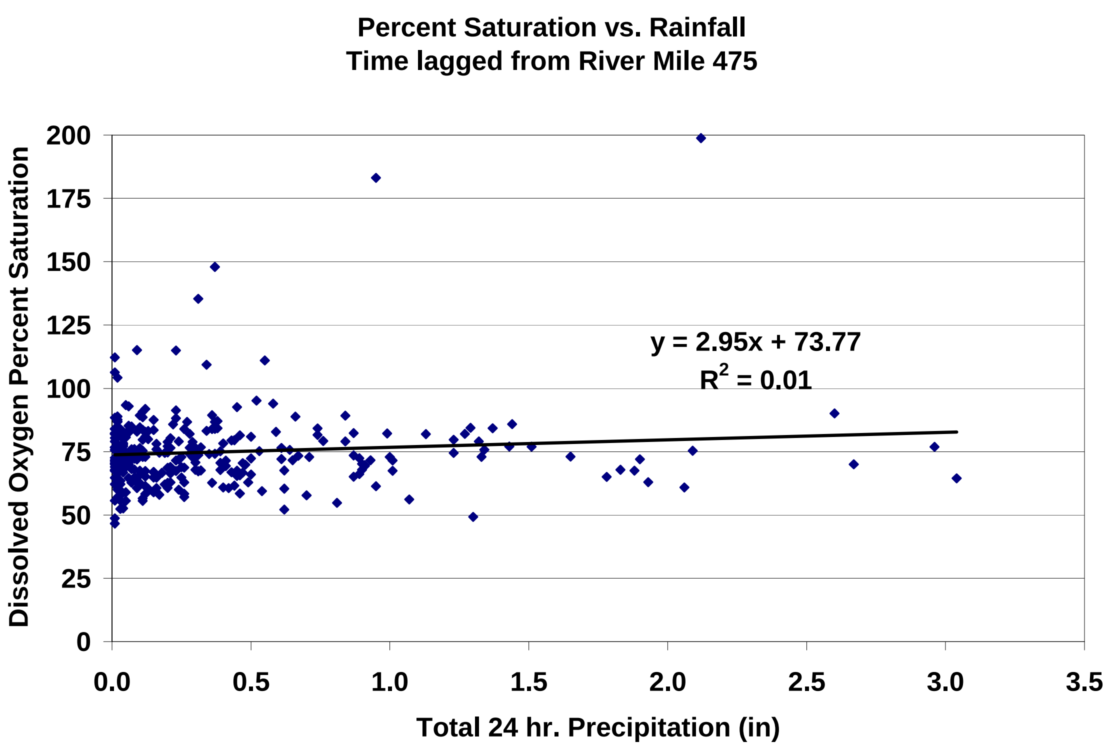


Figure 2.

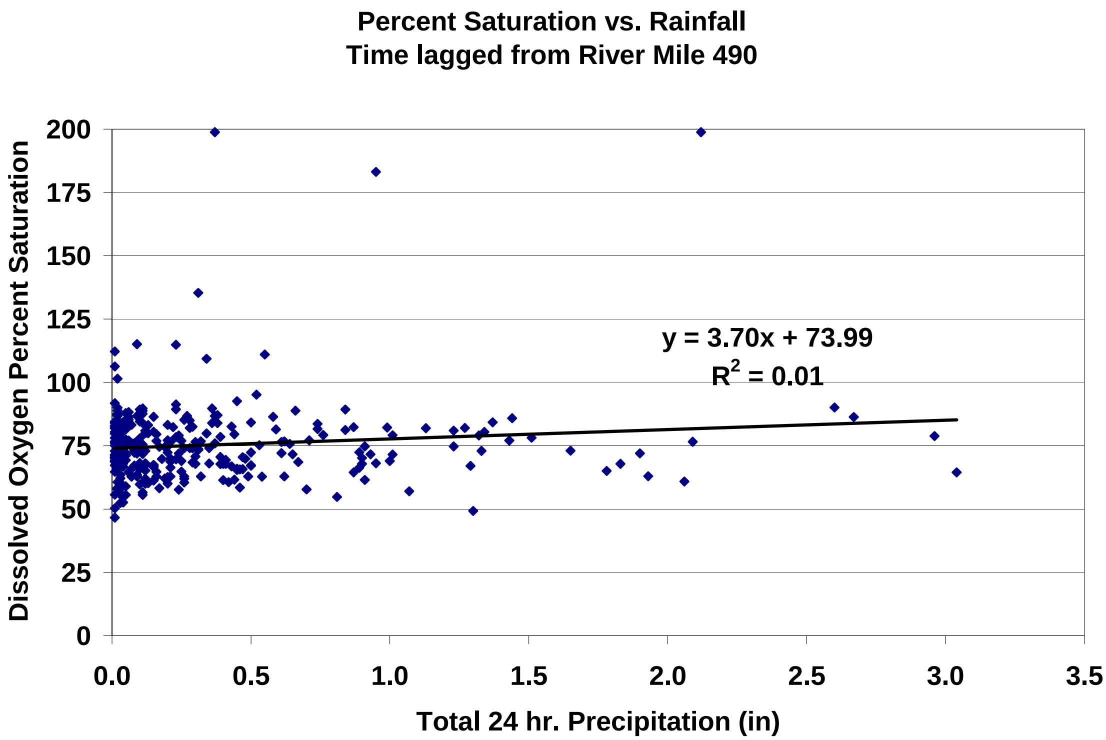


Figure 3.

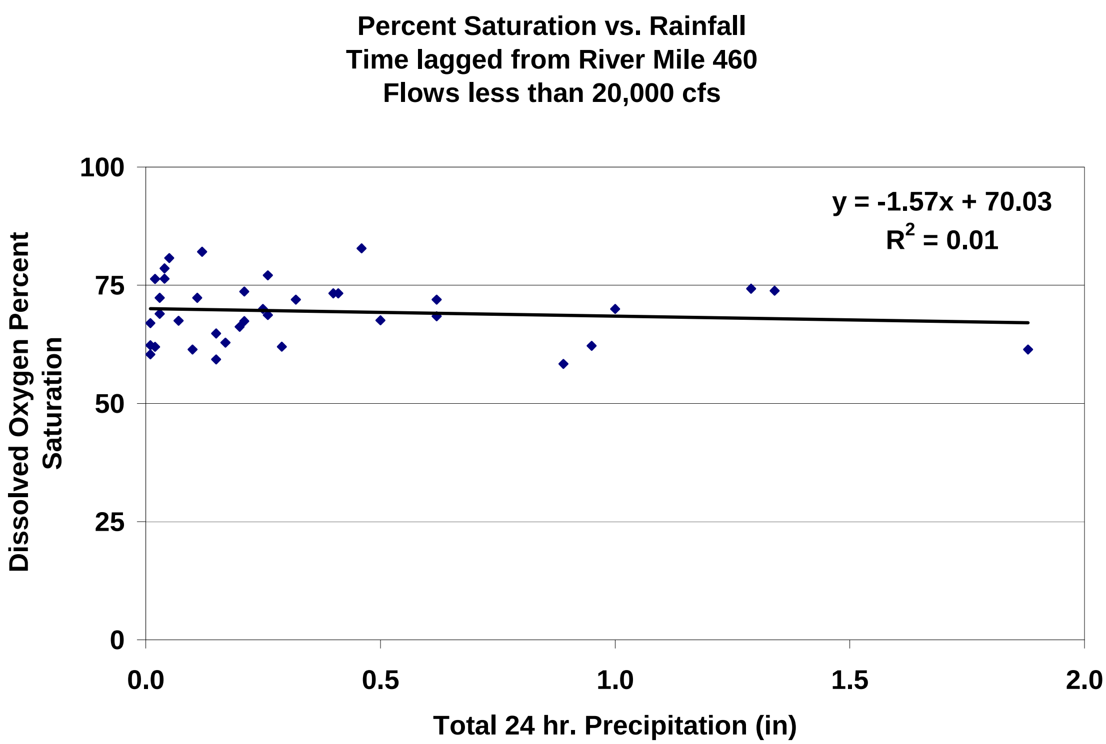


Figure 4.

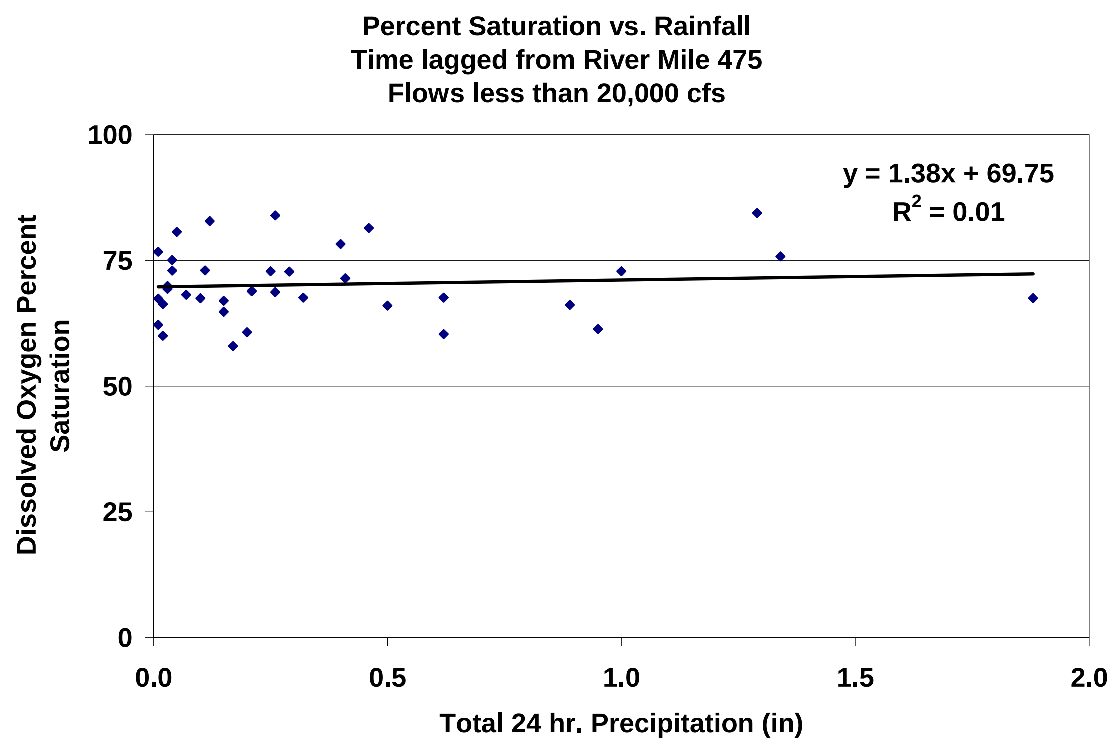


Figure 5.

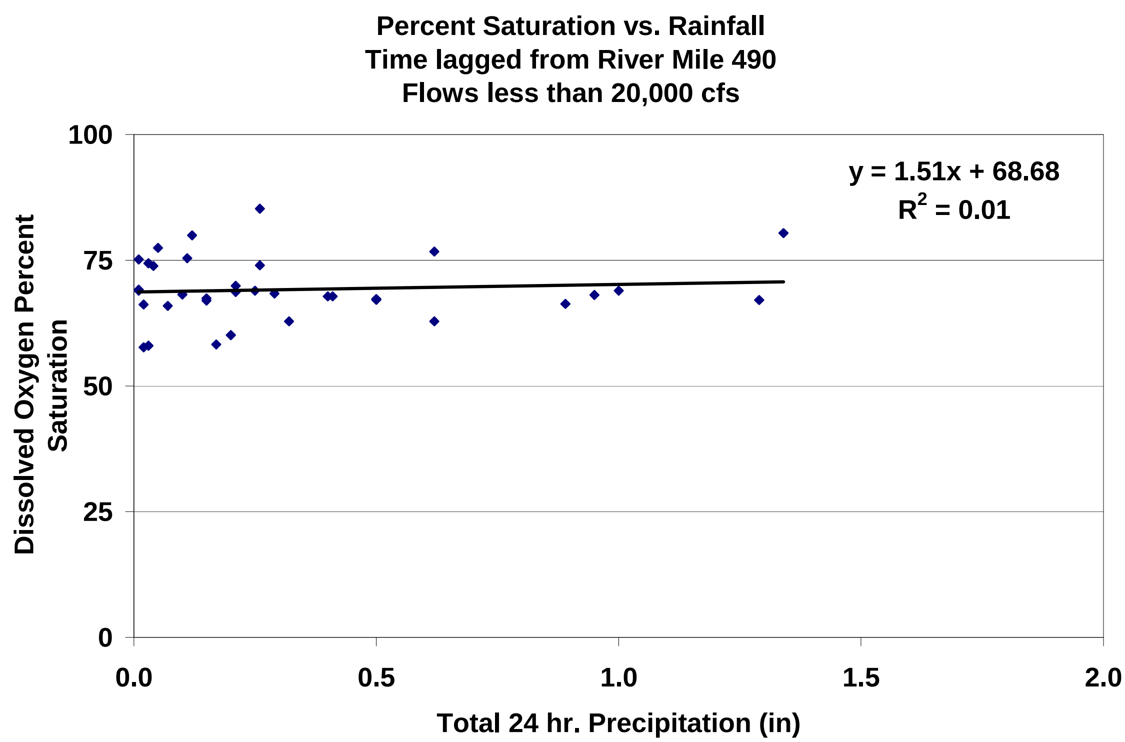


Figure 6.

Appendix C

Daily Combined Sewer Overflow Fecal Coliform Loadings During Calibration Event.

Appendix C. Daily Combined Sewer Overflow Fecal Coliform Loadings During Calibration Event.

KPDES#/ Ohio ID #	Description	Maximum Fecal Coliform Loading Rate (#/day)	Fecal Coliform Load on 5/27/00 (first day of storm)	Fecal Coliform Load on 5/28/00	Fecal Coliform Load on 5/29/00	Fecal Coliform Load on 5/30/00	Fecal Coliform Load on 5/31/00
SGPS	Silver Grove Pump Station	0	0	0	0	0	0
HHPS	Highland Heights Pump Station-Overflow#1	1.11E+14	5.25E+12	0	0	0	0
HHPS	Highland Heights Pump Station-Overflow#2	4.94E+14	7.59E+13	2.16E+13	1.35E+13	6.60E+12	0
11	Government Sewer	1.71E+14	1.06E+13	0	0	0	0
12	Tower Hill Road	8.49E+13	1.28E+13	8.56E+06	0	0	0
14	Burnet Ridge	1.98E+14	1.79E+13	0	0	0	0
13	Manor Lane	2.54E+14	1.83E+13	1.40E+08	0	0	0
15	Elsmar Street	9.59E+13	4.60E+12	0	0	0	0
OH-OF	SSO (bypass)	1.77E+14	5.66E+13	3.41E+13	1.69E+13	9.75E+12	0
BELL-OF	SSO (elevated OF into CR near Bellevue)	2.41E+14	5.82E+13	0	0	0	0
16	McKinney Street	9.24E+15	5.39E+14	9.78E+12	0	0	0
17	Main Street	4.05E+15	2.62E+14	8.02E+12	0	0	0
18	Foote Avenue	3.36E+14	2.18E+13	2.00E+12	4.42E+11	4.28E+11	4.28E+11
19	Ward Avenue	1.93E+15	1.25E+14	1.08E+13	1.35E+12	1.28E+12	1.28E+12
20	Washington Avenue	6.93E+14	4.00E+13	3.98E+11	0	0	0
21	Taylor Avenue	9.72E+14	5.54E+13	7.24E+11	0	0	0
22	Lafayette Avenue	3.72E+14	2.08E+13	1.01E+11	0	0	0
23	Patchen Street	6.01E+14	4.07E+13	3.57E+12	0	0	0
83	Riverside Drive	1.83E+09	7.64E+07	0.00E+00	0	0	0
24	Interceptor Overflow	1.63E+15	4.42E+14	3.83E+14	1.72E+14	1.68E+14	1.61E+14
24	Washington Ave Chmbr	1.93E+15	1.16E+14	4.47E+12	0	0	0
25	Geiger Avenue	8.62E+14	2.11E+14	4.80E+13	1.33E+12	1.32E+12	1.32E+12
26	Taylor Bottoms	2.48E+14	2.42E+13	0	0	0	0
28	Saratoga Street	5.75E+14	3.95E+13	5.71E+12	0	0	0
31	Columbia St. Chamber	1.23E+15	7.40E+13	2.75E+12	0	0	0
56	2nd St. @ Russell St. (and Wash. St)	6.40E+14	4.09E+13	2.93E+12	0	0	0
58	Madison Avenue (and 2nd St)	3.48E+14	2.32E+13	2.46E+12	0	0	0
59	Scott Street	1.54E+14	8.23E+12	0.00E+00	0	0	0
60	Greenup Street	2.52E+14	1.53E+13	6.82E+11	0	0	0
61	Garrard Street	1.73E+14	1.18E+13	8.50E+11	0	0	0
62	Philadelphia Street	3.03E+14	1.84E+13	8.39E+11	0	0	0
63	Bakewell Street	1.62E+14	9.39E+12	2.22E+11	0	0	0
63	Main Street	9.06E+14	5.68E+13	2.63E+12	0	0	0
63	Johnson Street	1.33E+14	8.89E+12	8.30E+11	0	0	0
30	Willow Run (and #49 and 7 others)	8.89E+15	7.34E+14	1.57E+14	5.03E+13	5.01E+13	5.02E+13
64	Swain Court	1.57E+13	1.01E+12	0	0	0	0
65	Parkway @ Highway	8.28E+14	6.78E+13	4.87E+12	0	0	0
66	Altamont Street	1.29E+15	9.48E+13	1.17E+13	0	0	0
68	Adela Street	0	0	0	0	0	0
69	Kenner Street	1.60E+14	9.62E+12	3.25E+11	0	0	0
70	Butler Street	1.42E+14	9.87E+12	3.77E+11	0	0	0
71	Carneal Street	2.95E+14	2.02E+13	2.13E+12	0	0	0
72	Ash Street	1.79E+14	1.31E+13	0.00E+00	0	0	0
73	Lagoon Street	5.29E+14	3.95E+13	3.96E+12	0	0	0
74	Rohman Street	4.56E+14	3.36E+13	3.65E+12	0	0	0
75	Pleasant Street	2.44E+14	1.93E+13	1.79E+12	0	0	0
BRPS	Bromley Pump Station	0	0	0	0	0	0
	1-ovf	0	0	0	0	0	0
	314-o	0	0	0	0	0	0
417	Bold Face #3 D.D.	2.06E+14	1.17E+13	6.71E+11	0	0	0
418	River Road A.D.D.	7.85E+12	3.51E+11	0.00E+00	0	0	0
419	Bold Face Sr. D.D.	2.12E+15	2.69E+14	1.31E+13	0	0	0

Appendix C. Daily Combined Sewer Overflow Fecal Coliform Loadings During Calibration Event.

KPDES#/ Ohio ID #	Description	Maximum Fecal Coliform Loading Rate (#/day)	Fecal Coliform Load on 5/27/00 (first day of storm)	Fecal Coliform Load on 5/28/00	Fecal Coliform Load on 5/29/00	Fecal Coliform Load on 5/30/00	Fecal Coliform Load on 5/31/00
420	Delhi Ave. D.D.	0	0	0	0	0	0
421	River Road & Delhi D.D.	0	0	0	0	0	0
422	Mt. Echo Rd Regulator	1.28E+15	9.86E+13	1.97E+13	6.32E+09	0	0
423	Mt. Hope Ave. Regulator	8.23E+14	6.55E+13	1.34E+13	6.32E+09	0	0
424	River Rd. at State D.D.	6.22E+13	2.59E+12	0	0	0	0
425	State Ave. D.D.	1.94E+14	1.16E+13	9.39E+11	0	0	0
426A	Evans & River Rd. #1 D.	1.05E+12	4.37E+10	0	0	0	0
426B	Evans & River Rd. # 2 D.	0	0	0	0	0	0
427	Perin & Evans D.D.	0	0	0	0	0	0
428	South St. Regulator	6.05E+14	3.98E+13	3.65E+12	0	0	0
429	Gest St. East D.D.	5.26E+13	2.19E+12	0	0	0	0
430	Gest St. West 2-A D.D.	4.03E+13	1.68E+12	3.98E-14	0	0	0
431	McLean St. D.D.	7.20E+14	6.05E+13	0	0	0	0
432	9th St & McLean D.D.	6.17E+11	2.57E+10	0	0	0	0
433	Carr St. Regulator	2.59E+13	1.28E+12	7.85E+09	0	0	0
434	Carr & Front D.D.	0	0	0	0	0	0
435	Baymiller St. Regulator	0	0	0	0	0	0
436	Gest & Front Regulator	4.90E+13	2.72E+12	1.33E+11	0	0	0
437	Smith St. Regulator	3.48E+13	1.96E+12	1.03E+11	0	0	0
438	Central Ave. West G.	9.53E+12	3.97E+11	0	0	0	0
442	Vine St. Regulator	0	0	0	0	0	0
445	Riverfront Stadium Regulator	5.21E+13	2.37E+12	0	0	0	0
447	Riverfront Colliseum Regulator	3.34E+12	1.39E+11	0	0	0	0
449	Pike St. D.D.	3.74E+12	1.56E+11	0	0	0	0
450	Butler St. D.D.	8.54E+12	3.56E+11	0	0	0	0
451	Sawyer Point East D.D.	0	0	0	0	0	0
452	Parsons St. D.D.	1.53E+14	7.37E+12	0	0	0	0
453A	Collard St. Regulator	1.76E+14	9.03E+12	3.07E+10	0	0	0
453	Collard St. East D.D.	1.24E+14	6.26E+12	3.40E+10	0	0	0
454	Litherbury St. D.D.	2.81E+14	1.40E+13	0	0	0	0
455	Walden St. D.D.	1.61E+14	8.10E+12	1.53E+09	0	0	0
456	Hazen St. D.D.	7.10E+13	3.56E+12	6.78E+10	0	0	0
457A	Colins St. West Regulator	4.49E+12	1.87E+11	0	0	0	0
457	Colins St. West D.D.	0	0	0	0	0	0
458	Colins St. West Regulator	4.51E+14	3.12E+13	5.42E+12	0	0	0
459	Bayou St. 120 West D.D.	4.32E+13	2.65E+12	2.49E+11	0	0	0
460	Bayou St. 100 West D.D.	4.42E+14	2.71E+13	2.18E+12	0	0	0
461	Eggleston & 4th D.D.	3.41E+11	1.70E+10	5.17E-14	0	0	0
463	Eggleston & 3rd D.D.	0	0	0	0	0	0
464	Eggleston & 3rd C. D.D.	1.94E+13	8.10E+11	0	0	0	0
465	Eggleston & 3rd D.D.	0	0	0	0	0	0
466	Eggleson & P.R. Way D.D.	2.24E+12	9.35E+10	0	0	0	0
468	468-o	2.34E+12	9.75E+10	0	0	0	0
489	7th & McLean D.D.	0	0	0	0	0	0
2000	Mill Creek	1.29E+16	1.85E+15	2.86E+14	1.64E+13	0	0
223	Foley	5.11E+14	3.00E+13	2.18E+12	0	0	0
401	Muddy Creek Pump Station	1.90E+15	2.52E+14	4.97E+13	2.90E-09	0	0
402	Topinabee	2.06E+14	1.08E+13	2.92E+11	0	0	0
403	Elco	8.64E+13	4.13E+12	0	0	0	0
404	Invanhoe	5.35E+14	3.21E+13	2.33E+12	0	0	0
405	Revere	2.42E+14	1.33E+13	5.68E+11	0	0	0
406	Belmore	4.03E+14	2.38E+13	1.91E+12	0	0	0

Appendix C. Daily Combined Sewer Overflow Fecal Coliform Loadings During Calibration Event.

KPDES#/ Ohio ID #	Description	Maximum Fecal Coliform Loading Rate (#/day)	Fecal Coliform Load on 5/27/00 (first day of storm)	Fecal Coliform Load on 5/28/00	Fecal Coliform Load on 5/29/00	Fecal Coliform Load on 5/30/00	Fecal Coliform Load on 5/31/00
408	Wochner	2.88E+14	1.47E+13	3.24E+11	0	0	0
410	Feinmore	1.48E+14	7.30E+12	7.22E+10	0	0	0
411	Anderson Ferry	9.43E+14	5.70E+13	4.60E+12	0	0	0
412	Colfax	1.39E+14	7.23E+12	2.15E+11	0	0	0
413	Tyler	3.07E+14	1.62E+13	4.53E+11	0	0	0
414	McGinnis	4.08E+13	1.87E+12	0	0	0	0
415	Fithian	4.78E+14	2.57E+13	1.03E+12	0	0	0
416	Idaho	3.86E+14	2.17E+13	1.15E+12	0	0	0
541	East of Bender	1.10E+13	4.60E+11	0	0	0	0
654	Stille	1.19E+14	6.04E+12	1.33E+11	0	0	0
4000	Muddy Creek	3.31E+15	3.02E+14	3.15E+11	2.48E+09	0	0
3000	Rapid Run Creek	2.32E+15	1.91E+14	1.63E+11	1.61E+09	0	0
7000	Muddy Creek WWTP-Treated	6.82E+14	2.48E+14	2.52E+14	2.81E+12	0	0
7000	Muddy Creek WWTP-Untreated	6.70E+14	6.70E+13	5.79E+12	0	0	0
6000	Mill Creek WWTP-Untreated (Bypass)	0	0	0	0	0	0
6000	Mill Creek WWTP-Treated (Bypass)	7.49E+15	2.26E+15	1.12E+15	5.02E+13	0	0
468	Humbert & Congress Avenue Regulato	2.78E+14	1.42E+13	1.22E+10	0	0	0
469	Delta & Eastern Avenue Regulator	1.74E+15	1.87E+14	1.04E+13	0	0	0
467A	Humbert & Delta Avenue Connection	3.58E+11	1.49E+10	0	0	0	0
657	Corbin	0	0	0	0	0	0
5000	Little Miami WWTP-Bypass 2	2.59E+15	2.41E+14	0	0	0	0
5000	Little Miami WWTP-Bypass 1	5.50E+13	9.95E+12	4.63E+15	1.21E-04	0	0
5000	Little Miami WWTP-Bypass 3	0	0	0	0	0	0
467	Humbert & Delta Avenue Regulator	2.24E+14	1.10E+13	0	0	0	0
1000	Little Miami River	8.78E+15	9.09E+14	2.37E+14	6.53E+13	0	0
9000	Direct Stormwater Drainage	5.30E+14	3.91E+13	8.77E+12	7.63E+10	0	0
5000	Little Miami WWTP-Treated	1.48E+14	8.42E+13	8.77E+16	8.89E+16	0	0

Appendix D

Model-Simulated Maximum Fecal Coliform Concentrations in the Ohio River for May, 2000.

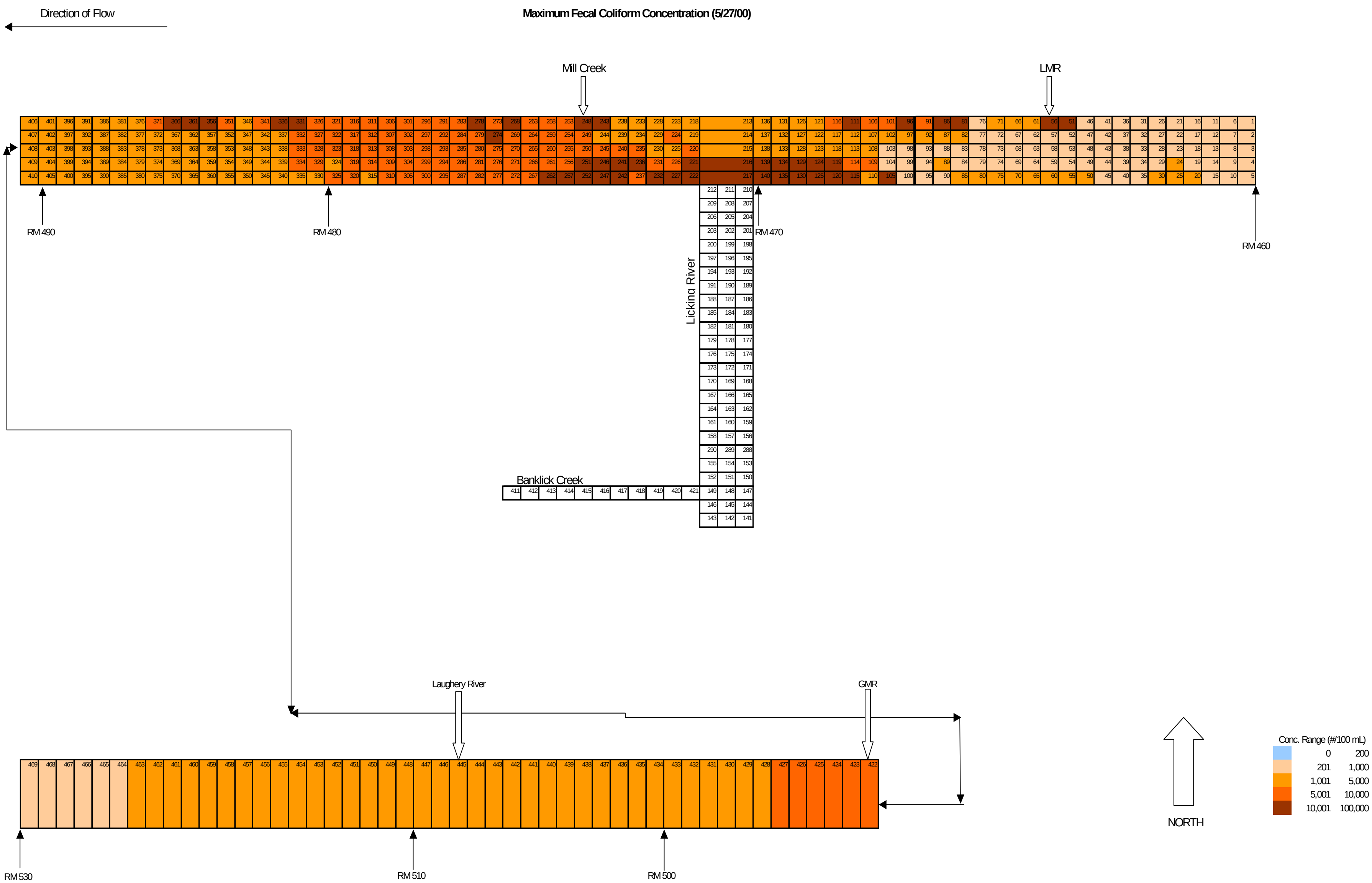


Figure D-1. Model Simulated Maximum Fecal Coliform Concentrations in Ohio River – 5/27/00.

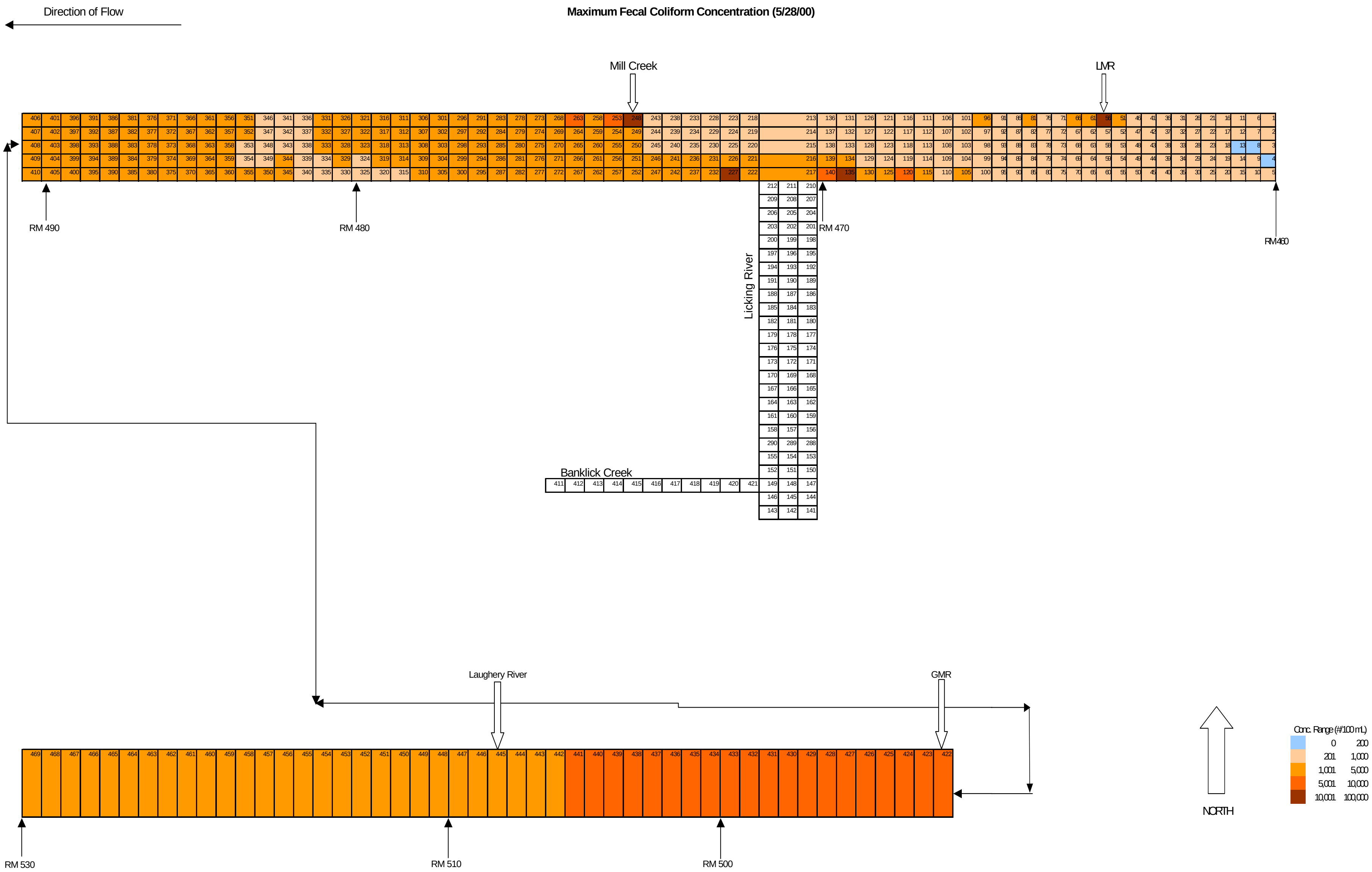


Figure D-2. Model Simulated Maximum Fecal Coliform Concentrations in Ohio River – 5/28/00.

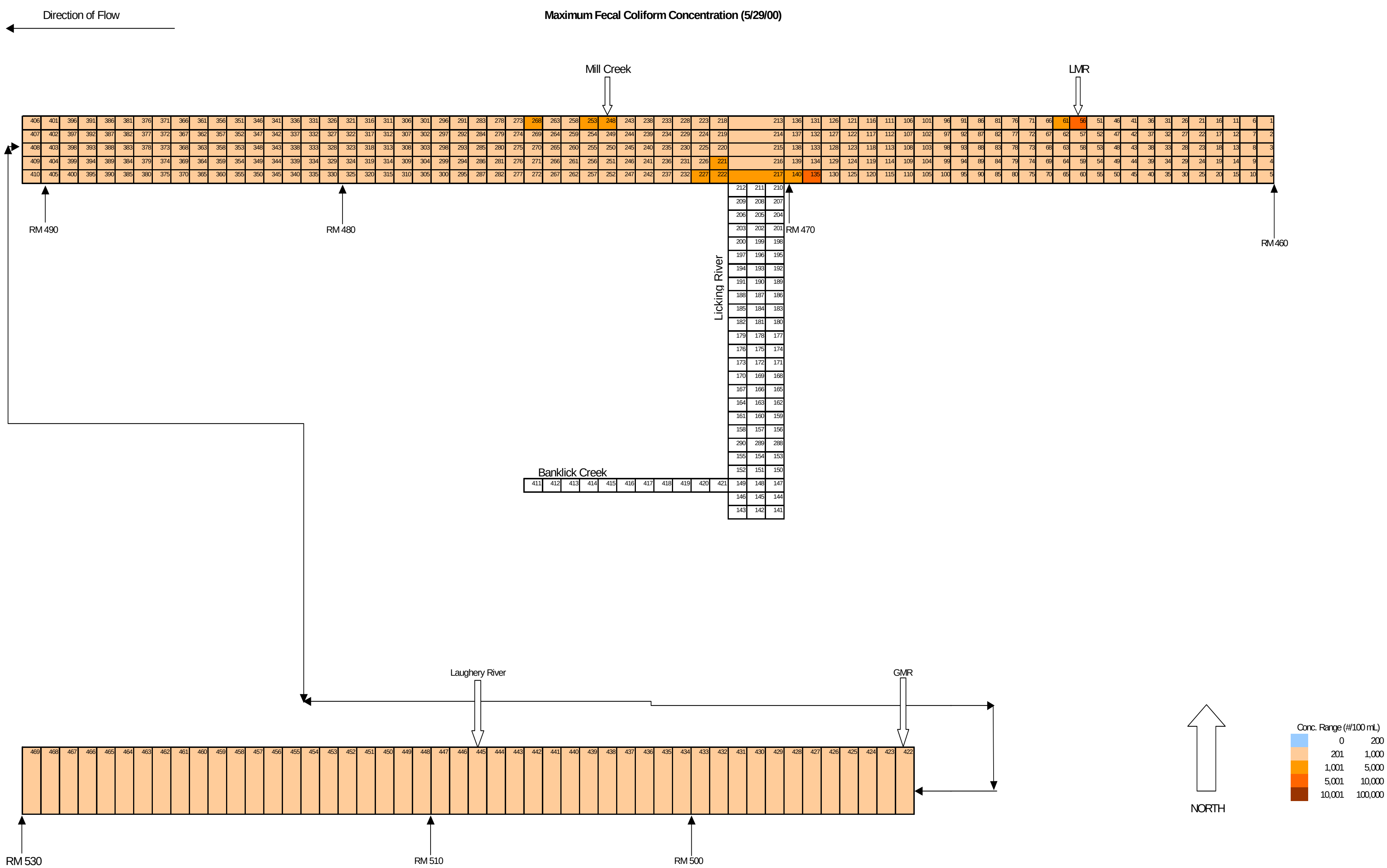


Figure D-3. Model Simulated Maximum Fecal Coliform Concentrations in Ohio River – 5/29/00.

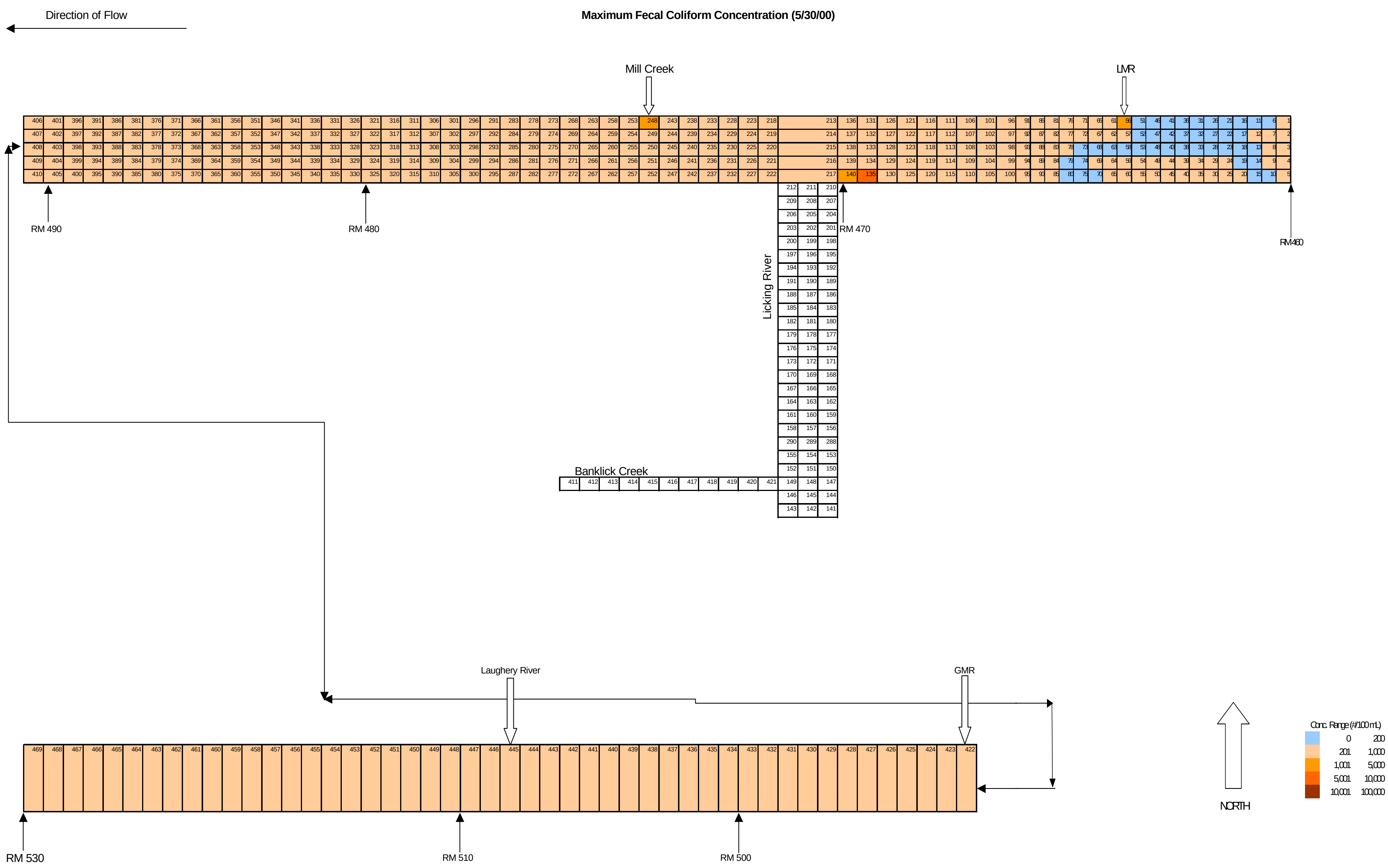


Figure D-4. Model Simulated Maximum Fecal Coliform Concentrations in Ohio River – 5/30/00.

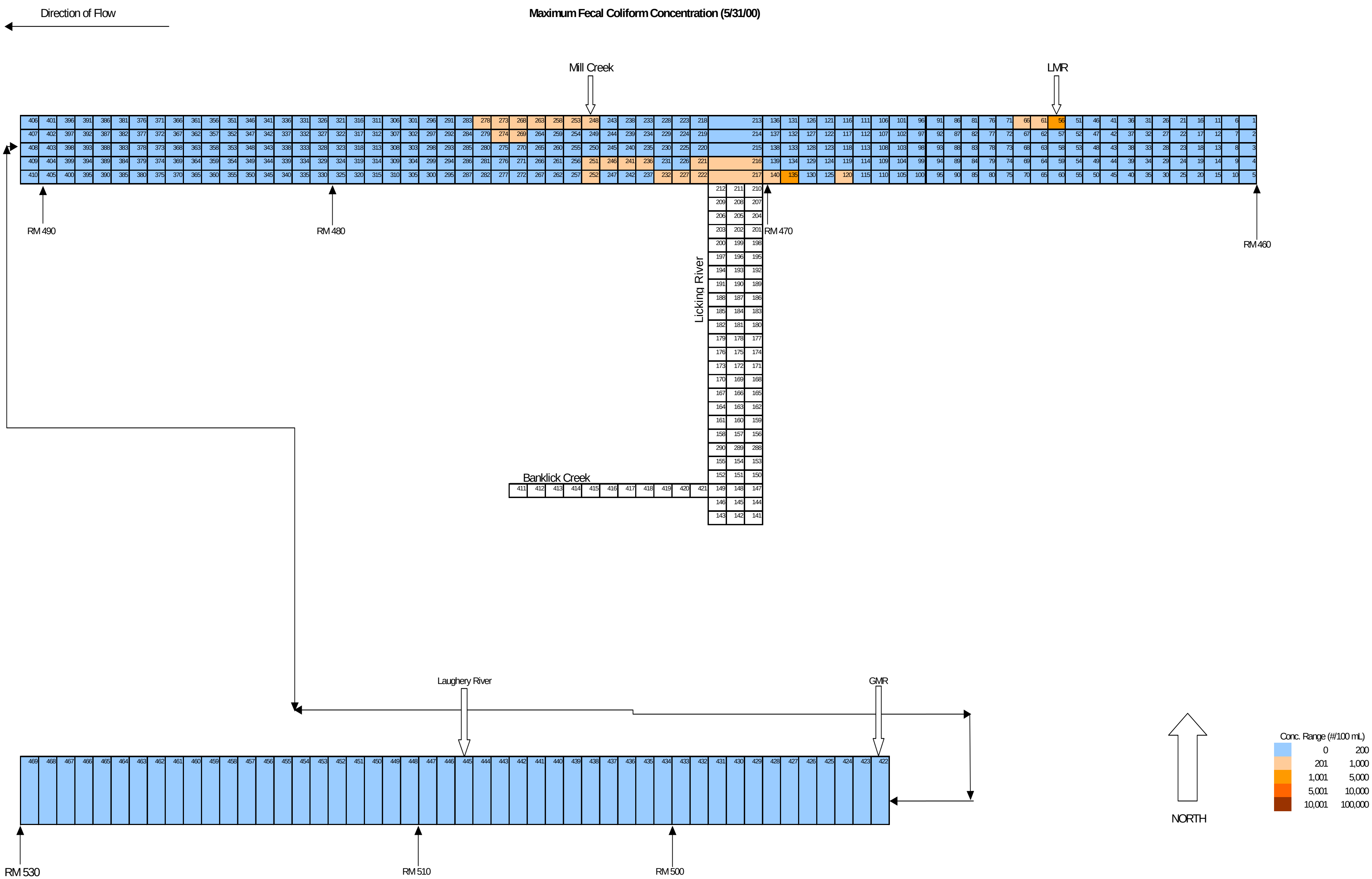


Figure D-5. Model Simulated Maximum Fecal Coliform Concentrations in Ohio River – 5/31/00.

Appendix E

Combined Sewer Overflow Characteristics Summary for the "Typical" Year

Appendix E. Combined Sewer Overflow Characteristics Summary for the "Typical" Year Baseline Scenario.

CSO ID	Description	State	Ohio River Mile	Water Quality Model Segment	Total CSO Volume (MG)	Number of CSO Event Overflows	Average Event CSO Volume (MG)	Average Event Duration (hrs)	Maximum Event Duration (hrs)	Max CSO Overflow Rate (cfs)	Total CSO Fecal Mass (#)
401-OVF	Muddy Creek Pump Station	Ohio	484.0	356	443.014	63	7.032	11.76	39	201.096	1.70E+16
402-OVF	Topinabee	Ohio	483.5	351	15.607	58	0.269	6.40	31	17.559	5.91E+14
403-OVF	Elco	Ohio	483.2	351	5.899	42	0.140	4.29	24	9.908	2.24E+14
404-OVF	Invanhoe	Ohio	482.1	341	47.199	63	0.761	7.61	34	42.770	1.79E+15
405-OVF	Revere	Ohio	482.0	341	19.554	58	0.337	6.28	31	23.837	7.41E+14
406-OVF	Belmore	Ohio	481.6	336	34.827	63	0.553	7.24	33	35.413	1.32E+15
541-OVF	East of Bender	Ohio	480.8	331	0.905	17	0.053	3.59	11	2.943	3.43E+13
408-OVF	Wochner	Ohio	480.0	321	21.098	55	0.384	5.87	31	27.859	8.04E+14
223-OVF	Foley	Ohio	479.4	316	45.256	63	0.718	6.81	33	56.013	1.71E+15
654-OVF	Stille	Ohio	479.4	316	8.810	53	0.166	5.70	31	13.047	3.37E+14
410-OVF	Feinmore	Ohio	478.8	311	10.940	45	0.243	4.93	27	18.344	4.15E+14
411-OVF	Anderson Ferry	Ohio	477.9	306	83.863	64	1.310	7.63	34	75.926	3.18E+15
412-OVF	Colfax	Ohio	476.9	296	10.606	58	0.183	6.67	32	13.341	4.02E+14
413-OVF	Tyler	Ohio	475.8	283	23.785	55	0.432	5.91	31	32.274	9.02E+14
414-OVF	McGinnis	Ohio	475.8	283	2.780	37	0.075	4.22	24	5.474	1.05E+14
415-OVF	Fithian	Ohio	475.0	278	37.498	58	0.647	6.84	31	40.612	1.42E+15
416-OVF	Idaho	Ohio	474.6	273	31.665	60	0.528	6.97	33	32.960	1.20E+15
419-OVF	Bold Face Sr. D.D.	Ohio	474.4	268	406.393	58	7.007	11.40	38	254.068	1.55E+16
417-OVF	Bold Face #3 D.D.	Ohio	474.4	268	16.405	62	0.266	7.36	34	16.382	6.21E+14
418-OVF	River Road A.D.D.	Ohio	474.4	268	0.466	32	0.015	4.28	24	1.050	1.77E+13
421-OVF	River Road & Delhi D.D.	Ohio	474.1	268	0.000					0.000	0.00E+00
420-OVF	Delhi Ave. D.D.	Ohio	474.1	268	0.000					0.000	0.00E+00
L173008	Rohman Street	Kentucky	474.0	272	10.144	60	0.169	7.23	33	13.244	3.36E+14
L173BRPS	Bromley Pump Station	Kentucky	474.0	272	3.023	1	3.023	7.00	7	23.486	1.00E+14
422-OVF	Mt. Echo Rd Regulator	Ohio	473.5	263	48.428	86	0.563	12.37	143	31.391	1.86E+15
L172005	Lagoon Street	Kentucky	473.4	267	18.571	63	0.295	16.52	135	15.234	6.15E+14
L173029	Pleasant Street	Kentucky	473.4	267	7.343	68	0.108	17.00	135	6.567	2.43E+14
423-OVF	Mt. Hope Ave. Regulator	Ohio	473.2	258	94.697	86	1.101	24.73	247	62.193	3.68E+15
425-ovf	State Ave. D.D.	Ohio	473.0	258	16.091	64	0.251	7.31	34	15.401	6.24E+14
424-ovf	River Rd. at State D.D.	Ohio	473.0	258	3.188	21	0.152	4.62	24	9.564	1.21E+14
L171003	Adela Street	Kentucky	472.9	262	16.437	56	0.294	17.30	135	13.378	5.44E+14
L171054	Kenner Street	Kentucky	472.9	262	1.186	26	0.046	4.54	24	3.578	3.93E+13
L171084	Carneal Street	Kentucky	472.7	257	8.140	58	0.140	12.72	103	7.819	2.70E+14
L171068	Butler Street	Kentucky	472.7	257	7.120	32	0.223	24.38	135	3.818	2.36E+14
429-o	Gest St. East D.D.	Ohio	472.6	248	2.814	27	0.104	4.33	24	7.259	1.07E+14
426A-O	Evans & River Rd. #1 D.	Ohio	472.6	248	0.193	10	0.019	2.20	3	1.707	7.32E+12
1-OVF	1-ovf	Ohio	472.6	248	0.114	3	0.038	3.00	4	1.354	4.32E+12
427-OVF	Perin & Evans D.D.	Ohio	472.6	248	0.028	2	0.014	1.50	2	0.471	1.08E+12
428-OVF	South St. Regulator	Ohio	472.6	248	57.588					43.947	0.00E+00
426B-o	Evans & River Rd. # 2 D.	Ohio	472.6	248	0.000					0.000	0.00E+00

CSO ID	Description	State	Ohio River Mile	Water Quality Model Segment	Total CSO Volume (MG)	Number of CSO Event Overflows	Average Event CSO Volume (MG)	Average Event Duration (hrs)	Maximum Event Duration (hrs)	Max CSO Overflow Rate (cfs)	Total CSO Fecal Mass (#)
L171098	Ash Street	Kentucky	472.4	252	18.019	23	0.783	32.35	135	6.819	5.97E+14
431-ovf	McLean St. D.D.	Ohio	472.4	243	104.138	25	4.166	5.52	24	177.553	3.95E+15
430-ovf	Gest St. West 2-A D.D.	Ohio	472.4	243	4.474	14	0.251	5.00	11	15.892	1.33E+14
432-O	9th St & McLean D.D.	Ohio	472.4	243	0.174	13	0.013	2.23	4	1.050	6.65E+12
489-O	7th & McLean D.D.	Ohio	472.4	243	0.083	4	0.021	2.25	3	0.628	3.13E+12
433-ovf	Carr St. Regulator	Ohio	472.1	238	2.024	48	0.042	5.19	27	5.376	7.73E+13
434-O	Carr & Front D.D.	Ohio	472.1	238	0.086	4	0.021	2.25	3	0.688	3.24E+12
L150009	Altamont Street	Kentucky	471.9	242	33.363	64	0.521	7.61	38	37.620	1.11E+15
435-ovf	Baymiller St. Regulator	Ohio	471.8	233	0.000					0.000	0.00E+00
436-ovf	Gest & Front Regulator	Ohio	471.6	228	4.194	59	0.071	6.20	31	8.750	1.62E+14
L149027	Parkway @ Highway	Kentucky	471.3	232	35.564	66	0.539	16.32	136	21.211	1.18E+15
L149015	Swain Court	Kentucky	471.3	232	<0.0005	1	<0.0005	2.00	2	0.010	1.65E+10
437-ovf	Smith St. Regulator	Ohio	471.2	223	2.762	59	0.047	6.27	31	3.237	1.06E+14
438-ovf	Central Ave. West G.	Ohio	471.0	223	1.255	13	0.097	3.15	11	7.239	4.77E+13
L148WROF	Willow Run (and #49 and 7 others)	Kentucky	470.9	227	382.774	86	4.391	100.76	339	176.125	1.27E+16
L147052	Main Street	Kentucky	470.9	227	9.918	43	0.231	4.84	26	15.856	3.29E+14
L147003	Philadelphia Street	Kentucky	470.9	227	2.963	33	0.090	4.61	24	6.542	9.82E+13
L147072	Johnson Street	Kentucky	470.9	227	2.396	55	0.044	6.13	31	3.432	7.94E+13
L147032	Bakewell Street	Kentucky	470.9	227	0.959	24	0.040	4.42	24	3.269	3.18E+13
4420ovf	Vine St. Regulator	Ohio	470.6	218	0.000					0.000	0.00E+00
L144002	2nd St. @ Russell St. (and Wash. St)	Kentucky	470.5	222	9.566	46	0.208	5.20	26	14.250	3.17E+14
L144072	Madison Avenue (and 2nd St)	Kentucky	470.5	222	7.130	56	0.127	6.39	31	8.674	2.36E+14
L144121	Greenup Street	Kentucky	470.5	222	2.531	33	0.077	4.58	24	5.749	8.38E+13
L144100	Scott Street	Kentucky	470.5	222	0.166	12	0.014	1.67	3	2.426	5.51E+12
L144156	Garrard Street	Kentucky	470.1	217	2.460	47	0.052	4.89	27	4.785	8.15E+13
445-ovf	Riverfront Stadium Regulator	Ohio	470.0	136	3.349	38	0.088	4.45	24	8.436	1.28E+14
447-ovf	Riverfront Colliseum Regulator	Ohio	470.0	136	0.386	13	0.030	3.08	11	1.756	1.47E+13
449-ovf	Pike St. D.D.	Ohio	469.9	136	0.383	15	0.026	3.80	11	1.481	1.46E+13
314-O	314-o	Ohio	469.9	136	0.005	2	0.003	2.00	2	0.066	2.04E+11
450-ovf	Butler St. D.D.	Ohio	469.8	136	0.513	20	0.026	4.75	24	1.471	2.00E+13
L079015	Columbia St. Chamber	Kentucky	469.7	140	30.048	53	0.567	8.49	32	29.130	9.95E+14
L077006	Saratoga Street	Kentucky	469.7	140	16.562	64	0.259	8.84	43	15.818	5.49E+14
461-ovf	Eggleston & 4th D.D.	Ohio	469.6	131	8.519	13	0.503	6.31	22	32.372	2.47E+14
464-ovf	Eggleston & 3rd C. D.D.	Ohio	469.6	131	1.212	22	0.055	4.64	24	3.531	4.62E+13
466-OVF	Eggleson & P.R. Way D.D.	Ohio	469.6	131	0.367	13	0.028	3.08	11	1.913	1.39E+13
465-ovf	Eggleston & 3rd D.D.	Ohio	469.6	131	0.071	6	0.012	2.17	3	0.471	2.68E+12
463-ovf	Eggleston & 3rd D.D.	Ohio	469.6	131	0.000					0.000	0.00E+00
L064084	Washington Ave Chmbr	Kentucky	469.5	135	186.646	70	2.705	29.33	194	57.333	6.18E+15
L063001	Riverside Drive	Kentucky	469.5	135	<0.0001	11	<0.0001	1.00	1	0.000	1.12E+09
451-ovf	Sawyer Point East D.D.	Ohio	469.4	126	0.123	9	0.014	3.11	4	0.771	4.67E+12
L065084	Taylor Bottoms	Kentucky	469.1	130	32.758	48	0.682	9.06	32	12.841	1.09E+15
L065041	Geiger Avenue	Kentucky	469.1	130	31.434	40	0.786	8.80	29	14.297	1.04E+15

CSO ID	Description	State	Ohio River Mile	Water Quality Model Segment	Total CSO Volume (MG)	Number of CSO Event Overflows	Average Event CSO Volume (MG)	Average Event Duration (hrs)	Maximum Event Duration (hrs)	Max CSO Overflow Rate (cfs)	Total CSO Fecal Mass (#)
L053083	SSO (elevated OF into CR near Bellevue)	Kentucky	469.1	130	9.401	33	0.285	5.15	25	10.188	3.11E+14
452-ovf	Parsons St. D.D.	Ohio	469.1	121	9.440	49	0.191	5.78	29	13.145	3.55E+14
L062031	Patchen Street	Kentucky	468.8	125	11.265	55	0.205	6.13	31	16.447	3.73E+14
L062015	Lafayette Avenue	Kentucky	468.8	125	2.938	39	0.075	4.69	26	6.846	9.73E+13
L0610311		Kentucky	468.8	120	12.083	56	0.216	17.95	51	15.911	4.00E+14
453a-ovf	Collard St. Regulator	Ohio	468.7	116	11.801	56	0.211	6.07	31	14.126	4.56E+14
453-ovf	Collard St. East D.D.	Ohio	468.7	116	8.334	55	0.152	6.00	31	10.496	3.16E+14
L060016	Ward Avenue	Kentucky	468.5	120	32.092	59	0.544	7.69	34	32.421	1.06E+15
L061006	Washington Avenue	Kentucky	468.5	120	9.107	53	0.172	6.49	31	11.846	3.02E+14
L060002	Foote Avenue	Kentucky	468.5	120	0.673	19	0.035	4.89	24	3.684	2.23E+13
454-ovf	Litherbury St. D.D.	Ohio	468.4	111	16.993	47	0.362	4.85	26	22.366	6.45E+14
455-ovf	Walden St. D.D.	Ohio	468.2	111	10.504	53	0.198	6.08	31	13.145	3.99E+14
L057011	McKinney Street	Kentucky	468.0	115	113.378	58	1.955	9.07	34	96.420	3.76E+15
456-ovf	Hazen St. D.D.	Ohio	467.9	106	4.827	53	0.091	5.70	31	6.984	1.83E+14
458-ovf	Colins St. West Regulator	Ohio	467.5	101	45.700	76	0.601	9.50	50	32.175	1.74E+15
457a-ovf	Colins St. West Regulator	Ohio	467.5	101	0.424	14	0.030	3.21	11	2.256	1.61E+13
457-ovf	Colins St. West D.D.	Ohio	467.5	101	0.015	2	0.007	1.50	2	0.368	5.69E+11
L057030	Main Street	Kentucky	467.2	105	80.044	58	1.380	9.71	35	63.243	2.65E+15
460-ovf	Bayou St. 100 West D.D.	Ohio	467.1	96	38.275	64	0.598	7.63	34	32.274	1.47E+15
459-ovf	Bayou St. 120 West D.D.	Ohio	467.1	96	3.731	63	0.059	7.29	34	3.904	1.41E+14
291	Corbin	Ohio	466.6	91	0.001	2	0.001	1.50	2	0.047	6.39E+10
257	Delta & Eastern Avenue Regulator	Ohio	466.0	81	270.406	61	4.433	10.69	38	186.382	1.04E+16
252	Humbert & Congress Avenue Regulato	Ohio	466.0	81	19.632	55	0.357	5.80	31	30.017	7.44E+14
4672	Humbert & Delta Avenue Regulator	Ohio	466.0	81	14.334	50	0.287	5.50	31	18.834	5.43E+14
282	Humbert & Delta Avenue Connection	Ohio	466.0	81	0.127	13	0.010	3.00	6	0.680	4.83E+12
468-O	468-o	Ohio	466.0	131	0.364	13	0.028	2.38	4	1.913	1.38E+13
L036018	SSO (bypass)	Kentucky	465.7	85	15.287	56	0.273	21.55	73	2.083	5.06E+14
L035003	Elsmar Street	Kentucky	465.2	80	0.072	13	0.006	2.69	5	0.656	2.39E+12
L034009	Tower Hill Road	Kentucky	464.5	70	3.739	28	0.134	8.29	27	4.043	1.24E+14
L034034	Burnet Ridge	Kentucky	463.6	60	0.898	15	0.060	4.13	11	3.600	2.98E+13
L034044	Manor Lane	Kentucky	462.9	50	2.728	31	0.088	4.58	24	4.488	9.04E+13
L020001	Government Sewer	Kentucky	462.9	50	0.156	10	0.016	2.70	4	1.379	5.16E+12
L005HHOF2	Highland Heights Overflow #2	Kentucky	460.8	20	37.101	53	0.700	18.94	66	11.856	1.23E+15
L005HHOF1	Highland Heights Overflow #1	Kentucky	460.8	20	0.000					0.000	0.00E+00
Little Miami CSOs		Ohio	463.5	56	3699.91	86	43.00	61.69	286	2874.21	3.63E+16
Mill Creek CSOs		Ohio	472.5	248	8844.94	86	102.85	93.55	339	4041.55	1.02E+17
Muddy Creek CSOs		Ohio	484.1	356	399.83	86	4.64	78.43	263	480.67	1.52E+16
Rapid Run CSOs		Ohio	480.8	331	270.99	86	3.10	27.53	249	248.18	1.02E+16
Licking River and Banklick Creek CSOs		Kentucky	470	217	1898.87	86	21.80	99.80	339	89.77	6.29E+16

Appendix F

Temporal Plots for Reduction Scenarios

Figure F-1. Dry Weather Period (8/16-22)-No Precipitation

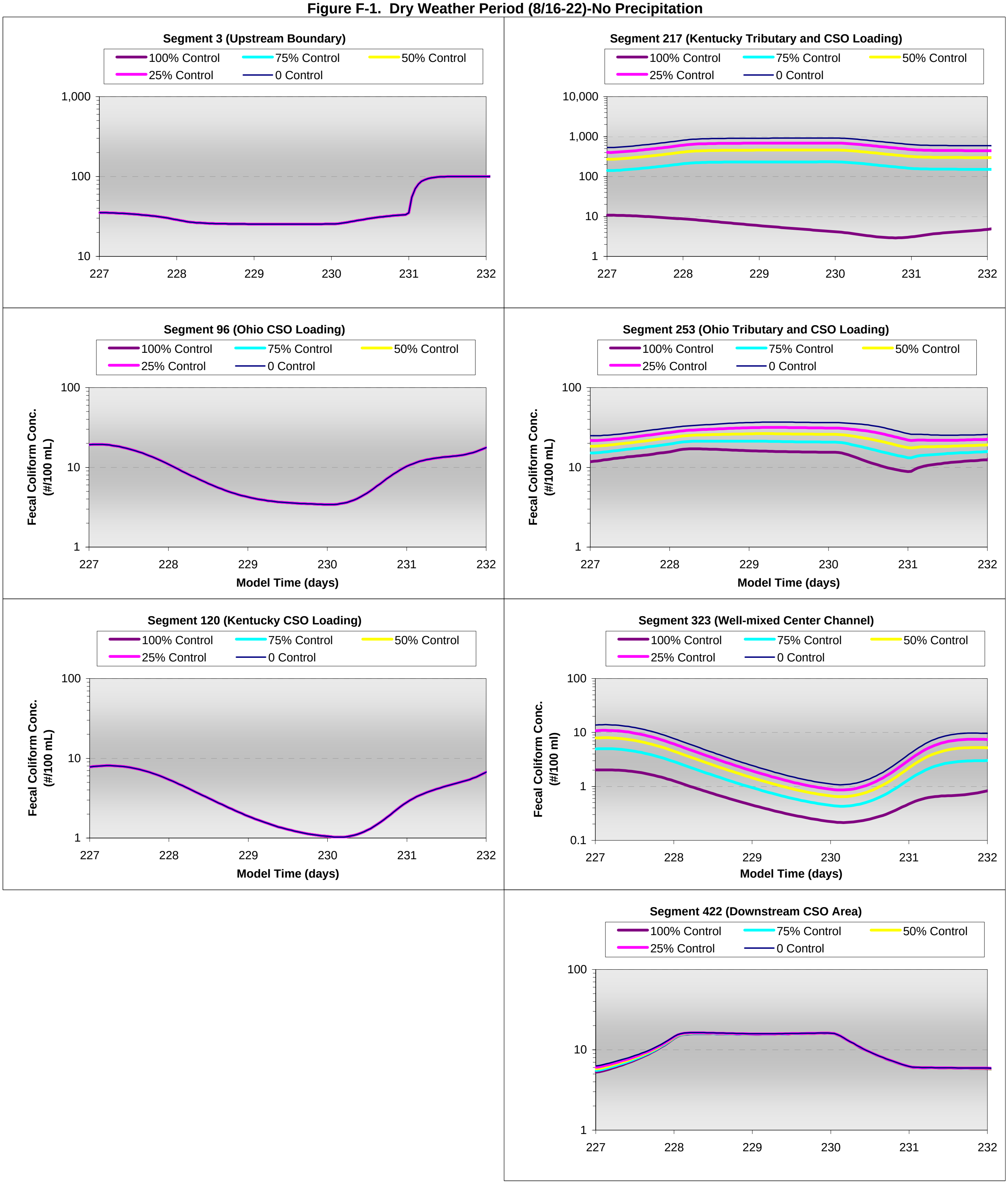


Figure F-2. Light Storm (Total Precipitation = 0.24 in)

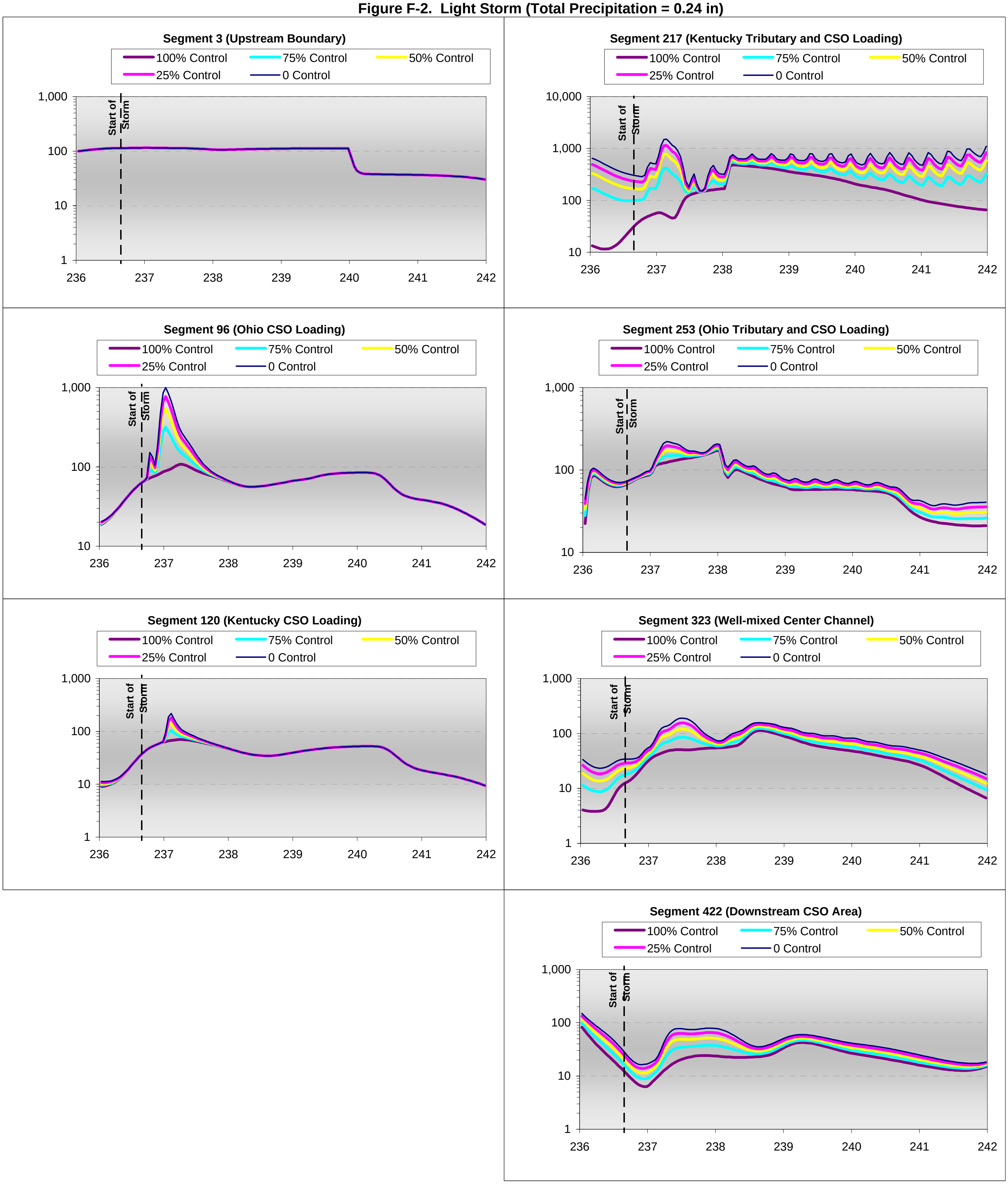


Figure F-3. Average Storm (Total Precipitation = 0.54 in)

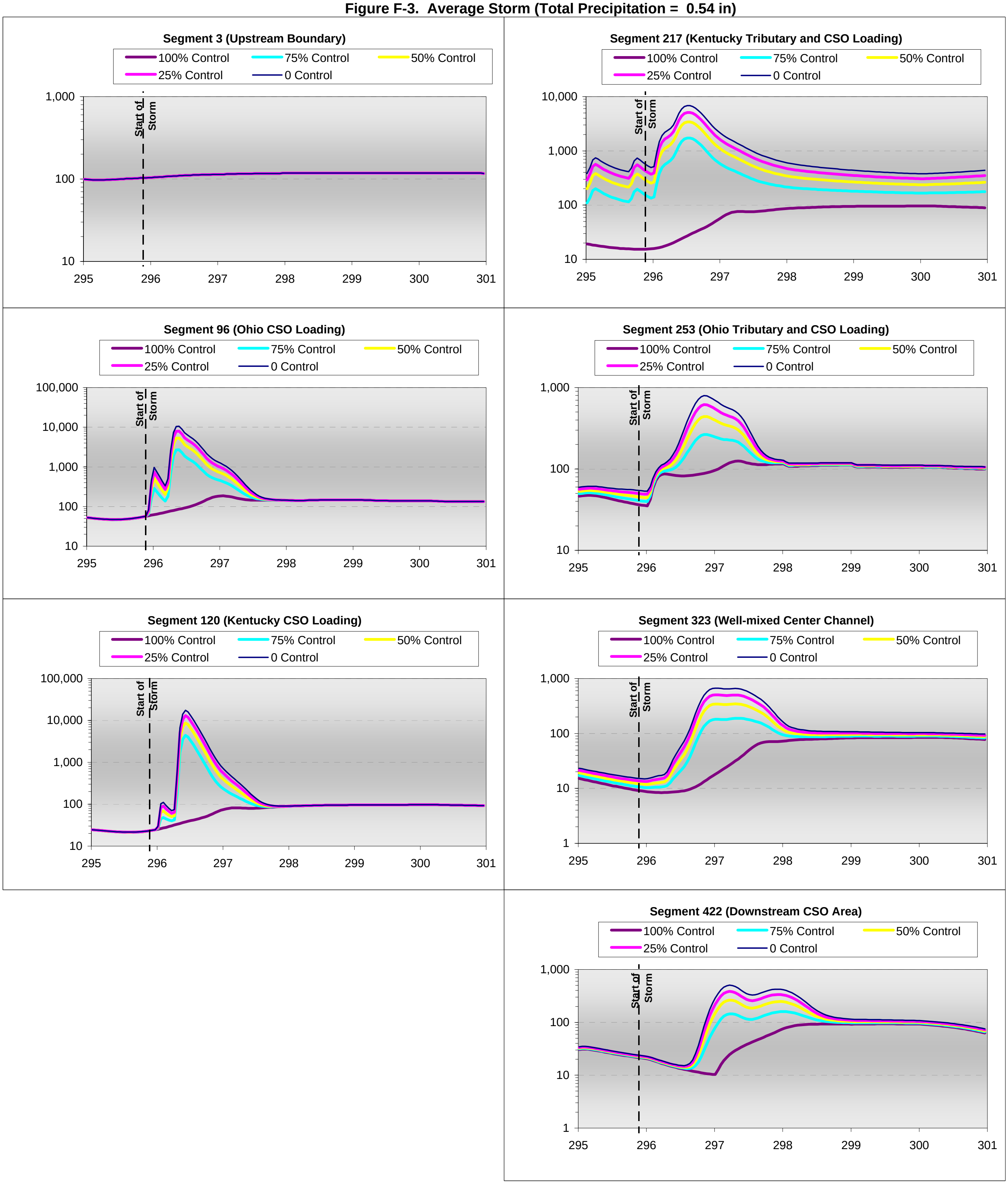
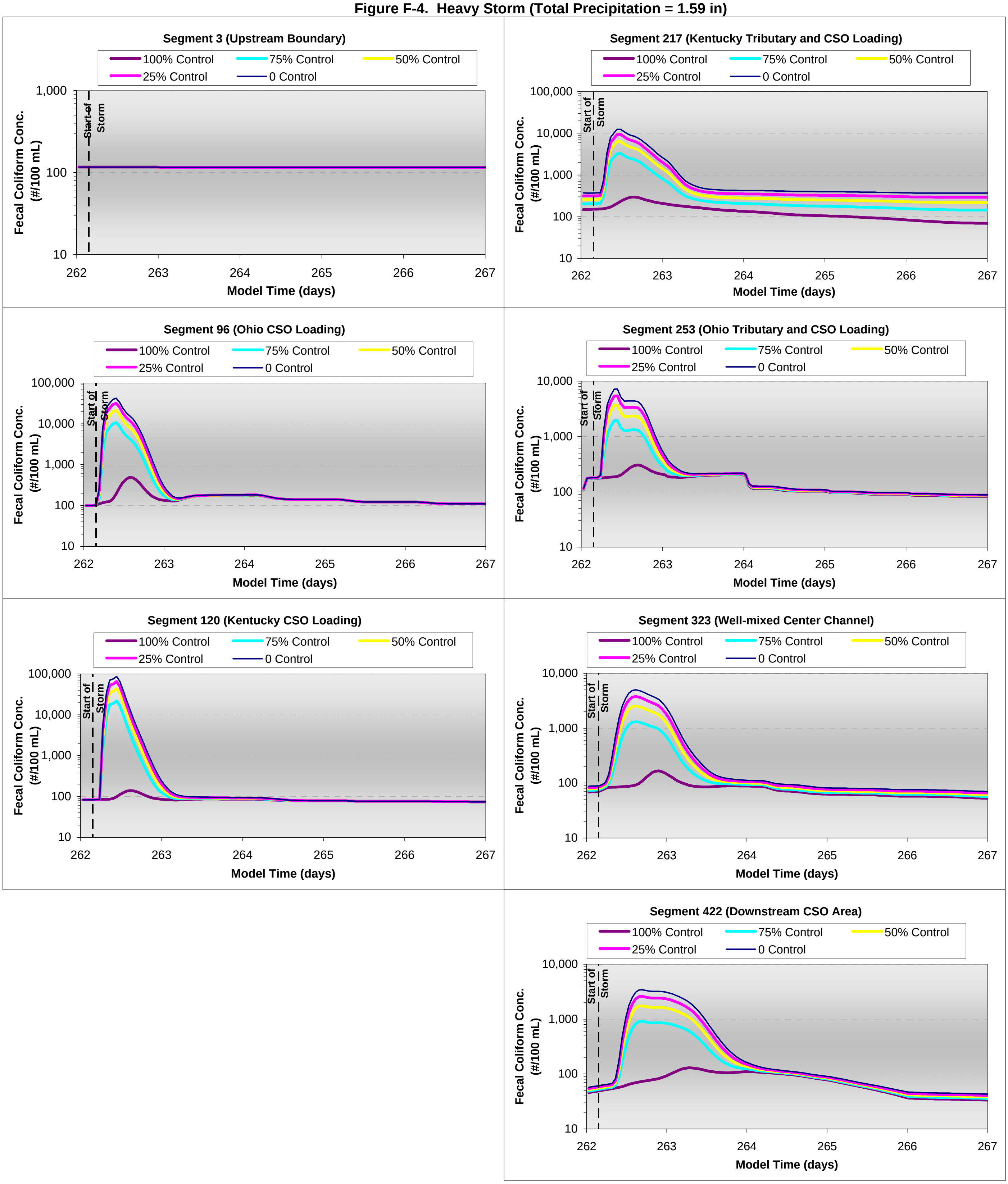
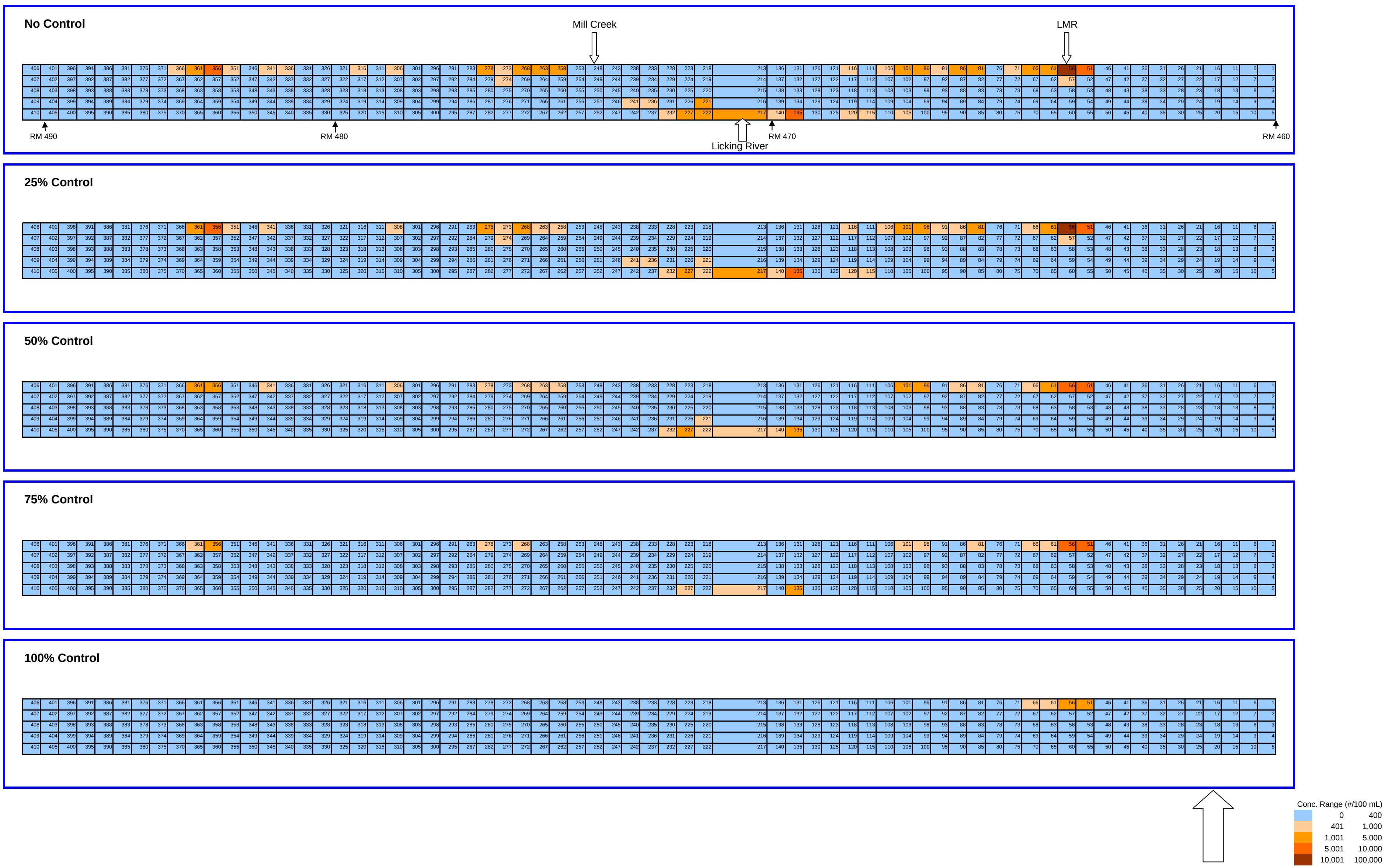


Figure F-4. Heavy Storm (Total Precipitation = 1.59 in)



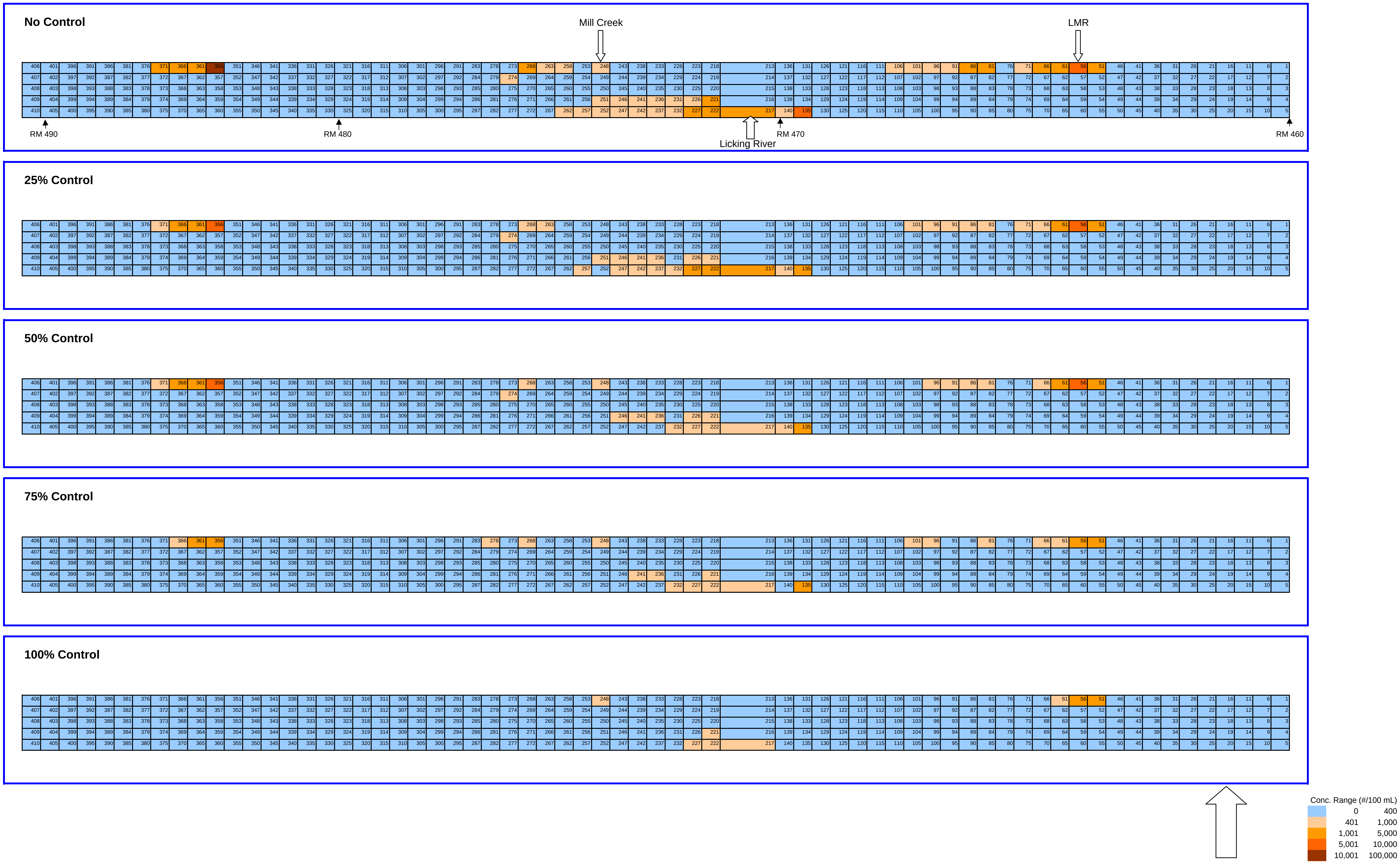
Direction of Flow

Figure F-5. Maximum Fecal Coliform Concentration-Dry Period (8/16-21/71)



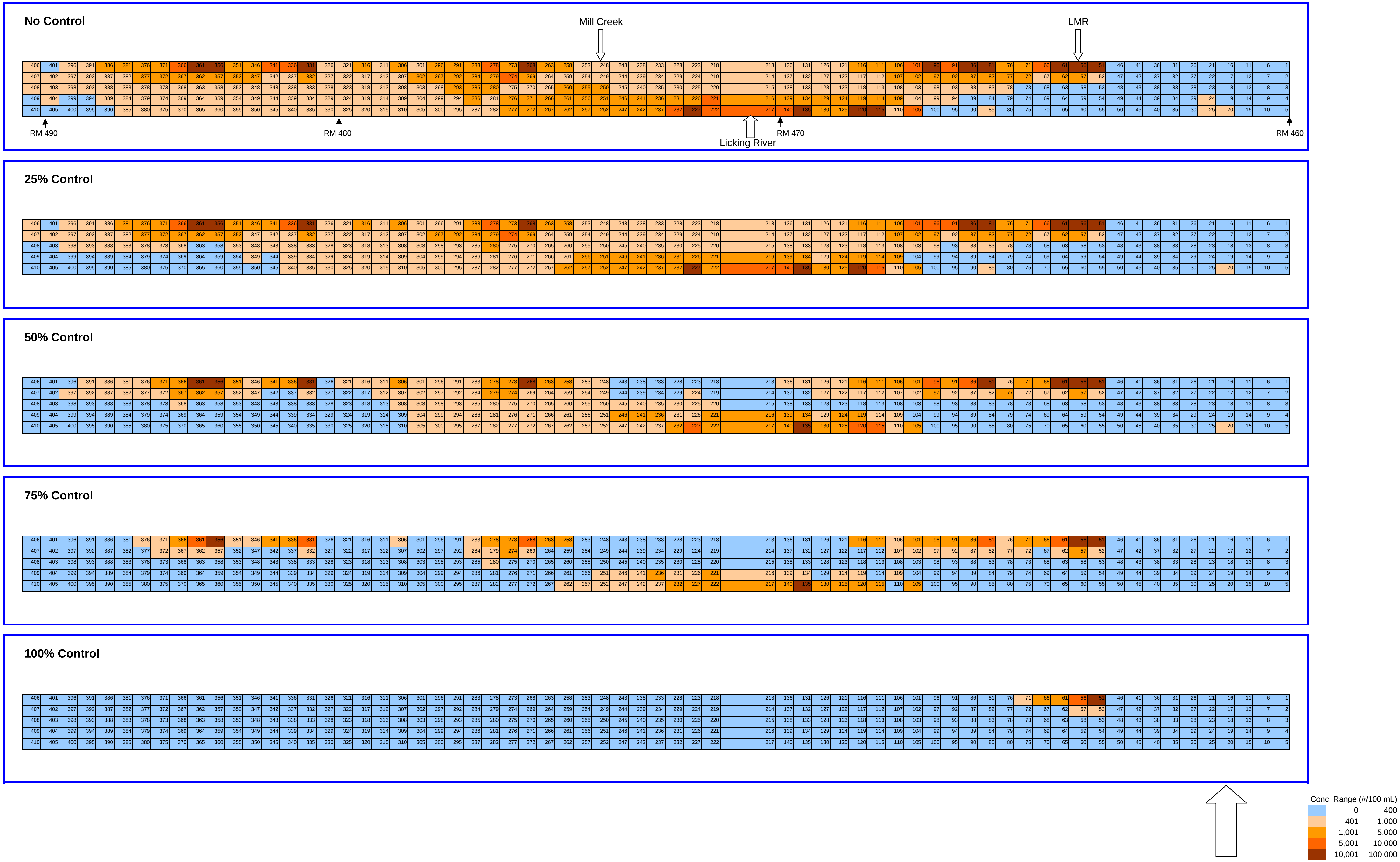
Direction of Flow

Figure F-6. Maximum Fecal Coliform Concentration-Light Storm Period (8/25-26/71)



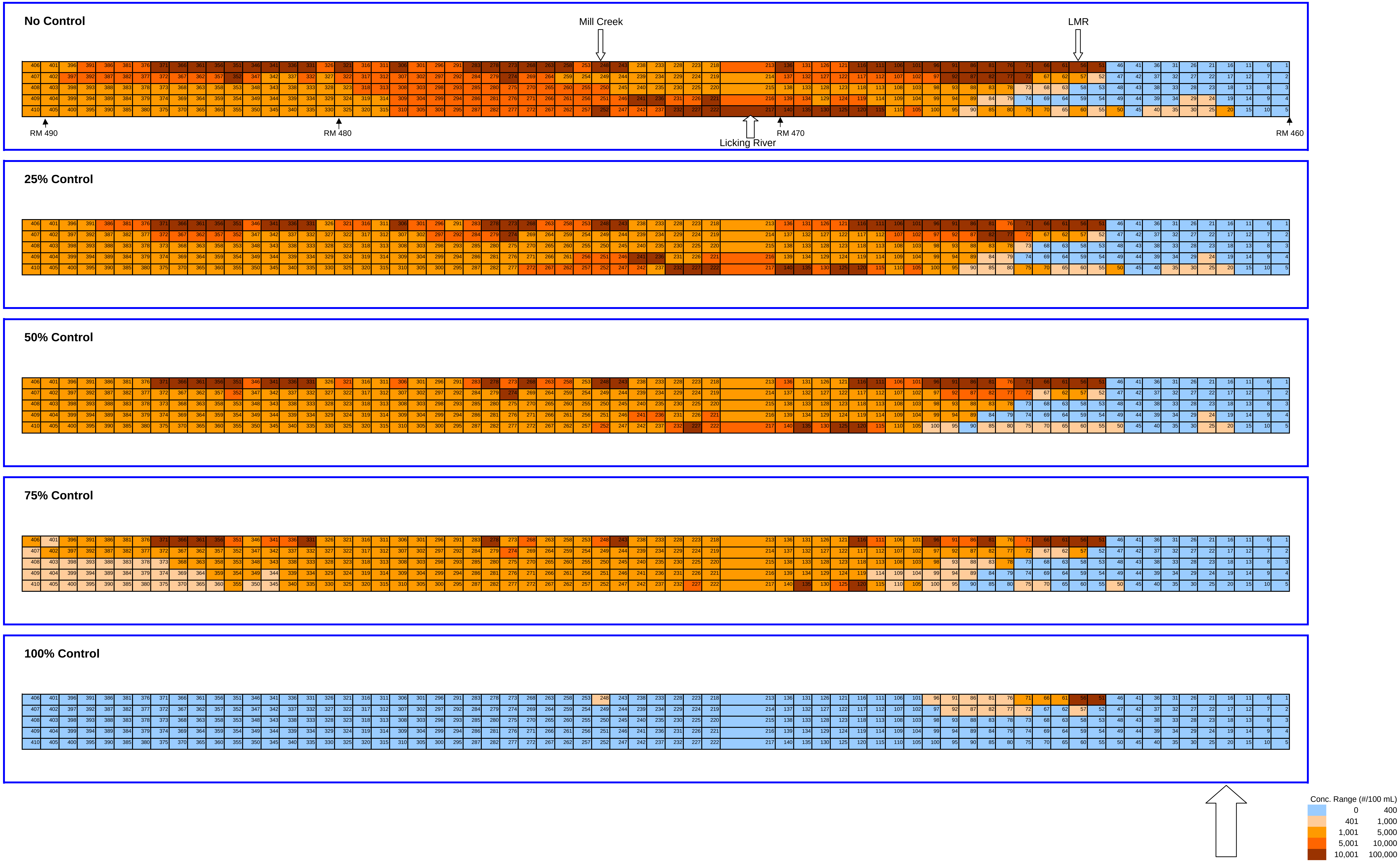
Direction of Flow

Figure F-7. Maximum Fecal Coliform Concentration-Average Storm Period (10/23-25/71)



Direction of Flow

Figure F-8. Maximum Fecal Coliform Concentration-Heavy Storm Period (9/21-22/71)



Appendix G

Model Animator Users Guide

Limno-Tech, Inc.

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Memorandum

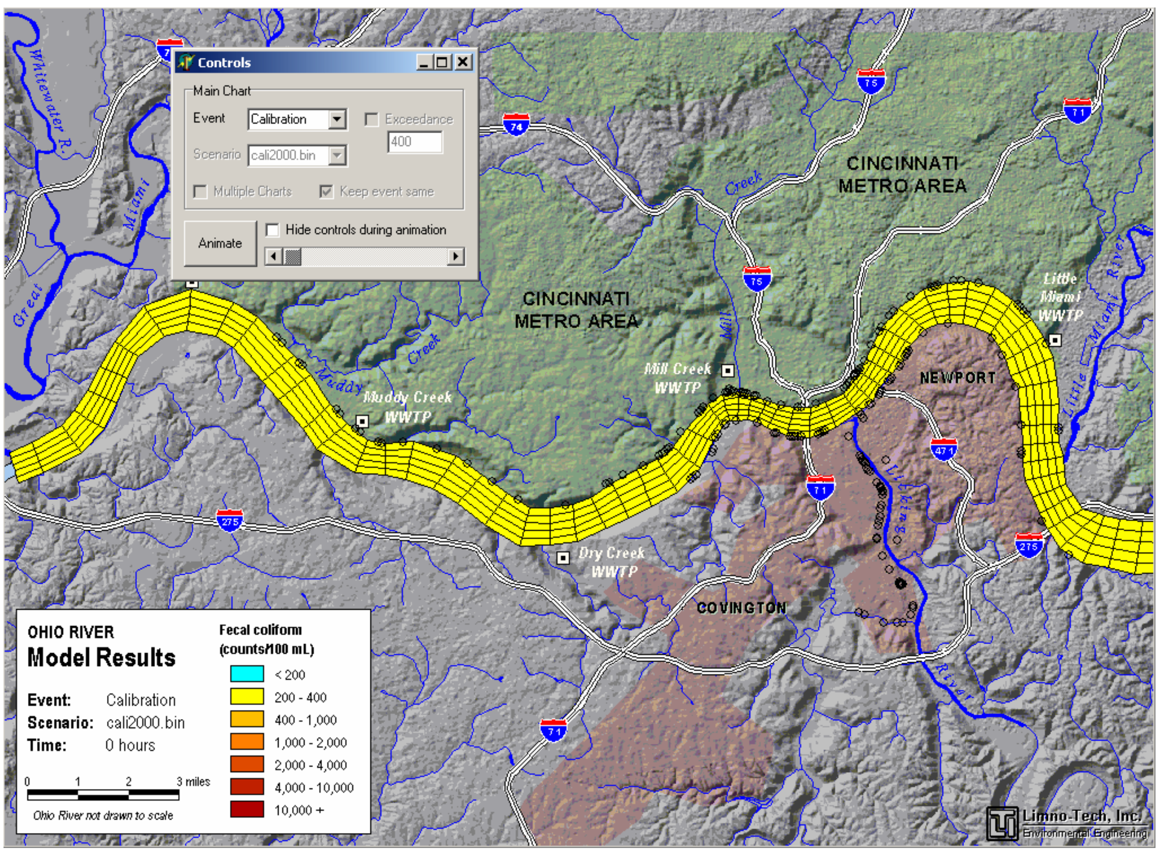
DATE: May 19, 2009
PROJECT: **ORSA2**

TO: **Jason Heath**
ORSANCO
5735 Kellogg Ave.
Cincinnati, OH 45228

FROM: **Tad Slawecki**
CC:

SUBJECT: **Ohio River Model Results Viewer**

This memorandum summarizes usage of the OV-CV.EXE and OV-SCEN.EXE computer programs which are used to view post-processed WASP model results for the Ohio River near Cincinnati. OV-CV is used to view calibration and verification runs, and OV-SCEN is used to compare results and exceedances for different storms in the "typical year" simulation under different control scenarios. Both programs are designed to be used on computers running then Microsoft Windows 95, 98, ME, NT 4.0, 2000, or XP operating systems on a display with 1024x768 resolution.



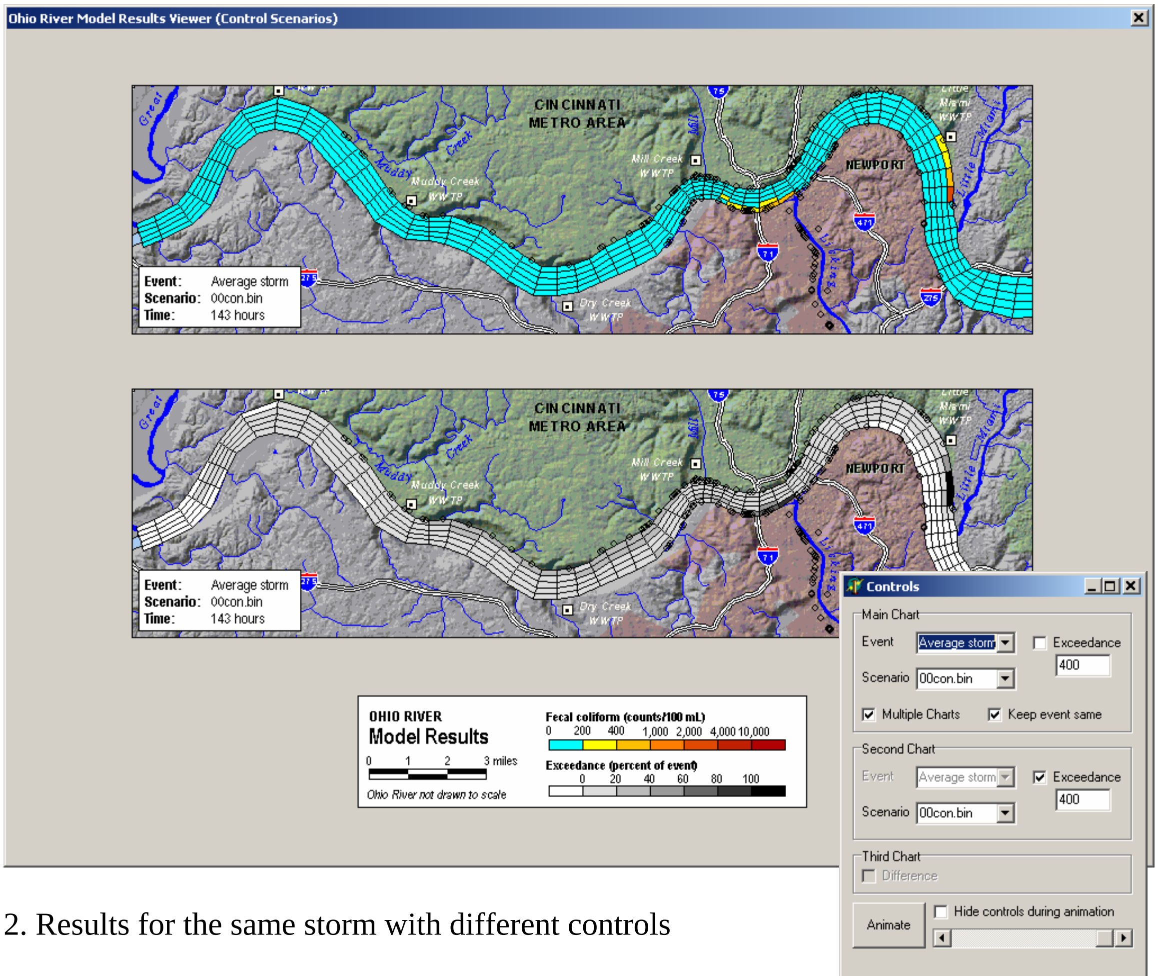
At startup, both programs display a full-screen (1024x768) image of the study area with a simple control panel superimposed. The control panel may be hidden by left-clicking on any portion of the image, and restored by right-clicking and selecting the “Controls…” option from the popup menu. Left-clicking repeatedly on the image also advances the displayed model time step, which will be reflected in the “Time:” field in the legend.

For the OV-CV program, the user may use the control panel to select between the calibration and two validation runs for model display, and to scroll through the available timesteps manually (with the scrollbar) or automatically by pressing the “Animate” button. Checking the “Hide Controls during animation” box causes the control panel to be hidden for cleaner display when the Animate button is pressed.

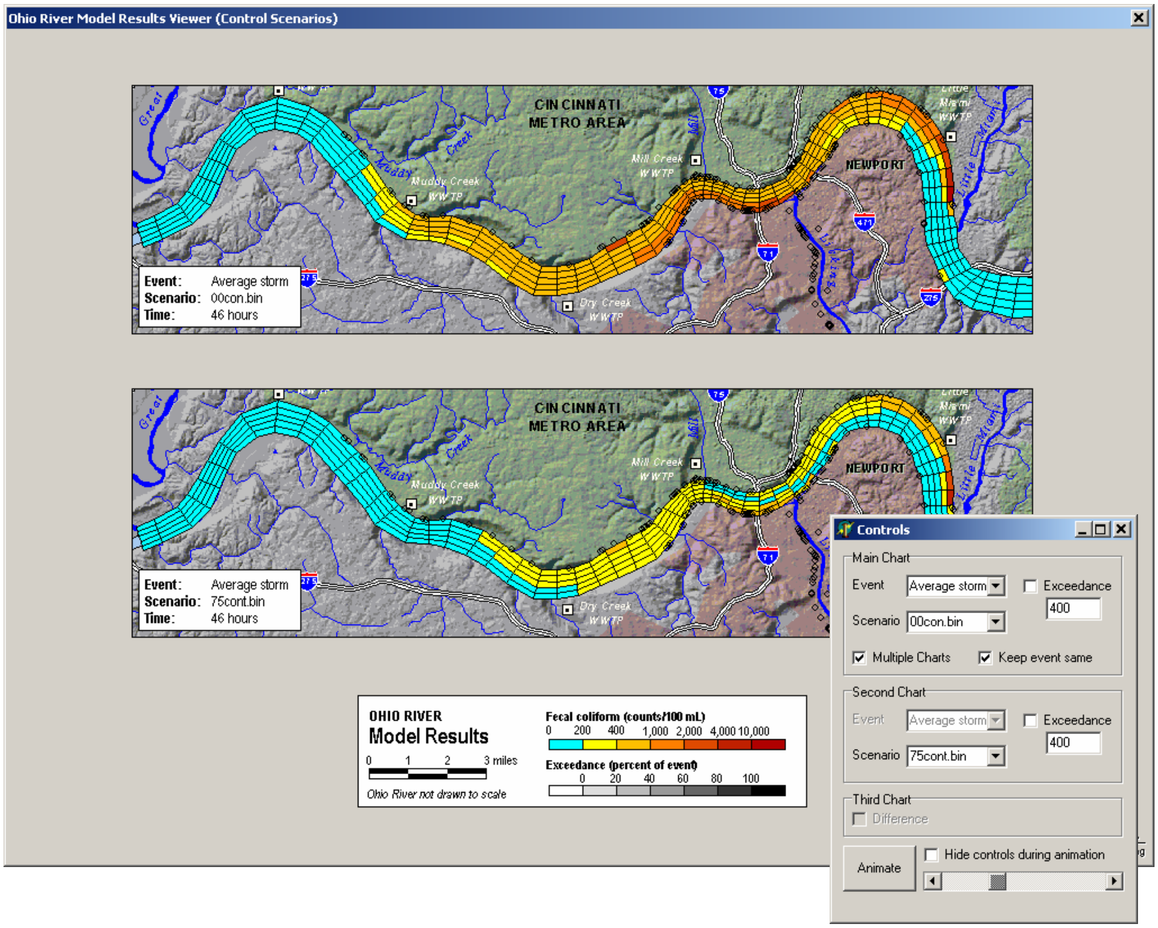
For the OV-SCEN program, the control panel allows the user to select the storm event and scenario of interest, scroll through available timesteps, and display cumulative exceedance values instead of model results. In addition, the user can check the “Multiple Charts” option to provide additional options.

With “Multiple Charts” checked, the control panel is expanded to allow the user to set display parameters for each of two smaller depictions of the study area. The “Keep event same” should be checked to make sure the same event is being displayed in both charts; this is the default setting because it is assumed that comparisons will generally be made between different scenarios for the same storm. Three examples are shown below with the corresponding control panel settings:

1. Results and exceedance for a single storm

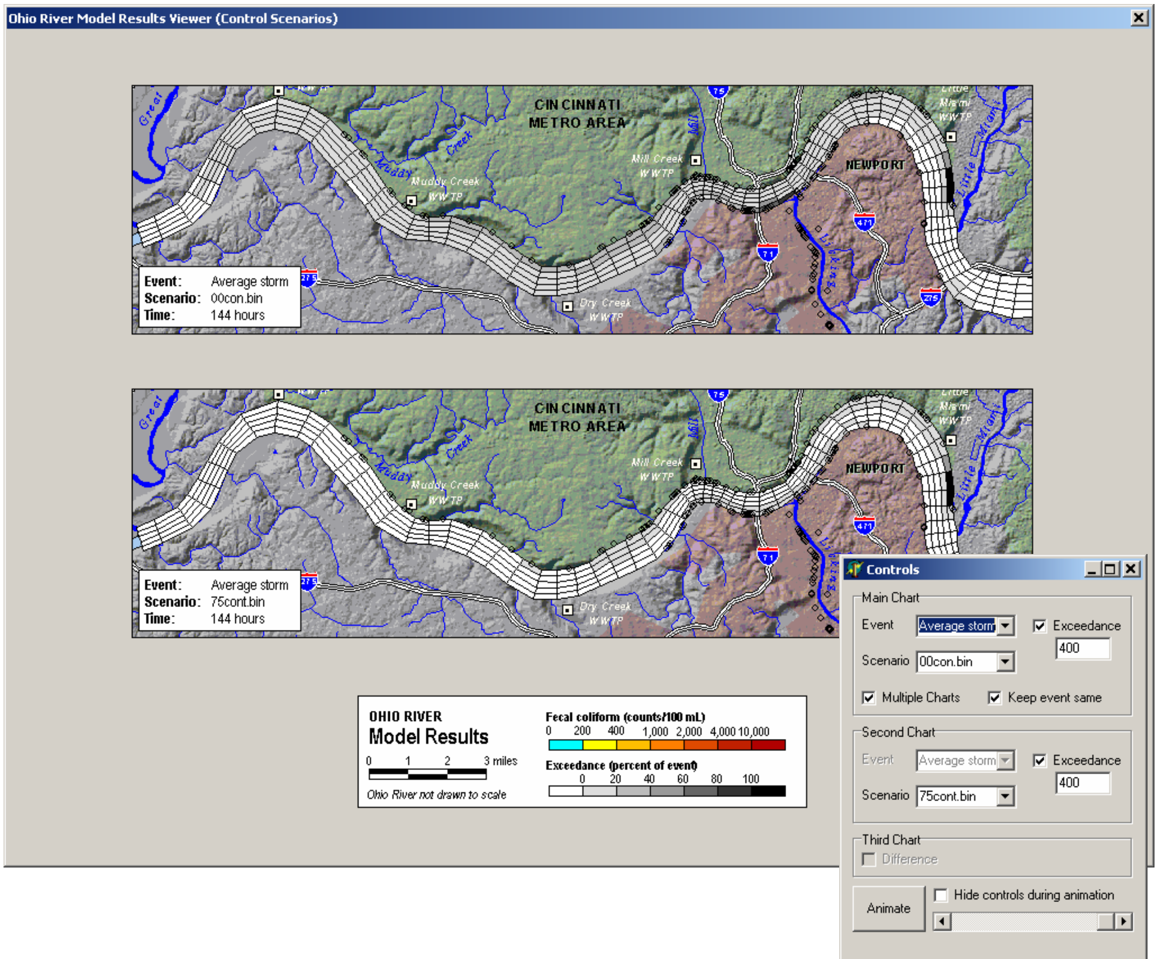


2. Results for the same storm with different controls



Ohio River Model Results Viewer (Control Scenarios)
CINCINNATI METRO AREA
NEWPORT
Event: Average storm
Scenario: 00con.bin
Time: 46 hours
Event: Average storm
Scenario: 75cont.bin
Time: 46 hours
OHIO RIVER
Model Results
0 1 2 3 miles
Ohio River not drawn to scale
Fecal coliform (counts/100 mL)
0 200 400 1,000 2,000 4,000 10,000
Exceedance (percent of event)
0 20 40 60 80 100
Controls
Main Chart
Event
Average storm
Exceedance
400
Scenario
00con.bin
Multiple Charts
Keep event same
Second Chart
Event
Average storm
Exceedance
400
Scenario
75cont.bin
Third Chart
Difference
Animate
Hide controls during animation

3. Exceedances for the same storm with different controls



Appendix H

Holding Time Study

Fecal Coliform Sample Holding Time Study

Purpose of the Study

The purpose of the holding time study was to evaluate the effect of bacteria samples being held outside the standard six-hour hold time. It was necessary to analyze samples outside the six-hour hold time, but within 24 hours of collection. Wet Weather Demonstration Study samples are collected on tributaries prior to a rain event and every two hours for the first twelve hours of the event. Ohio River main stem samples are collected over a large area on the river in consecutive, longitudinal fashion. These sampling protocols are prohibitive to meeting the six-hour holding time requirement for microbiological examination. The Holding Time Study provided data for comparison of bacteria samples held for twenty-four hours versus those plated within the standard six-hour holding time.

Objectives

The objective of the study was to determine if a statistically significant difference existed between Wet Weather Demonstration Study fecal coliform results from samples analyzed within a six or twenty-four hour holding time. Standard Methods for the Examination of Water and Wastewater states that six-hour holding times should be used "If it is known that the results will be used in legal action…" Standard Methods further states about the preservation and storage of samples for microbiological examination:

> *"Unfortunately, these requirements [6-hour] seldom are realistic in the case of individual potable water samples shipped directly to the laboratory by mail, bus, etc., but the time elapsing between collection and examination should not exceed 24h."* (1)

Based on this ambiguity and a lack of reference to non-potable or surface water the holding time study was designed to provide data specifically relating to Ohio River and in-stream samples.

Description of Study

Samples were collected September 30, 1999 at ten regular Wet Weather Demonstration Study locations on tributaries and the Ohio River main stem. Cincinnati recorded 0.4 inches of rain September 29, 1999. The samples were transported to Cardinal Laboratories within the recommended six-hour holding time. Fecal coliform analysis was performed on each sample three times at six hours, fifteen hours, and twenty-four hours after collection.

Study Methods

Samples were collected in standard bacteria sampling bottles, preserved at 4°C, and analyzed using Method 9222 D (Standard Methods for the Examination of Water and Wastewater, 20th Edition).

Data and Results

Interpretation of the holding time study results reveals no significant difference between the 6-hour result and the 24-hour result. The inherent lack of precision in the method is acknowledged in Standard Methods where a 95% confidence interval test for the membrane filter plate count is described [2]. The confidence interval is calculated by the following normal distribution equations:

$$\text{Upper Limit} = c + 2c^{1/2} \qquad \text{Lower Limit} = c - 2c^{1/2}$$

Where: c = count of plated colonies

In samples with equivalent dilutions a 90% agreement between 6 and 24-hour methods is observed. The 24-hour recount of the Ohio River mile 470 (RM 470-RDB) sample does not fall within the 95% confidence interval. The individual results of each analysis follow in tabular form:

	Fecal coliform (CFU/100mL)		
Sample Site	6-hour Result	15-hour Result	24-hour Result
RM 463.8 – RDB	24	56	40
RM 470 – RDB	580 (520 dup)	460	340 (520 dup)
RM 477.8 – MID	17,200	16,800	12,200
RM 483.9 – RDB	140	180	170
Kellogg – MID	11,000	11,800	9,200
12th Street – MID	14,000	19,700	****85,500
Gest Street – MID	120,000	**250,000	90,000
Lost Bridge – MID	240	200	120
Route 50 – MID	*400	***320/1,000	500
Suspension Bridge Rd. - MID	200	330	320
Field Blank (FB)	<2	NA	NA
Equipment Blank (EB)	<2	NA	NA

* “countable” dilution was confluent, so 0.5mL volume used, had 2 colonies
** The only “countable” dilution was 0.01mL volume
*** The 32 colonies were estimated from a 10mL dilution which was slightly confluent, the other “countable” dilution was 0.5mL with 5 colonies
**** These plates were loaded with bacteria

Conclusions

Fecal Coliform analysis of Ohio River and tributary water samples by the membrane filter method at both 6 and 24-hour hold times shows no statistically important difference.

[1]Standard Methods 19th Edition 1995; American Public Health Association, American Water Works Association, Water Environment Federation; pg. 9-19, Mircrobiological Examination (9000), method 9060 B (1).

[2]Standard Methods 19th Edition 1995; American Public Health Association, American Water Works Association, Water Environment Federation; pg. 9-58, Mircrobiological Examination (9000), method 9222 B (6).

ORSANCO FECAL COLIFORM
HOLDING TIME STUDY

Sample ID	*Station/Location*	*6-hr CLI ID*	*6-hr Result*	*15-hr CLI ID*	*15-hr Result*	*24-hr CLI ID*	*24-hr Result*
OR1	RM 462.8 - RBD	*CL01367*	**24**	*CL01379*	**56**	*CL01391*	**40**
OR2	RM 470 - RBD	*CL01368*	**580 (520-Dup)**	*CL01380*	**460**	*CL01392*	**340 (520-Dup)**
OR3	RM 477.8 - MID	*CL01369*	**17,200**	*CL01381*	**16,800**	*CL01393*	**12,200**
OR4	RM 483.9 - RBD	*CL01370*	**140**	*CL01382*	**180**	*CL01394*	**170**
LMR	Kellog - MID	*CL01373*	**7,600**	*CL01385*	**11,800**	*CL01397*	**9,200**
LR	12th St. - MID	*CL01374*	**14,000**	*CL01386*	**19,700**	*CL01398*	******85,500**
MC	Gest St. - MID	*CL01375*	**120,000**	*CL01387*	****250,000**	*CL01399*	**90,000**
GMR1	Lost Bridge - MID	*CL01376*	**240**	*CL01388*	**200**	*CL01400*	**120**
GMR2	Route 50 - MID	*CL01377*	***400**	*CL01389*	*****320/1,000**	*CL01401*	**500**
WW	Suspension Bridge Rd. - MID	*CL01378*	**200**	*CL01390*	**330**	*CL01402*	**320**
FB	Field Blank	*CL01371*	**<2**	*X*	*X*	*X*	*X*
EB	Equipment Blank	*CL01372*	**<2**	*X*	*X*	*X*	*X*

** "countable" dilution was confluent, so we used the 0.5ml volume, which had 2 colonies.*

*** The only "countable" dilution was the 0.01ml volume.*

**** The 32 colonies were estimated from a 10ml dilution which was slightly confluent, the other "countable" dilution was 0.5ml with 5 colonies.*

***** These plates were just loaded with bacteria.*

Appendix I

Bacteria Dilutions and Colony Count Reporting

Calculation Procedure for Determining Bacteria Densities

The following procedures will be followed for determining plate counts for bacteria samples.

1) Report coliform density as CFU/100mL.

   Compute the density using membrane filters with counts of 20 to 60 (ideal range) fecal coliform (FC) or *E. coli* (EC) colonies (and not more than 200 colonies of all types) by the following equation.

$$\text{CFU/100mL} = \frac{\text{FC or EC colonies counted x 100}}{\text{mL sample filtered}}$$

   Calculated densities less than 100 CFU/100mL will be reported with no more than two significant figures, while densities greater than 100 CFU/100mL will be reported with no more than 3 significant figures.

   If more than 200 colonies of all bacteria types are present on a plate or if the colonies are not distinct enough for counting, the result should be reported as "too numerous to count" (TNTC) on the bench sheet for the specific dilution. If a count can not be achieved for a specific dilution due to confluent growth, it should be reported as "confluent growth" (CG) on the bench sheet. If all dilutions for a particular sample are reported as TNTC or CG the sample density is reported as TNTC or CG.

2) If one or more dilutions has a FC or EC count in the acceptable range, use only those in the calculation. These calculated densities will not contain any qualifiers.

example:	filter	count	CFU	=	(45 + 20) x 100)	=	190 CFU/100ml
	25mL	45	100mL		(25 + 10)		
	10mL	20					
	1mL	3					

3) If none of the dilutions has a FC or EC count in the acceptable range, use one of the following calculations. Do not include any colony counts less than 5 during the calculation procedures. Any data determined using calculations 3a, 3b, or 3c will be flagged as estimated densities.

a) If all the filters for a particular sample have counts less than the ideal range, total the FC or EC counts on all filters which contain colonies and report as CFU/100mL.

example:	filter	count	CFU	=	(17 + 6) x 100)	=	66 CFU/100ml
	25mL	17	100mL		(25 + 10)		
	10mL	6					
	1mL	0					

b) If all the filters for a particular sample have some counts less than and some counts greater (but <100) than the ideal range, total the FC or EC counts on all filters and report as CFU/100mL.

example:	filter	count	CFU	=	(80 + 10) x 100)	=	820 CFU/100ml
	10mL	80	100mL		(10 + 1)		
	1mL	10					
	0.1mL	2					

c) If all the filters for a particular sample have more than 60 colonies and at least one dilution with a count below 100, use the dilution with the lowest count of FC or EC colonies in calculating the density.

example:

filter	count
10mL	TNTC
1mL	110
0.1mL	68

$$\frac{\text{CFU}}{\text{100mL}} = \frac{(68) \times 100}{(0.1)} = 68{,}000 \text{ CFU/100ml}$$

4) If no FC or EC colonies are observed on any of the dilutions, select the largest sample dilution and report as “less than” the computed CFU/100mL as if 1 colony were observed. One colony on the 25mL dilution would be 4 CFU/100mL, so report as <4 CFU/100mL

example:

filter	count
25mL	0
10mL	0
1mL	0

$$\frac{\text{CFU}}{\text{100mL}} = \frac{(1) \times 100}{(25)} = <4 \text{ CFU/100ml}$$

5) Under circumstances when an estimated density is more useful than a TNTC (i.e. utilizing dilution counts that are greater than 100 and/or dilutions that contain greater than 200 colonies of all types of bacteria in order to calculate densities), the following calculations may be utilized. Any data determined using calculations 5a, 5b, or 5c will be flagged as estimated densities.

a) If a density is desired even though all dilutions have counts above 100, use the dilution with the lowest count of FC or EC colonies and report as “greater than” in calculating the density.

example:

filter	count	total
10mL	CG	
1mL	TNTC	
0.5mL	122	(<200)

$$\frac{\text{CFU}}{\text{100mL}} = \frac{(122) \times 100}{(0.5)} = >24{,}400 \text{ CFU/100ml}$$

b) If a density is desired even though the dilution to be used in the calculation has a count greater than 200 colonies of all types of bacteria, report as “greater than” in calculating the density.

example:

filter	count	total
10mL	TNTC	
1mL	31	(>200)
0.1mL	3	

$$\frac{\text{CFU}}{\text{100mL}} = \frac{(31) \times 100}{(1)} = >3{,}100 \text{ CFU/100ml}$$

c) If an approximate density is desired and all dilutions are reported as TNTC or CG, select the smallest sample dilution and report as “greater than” the computed CFU/100mL as if 60 colonies were observed. Sixty colonies on the 0.1mL dilution would be 60,000 CFU/100mL, so report as >60,000 CFU/100mL

example:

filter	count	total
10mL	CG	
1mL	TNTC	
0.1mL	TNTC	

$$\frac{\text{CFU}}{\text{100mL}} = \frac{(60) \times 100}{(0.1)} = >60{,}000 \text{ CFU/100ml}$$

Appendix J

Cryptosporidium/Giardia Study Data

WATER SUPPLY CONCERNS
Laboratory Results

Event #1, 7/8 - 7/9/96
River Stage (ft): 26.6 - 26.1
River Velocity (mph): 0.90 - 0.85
River Flow (kcfs): 40.7 - 38.4
Precipitation (in): 0.61

Parameter	Units	Beckjord Power Plant	Nine Mile WWTP	Cincinnati Water Works	Miami Fort Power Plant
Suspended Solids, Total	mg/l	14.3	7.5	<10	34.5
Suspended Solids, Dissolved	mg/l	296	628	237	237
Turbidity	N.T.U.	10.9	7.87	9.44	35.3
Total Organic Carbon	mg/l	3.74	9.3	3.52	4.12
Sulfite	mg/l	<68	<82	<68	<70
Hardness	mg/l CaCO3	130	226	119	129
Phosphate	mg/l	<0.75	7.94	<0.75	<0.75
Chloride	mg/l	28.8	96.5	27.7	32.6
Chlorine, Total Residual	mg/l	<0.1	<0.1	<0.1	<0.1
Nitrate	mg/l NO3-N	0.842	14.7	0.854	0.976
Nitrite	mg/l	<0.1	<0.1	<0.1	<0.1
Total Coliform	C.F.U./100 ml	600	>30,000	200	5,000
Fecal Coliform	C.F.U./100 ml	70	>30,000	10	300
Escherichia Coli	C.F.U./100 ml	70	>30,000	10	150
Total Plate Count	C.F.U./ml	>3,000	>3,000	>3,000	5,500
Giardia cysts confirmed	# Observed - # Calculated	0 - 0	n/a	0 - 0	0 - 0
Giardia cysts presumptive	# Observed - # Calculated	1 - 33.3/100L	n/a	2 - 40/100L	4 - 133.3/100L
Cryptosporidium oocysts confirmed	# Observed - # Calculated	0 - 0	n/a	0 - 0	0 - 0
Cryptosporidium oocysts presumptive	# Observed - # Calculated	1 - 33.3/100L	n/a	0 - 0	0 - 0
Viruses detected	#Observed	none	none	none	none

WATER SUPPLY CONCERNS
Laboratory Results

Event #2, 8/6 - 8/7/96
River Stage (ft): 27.5 - 26.7
River Velocity (mph): 1.49 - 1.32
River Flow (kcfs): 74.6 - 64.1
Precipitation (in): 0.00

Parameter	Units	Beckjord Power Plant	Nine Mile WWTP	Cincinnati Water Works	Miami Fort Power Plant
Suspended Solids, Total	mg/l	21.8	<10	17.0	23.5
Suspended Solids, Dissolved	mg/l	188	608	218	178
Turbidity	N.T.U.	41.0	5.02	29.1	37.5
Total Organic Carbon	mg/l	3.47	7.00	3.26	3.49
Sulfite	mg/l	<61	<95	<58	<58
Hardness	mg/l CaCO3	97.2	252	94.4	97.6
Phosphate	mg/l	<0.75	8.41	<0.75	<0.75
Chloride	mg/l	21.2	117	17.2	20.9
Chlorine, Total Residual	mg/l	<0.1	<0.1	<0.1	<0.1
Nitrate	mg/l NO3-N	0.680	16.0	0.710	0.732
Nitrite	mg/l	<0.1	<0.1	<0.1	<0.1
Total Coliform	C.F.U./100 ml	5,500	>2,500,000	1,600	4,000
Fecal Coliform	C.F.U./100 ml	210	160,000	160	900
Escherichia Coli	C.F.U./100 ml	50	250,000	<10	210
Total Plate Count	C.F.U./ml	1,100	710,000	910	1,600
Giardia cysts confirmed	# Observed - # Calculated	0 - 0	2 - 2222/100 L	1 - 91/100 L	0 - 0
Giardia cysts presumptive	# Observed - # Calculated	2 - 100/100 L	14 - 15,554/100 L	0 - 0	6 - 468/100 L
Cryptosporidium oocysts confirmed	# Observed - # Calculated	0 - 0	0 - 0	0 - 0	0 - 0
Cryptosporidium oocysts presumptive	# Observed - # Calculated	0 - 0	0 - 0	0 - 0	0 - 0
Viruses detected	#Observed	none	20.32/100 L	none	none

WATER SUPPLY CONCERNS
Laboratory Results

Event #3, 10/8 - 10/9/96
River Stage (ft): 27.2 - 26.5
River Velocity (mph): 1.25 - 1.19
River Flow (kcfs): 60.3 - 56.4
Precipitation (in): 0.00

Parameter	Units	Beckjord Power Plant	Nine Mile WWTP	Cincinnati Water Works	Mill Creek (RM 2.90)	Miami Fort Power Plant
Suspended Solids, Total	mg/l	12.0	<10.0	13.0	17.5	19.5
Suspended Solids, Dissolved	mg/l	214	63.4	226	542	204
Turbidity	N.T.U.	18.5	3.05	22.6	10.5	24.0
Total Organic Carbon	mg/l	4.57	8.75	8.36	6.14	4.93
Sulfite	mg/l	<53.7	<92.2	<55.3	<100	<49
Hardness	mg/l CaCO3	93.6	235	94.2	327	93.9
Phosphate	mg/l	<0.75	8.47	<0.75	<0.75	<0.75
Chloride	mg/l	24.7	101	28.0	92.3	25.6
Chlorine, Total Residual	mg/l	<0.1	<0.1	<0.1	<0.1	<0.1
Nitrate	mg/l NO3-N	0.645	21.3	0.658	1.73	0.720
Nitrite	mg/l	<0.1	0.650	<0.1	<0.1	<0.1
Total Coliform	C.F.U./100 ml	3,700	970,000	1,700	29,000	3,100
Fecal Coliform	C.F.U./100 ml	280	360,000	20	570	100
Escherichia Coli	C.F.U./100 ml	60	140,000	<10	130	<10
Total Plate Count	C.F.U./ml	8,000	>2,500,000	680	45,000	1,965
Giardia cysts confirmed	# Observed - # Calculated	0	0	0	0	0
Giardia cysts presumptive	# Observed - # Calculated	9 - 225/100 L	3 - 2500/100 L	2 - 33/100 L	7 - 636/100 L	1 - 7/100 L
Cryptosporidium oocysts confirmed	# Observed - # Calculated	0	0	0	0	0
Cryptosporidium oocysts presumptive	# Observed - # Calculated	0	0	0	0	0

WATER SUPPLY CONCERNS
Laboratory Results

Event #4, 12/17/96
River Stage (ft): 37.5
River Velocity (mph): 3.57
River Flow (kcfs): 248.1
Precipitation (in): 0.65 - 0.71

Parameter	Units	Beckjord Power Plant	Nine Mile WWTP	Cincinnati Water Works	Mill Creek (RM 2.90)	Miami Fort Power Plant
Suspended Solids, Total	mg/l	135	27.5	95.0	217	113
Suspended Solids, Dissolved	mg/l	176	342	228	224	176
Turbidity	N.T.U.	137	11.1	85	208	89.9
Total Organic Carbon	mg/l	4.99	7.17	3.85	6.95	3.93
Sulfite	mg/l	<43.2	<54.9	<46.1	<30.2	46.4
Hardness	mg/l CaCO3	106	194	105	178	117
Phosphate	mg/l	<0.25	0.889	<0.25	0.327	<0.25
Chloride	mg/l	14.8	66.1	13.5	19.4	18.1
Chlorine, Total Residual	mg/l	0.45	<0.1	<0.1	<0.1	<0.1
Nitrate	mg/l NO3-N	0.847	6.92	0.865	0.732	0.944
Nitrite	mg/l	<0.1	<0.1	<0.1	<0.1	<0.1
Total Coliform	C.F.U./100 ml	180	>400,000	29,000	>400,000	60,000
Fecal Coliform	C.F.U./100 ml	<10	290,000	950	77,000	5,300
Escherichia Coli	C.F.U./100 ml	<10	210,000	560	53,000	3,300
Total Plate Count	C.F.U./ml	41	1,300	42	129	57
Giardia cysts confirmed	# Observed - # Calculated	0 - 0	0 - 0	0 - 0	0 - 0	1 - 417/100 L
Giardia cysts presumptive	# Observed - # Calculated	19 - 3,393/100 L	7 - 100,000/100 L	7 - 1,628/100 L	22 - 27,500/100 L	14 - 5,834/100 L
Cryptosporidium oocysts confirmed	# Observed - # Calculated	0 - 0	0 - 0	0 - 0	0 - 0	0 - 0
Cryptosporidium oocysts presumptive	# Observed - # Calculated	7 - 1,250/100 L	0 - 0	1 - 233/100 L	2 - 2,500/100 L	1 - 417/100 L

WATER SUPPLY CONCERNS
Laboratory Results

Event #5, 3/12/97
River Stage (ft): 48.7
River Velocity (mph): 4.41
River Flow (kcfs): 373.6
Precipitation (in): 0.00

Parameter	Units	Beckjord Power Plant	Nine Mile WWTP	Cincinnati Water Works	Mill Creek (RM 2.90)	Miami Fort Power Plant
Suspended Solids, Total	mg/l	177	14.0	120	21.0	63
Suspended Solids, Dissolved	mg/l	161	571	158	348	181
Turbidity	N.T.U.	121	90.1	124	55.3	79.6
Total Organic Carbon	mg/l	4.64	15.9	26.0	16.2	4.97
Sulfite	mg/l	<45	<80	<44	<39.1	<45.2
Hardness	mg/l CaCO3	93.0	245	92.0	182	99.0
Phosphate	mg/l	<0.75	6.23	<0.75	<0.75	<0.75
Chloride	mg/l	22.1	113	26.4	60.7	13.3
Chlorine, Total Residual	mg/l	0.180	<0.1	0.150	0.11	0.16
Nitrate	mg/l NO3-N	<2.5	16.0	<2.5	<2.5	<2.5
Nitrite	mg/l	0.029	0.473	0.028	0.033	0.023
Total Coliform	C.F.U./100 ml	10,000	>400,000	13,000	29,000	11,000
Fecal Coliform	C.F.U./100 ml	1,000	92,000	600	4,000	750
Escherichia Coli	C.F.U./100 ml	300	40,000	160	1,300	240
Total Plate Count	C.F.U./ml	610	>400,000	610	1,000	760
Giardia cysts confirmed	# Observed - # Calculated	0 - 0	0 - 0	0 - 0	0 - 0	0 - 0
Giardia cysts presumptive	# Observed - # Calculated	2 - 400/100 L	11 - 27,500/100 L	4 - 741/100 L	7 - 584/100 L	2 - 200/100 L
Cryptosporidium oocysts confirmed	# Observed - # Calculated	0 - 0	0 - 0	0 - 0	0 - 0	0 - 0
Cryptosporidium oocysts presumptive	# Observed - # Calculated	1 - 200/100 L	1 - 2,500/100 L	0 - 0	0 - 0	0 - 0

WATER SUPPLY CONCERNS
Laboratory Results

Event #6, 3/20/97
River Stage (ft): 38.3
River Velocity (mph): 3.48
River Flow (kcfs): 237.7
Precipitation (in): 0.00

Parameter	Units	Beckjord Power Plant	Nine Mile WWTP	Cincinnati Water Works	Mill Creek (RM 2.90)	Miami Fort Power Plant
Suspended Solids, Total	mg/l	85.0	15.0	193	90.0	42.5
Suspended Solids, Dissolved	mg/l	201	496	187	349	183
Turbidity	N.T.U.	61.7	9.95	169	80.6	57.5
Total Organic Carbon	mg/l	3.26	8.78	3.56	5.90	4.16
Sulfite	mg/l	<52	<71	<53	<56	<51
Hardness	mg/l CaCO3	108	232	102	220	122
Phosphate	mg/l	<0.75	5.96	<0.75	<0.75	<0.75
Chloride	mg/l	36.5	73.8	24.9	63.2	37.7
Chlorine, Total Residual	mg/l	0.200	<0.1	0.200	<0.1	<0.1
Nitrate	mg/l NO3-N	<2.5	14.1	<2.5	<2.5	<2.5
Nitrite	mg/l	0.025	0.340	0.023	0.042	0.024
Total Coliform	C.F.U./100 ml	46,000	>400,000	11,000	>400,000	16,000
Fecal Coliform	C.F.U./100 ml	600	250,000	300	61,000	450
Escherichia Coli	C.F.U./100 ml	435	175,000	260	14,000	550
Total Plate Count	C.F.U./ml	1,500	>400,000	1,400	>400,000	1,300
Giardia cysts confirmed	# Observed - # Calculated	0 - 0	0 - 0	0 - 0	0 - 0	0 - 0
Giardia cysts presumptive	# Observed - # Calculated	9 - 928/100 L	13 - 21,666/100 L	3 - 1,071/100 L	42 - 12,353/100 L	0 - 0
Cryptosporidium oocysts confirmed	# Observed - # Calculated	0 - 0	0 - 0	0 - 0	0 - 0	0 - 0
Cryptosporidium oocysts presumptive	# Observed - # Calculated	0 - 0	0 - 0	0 - 0	0 - 0	0 - 0

WATER SUPPLY CONCERNS
Laboratory Results

Event #7, 5/12/97
River Stage (ft): 29.6
River Velocity (mph): 2.11
River Flow (kcfs): 113.4
Precipitation (in): 0.00

Parameter	Units	Ohio River (RM 470.5) Upstream Mill Creek	Mill Creek (RM 2.90)	Mill Creek WWTP Influent	Mill Creek WWTP Effluent	Ohio River (RM 472.8) Downstream Mill Creek	Ohio River (RM 475.8) Downstream WWTP Diffuser	Miami Fort Power Plant
Suspended Solids, Total	mg/l	22.0	27.0	174	<10	30.0	48.5	14.5
Suspended Solids, Dissolved	mg/l	225	473	1,060	161	267	161	224
Turbidity	N.T.U.	11.5	12.7	81.6	3.08	19.7	15.4	13.7
Total Organic Carbon	mg/l	3.76	4.56	79.8	14.1	3.92	3.20	3.39
Sulfite	mg/l	<68	<76	<216	<185	<65	<69	<69
Hardness	mg/l CaCO3	136	310	333	330	235	137	134
Phosphate	mg/l	<0.75	<0.75	6.45	<0.75	<0.75	<0.75	<0.75
Chloride	mg/l	20.8	91.5	374	343	28.7	30.4	21.5
Chlorine, Total Residual	mg/l	0.120	0.150	<0.1	0.170	<0.1	0.150	<0.1
Nitrate	mg/l NO3-N	0.882	1.36	<0.1	<0.1	1.01	0.825	0.871
Nitrite	mg/l	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Total Coliform	C.F.U./100 ml	8,400	704,000	>400,000	>400,000	10,000	108,000	2,100
Fecal Coliform	C.F.U./100 ml	140	30,000	>400,000	98,000	140	2,300	320
Escherichia Coli	C.F.U./100 ml	60	14,000	>400,000	30,000	4,100	386	80
Total Plate Count	C.F.U./ml	350	7,500	620	>2,000,000	8,900	>2,000,000	405
Giardia cysts confirmed	# Observed - # Calculated	0 - 0	0 - 0	0 - 0	1 - 67/100 L	0 - 0	0 - 0	0 - 0
Giardia cysts presumptive	# Observed - # Calculated	3 - 54/100 L	30 - 2,308/100 L	41 - 12,813/100 L	3 - 200/100 L	20 - 333/100 L	4 - 19/100L	9 - 258/100 L
Cryptosporidium oocysts confirmed	# Observed - # Calculated	1 - 18/100 L	0 - 0	0 - 0	0 - 0	0 - 0	0 - 0	0 - 0
Cryptosporidium oocysts presumptive	# Observed - # Calculated	4 - 72/100 L	1 - 77/100 L	0 - 0	2 - 133/100 L	1 - 17/100 L	1 - 5/100 L	2 - 57/100 L

WATER SUPPLY CONCERNS
Laboratory Results

Event #8, 5/28/97
River Stage (ft): 35.9
River Velocity (mph): 3.29
River Flow (kcfs): 214.5
Precipitation (in): 0.00

Parameter	Units	Ohio River (RM 470.5) Upstream Mill Creek	Mill Creek (RM 2.90)	Mill Creek (RM 2.90) Duplicate	Mill Creek WWTP Influent	Mill Creek WWTP Effluent	Ohio River (RM 472.8) Downstream Mill Creek	Ohio River (RM 475.8) Downstream WWTP Diffuser	Miami Fort Power Plant
Suspended Solids, Total	mg/l	138	24.8	40.5	140	13.0	35.5	132	237
Suspended Solids, Dissolved	mg/l	184	377	373	13.0	762	187	185	239
Turbidity	N.T.U.	82.7	27.2	27.9	10.0	10.0	32.6	90.4	257
Total Organic Carbon	mg/l	4.62	7.20	6.37	74.6	16.4	3.45	4.60	4.04
Sulfite	mg/l	<68.6	<61.2	<60.8	<153	<165	<69.4	<74.1	<72
Hardness	mg/l CaCO3	118	249	258	228	239	124	120	131
Phosphate	mg/l	<0.75	1.65	1.77	1.83	7.34	<0.75	<0.75	<0.75
Chloride	mg/l	16.2	39.5	39.2	128	175	32.0	17.4	17.6
Chlorine, Total Residual	mg/l	0.21	0.11	0.15	<0.1	<0.1	0.23	0.21	<0.1
Nitrate	mg/l NO3-N	0.757	1.88	1.84	<0.1	<0.1	0.840	0.711	0.883
Nitrite	mg/l	<0.1	<0.1	<0.1	0.245	<0.1	<0.1	<0.1	<0.1
Total Coliform	C.F.U./100 ml	5,900	57,000	62,000	>400,000	>400,000	25,000	14,000	36,000
Fecal Coliform	C.F.U./100 ml	2,100	4,900	5,100	>400,000	>400,000	2,900	1,800	1,800
Escherichia Coli	C.F.U./100 ml	280	2,900	3,000	>400,000	>400,000	1,600	280	930
Total Plate Count	C.F.U./ml	700	5,800	9,800	520	>2,000,000	4,900	>2,000,000	1,900
Giardia cysts confirmed	# Observed - # Calculated	0 - 0	0 - 0	n/a	0 - 0	0 - 0	0 - 0	0 - 0	0 - 0
Giardia cysts presumptive	# Observed - # Calculated	0 - 0	5 - 45/100 L	n/a	1 - 53/100 L	0 - 0	0 - 0	3 - 81/100 L	0 - 0
Cryptosporidium oocysts confirmed	# Observed - # Calculated	0 - 0	0 - 0	n/a	0 - 0	0 - 0	0 - 0	0 - 0	0 - 0
Cryptosporidium oocysts presumptive	# Observed - # Calculated	0 - 0	0 - 0	n/a	0 - 0	0 - 0	0 - 0	0 - 0	0 - 0

WATER SUPPLY CONCERNS
Laboratory Results

Event #9, 5/29/97
River Stage (ft): 37.0
River Velocity (mph): 3.35
River Flow (kcfs): 222.1
Precipitation (in): 0.32

Parameter	Units	Ohio River (RM 470.5) Upstream Mill Creek	Mill Creek (RM 2.90)	Mill Creek (RM 2.90) Duplicate	Mill Creek WWTP Effluent	Ohio River (RM 472.8) Downstream Mill Creek	Ohio River (RM 475.8) Downstream WWTP Diffuser	Miami Fort Power Plant
Suspended Solids, Total	mg/l	174	39.5	36.0	67.3	115	146	27.0
Suspended Solids, Dissolved	mg/l	210	382	360	704	231	228	233
Turbidity	N.T.U.	111	31.9	32.7	38.0	61.6	78.1	19.5
Total Organic Carbon	mg/l	3.71	6.09	6.25	13.4	3.83	3.90	3.63
Sulfite	mg/l	<70	<60	<59	<71	<69	<73	<73
Hardness	mg/l CaCO3	118	226	227	181	142	118	120
Phosphate	mg/l	<0.75	0.878	1.01	2.70	<0.75	<0.75	<0.75
Chloride	mg/l	71.6	42.0	93.0	274	32.9	18.0	17.7
Chlorine, Total Residual	mg/l	0.180	<0.1	<0.1	<0.1	0.130	0.180	<0.1
Nitrate	mg/l NO3-N	0.845	1.42	1.41	<0.1	0.969	0.781	0.940
Nitrite	mg/l	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Total Coliform	C.F.U./100 ml	11,000	>400,000	>400,000	>400,000	22,000	16,000	5,200
Fecal Coliform	C.F.U./100 ml	4,000	181,000	195,000	>400,000	4,800	1,400	600
Escherichia Coli	C.F.U./100 ml	3,600	>400,000	>400,000	61,000	2,300	1,600	160
Total Plate Count	C.F.U./ml	630	5,500	7,000	>2,000,000	680	350	139
Giardia cysts confirmed	# Observed - # Calculated	0 - 0	0 - 0	n/a	0 - 0	0 - 0	0 - 0	0 - 0
Giardia cysts presumptive	# Observed - # Calculated	1 - 40/100 L	19 - 905/100 L	n/a	0 - 0	2 - 182/100 L	0 - 0	7 - 179/100 L
Cryptosporidium oocysts confirmed	# Observed - # Calculated	0 - 0	0 - 0	n/a	0 - 0	0 - 0	0 - 0	0 - 0
Cryptosporidium oocysts presumptive	# Observed - # Calculated	3 - 120/100 L	0 - 0	n/a	0 - 0	3 - 273/100 L	0 - 0	0 - 0

WATER SUPPLY CONCERNS
Laboratory Results

Event #10, 6/17/97
River Stage (ft): 28.1
River Velocity (mph): 1.92
River Flow (kcfs): 100.4
Precipitation (in): 0.99

Parameter	Units	Ohio River (RM 470.5) Upstream Mill Creek	Mill Creek (RM 2.90)	Mill Creek WWTP Effluent	Ohio River (RM 472.8) Downstream Mill Creek	Ohio River (RM 475.8) Downstream WWTP Diffuser	Miami Fort Power Plant
Suspended Solids, Total	mg/l	276	404	14.5	212	<10	142
Suspended Solids, Dissolved	mg/l	192	281	795	237	213	<20
Turbidity	N.T.U.	127	245	4.62	103	103	84.3
Total Organic Carbon	mg/l	4.85	3.90	10.8	6.25	5.00	4.83
Sulfite	mg/l	<43	<47	<146	<39	<45	<39
Hardness	mg/l CaCO3	125	203	255	158	127	126
Phosphate	mg/l	<0.75	<0.75	0.967	0.867	<0.75	<0.75
Chloride	mg/l	13.9	28.2	216	24.1	14.9	16.5
Chlorine, Total Residual	mg/l	0.150	0.120	0.190	0.130	0.180	0.150
Nitrate	mg/l NO3-N	1.10	1.45	<0.1	0.185	1.05	0.674
Nitrite	mg/l	0.036	0.057	0.483	0.095	0.051	0.039
Total Coliform	C.F.U./100 ml	45,000	>400,000	>400,000	>400,000	54,000	28,000
Fecal Coliform	C.F.U./100 ml	15,000	238,000	97,000	123,000	10,900	9,950
Escherichia Coli	C.F.U./100 ml	4,300	170,000	30,000	5,500	80,000	6,300
Total Plate Count	C.F.U./ml	>2,000,000	>2,000,000	>2,000,000	>2,000,000	>2,000,000	>2,000,000
Giardia cysts confirmed	# Observed - # Calculated	0 - 0	0 - 0	0 - 0	0 - 0	0 - 0	0 - 0
Giardia cysts presumptive	# Observed - # Calculated	0 - 0	3 - 857/100 L	5 - 1351/100 L	2 - 182/100 L	0 - 0	1 - 27/100 L
Cryptosporidium oocysts confirmed	# Observed - # Calculated	0 - 0	0 - 0	0 - 0	0 - 0	0 - 0	0 - 0
Cryptosporidium oocysts presumptive	# Observed - # Calculated	1 - 53/100 L	1 - 286/100 L	1 - 270/100 L	1 - 91/100 L	0 - 0	0 - 0

WATER SUPPLY CONCERNS

Laboratory Results

Event #11, 7/10/97
River Stage (ft): 26.4
River Velocity (mph): 0.92
River Flow (kcfs): 41.4
Precipitation (in): 0.0

Parameter	Units	Mill Creek WWTP Influent	Mill Creek WWTP Effluent
Suspended Solids, Total	mg/l	<10	<10
Suspended Solids, Dissolved	mg/l	1,180	1,370
Turbidity	N.T.U.	115	3.31
Total Organic Carbon	mg/l	115	17.5
Sulfite	mg/l	<242	<258
Hardness	mg/l $CaCO_3$	287	320
Phosphate	mg/l	8.27	<0.8
Chloride	mg/l	347	502
Chlorine, Total Residual	mg/l	<0.1	<0.1
Nitrate	mg/l NO_3-N	<0.1	0.490
Nitrite	mg/l	0.018	2.10
Total Coliform	C.F.U./100 ml	>4,000,000	550,000
Fecal Coliform	C.F.U./100 ml	>4,000,000	75,000
Escherichia Coli	C.F.U./100 ml	>4,000,000	11,200
Total Plate Count	C.F.U./ml	>20,000,000	12,700
Giardia cysts confirmed	# Observed - # Calculated	0 - 0	0 - 0
Giardia cysts presumptive	# Observed - # Calculated	4 - 6,667/100 L	0 - 0
Cryptosporidium oocysts confirmed	# Observed - # Calculated	0 - 0	0 - 0
Cryptosporidium oocysts presumptive	# Observed - # Calculated	1 - 1,667/100 L	0 - 0

WATER SUPPLY CONCERNS
Laboratory Results

Event #12, 9/18/97
River Stage (ft): 26.6
River Velocity (mph): 0.49
River Flow (kcfs): 22.0
Precipitation (in): 0.0

Parameter	Units	Mill Creek WWTP Influent	Mill Creek WWTP Effluent
Suspended Solids, Total	mg/l	238	<10
Suspended Solids, Dissolved	mg/l	1,500	1,570
Turbidity	N.T.U.	194	5.35
Total Organic Carbon	mg/l	14.1	18.9
Sulfite	mg/l	260	298
Hardness	mg/l CaCO3	292	265
Phosphate	mg/l	11.0	2.28
Chloride	mg/l	509	508
Chlorine, Total Residual	mg/l	<0.1	<0.1
Nitrate	mg/l NO3-N	<0.1	8.09
Nitrite	mg/l	<0.1	1.90
Total Coliform	C.F.U./100 ml	>400,000	>400,000
Fecal Coliform	C.F.U./100 ml	>400,000	>400,000
Escherichia Coli	C.F.U./100 ml	>400,000	188,000
Total Plate Count	C.F.U./ml	>2,000,000	>2,000,000
Giardia cysts confirmed	# Observed - # Calculated	0 - 0	0 - 0
Giardia cysts presumptive	# Observed - # Calculated	1 - 14,286	1 - 323
Cryptosporidium oocysts confirmed	# Observed - # Calculated	0 - 0	0 - 0
Cryptosporidium oocysts presumptive	# Observed - # Calculated	0 - 0	0 - 0

WATER SUPPLY CONCERNS
Laboratory Results

Event #13, 4/16/98
River Stage (ft): 33.8
River Velocity (mph): 3.12
River Flow (kcfs): 194
Precipitation (in): 2.99

Parameter	Units	**Mill Creek WWTP Influent** Filtered Sample	**Mill Creek WWTP Influent** Grab Sample	**Mill Creek WWTP Effluent** Filtered Sample	**Mill Creek WWTP Effluent** Grab Sample
Suspended Solids, Total	mg/l	148	N/A	<10	N/A
Suspended Solids, Dissolved	mg/l	519	N/A	527	N/A
Turbidity	N.T.U.	123	N/A	6.8	N/A
Total Organic Carbon	mg/l	22.2	N/A	5.24	N/A
Sulfite	mg/l	86.7	N/A	92.5	N/A
Hardness	mg/l CaCO3	228	N/A	219	N/A
Phosphate	mg/l	3.09	N/A	<0.8	N/A
Chloride	mg/l	165	N/A	136	N/A
Chlorine, Total Residual	mg/l	<0.1	N/A	<0.1	N/A
Nitrate	mg/l NO3-N	<0.1	N/A	<1	N/A
Nitrite	mg/l	<0.01	N/A	0.910	N/A
Total Coliform	C.F.U./100 ml	2,400,000	N/A	172,000	N/A
Fecal Coliform	C.F.U./100 ml	588,000	N/A	10,250	N/A
Escherichia Coli	C.F.U./100 ml	300,000	N/A	7,050	N/A
Total Plate Count	C.F.U./ml	111,000	N/A	6,500	N/A
Giardia cysts confirmed	# Observed - # Calculated	Non-detect	Non-detect	Non-detect	Non-detect
Giardia cysts presumptive	# Observed - # Calculated	28 - 46,666	6 - 60,000	6 - 600	Non-detect
Cryptosporidium oocysts confirmed	# Observed - # Calculated	Non-detect	Non-detect	Non-detect	Non-detect
Cryptosporidium oocysts presumptive	# Observed - # Calculated	Non-detect	Non-detect	Non-detect	Non-detect

WATER SUPPLY CONCERNS
Laboratory Results

Event #14, 4/30/98
River Stage (ft): 35.6
River Velocity (mph): 3.60
River Flow (kcfs): 251.6
Precipitation (in): 2.11

Parameter	Units	Mill Creek WWTP Influent	Mill Creek WWTP Effluent
Suspended Solids, Total	mg/l	190	40.3
Suspended Solids, Dissolved	mg/l	337	420
Turbidity	N.T.U.	130	27
Total Organic Carbon	mg/l	28.8	10.7
Sulfite	mg/l	32	51.2
Hardness	mg/l CaCO3	146	161
Phosphate	mg/l	3.73	2.69
Chloride	mg/l	56.6	79.7
Chlorine, Total Residual	mg/l	<0.1	<0.1
Nitrate	mg/l NO3-N	<0.1	0.226
Nitrite	mg/l	<0.1	<0.1
Total Coliform	C.F.U./100 ml	>400,000	520,000
Fecal Coliform	C.F.U./100 ml	1,430,000	53,000
Escherichia Coli	C.F.U./100 ml	470,000	25,500
Total Plate Count	C.F.U./ml	>20,000,000	2,960,000
Giardia cysts confirmed	# Observed - # Calculated	Non-detect	Non-detect
Giardia cysts presumptive	# Observed - # Calculated	27,500	Non-detect
Cryptosporidium oocysts confirmed	# Observed - # Calculated	Non-detect	Non-detect
Cryptosporidium oocysts presumptive	# Observed - # Calculated	500	Non-detect