Ohio River Bacteria TMDL Development: Estimating Initial Tributary Boundary Conditions - Report Summary

United States Environmental Protection Agency

May 2013

Introduction

The Ohio River is the largest tributary, by volume, to the Mississippi River and much of it is impaired due to high bacteria counts that affect the recreational uses of the river. The river is 981 miles long and 630.8 miles are impaired for primary contact recreation (e.g., swimming).

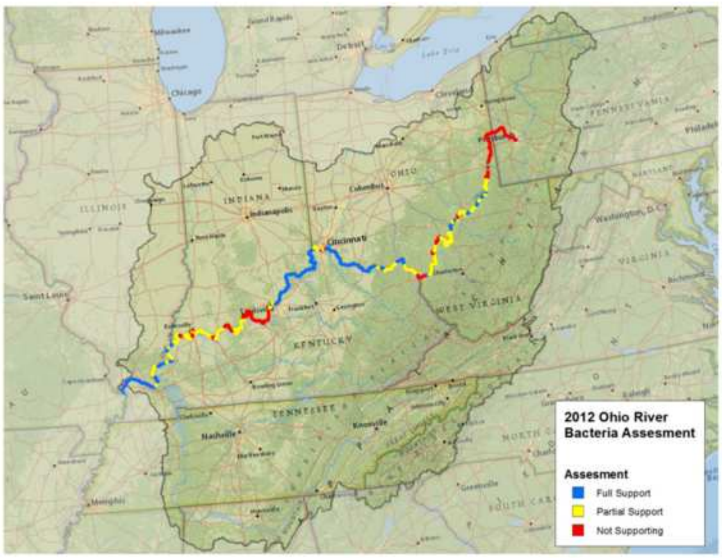

Figure 1. Primary contact recreational use impairment by bacteria in segments along the mainstem of the Ohio River (ORSANCO 2012).

The Clean Water Act and U.S. Environmental Protection Agency (U.S. EPA) regulations require that Total Maximum Daily Loads (TMDLs) be developed for impaired waterbodies such as the Ohio River. The Ohio River bacteria TMDL is in the early stages of model development.

U.S. EPA Region 5 has taken the lead in the development of the TMDL and has convened a TMDL Workgroup composed of representatives of affected state agencies, U.S. EPA Regional Offices, and the Ohio River Valley Water Sanitation Commission (ORSANCO). U.S. EPA Region 5 has also hired Tetra Tech, Inc. to provide technical support to the project.

Development of the TMDL will involve using a series of analytical tools. The most important tool will be a mathematical model to address the sources, fate, and transport of water and bacteria in the Ohio River and portions of its tributaries. The United States Army Corps of Engineers' (USACE) Hydrologic Engineering Center's River Analysis System (HEC-RAS) for the Ohio River will be used to simulate bacteria loads in the Ohio River.

The TMDL and water quality restoration planning process involves several steps, including watershed characterization, target identification, source assessment, and allocation of loads. Quality assurance planning, the conceptual model, data gathering and analysis are near completion. The ultimate purpose of the TMDL is to identify the allowable loads of pathogen indicators (fecal coliform bacteria and *E. coli*) that will result in full attainment of the applicable water quality standards throughout the Ohio River.

The purpose of this report is to summarize the available flow and bacteria data for tributaries of the Ohio River that were used to develop initial boundary conditions for the Ohio River HEC-RAS model.

Ohio River TMDL Website

http://www.orsanco.org/index.php/bacteria-tmdl

Pertinent documents and notices related to the Ohio River bacteria TMDL will be posted at this website.

Categorization

Each of the tributaries flowing directly into the Ohio River was categorized as being either a major or a minor tributary. The categorization was based primarily on the size (drainage area) of the tributary but also accounted for the availability of observed flow data.

Major Tributaries Description

The 22 major tributaries range in size from over 700 square miles to 41,000 square miles. They drain approximately 90 percent of the entire Ohio River Basin, which is approximately 200,000 square miles.

Figure 2. Major tributaries in the Ohio River Basin.

Minor Tributaries Description

A minor tributary is defined as a stream that discharges directly to the Ohio River that is not a major tributary. There are more than 500 minor tributaries to the Ohio River, although they cumulatively drain less than 10 percent of the watershed.

Minor tributaries whose lower reaches flow through urbanized areas are considered to be *urban minor tributaries*. Examples of such tributaries include:

- Beargrass Creek, Louisville, KY
- Chartiers Creek, Pittsburgh, PA
- Mill Creek, Cincinnati, OH
- Sawmill Run, Pittsburgh, PA

Ohio River HEC-RAS Model

USACE developed the HEC-RAS model, which is a one-dimensional model that simulates steady and unsteady flow, model (2010, p. 1-2). The *Community Ohio River HEC-RAS Model* was developed by the National Oceanic and Atmospheric Administration, the National Weather Service's Ohio River Forecast Center (OHRFC), and the USACE Great Lakes and Ohio River Division (LRD) (Adams et al. 2009). The objectives of the model include facilitating hydrologic forecasting (e.g., flood forecasting) for the OHRFC and stage management for navigation for the USACE LRD.

The model was developed using 2,800 cross-sections along 1,300 miles of modeled reaches (Adams et al. 2009). The model simulates flow within the Ohio River, the Mississippi River in segments above and below the confluence with the Ohio River, and the lower, navigable segments of major tributaries of the Ohio River. USACE used continuous flow data from USGS gages and other sources to develop time series of sub-daily flow from direct tributaries to the Ohio River (referred to as model boundary conditions). The largest navigable tributaries were dynamically simulated (i.e., flow hydrographs) while larger tributaries are simulated as individual model boundary conditions (i.e., lateral inflow hydrographs) and smaller tributaries and other sources of flow were simulated in aggregate as uniform lateral inflows (ULIs). The major tributaries and the larger minor tributaries are individual model boundary conditions and the smaller minor tributaries and other sources of flow are compiled together to generate the ULIs.

The model was calibrated sequentially, for a calibration period of September 25, 2004 to July 1, 2008, as described in Adams et al. (2009).

The *Community Ohio River HEC-RAS Model* was modified by USACE to support this project through the addition of a water quality module under development for HEC-RAS. Additional information on the water quality module will be available in the modeling report.

Flow Data

The water quality component of the HEC-RAS model requires concentration time series of selected water quality parameters associated with the flow time series for each tributary boundary condition. For the Ohio River HEC-RAS model, bacteria time series were developed for each tributary based upon either observed relationships between flow and bacteria; previous modeling efforts; or summary statistics of observed data for the tributary.

While USGS monitors flow when the agency samples water quality, ORSANCO does not; therefore, a method to estimate flows for the tributaries of the Ohio River was necessary. The drainage area ratio method was used to estimate flow at ungaged ORSANCO sample sites.

Drainage Area Ratio Method

The area weighting method was used to estimate (1) incremental flow between the most downstream gage and the confluence of the tributary and the Ohio River and (2) the flow for ungaged streams. The drainage area ratio method uses the following equation:

$$Q_{ungaged} = \frac{A_{ungaged}}{A_{gaged}} \times Q_{gaged}$$

where

$Q_{ungaged}$: Flow at the tributary confluence with the Ohio River
Q_{gaged}: Flow at upstream USGS gage
$A_{ungaged}$: Drainage area of the tributary
A_{gaged}: Drainage area at upstream USGS gage

For ungaged streams, a representative gage was selected as the nearest gage in a similarly sized watershed on a direct tributary to the Ohio River. The proximity of a gage to an ungaged watershed was estimated by calculating the linear distance from the gage to the centroid (i.e., the center of an irregular shape) of each ungaged watershed.

This methodology requires the following assumptions:

- The gages assigned to the ungaged sites are in hydrologically similar watersheds.
- The gages assigned to the ungaged sites experience similar climatological conditions.
- Both gage and ungaged sites are on 'naturally' flowing rivers (i.e., not in areas with regulated flow).

USGS Gages

One or more USGS gages were located on each of the 22 major tributaries. Typically, the most downstream gage were used, except in cases where the most downstream gage had significant data gaps during the period of interest or if the river was highly regulated above a gage.

There are no USGS gages on most of the minor tributaries. Where gages do exist, data are often not available for the period of interest. Flow for the minor tributaries was therefore estimated based upon using flows from the nearest USGS gage with appropriate flow data. Twenty gages on minor tributaries in all six states along the Ohio River mainstem were used to estimate flow at ungaged ORSANCO sample sites.

Bacteria Data

Organizations throughout the Ohio River basin regularly evaluate water quality for multiple reasons, including the assessment of designated uses, evaluation of clean-up efforts, and to address nuisance complaints. Available data from federal, state, and interstate agencies were used to support model development.

Data Availability

Bacteria data for the tributaries to the Ohio River were primarily available from three sources:

- **USGS** fecal coliform data collected from 14 major tributaries (1985 - 2005)[1]. Sample counts range from 35 to over 200 samples per site.
- **ORSANCO** *E. coli* data collected from all 22 major tributaries (2003 - 2012; Table 1).
- **States** fecal coliform and E. coli data. Sampling and laboratory methods varied by state.

A review of each data source illustrates that (1) limited data are available to represent tributary conditions and (2) flow conditions varied among the various rivers, with samples usually not collected equally for different flow conditions. Both of these factors affect the quality of the tributary bacteria count estimations and should be considered as the project continues.

Table 1. Tributary *E. coli* samples.

Pool Name	RM	Waterbody	n
Emsworth (#1)	0.0	**Allegheny River**	160
	0.0	**Monongahela River**	162
	0.8	*Sawmill Run*	72
	2.5	*Chartiers Creek*	97
Dashields (#2)	8.7	Moon Run	11
	9.4	Montour Run	10
Montgomery (#3)	13.6	Little Sewickley Creek	10
	14.2	Flaugherty Run	10
	22.7	Elkhorn Run	10
	25.4	**Beaver River**	35
	29.6	Raccoon Creek (PA)	10
New Cumberland (#4)	39.5	Little Beaver Creek	15
	44.5	Carpenter Creek	10
	47.2	Little Yellow	10
Pike Island (#5)	50.4	Yellow Creek	15
	61.9	Island Creek	10
	70.3	Allegheny Steel Run	10
	71.6	Cross Creek [OH]	15
Hannibal (#6)	74.7	Buffalo Creek	29
	81.4	Short Creek	16
	91.0	Big Wheeling Creek (WV)	10
	91.0	Wheeling Creek (OH)	16
	91.7	Caldwell Run	10
	93.4	Bogg's Run	10
	94.7	McMahon Creek	10
	95.8	McMechen's Run	15
	96.8	Jim's Run	25
	101.6	Little Grave Creek	15
	102.5	Grave Creek	10
	105.0	Pipe Creek	30
	109.6	Captina Creek	15
	113.8	Fish Creek	10
	118.0	Sunfish Creek	15
	119.8	Opossum Creek	10
	122.1	Proctor Creek	10
Willow Island (#7)	128.3	Fishing Creek	10
	154.0	Middle Island Creek	10
Belleville (#8)	168.3	Little Muskingum River	30
	170.7	Duck Creek	15
	172.2	**Muskingum River**	40
	184.6	**Little Kanawha River**	40
	191.8	Little Hocking River	16
	199.3	**Hocking River**	40
Racine (#9)	210.6	Shade River	30
	220.6	Sandy Creek	25
	231.5	Mill Creek (WV)	25
Robert C. Byrd (#10)	254.2	Leading Creek	14
	265.7	**Kanawha River**	40
	270.1	Chickamauga Creek	30
	276.0	Raccoon Creek (OH)	15
	299.0	Nine Mile Creek	9

[1] Data collected prior to 1985 were excluded because prior to 1985, water quality conditions associated with wastewater treatment plants were in transition because of the significant investment that was made during the late 1970s and early 1980s to improve the operation of many facilities.

Greenup (#11)	305.2	**Guyandotte River**	37
	308.7	Symmes Creek	15
	311.8	Fourpole Creek	10
	313.2	Twelvepole Creek	8
	317.1	**Big Sandy River**	39
	323.0	Long Branch Creek	16
	324.0	Little Hoods Creek	15
	328.1	Storms Creek	30
	331.0	Pond Run	14
	336.4	**Little Sandy River**	40
Medahl (#12)	346.9	Pine Creek	15
	349.0	Little Scioto River	15
	353.3	Tygarts Creek	15
	356.5	**Scioto River**	40
	368.1	Kinniconick Creek	15
	378.4	Salt Lick Creek	16
	388.0	Ohio Brush Creek	15
	408.5	Limestone Creek	30
	415.7	Eagle Creek	15
	424.4	White Oak Creek	15
Markland (#13)	445.3	Big Indian Creek (OH)	10
	451.3	Twelve Mile Creek (OH)	9
	451.5	Twelve Mile Creek (KY)	9
	455.1	Ten Mile Creek	9
	464.1	**Little Miami River**	40
	470.2	**Licking River**	39
	472.5	*Mill Creek (OH)*	23
	480.7	Rapid Run	12
	484.1	Muddy Creek	14
	491.1	**Great Miami River**	39
	494.8	Tanners Creek	10
	498.7	Laughery Creek	9
McAlpine (#14)	545.8	**Kentucky River**	33
	546.5	Little Kentucky River	8
	550.5	Indian Kentuck River	8
	595.9	Harrods Creek	8
	597.0	Goose Creek	9
	605.2	*Beargrass Creek*	8
	445.3	Cane Run	28
Cannelton (#15)	606.2	Mill Creek (IN)	28
	606.5	Silver Creek	14
	609.3	Falling Run Creek	13
	616.4	Mill Creek Cutoff	28
	625.0	Mill Creek (KY)	28
	629.9	**Salt River**	37
	636.5	Otter Creek	28
	657.0	Big Indian Creek (IN)	9
	663.0	Blue River	9
	678.7	Little Blue River	9
	691.7	Oil Creek	9
	700.9	Sinking Creek	10
	711.0	Clover Creek	10
	718.9	Deer Creek (IN)	9
Newburgh (#16)	731.5	Anderson River	9
	742.2	Blackford Creek	25
	773.0	Little Pigeon Creek	10
	776.5	Cypress Creek	10
Uniontown (#17)	784.2	**Green River**	35
	792.9	Pigeon Creek	25
	806.9	Canoe Creek	11
	815.1	Bayou Creek	9
	841.8	Highland Creek	10
	843.0	Lost Creek	10
Smithland (#18)	848.0	**Wabash River**	35
	867.5	**Saline River**	35
	873.5	**Tradewater River**	35
	877.7	Crooked Creek (KY)	10
	893.0	Deer Creek (KY)	10
Lock & Dam 52 (#19)	920.4	**Cumberland River**	35
	934.5	**Tennessee River**	35
	939.4	Perkins Creek	10
Lock & Dam 53 (#20)	941.9	Massac Creek (IL)	10
	957.7	Post Creek Cutoff	10
	975.7	Cache River	11
(#21)		Cottonwood Slough	--

Major tributaries; *urban minor tributaries*.
n = Number of *E. coli* samples January 2013. The numbers of samples include *E. coli* samples collected by ORSANCO and USGS for Pittsburgh-area waters.

Relationship between Flow and Bacteria

Daily flow was chosen as the independent variable with which to predict corresponding daily bacteria counts for tributaries, which are needed for the modeling. A variety of factors other than flow affect bacteria counts (e.g., land use, soil, human and animal populations). However, flow was determined to be the most feasible of these factors that could be used to make daily load estimates.

Methodology

Power regressions (nonlinear regression analysis technique) were constructed for each tributary with sufficient data. Flow represented the independent variable and bacteria represented the dependent variable. The generic equation for a power regression is:

$$y = b*x^m$$

where y is the dependent variable, b is the intercept, x is the independent variable, and m is the slope.

The strength of the relationship was measured as the coefficient of determination (R^2), with R^2 approaching 1 considered to be a stronger relationship and R^2 approaching 0 to be a weaker relationship.

Exploratory Analyses

USGS fecal coliform data from the 12 major tributaries were used to explore potential patterns. The analyses included the assessment of variables (e.g., flow, unit area flow) and univariate (i.e., flow) versus multivariate (e.g., flow, water temperature, conductivity, and turbidity) regressions. Datasets (i.e., individual tributaries versus groups of tributaries) were also evaluated. Ultimately, it was found that individual regressions for each waterbody were most appropriate for estimating daily bacteria loads for model input.

Numerous additional analyses were performed but are not presented here. Many of these analyses evaluated different techniques of removing outliers and extremes. Since these analyses tended to bias the data (e.g., outlier removal in Beargrass Creek negated effects from CSOs), they were abandoned.

Following additional data collection in 2011 and 2012, performed by ORSANCO and funded by U.S. EPA Region 5, power regressions were developed using ORSANCO *E. coli* samples from 2003 through 2012.

E. coli Power Regressions

Power regressions of *E. coli* (dependent variable) versus flow (independent variable) were developed with ORSANCO *E. coli* data for 35 rivers and streams. Also, recent USGS *E. coli* data (Buckwalter et al. 2006) were used to develop power regressions for three Pittsburgh-area rivers and streams. Regressions show that the relationships can vary greatly at each location. Examples are shown in Figure 3 and Figure 4.

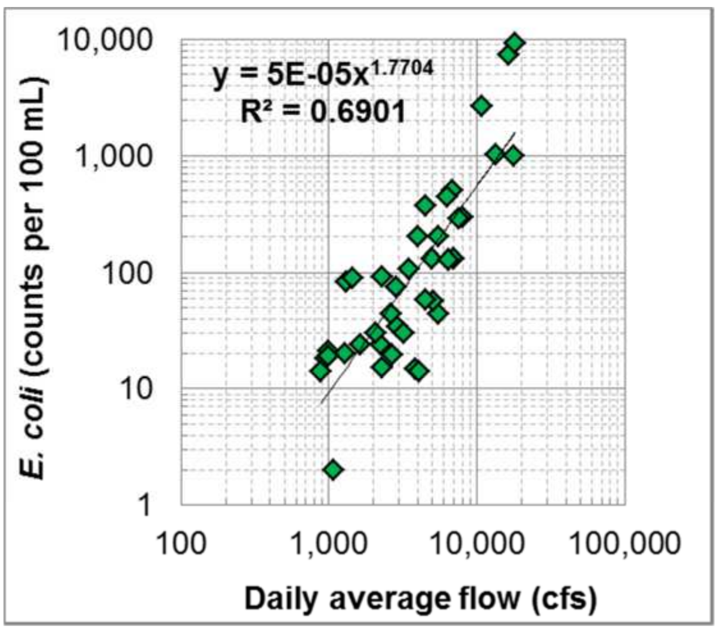

Figure 3. Power regression for the Great Miami River.

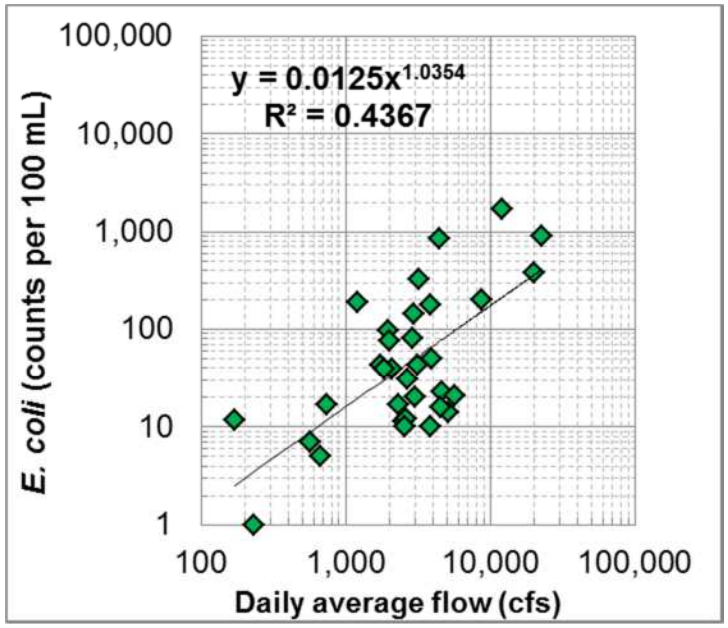

Figure 4. Power regression for the Kentucky River.

Initial Tributary Bacteria Boundary Conditions

While bacteria levels along the tributaries of the Ohio River will not be explicitly modeled, bacteria loads from direct tributaries of the Ohio River will be input as boundary conditions. Daily flow from the major tributaries and larger minor tributaries is already included in the HEC-RAS model as boundary conditions. The initial tributary bacteria boundary conditions for the major and minor tributaries were developed using the following three methods:

- **Individual power regressions** of daily average flow and *E. coli* data to yield *E. coli* concentrations time series
- **Previous model output** to yield *E. coli* concentrations time series
- **Medians** of *E. coli* data to yield constant *E. coli* concentrations

The initial tributary bacteria boundary conditions presented in this document may differ from the final tributary bacteria boundary conditions because the tributary bacteria boundary conditions may need to be changed during model development and calibration. The final tributary bacteria boundary conditions for the Ohio River HEC-RAS model will be presented in a modeling report that will be developed after the modeling is completed.

Individual Power Regressions

Individual power regressions were used to develop dynamic initial tributary bacteria boundary conditions for 28 tributaries (Table 2). These 28 tributaries represent 46 percent of the total tributary inflow to the Ohio River.

Table 2. Individual *E. coli* power regressions

Tributary	Size	Slope	Intercept
Monongahela River	major	0.1949	1,480.7
Sawmill Run	minor (urban)	0.6916	723.1
Chartiers Creek	minor (urban)	1.6748	1.309
Beaver River	major	0.00005	1.5914
Little Muskingum River	minor	0.8704	1.9137
Muskingum River	major	1.1059	0.0088
Little Kanawha River	major	0.8426	0.4262
Hocking River	major	1.1724	0.0576
Shade River	minor	0.5014	56.505
Kanawha River	major	1.0892	0.0017
Chickamauga Creek	minor	-0.4200	5,752.2
Big Sandy River	major	0.8219	0.133
Little Sandy River	major	0.5391	2.7951
Little Miami River	major	0.7480	2.2869
Great Miami River	major	1.7704	0.00005
Kentucky River	major	1.0354	0.0125
Beargrass Creek	minor (urban)	1.2832	0.0019
Cane Run	minor	0.5468	1,863.7
Mill Creek (IN)	minor	0.6807	194.99
Mill Creek (KY)	minor	0.6851	7.3225
Salt River	major	0.7867	0.4459
Otter Creek	minor	0.6535	21.924
Blackford Creek	minor	0.4955	119.41
Green River	major	0.6203	0.173
Pigeon Creek	minor	0.4961	48.789
Wabash River	major	0.9888	0.0022
Saline River	major	0.5301	3.0251
Tradewater River	major	0.3004	29.501

Previous Model Output

West Virginia DEP developed Loading Simulation Program in C++ (LSPC) models to simulate fecal coliform in 40 direct tributaries to the Ohio River for separate TMDL development projects. Many of these tributaries are small and not explicitly simulated in the HEC-RAS model. Outputs from 11 tributaries LSPC models were used to establish dynamic initial tributary bacteria boundary conditions, including three tributaries that had weak power regressions (i.e., Guyandotte River, Jim's Run, and Mill Creek [WV]).

Statistics

The median of available ORSANCO *E. coli* data were used to create static initial tributary bacteria boundary conditions for 83 waterbodies, which represent 52 percent of the tributary inflow to the Ohio River. Medians were used in two cases: (1) too few *E. coli* data were available to develop a power regression or (2) sufficient *E. coli* data were available to develop a power regression but the regression was not representative of in-stream bacteria conditions. The Tennessee and Cumberland Rivers, which contribute 30 percent of the tributary inflow to the Ohio River, were represented by medians; 97 and 88 percent (respectively) of the samples from these rivers were less than or equal to 30 counts/100 milliliter.

Contacts

The following individuals can be contacted for more information regarding the Ohio River bacteria TMDL:

Agency	Name	Phone
*U.S. EPA, Region 5	Jean Chruscicki	312-353-1435
U.S. EPA, Region 3	K-L Lai	215-814-5473
U.S. EPA, Region 4	Bill Melville	404-562-9266
ORSANCO	Jason Heath Sam Dinkins	513-231-7719
Illinois EPA	Jennifer Clarke	217-782-3362
Indiana DEM	Bonnie Elifritz Staci Goodwin	317-308-3082 317-308-3387
Kentucky DOW	Ann Fredenburg	502-564-3410
Ohio EPA	Trinka Mount	614-644-2140
Pennsylvania DEP	Bill Brown	717-783-2951
West Virginia DEP	Dave Montali	304-926-0499

* U.S. EPA Region 5 is leading the TMDL effort and Jean Chruscicki is the primary contact.

References

Adam, T., S. Chen, R. Davis, T. Shade, and D. Lee. 2009. The Ohio River Community HEC-RAS model. http://www.erh.noaa.gov/er/ohrfc/The%20Ohio%20River%20Community%20HEC-RAS%20model.pdf. Accessed February 7, 2013.

Buckwalter, T.F., Zimmerman, T.M., and Fulton, J.W., 2006, Fecal-indicator bacteria in the Allegheny, Monongahela, and Ohio Rivers and selected tributaries, Allegheny County, Pennsylvania, 2001–2005:U.S. Geological Survey Scientific Investigations Report 2006-5126, 27 p.

ORSANCO (Ohio River Valley Water Sanitation Commission). 2012. *Biennial Assessment of Ohio River Water Quality Conditions, 2007-2011*. Cincinnati, OH

USACE. (United States. Army Corps of Engineers). 2010. HEC-RAS River Analysis System. User's Manual. Version 4.1. CPD-68. U.S. Army Corps of Engineers, Institute of Water Resources, Hydrologic Engineering Center. Davis, CA.