Modeling Quality Assurance Project Plan

for

Ohio River Bacteria TMDL Development

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Tt Account No. 94150

Prepared for:

U.S. Environmental Protection Agency

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This quality assurance project plan (QAPP) has been prepared according to guidance provided in *EPA Requirements for Quality Assurance Project Plans* (EPA QA/R-5, EPA/240/B-01/003, U.S. Environmental Protection Agency, Office of Environmental Information, Washington, DC, March 2001) and *EPA Guidance for Quality Assurance Project Plans for Modeling* (EPA QA/G-5M, EPA/240/R-02/007, U.S. Environmental Protection Agency, Office of Environmental Information, Washington, DC, December 2002) to ensure that environmental and related data collected, compiled, and/or generated for this project are complete, accurate, and of the type, quantity, and quality required for their intended use. Tetra Tech will conduct the work in conformance with the quality assurance program described in the quality management plan for Tetra Tech's Fairfax Center and with the procedures detailed in this QAPP.

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Acronyms and Abbreviations

BMPs	best management practices
CAFO	confined animal feeding operation
CE-QUAL-W2	U.S. Army Corps of Engineers' two-dimensional (2D) water quality model
CSO	combined sewer overflow
CVS	concurrent version control system
DMR	discharge monitoring report
DQI	data quality indicator
DQO	data quality objective
EFDC	Environmental Fluid Dynamics Code
EPA	U.S. Environmental Protection Agency
GIS	geographical information system
LCTP	Long-Term Control Plan
MS4	municipal separate storm sewer
ORSANCO	Ohio River Valley Water Sanitation Commission
NPDES	National Pollutant Discharge Elimination System
QA	quality assurance
QAPP	quality assurance project plan
QC	quality control
RAM	random access memory
SSO	sanitary sewer overflow
TM	Technical Monitor
TMDL	Total Maximum Daily Load
TOL	Task Order Leader
TOM	Task Order Manager
USGS	U.S. Geological Survey
WASP	Water Analysis Simulation Program (USEPA-supported water quality model)
W2	See CE-QUAL-W2
WWTP	wastewater treatment plant

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1 PROJECT MANAGEMENT

1.1 PROJECT/TASK ORGANIZATION

The U.S. Environmental Protection Agency (EPA) Region 5 has retained Tetra Tech, Inc., to provide consulting services for the development of a bacteria Total Maximum Daily Load (TMDL) for the Ohio River. The Ohio River is one of the nation's great natural resources because it provides drinking water to nearly 3 million people, provides numerous recreational opportunities, is used as a major transportation route, and is a widely used source of water for manufacturing and power generation. Almost 500 miles of the Ohio River were considered impaired on the 2006 Section 303(d) lists due to high bacteria counts that affect the recreational uses of the river.

The Clean Water Act and EPA regulations require that states develop TMDLs for impaired waterbodies such as 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. The purpose of the TMDL is to identify the allowable loads of pathogen indicators (fecal coliform bacteria and *Escherichia coli*) that will result in full attainment of the applicable water quality standards throughout the Ohio River.

Development of the TMDL will involve using a series of analytical tools, most significantly a mathematical model, to address the sources, fate, and transport of water and pathogen indicators in the Ohio River and portions of its tributaries. A sophisticated model has been determined to be necessary for the following reasons:

- To determine the fate and transport of bacteria loads as they travel from upstream sources to downstream assessment locations.
- To determine the load reductions needed from each source to meet water quality standards.
- To provide predicted bacteria counts at the spatial and temporal scales needed to make a direct comparison to the various water quality standards that apply to the Ohio River.
- To assess the potential benefits of a variety of implementation scenarios.

This quality assurance project plan (QAPP) provides a general description of the modeling and associated analytical work to be performed for the project, including data quality objectives (DQOs) and quality control (QC) procedures to ensure that the final product satisfies user requirements. This QAPP also addresses the use of secondary data (data collected for another purpose or collected by an organization or organizations not under the scope of this QAPP) to support TMDL development.

The organizational aspects of the program provide the framework for conducting the necessary tasks. The organizational structure and function can also facilitate task performance and adherence to QC procedures and quality assurance (QA) requirements. Key task roles are filled by the persons who are leading the various technical phases of the project and the persons who are ultimately responsible for approving and accepting final products and deliverables.

Because this TMDL project involves the Ohio River watershed, EPA Region 5 has convened a TMDL Workgroup composed of representatives of affected state agencies, EPA Regional Offices, and the Ohio River Valley Water Sanitation Commission (ORSANCO). EPA Region 5 intends for the bacteria TMDL to be a mainstem TMDL; therefore, the six states adjacent to the mainstem of the Ohio River are those that are expected to most actively participate in the Workgroup. TMDL coordinators for the EPA Regional offices responsible for TMDL development in the six participating states (i.e., Regions 3, 4, and 5) have also been invited to be a part of the TMDL Workgroup. ORSANCO is an interstate commission representing eight states within the Ohio River Basin and the federal government. ORSANCO is an integral agency for this TMDL project because it is responsible for setting pollution control standards for municipal and industrial wastewater discharges to the Ohio River and conducts comprehensive ambient monitoring of the Ohio River. Participants of the TMDL Workgroup will provide valuable data and input throughout the TMDL development process.

The program organization chart, provided in Figure 1, illustrates the relationships and lines of communication among all participants and data users. The responsibilities of these persons are described below.

Kevin Pierard, EPA Region 5 Watersheds and Wetlands Branch Chief, and Tinka G. Hyde, acting EPA Region 5 Water Division Director, will provide oversight for this contract. They will review and approve the QAPP and ensure that all contractual issues are addressed as work is performed.

Jean Chruscicki will provide overall project/program oversight for this study as the EPA Region 5 Task Order Manager (TOM). The EPA Region 5 TOM will work with the Tetra Tech Task Order Leaders (TOLs) to ensure that project objectives are attained. The EPA Region 5 TOM will also have the following responsibilities:

- Providing oversight for TMDL design, model selection, data selection, model calibration, model validation, and adherence to project objectives
- Maintaining the official approved QAPP
- Facilitating participation of state, EPA, and ORSANCO participants on the TMDL workgroup
- Coordinating with contractors, reviewers, and others to ensure technical quality and contract adherence

The EPA Region 5 QA Officer, Simon Manoyan, will be responsible for reviewing and approving this QAPP. His responsibilities will also include conducting external performance and system audits and participating in Agency QA reviews of the study.

Given the complexity of the project and the size of the watershed, Tetra Tech is providing two TOLs to support the bacteria TMDL for the Ohio River. Kevin Kratt (Cleveland, Ohio) and Jon Ludwig (Charleston, West Virginia) will serve as the Tetra Tech TOLs. They will supervise the overall project, including study design and model application. They will provide general oversight and guidance to the TMDL Development Leader and the Modeling Leader. The TMDL Development Leader, Andrew Parker, and the Modeling Leader, Dr. Rui Zou, will assist the TOLs in fulfilling their responsibilities. Specific responsibilities of the Tetra Tech TOLs include the following:

- Coordinating project assignments, establishing priorities, and scheduling
- Ensuring completion of high-quality products within established budgets and time schedules
- Acting as primary point of contact for the EPA Region 5 TOM
- Providing guidance, technical advice, and performance evaluations to those assigned to the project
- Implementing corrective actions and providing professional advice to staff

- Preparing and reviewing preparation of project deliverables, including the QAPP, draft TMDL report, final TMDL report, and other materials developed to support the project
- Providing support to EPA in interacting with the project team, technical reviewers, TMDL workgroup participants, and others to ensure that technical quality requirements of the study design objectives are met

The Tetra Tech QA Officer is Dr. Esther Peters, whose primary responsibilities include the following:

- Providing support to the Tetra Tech TOL in preparing and distributing the QAPP
- Reviewing and internally approving the QAPP
- Monitoring QC activities to determine conformance

Tetra Tech modeling staff will be responsible for developing model input data sets, applying the model, comparing model results to observed data, calibrating the model, and writing documentation. They will implement the QA/QC program, complete assigned work on schedule and with strict adherence to the established procedures, and complete required documentation. Other technical staff will perform literature searches; assist in secondary data gathering, compilation, and review; and help complete other deliverables to support the development of the draft and final TMDL report by EPA.

The TMDL Development QC Officer, Dr. Leslie Shoemaker, and the Modeling QC Officer, Dr. Jonathan Butcher, will provide additional oversight. Dr. Leslie Shoemaker, a Vice President with Tetra Tech, is experienced in the TMDL development process and will review final work products before submittal to EPA. Dr. Jonathan Butcher, an Associate Director with Tetra Tech, is familiar with the model and its application for TMDL development and will provide final review of the model setup and output. The TMDL Development QC Officer and the Modeling QC Officer will be responsible for performing evaluations to ensure that QC is maintained throughout the data collection and analysis process. QC evaluations will include reviewing site-specific model equations and codes (when necessary), double-checking work as it is completed, and providing written documentation of these reviews to ensure that the standards set forth in the QAPP and in other planning documents are met or exceeded. Other QA/QC staff, including technical reviewers and technical editors selected as needed, will provide peer review oversight of the content of the work products and ensure that they comply with EPA’s specifications.

The EPA Region 5 TOM and the Tetra Tech TOLs will communicate regularly with the TMDL Workgroup to obtain data and information and to explain the modeling to ensure it addresses the study questions raised by all participants and can be implemented by all TMDL Workgroup participants. Figure 1 identifies the TMDL Workgroup participants representing the six state agencies, three EPA Regional Offices, and ORSANCO. It should be noted that the ORSANCO Technical Committee will also be providing input to the Coordinators Workgroup but will not be a part of the formal decision-making process. Users of the model output will include the agencies and organizations represented by members of the TMDL Workgroup, EPA, Tetra Tech, and other decision makers in the Ohio River watershed.

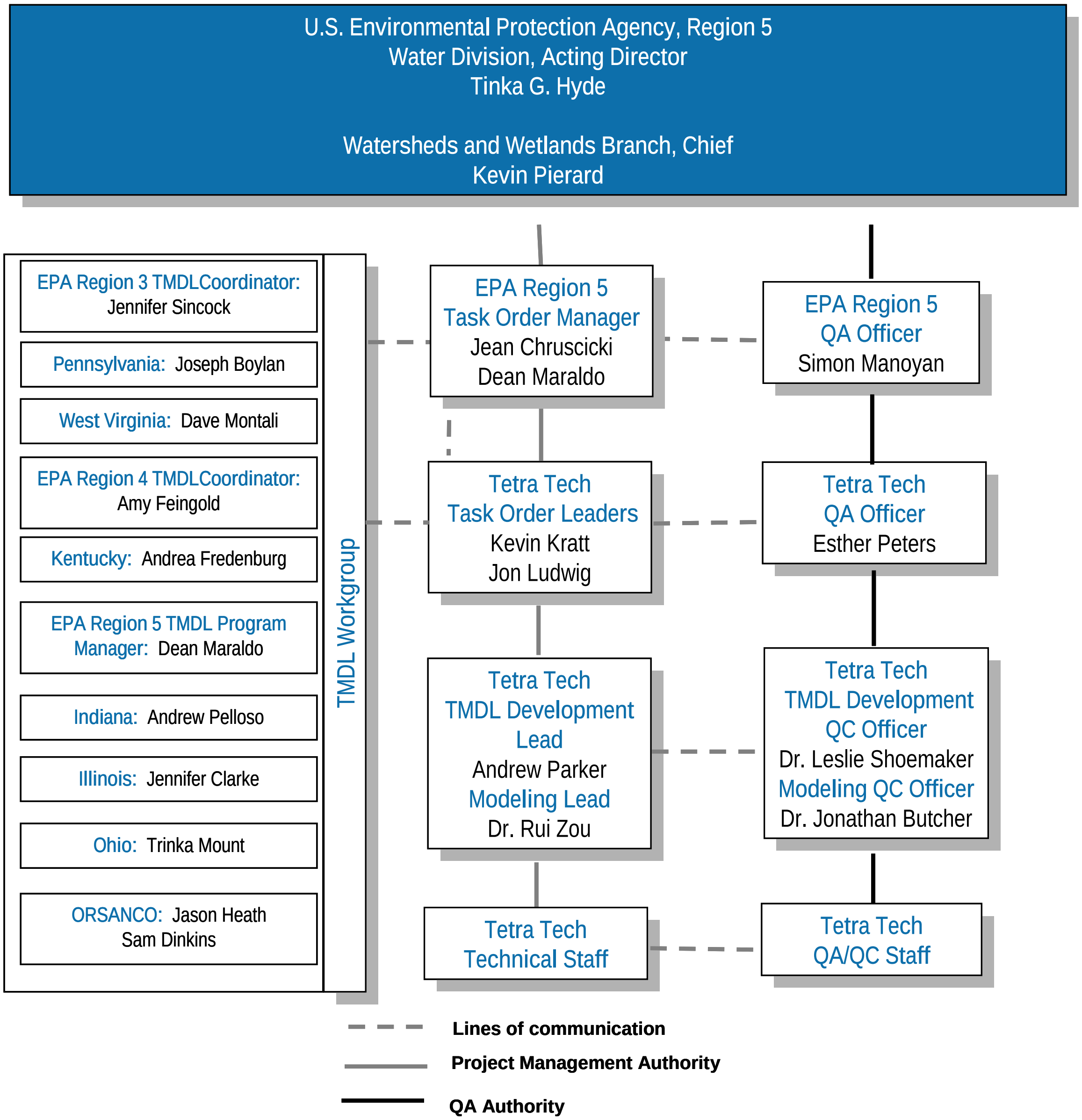


Figure 1. Organizational Structure of the Ohio River Bacteria TMDL Coordinators Workgroup.

1.2 PROBLEM DEFINITION/BACKGROUND

The Ohio River is impaired for recreational use by elevated concentrations of bacterial pathogens, and the ultimate goal of this project is to reduce pathogens in the mainstem of the Ohio River to achieve recreational use standards. The TMDL is a tool to initiate actions that will be needed to reduce pathogen indicators. EPA Region 5 has retained Tetra Tech to provide consulting services toward the development of a bacteria TMDL for the Ohio River. The TMDL will cover a huge geographic area, with the Ohio River basin draining more than 200,000 square miles and the river itself covering more than 900 miles (including almost 500 of which are impaired). There are also a variety of overlapping water quality standards that will need to be addressed during TMDL development, with different segments of the river designated for Primary Contact Recreation, Secondary Contact Recreation, and Drinking Water Supply, and different pathogen indicators used by different states (Figure 2).

The Ohio River watershed encompasses large portions of seven states, and smaller portions of eight states (Figure 2). The watershed area spans various geographic features that include a variety of potential pathogen point and nonpoint sources. Cities along the Ohio River have played an important part of American history, as the Ohio River was a key conduit of people and economic activity during rapid westward expansion in the early 1800s. Today, industrial activity is common along much of the river, with one of its headwater tributaries, the Monongahela River watershed, being one of the most industrialized areas in the country. Twenty lock and dam structures facilitate barge traffic and regulate flow as more than 230 million tons of cargo is transported on the Ohio River each year. Urban areas vary from long-established river cities to recent suburban sprawl. Agriculture is prevalent in mainstem floodplains; however, the intensity varies from region to region in tributary subwatersheds. Nonpoint source runoff from these urban centers and agricultural areas are considered as potential pathogen sources.

Point sources directly discharging to the Ohio River are also considered as significant pathogen sources. There are approximately 800 permitted discharges to the Ohio River with more than 180 of those being municipal wastewater discharges. In addition, there are 49 combined sewer overflow (CSO) communities with more than 1,000 CSOs that discharge directly to the Ohio River or to small tributaries that drain to it. Overflow during wet-weather events can result in direct discharges of stormwater and untreated human and industrial waste. Sanitary sewer overflows (SSOs) also occur in many of the municipal collection systems.

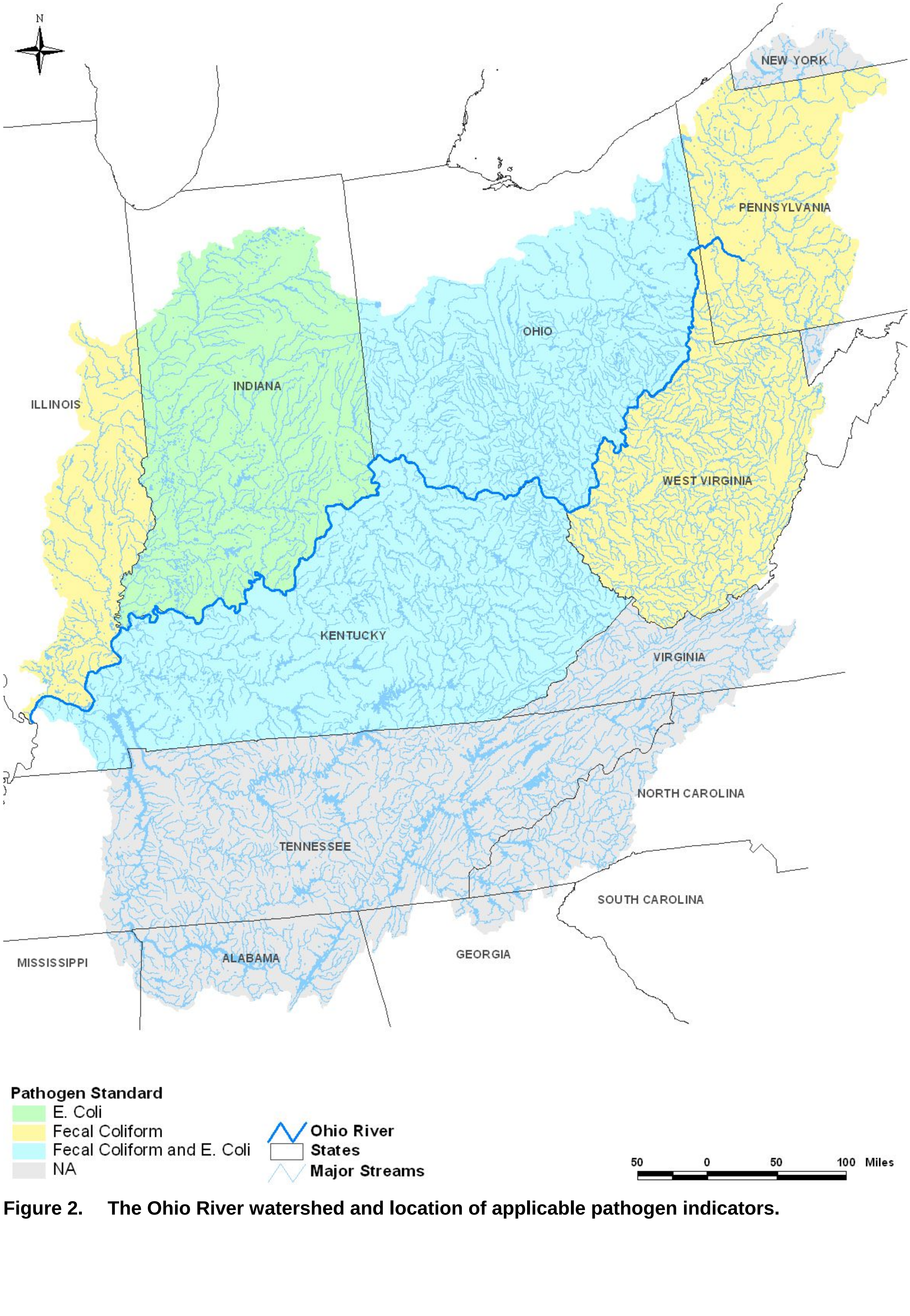


Figure 2. The Ohio River watershed and location of applicable pathogen indicators.

Figure 3 illustrates that land use/land cover throughout the Ohio River watershed is diverse and includes heavily urbanized areas, medium- to low-density residential lands, agriculture, and forests. The sections below provide a summary of the geographic diversity of the potential point and nonpoint pathogen sources in the TMDL project area.

Appalachian Headwaters: The Ohio River headwaters begin on the western slope of the Appalachian Mountains. Deciduous forests blanket watersheds of headwater tributaries such as the Allegheny, Monongahela, and the Kanawha. Mills, mines, and chemical plants are common along the banks of the Ohio River in the industrial centers of Pittsburgh, Pennsylvania; Weirton, West Virginia; and Wheeling, West Virginia. These industrial centers are also significant CSO communities. Potential human sources of pathogens in this region include CSOs, failing onsite wastewater systems, and runoff from urban areas.

Upper Middle: The Ohio River flows south and west from Wheeling to Cincinnati, where the river forms the state boundary between Ohio, West Virginia, and Kentucky. This stretch features small cities and towns, often in pairs on opposite sides of the river. Parkersburg, West Virginia–Marietta, Ohio; Point Pleasant, West Virginia–Gallipolis, Ohio; and Huntington, West Virginia–Ashland, Kentucky, are all examples of such communities. Industrial plants are common in the Ohio River floodplain, and agricultural lands become increasingly abundant as the river departs the Appalachian region. Potential human sources of pathogens in this region include CSOs, failing onsite wastewater systems, and runoff from urban and agricultural lands.

Urban Centers: Large urban centers of Cincinnati, Ohio, and Louisville, Kentucky, dominate the Ohio River and its tributaries through this stretch. These large cities feature rapidly growing suburbs, as well as older urban environments that have abundant urban point sources (including CSOs) and nonpoint sources of pathogens. Significant CSO communities include Cincinnati Metropolitan Sewer District, North Kentucky Sanitation District No.1, and Louisville Metropolitan Sewer District. Agricultural nonpoint sources are abundant in southwestern Ohio. Potential human sources of pathogens in this region include CSOs, SSOs, failing onsite wastewater systems, and runoff from urban and agricultural lands.

Lower River to Confluence: Medium sized cities and small towns flank the floodplain as the Ohio River flows between Kentucky, Indiana, and Illinois on its way to the Mississippi confluence. Floodplain forests are interspersed with agriculture. Potential human sources of pathogens in this region include CSOs, SSOs, failing onsite wastewater systems, and runoff from urban and agricultural lands.

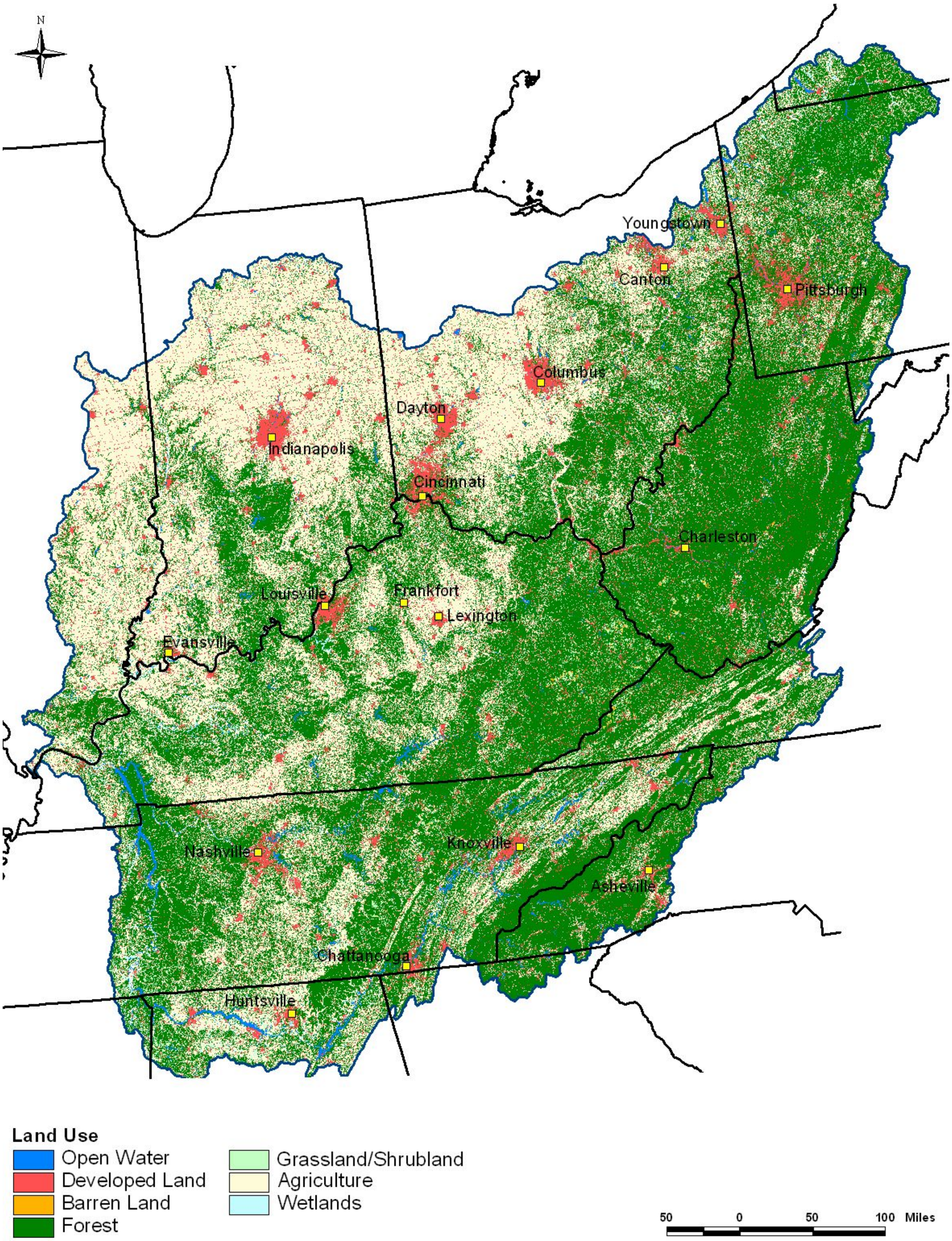


Figure 3. Land use/land cover within the Ohio River watershed.

1.3 PROJECT/TASK DESCRIPTION

Development of the TMDL will involve the following primary tasks:

- Task 1. Compile and Analyze Available Data
- Task 2. Set up model
- Task 3. Calibrate/validate model
- Task 4. Prepare modeling report
- Task 5. Run model to determine TMDL scenarios
- Task 6. Develop draft TMDL report
- Task 7. Participate in agency and public meetings
- Task 8. Develop final TMDL report

Throughout this process, Tetra Tech will work with the Ohio River TMDL Workgroup to ensure strong agency participation and support for the final outcome. The approach is designed to be science-based and support informed decision making by the agencies. To meet these needs, the project is being initiated in three phases:

I. Preliminary Review of Data and Development of QAPP and Workplan
II. Source Characterization and Initial Model Setup
III. Model Refinement and Development of Draft and Final TMDL Documents

Tetra Tech is in the process of completing Phase I, which will provide a strong information foundation on which to plan Phases II and III. Under Phase I, the TMDL Workgroup has been formed and will serve as the primary basis for coordinating stakeholder participation. Existing information has been compiled and reviewed to develop a preliminary understanding of river conditions; issues that will need to be addressed by the TMDL have been identified and discussed by the workgroup; and a modeling platform has been identified. Completion of this QAPP and an associated workplan is therefore the final step to Phase I so that these documents can guide model setup, calibration, and TMDL development. The tasks to be implemented in Phases II and III of the project are described below in Section 1.3.1 through Section 1.3.8.

The Ohio River bacteria TMDL is being planned consistently with EPA’s DQO Process. A key component of the DQO Process is identifying and documenting the decision context for the project (the principal study questions). Identifying decision needs began in Phase I through two Workgroup meetings and additional conference calls. This process identified the following Draft Goals and Objectives for the project:

- Assess the water quality of the Ohio River for recreational use
- Determine current bacteria loads, maximum allowable loads, and necessary reductions to meet water quality standards
- Identify the most significant sources and actions that can be taken to reduce loads from those sources
- Inform and involve the public throughout the project

Answers to the following study questions will help achieve these objectives:

- What are the maximum fecal coliform and *E. coli* loads that the Ohio River can assimilate and not exceed the applicable water quality standards at various key assessment locations along the river?
- What can be allocated/permitted to the various National Pollutant Discharge Elimination System (NPDES) entities (e.g., municipal wastewater treatment plants (WWTPs), industrial dischargers, municipal separate storm sewer systems (MS4s), confined animal feeding operations (CAFOs)) to ensure that no locations exceed applicable water quality standards?
- What can be allocated to the various nonpoint sources directly draining to the Ohio River to ensure that no locations exceed applicable water quality standards?
- What can be allocated to the various major tributaries directly draining to the Ohio River to ensure that no locations exceed applicable water quality standards?
- Do modeling outputs correspond to the Workgroup's expected outputs on the spatial level of detail and are they applicable to the regulated community?

The second step in the identification decision needs is defining the types of alternative actions that could be used to help ensure the achievement of the objectives. This is important to consider, because the analytical tools must be capable of representing the effects of such alternative actions on the objectives. While the identification of potential management options is not complete, it is clear that they could potentially include recommended load reductions for the various types of sources:

- Significant tributaries and subwatersheds draining directly to the Ohio River
- NPDES facilities that discharge directly to the Ohio River or to small tributaries that drain to it
- CSO communities that discharge directly to the Ohio River or to small tributaries that drain to it
- Stormwater Phase II communities that discharge directly to the Ohio River or to small tributaries that drain to it
- Confined feeding operations and CAFOs that discharge directly to the Ohio River or to small tributaries that drain to it
- A variety of nonpoint sources not covered through the NPDES permitting program (e.g., agricultural runoff, stormwater runoff from outside Phase II communities, natural sources)

These sources encompass a variety of spatial and temporal scales, including continuous and discontinuous point and nonpoint sources. For this reason, the modeling tools must also be able to address multiple spatial and temporal scales, and this factor was taken into account in identifying the preferred model (for more detail, see Section 2.1).

1.3.1 Task 1. Characterize Sources and Develop Conceptual Model

A significant aspect of the Ohio River bacteria TMDL development effort will involve compiling and assessing all of the available data regarding potential sources of bacteria. Many of these data have already been collected and preliminarily assessed during Phase I (summarized in Table 1). As part of Task 1, Tetra Tech will compile any remaining data and begin to organize the data such that it can be used to support the modeling effort.

Table 1. Project data collected during Phase I

State or entity	Data summary
ORSANCO	Ohio River mainstem and tributary monitoring data in spreadsheets and database
Illinois	CSO locations, NPDES permitted facilities, and tributary monitoring data
Indiana	NPDES facilities background information, written permits, 303(d) list impaired streams, DMR reports, and tributary monitoring data
Kentucky	MS4 reports, contact info, monthly discharge monitoring reports (DMRs), tributary monitoring data, and 2006 monitoring data
Ohio	CSO location data and limited monitoring data
Pennsylvania	NPDES permitted facility information[a]
West Virginia	Ohio River tributary ambient water quality monitoring data and station locations
Tennessee	Background info on 303(d) list, water quality standards, and watershed management plans

[a] Pennsylvania is in the process of compiling these data.

Task 1 will also involve characterizing the entire Ohio River watershed to provide perspective on the potential sources of pathogens and to help frame future implementation activities. The size of the watershed will preclude a detailed inventory of watershed conditions, but a summary by major subwatershed (Table 2) will provide insight into potentially important issues to be addressed during TMDL implementation.

Table 2. Major subwatersheds draining to the Ohio River

Tributary name (state)	Confluence mile point (miles)	Drainage area (square miles)
Allegheny River (PA)	0.0	11,700
Monongahela River (PA)	0.0	7,400
Beaver River (PA)	25.4	3,130
Muskingum River (OH)	172.2	8,040
Little Kanawha River (WV)	184.6	2,320
Hocking River (OH)	199.3	1,190
Kanawha River (WV)	265.7	12,200
Guyandotte River (WV)	305.2	1,670
Big Sandy River (WV-KY)	317.1	4,280
Scioto River (OH)	356.5	6,510
Little Miami River (OH)	463.5	1,670
Licking River (KY)	470.2	3,670
Great Miami River (OH)	491.1	5,400
Kentucky River (KY)	545.8	6,970
Salt River (KY)	629.9	2,890
Green River (KY)	784.2	9,230
Wabash River (IN-IL)	848.0	33,100
Saline River (IL)	867.3	1,170
Tradewater River (KY)	873.5	1,000
Cumberland River (KY)	920.4	17,920
Tennessee River (KY)	934.5	40,910

(Adapted from ORSANCO 2007)

Information on the land use, soils, topographic, and other landscape information for the area directly adjacent to the Ohio River must also be assessed to better characterize potentially significant pathogen sources. Additionally, information will be compiled on the river channel dimensions and an analysis will be conducted to evaluate how those might affect bacteria conditions (e.g., whether bacteria counts decrease in slow-moving areas behind lock and dams).

Tetra Tech will also perform correlative and statistical analyses to identify relationships among water quality parameters and flow conditions, to assess the degree of attainment or nonattainment under critical conditions. On the basis of the available data, Tetra Tech will estimate screening-level loads from each of the potential sources as a means of prioritizing what issues need focused attention during the modeling and TMDL development process. Sources to be assessed will include tributaries, WWTPs, CSOs, SSOs, boats, stormwater runoff, and wildlife. Tetra Tech will also develop a conceptual model that describes other factors believed to affect bacteria conditions, such as settling and resuspension and seasonal growth patterns. Tetra Tech will also consult with other researchers who are using bacteria source tracking techniques to better understand the sources of *E. coli* and fecal coliforms within the basin. For example, the West Virginia Department of Environmental Protection and Dr. Charles Summerville of Marshall University are applying innovative, antibiotic-resistant-bacteria source-tracking techniques. This is to identify human and animal sources of pathogen impairments in West Virginia that might prove relevant to the Ohio River bacteria TMDL.

1.3.2 Task 2. Set up model

The Workgroup has decided that a comprehensive modeling framework will be needed for developing the Ohio River bacteria TMDLs. The size, scale, and spatial distribution of potential point and nonpoint sources require an approach that includes a proven method for organizing and integrating the large number of watershed and environmental data sources. Also, given the time-variable impact that watershed hydrology and stressors typically exhibit on in-stream bacteria levels, a continuous simulation approach is needed to best represent the observed conditions. The proposed framework will facilitate the simulation of *what if* scenarios resulting from comparing the current impaired baseline scenario to future possible changes, such as reduced loadings from the various sources.

Task 2 will involve setting up the model, including configuring the computational grid using available bathymetry data and setting initial conditions, boundary conditions, and hydraulic and kinetic parameters for the hydrodynamic and quality simulations. The setup of the model is further described in Section 2.2.2.

1.3.3 Task 3. Calibrate/validate model

Task 3 will involve calibration and validation of the Ohio River bacteria model. Calibration consists of the process of adjusting model parameters to provide a suitable representation of observed conditions. Calibration can also consist of making adjustments to the initially estimated boundary conditions in situations where those conditions are not well characterized. Calibration is necessary because of the semi-empirical nature of water quality models. Although these models are formulated from mass balance principles, most of the kinetic descriptions in the models are empirically derived. These empirical derivations contain a number of coefficients that are usually determined by calibration to data collected in the waterbody of interest. In addition, there is uncertainty associated with the specification of boundary conditions—particularly bacteria loads from tributaries, CSOs, and other sources. These boundary conditions might need to be adjusted within the uncertainty bounds of available data to achieve model calibration.

Calibration tunes the models to represent conditions appropriate to the waterbody and watershed under study. However, calibration alone is not sufficient to assess the predictive capability of the model or to determine whether the model developed via calibration contains a valid representation of cause and effect relationships. To help determine the adequacy of the calibration and to evaluate the uncertainty associated with the calibration, the model is subjected to a validation step. In the validation step, the model is applied to a set of data independent from that used in calibration.

The calibration and validation of the model is further described in Section 2.2.2.

1.3.4 Task 4. Prepare modeling report

Once the model has been calibrated and validated, a modeling report will be prepared to explain the process of selecting, setting up, and calibrating/validating the model. The report will include a section describing model use, limitations and uncertainty, as well as steps that could be taken in the future to improve model performance. The modeling report will be distributed to the Workgroup for review and approval before applying the model to determine TMDL scenarios (Task 5).

1.3.5 Task 5. Run model to determine TMDL scenarios

Once the model calibration and validation has been approved, the model will be used to determine allowable loads for fecal coliform and *E. coli*. Analyses performed during Task 5 will provide the information to develop several possible allocation schemes. Among these scenarios, several could meet water quality standards; however, their implementation might not be technically feasible or accepted by stakeholders. Therefore, before establishing a final allocation, a set of feasible alternatives will be developed, taking into account the level of control for each source or source category necessary to achieve water quality targets. The allocation analysis is typically performed by following these discrete steps:

1. Step 1: Applying the Model to Existing Conditions. This application forms the current condition that is used to evaluate the magnitude of load reductions that are needed to meet water quality standards.
2. Step 2: Applying the Model to Existing Conditions with Point Sources at Permit Limits. This application forms the baseline condition which will be reduced to meet the allowable load. The point sources are set at permit conditions using the permitted flow and mean daily concentration allowed for in the permit. If no permitted flow is available, the design flow or historic observed flow can be used. If the permit does not include a permit limit for the affected pollutant, then the observed concentration can be used. For CSOs the *permit limits* will be constructed to be consistent with the number of overflows specified in the applicable Long-Term Control Plans (LTCPs). Where no LTCPs are available, each state will provide guidance as to whether the CSOs should be allocated a wasteload allocation of zero, a wasteload allocation based on the CSOs discharging at water quality standards, or some other condition.
3. Step 3: Applying the Model to Future Conditions. To address future growth, increased populations and land use change can be incorporated into the model.
4. Step 4: Developing and Testing Allocation Scenarios. Working from the baseline condition and considering the primary pollutant sources, sample allocation scenarios are developed and applied. The results of each scenario are compared with the applicable water quality standard. The scenarios are adjusted until the interim water quality targets (or loading capacity) are achieved.
5. Step 5: Selecting Final TMDL Scenario(s). The stakeholders will select the final TMDL scenario (or potentially several final scenarios customized to each state) and results will be processed to provide the required TMDL elements. Data processing will be conducted to provide annual, monthly, and daily loads for each category stipulated in the TMDL. The final scenario model input and output file is saved for the administrative record.

During Task 5, wasteload allocations will be established for facilities with individual NPDES permits as well as for other regulated sources (e.g., MS4s and CAFOs). Information will also be generated to identify the most significant sources not covered by the NPDES program (and thus receiving a load allocation).

Tetra Tech also understands that lateral variability in bacterial counts is an important characteristic of the Ohio River with potentially significant consequences to the TMDL allocations. For example, if two cities are on opposite banks of the river, the TMDL study will need to be able to differentiate their impact and allocate appropriately. Although the CE-QUAL-W2 model does not allow for the direct simulation of lateral variability, it can be accounted for during TMDL allocations as follows:

The lateral variability appears to be an issue only at locations close to significant sources, which suggests a mixing zone type of problem. Tetra Tech will therefore first conduct a detailed analysis to determine these locations and to confirm that the lateral variability is indeed related to certain sources (and not something else such as sampling variability). In cases where the lateral variability is determined to be primarily due to (a) upstream lateral variability or (b) the combined impact of upstream lateral variability and a local source on only one side of the river, reductions will be based on achieving water quality standards in the segment of the river with the highest bacterial counts. Specifically, the ratio (R1) between the maximum observed bacterial count and the average bacterial count will be calculated based on all of the available lateral data at that location. If the simulated lateral average concentration at this location is C, then the TMDL allocation will be derived by reducing upstream sources and the local source until $R1 \times C$ (instead of C) meets the water quality standard. This approach will thus ensure that the reductions are sufficient to achieve water quality standards in the portion of the river with the highest existing bacterial counts.

In cases where the observed lateral variability is due to the combined impact of upstream variability and/or local sources on both sides of the river, a differential reduction approach will be used. Ratios between the maximum observed counts in the left, middle, and right portions of the river and the average count across the river will first be calculated as RL, RM, and RR. Reductions will then begin by reducing upstream loads and local source loads by the same amount, calculating $RL \times C$, $RM \times C$, $RR \times C$, and evaluating compliance against the appropriate water quality standard. This process will continue until water quality standards are met on one side of the bank (e.g., the left bank). After this, local sources on the left bank will no longer be reduced and reductions will focus on the right bank until $RR \times C$ also meets water quality standards.

1.3.6 Task 6. Develop draft TMDL report

Task 6 will involve preparing a draft TMDL report that is technically sound, clearly presented, and meets all regulatory requirements. Tetra Tech expects that different portions of the report might be prepared by different states or ORSANCO, and Tetra Tech will synthesize these sections to produce an understandable and complete report that documents all aspects of the TMDL development process as well as the final allocations. Tetra Tech will work with EPA, ORSANCO, and the states to include appropriate background information (including descriptions of the selection of targets, source identification and characterization, technical analysis of source loadings and water quality response, and all legally required elements of a TMDL) to facilitate review and approval as well as achieve public understanding. Tetra Tech will also prepare a presentation and fact sheet summarizing the TMDL. Tetra Tech will place the final QAPP, TMDL approach workplan, fact sheets, and any presentation files on the project FTP site. The fact sheets and presentation will be designed as a tool for EPA, states, and ORSANCO to use in presenting the QAPP and TMDL approach to the public.

1.3.7 Task 7: Participate in agency and public meetings

The TMDL process should develop a plan that will attain water quality standards. Although the regulatory requirements must be fulfilled, it is even more important that stakeholders and interested members of the public take ownership of the products and understand all components and assumptions. Tetra Tech will therefore provide support to individual states for public meetings explaining the TMDL process and the modeling and allocation results. Tetra Tech has supported numerous public meetings on TMDLs, including developing presentation materials and attending public meetings to present technical aspects of the TMDL and answer public questions and concerns. A tentative schedule for public meetings is shown in Table 3, with the actual dates to be determined as the project unfolds. It is anticipated that Tetra Tech will provide support at one meeting in each of the six mainstem states, with additional meetings potentially to be held and supported by the states without Tetra Tech support. The Workgroup agreed that there were several purposes of these kickoff meetings:

- Inform the public about the TMDL process and explain that it has started for the Ohio River.
- Provide a summary of the initial Task 1 findings (e.g., spatial and temporal trends of available water quality data, most likely bacteria sources).
- Describe the modeling approach and explain the status of model setup. Tetra Tech expects that model setup will have begun before the kickoff meetings but no calibration results will be available.
- Request any data that might be useful for purposes of TMDL development.

Because states will be requesting data from the public at the kickoff meetings and soliciting feedback on the scope of the TMDL, the kickoff meetings will be held shortly after the initiation of Task 1.

Table 3. Schedule for Ohio River bacteria TMDL stakeholder public meetings

Public meetings	Location	Schedule
Kickoff meetings	Pennsylvania, West Virginia, Ohio, Indiana, Kentucky, Illinois	Spring/Summer 2008
Draft TMDL meeting	Pennsylvania, West Virginia, Ohio, Indiana, Kentucky, Illinois	Spring 2010

1.3.8 Task 8. Develop final TMDL report

During Task 7, Tetra Tech will help EPA, ORSANCO, and the states address public comments on the draft TMDL report to create a final report, including the files necessary to create an Administrative Record.

The anticipated schedule for Tasks 1 to 8 is provided in Table 4.

Table 4. Schedule for Ohio River bacteria TMDL development

Task	Schedule
Task 1. Characterize Sources and Develop Conceptual Model	January 2008 to December 2008
Task 2. Set up model	June 2008 to December 2008
Task 3. Calibrate/validate model	January 2009 to April 2009
Task 4. Prepare modeling report	April 2009 to June 2009
Task 5. Run model to determine TMDL scenarios	July 2009 to September 2009
Task 6. Develop draft TMDL report	October 2009 to January 2010
Task 7: Participate in agency and public meetings	Spring 2008 and Spring 2010
Task 8. Develop final TMDL report	February 2010 to April 2010

1.4 Quality Objectives and Criteria for Model Inputs/Outputs

This section describes the quality objectives for the project and the general performance criteria to achieve those objectives. Specific quantitative tests are described further in Section 2.

EPA policy is to use a systematic planning process to define quality objectives and performance criteria. Systematic planning identifies the expected outcome of the modeling project, its technical goals, cost and schedule, and the criteria for determining whether the inputs and outputs of the various intermediate stages of the project, as well as the project's final product, are acceptable.

The DQO process also requires definition of inputs to the decision. The general quality objectives for modeling are to provide information sufficient to answer each of the study questions identified in Section 1.3. These questions must be answered at a level of accuracy appropriate to make decisions as to how control each of the various sources of bacteria, both through the NPDES permitting process and through other mechanisms.

The credibility and level of accuracy associated with model predictions will be established using a calibration and validation process. Specific quantitative tests are described further in Section 2.

1.4.1 Project Quality Objectives

In establishing and implementing a TMDL, loadings from all sources are estimated, links are established between sources and impacts on water quality, maximum loads are allocated to each source, and appropriate control mechanisms are established or modified so that water quality standards can be achieved (USEPA 1999). The model provides the linkage between pollutant sources and impacts on uses and will be used to evaluate load reductions and the efficacy of different control options. All models are approximations of reality, and inevitably contain uncertainty. To be useful, the uncertainty present in model results must be identified and controlled to levels sufficient to inform decision needs. This process is formalized through the systematic planning process.

The quality of an environmental analysis program can be evaluated in three steps: (1) establishing scientific assessment quality objectives, (2) evaluating program design for whether the objectives can be met, and (3) establishing assessment and measurement quality objectives that can be used to evaluate the appropriateness of the methods used in the program

Sections 1.4.2 through 1.4.7 describe DQOs and criteria for TMDL development for this project, written in accordance with the seven steps described in EPA's *Guidance for the Data Quality Objectives Process* (EPA QA/G-4) (USEPA 2006).

1.4.2 State the Problem

Numerous segments of the Ohio River are not meeting their applicable fecal coliform or *E. coli* water quality standards. The Clean Water Act and EPA regulations require that states develop TMDLs for waters not meeting water quality standards. Through the TMDL process the allowable pollutant load is allocated among all the various sources and voluntary (for nonpoint sources) and regulatory (for point sources) control measures are identified for attaining the source allocations. In addition, the TMDL must include a margin of safety (MOS), either implicitly or explicitly, that accounts for the uncertainty in the relationship between pollutant loads and the quality of the receiving waterbody.

1.4.3 Identify the Decision

The decisions to be made as a result of this study are (1) to determine the allowable fecal coliform and *E. coli* loads for each of the various sources such that the applicable water quality standards throughout the Ohio River can be achieved, and (2) to determine appropriate control strategies to achieve the allowable loading rates.

1.4.4 Identify the Inputs to the Decision

The output of the calibrated model will provide key inputs to the decision. Specific considerations for use of the model for decision purposes include the following:

1.4.4.1 Varying Water Quality Standards

A unique aspect of the Ohio River TMDL is the variety of overlapping water quality standards that need to be addressed. Different segments of the river are designated for Primary Contact Recreation, Secondary Contact Recreation, and Drinking Water Supply, and each of the six states has promulgated somewhat different numeric criteria to protect these uses (Table 5). The TMDL will need to be written in such a way that the allocated loads ensure that all water quality standards are met throughout the river. In some cases, this will require that a downstream state's more stringent standard will take precedence over an upstream state's standard. For example, Indiana's not-to-exceed criteria do not allow for any water quality samples to exceed 235 counts of *E. coli* per 100 milliliters (mL), whereas Kentucky's rules allow for a 20 percent exceedance rate of 24 counts per 100 mL. The TMDL allocations will be based on reducing loads such that Indiana's criteria are met, even if that entails allocating larger reductions to Kentucky sources than would be needed to meet Kentucky's standard for the Ohio River. Similarly, sources in upstream states might be given allocation reductions that are needed to meet water quality standards in downstream states.

Table 5. Summary of bacteria water quality standards that apply to the Ohio River

State or entity	Indicator	Geometric mean standard[a]	Not-to-exceed standard[b]	Duration
ORSANCO	Fecal coliform	200 counts per 100 mL	400 counts per 100 mL	May 1 to Oct 31
		2000 counts per 100 mL	None	Nov 1 to April 30
	E. coli	130 counts per 100 mL	240 counts per 100 mL[c]	May 1 to Oct 31
Pennsylvania	Fecal coliform	200 counts per 100 mL	400 counts per 100 mL	May 1 to Sep 30
		2000 counts per 100 mL	None	Oct 1 to Apr 30
Ohio	Fecal coliform	200 counts per 100 mL	400 counts per 100 mL	May 1 to Oct 15
	E. coli	126 counts per 100 mL	235 counts per 100 mL	May 1 to Oct 15
West Virginia	Fecal coliform	200 counts per 100 mL	400 counts per 100 mL	May 1 to Oct 31
		200 counts per 100 mL[e]	400 counts per 100 mL[e]	Nov 1 to Apr 30
Kentucky	Fecal coliform	200 counts per 100 mL	400 counts per 100 mL[d]	May 1 to Oct 31
		1000 counts per 100 mL	2000 counts per 100 mL[d]	Nov 1 to Apr 30
	E. coli	130 counts per 100 mL	240 counts per 100 mL[d]	May 1 to Oct 31
Indiana	*E. coli*	125 counts per 100 mL	235 counts per 100 mL[c]	Apr 1 to Oct 31
Illinois	Fecal coliform	200 counts per 100 mL	400 counts per 100 mL	May 1 to Oct 30

[a] Geometric mean fecal coliform content should not exceed this standard on the basis of no less than five samples within a 30-day period.
[b] Observations should not exceed this standard in more than 10 percent of the samples taken in any 30-day period.
[c] Observations should not exceed this standard in any single sample collected.
[d] Observations should not exceed this standard in more than 20 percent of the samples taken in any 30-day period.
[e] West Virginia is revising its fecal coliform criteria for the nonrecreational season to match ORSANCO's.

The TMDL allocations will also need to ensure that both the geometric mean and not-to-exceed components of each state's water quality standards, as defined and interpreted by that state, are met. The TMDL Workgroup agreed on the following approach, and it will be used to compare the modeling output to these different parts of the standard:

- Geometric Mean. Hourly output from the model will be used to calculate a geometric mean for each month. These values will then be evaluated on a month-by-month (for the months in which the standard applies) basis against the geometric mean portion of the standard (rather than on a rolling, 30-day basis).

- Not-to-Exceed. Hourly output from the model will be used to calculate an arithmetic mean for each day, and this value will be compared to the not-to-exceed portion of the standard (as opposed to using the maximum value within any given day).

1.4.4.2 Different Indicators

Both fecal coliform and *E. coli* water quality standards apply to the Ohio River (Table 5) and, because of this, both types of data have been collected and are available for the modeling. To ensure consistency in the modeling results, Tetra Tech recommends that the model be developed to simulate counts and loads of both *E. coli* and fecal coliform. To estimate inputs to the model where only one parameter is available (e.g., a WWTP that samples only fecal coliform), the ratio between the geometric mean components of the standards will be used to initially estimate the other parameter (e.g., fecal coliform = 200/125 = 1.6 $\times$ *E. coli*); this initial estimate will be subject to adjustment during the model calibration process if necessary. EPA's *Ambient Water Quality Criteria for Bacteria* (USEPA 1986) suggests that a fecal coliform count of 200 counts/100 mL and an *E. coli* count of 125 counts/100 mL are similar in that they would both cause approximately 8 illnesses per 1,000 swimmers in fresh waters. Although there is some uncertainty associated with this approach, it was determined to be appropriate on the basis of the available information and scope of the study. A preliminary screening of paired fecal coliform and *E. coli* collected by ORSANCO also demonstrates that this relationship generally applies to paired data collected in the Ohio River, although the relationship is not as valid at high fecal coliform and *E. coli* counts (Figure 4).

1.4.4.3 Complex Hydrology

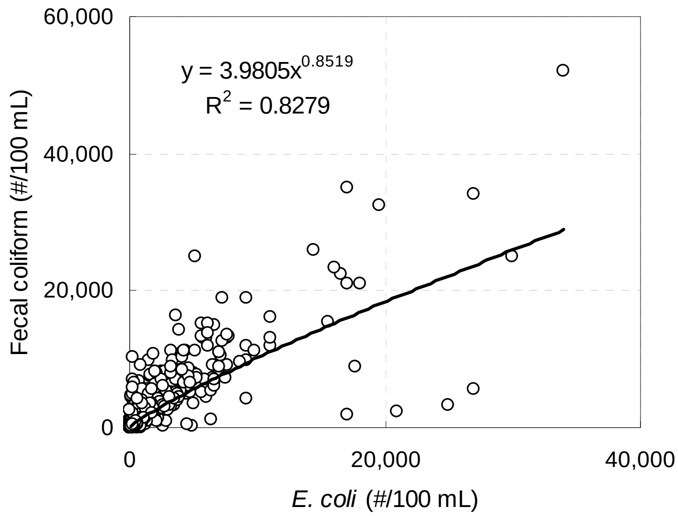
The hydrology of the Ohio River is very complex because of a number of factors including the impacts of locks and dams, the size of the river, sudden changes in lateral and vertical flows and velocities, marine traffic, and other factors. This complexity will pose a significant challenge to the modeling efforts, as described further in Section 2.1.

1.4.4.4 CSO Consent Decrees

There are 49 Ohio River CSO communities with more than 1,000 CSOs. Most small communities do not have approved CSO LTCPs, but several of the large cities along the river have entered into CSO consent decrees with EPA. It will be important to factor these consent decrees into the final TMDL report. For example, the degree of controls and the schedule for the consent decrees will serve as important assumptions in running the *Point Sources at Permit Limits* scenario (see Section 5).

1.4.4.5 Multiple Wasteload Allocations

The Ohio River TMDL will require a variety of separate wasteload allocations to cover municipal wastewater plants and industries that discharge directly to the river, CAFOs that are in the riparian corridor, and MS4s for the cities along the river. The sheer number of such entities involved with this project will be unique, and the TMDL will need to identify each of these entities, describe the allocation approach, and specify how they will be specifically responsible for TMDL implementation.



Note that the relationship is not as strong at high fecal coliform and E. coli counts.

Figure 4. The relationship between fecal coliform and *E. coli* in the Ohio River based on more than 7,000 samples collected by ORSANCO between 1992 and 2005.

1.4.5 Define the Boundaries of the Study

The Ohio River watershed covers a huge geographic area draining more than 200,000 square miles, and the Workgroup decided that explicitly modeling this entire area was beyond the scope of the current effort. Instead, the TMDL will focus on the mainstem of the Ohio River, as well as the most downstream ends of major tributaries. The following techniques will be employed to facilitate this approach:

- The entire river will be assessed using one comprehensive model, rather than trying to evaluate separate segments of the river independently.
- Allocations will be made for specific, large, Ohio River tributaries (as requested by each state) with other, smaller tributaries receiving grouped allocations on the basis of location. No attempt will be made to quantify the pollutant sources (e.g., point or nonpoint) within any of these tributaries. The purpose of this approach is to establish protective tributary loading limits while allowing the focus of the analysis to be on the Ohio River. The tributary loading limits will need to later be refined (and source allocations made) when individual tributary TMDLs are developed by each state. Furthermore, states have agreed to add tributaries to their Section 303(d) lists of impaired waters if sampling data compiled and analyzed through this process indicate a tributary is impaired but is not currently listed.
- All permittees that discharge directly to the Ohio River will receive their own wasteload allocations.
- Various *assessment locations* will be selectively identified along the river to represent the necessary load reductions in an attempt to make the TMDL results more understandable to members of the general public and to allow them to focus in on their particular area of interest. The specific assessment locations will be finalized once an initial draft of the model segmentation scheme is available for the Workgroup to review, but, at a minimum, they will include the following:
    - State borders
    - Each lock and dam
    - Major tributaries (defined as those having a drainage area greater than 800 square miles; see Table 2)

- Large WWTPs
- Each CSO community

1.4.6 Develop a Decision Rule for Information Synthesis

The purpose of a decision rule is to integrate the outputs from the study into a single statement that describes the logical basis for choosing among alternative actions. Output from the previous DQO steps will be used to guide decision makers to choose from among alternative actions. The decision rule for this project is:

> If existing bacteria concentrations exceed standards because of current loading, new load allocations and wasteload allocations will be identified to achieve the standard. Otherwise, the river will continue to be impaired for recreational use by bacteria; alternative actions must be identified to achieve the standard.

The alternative actions might include the following: facility upgrades to achieve new wasteload allocations; recommendations for reduced nonpoint loadings from various source categories; revised LTCPs to achieve reduced loads from CSOs; use attainability analysis; variances, and so on.

1.4.7 Specify Tolerance Limits on Decision Errors

Proposed tolerance limits for the Ohio River bacteria model are described in Section 2.2.3 and are summarized below. The tolerance limits are listed below and are based on generally accepted values in the literature and from previous TMDL projects (e.g., Bicknell et al. 1996; Donigian 2000).

- The relative error between observed and simulated flows will be less than the following:
    - Error in total volume—10 percent
    - Error in recreation season volume—30 percent
    - Error in 50 percent lowest flows—10 percent
    - Error in 10 percent highest flows—15 percent
- A goal of the modeling will be for the frequency at which observed concentrations greater than the applicable standards are predicted within 0.5 log values to be at least 80 percent.
- A standard t-test will be used to test the null hypothesis of equality between the observed and simulated geometric mean of *E. coli* and fecal coliform observations over the entire calibration period and the entire validation period. (There are not sufficient data to adequately evaluate performance on individual seasons or years, particularly given the presence of analytical and sampling uncertainty.) In these tests, the equality of observed and sample geometric means on paired daily average data are taken as the null hypothesis or a rebuttable proposition. That is, model performance is judged acceptable unless the statistical analysis proves otherwise.

It should be noted that the tolerance limits will not be the sole arbiter of the usefulness of the model. Instead, meeting the tolerance limits will mean that the model is proven to perform well enough. However, if some or all limits are not met, the model could still be usable, for instance through an increased MOS, but decision makers need to be clearly informed about the increased level of uncertainty. In cases where the tolerance limits are not met, Tetra Tech will provide a discussion summarizing the most likely reasons as to why the model did not perform as well as desired.

1.5 Special Training Requirements/Certification

Tetra Tech staff involved in developing model input data sets and model application have experience in numerical modeling gained through their work on numerous similar projects. The Tetra Tech TOLs, who have extensive experience managing projects that involve the use of models to develop TMDLs, will provide guidance to the modelers. The TOLs will ensure strict adherence to the project protocols.

Dr. Esther Peters is the QA Officer for this project. She is the QA Manager for Tetra Tech's Fairfax Center offices and has been QA Officer for several contracts, including EPA contracts with the Office of Science and Technology; Office of Wastewater Management; and Office of Wetlands, Oceans, and Watersheds. Dr. Peters has provided technical oversight for projects involving data review, verification, and validation. She has developed QA/QC training programs, prepared contract-specific quality management plans, and reviewed work plans and prepared QAPPs for diverse projects. Dr. Peters is a senior member of the American Society for Quality.

Mr. Kevin Kratt, one of Tetra Tech's TOLs, is a water resources scientist with 12 years of experience studying a variety of water quality issues for federal, state, and local government clients. He specializes in using a holistic approach to watershed management that includes applying knowledge of technical issues such as hydrology, water quality, biology, and land use, with regulatory issues such as water quality standards, TMDLs, and the NPDES program. Mr. Kratt has managed numerous large TMDL projects and serves as Tetra Tech's national coordinator for TMDL issues in EPA Region 5. Mr. Kratt has helped to prepare several policy and technical guidance documents for EPA Headquarters, including the *Compendium of Tools for Watershed Assessment and TMDL Development (USEPA, 1997)*, the *Protocol for Developing Nutrient TMDLs (USEPA, 1999)*, and the *Protocol for Developing Pathogen TMDLs (USEPA, 2001)* . He has been extensively involved in the national and local evaluation of TMDL development activities and is familiar with most of the loading and receiving water quality models used for watershed management, including their strengths and weaknesses for various applications. He has presented at numerous TMDL public meetings and one of his specialties is explaining complex technical and regulatory water quality issues to the general public.

Mr. Jon Ludwig, one of Tetra Tech's TOLs, is a senior environmental scientist with more than 9 years' experience providing technical and management support to federal, state, regional, and private clients in the areas of water resource, watershed, and water quality assessment; watershed modeling; and TMDL development. In support of EPA Region 3 and West Virginia Department of Environmental Protection Division of Water and Waste Management (WVDEP DWWM), he has served as project manager in developing more than 1,900 EPA approved TMDLs in West Virginia. He is the director of the Charleston, West Virginia, office of Tetra Tech's TMDL and Water Resources Center and serves as project manager for the existing TMDL contract with WVDEP DWWM that includes the development of TMDLs for total iron, total manganese, dissolved aluminum, pH, selenium, fecal coliform bacteria, and biological impairments throughout the state of West Virginia. Mr. Ludwig also oversees development of a stressor identification process for biologically impacted streams throughout West Virginia including development of macroinvertebrate tolerance values. Mr. Ludwig also has extensive experience implementing various hydrologic and water quality models, including EFDC, SWMM, BASINS, HEC-2, HEC-RAS, LSPC, GWLF, HSPF, WASP, and DESC-R. Additionally, he has reviewed NPDES permits and assessed measures taken to model the effects of discharge to stream systems. He has also conducted a series of training courses to support EPA and various states (West Virginia, Pennsylvania, Kentucky, Arizona) in modeling and TMDL development. These courses included bacteria, sediment, mining, and TMDL report writing.

Mr. Andrew Parker, Tetra Tech's TMDL Development Lead, is an environmental engineer with more than 10 years of experience providing technical and management support to federal, state, regional, municipal, and private clients in the areas of watershed and receiving water modeling, watershed and water quality assessment, water resource planning, and TMDL development. He is director of the Water Resources Modeling and Assessment Group and supervises 25 engineers and scientists focusing on watershed and receiving water modeling, advanced model development, stormwater management, and TMDL development. Mr. Parker has conducted watershed assessments and modeling efforts for nutrients, dissolved oxygen, sediment, metals, bacteria, temperature, and PCBs in more than 25 states and territories. His TMDL development and modeling support efforts over the past 10 years have led directly to the completion of more than 2,000 defensible TMDLs. Mr. Parker has extensive experience implementing hydrologic and water quality models, including LSPC, BASINS, MDAS, HSPF, SWMM, WASP, QUAL2E, EFDC, CE-QUAL-W2, and PHOSMOD. He has been part of the team developing and maintaining BASINS, LSPC, and the TMDL Modeling Toolbox for EPA. Mr. Parker also has extensive experience training individuals in the use of watershed and water quality models and presenting modeling applications and methodologies through public forums and at conferences.

Dr. Rui Zou, Tetra Tech's Modeling Lead, is an environmental engineer with more than 10 years of experience (including professional and academic) specializing in environmental system analysis, hydrodynamic modeling, water quality modeling, uncertainty analysis, and risk assessment. He has developed and applied a variety of computational methodologies for water quality modeling and uncertainty-based environmental system simulation and decision making, including a series of hybrid, hard-soft computing approaches for automatic calibration of water quality model; a fuzzy-parameter-based water quality modeling approach; a neural network embedded Monte Carlo approach for water quality modeling; and a series of grey-fuzzy mathematical programming approaches for wasteload allocation. He has developed an enhanced CE-QUAL-W2 model with piece-wise simulation and other advanced capability to support EPA Region 10's Lost River TMDL modeling project. He has developed a general bacteria simulation modeling system (GBMS) and incorporated the GBMS into the EFDC hydrodynamic and water quality modeling framework. He has developed a linking interface between CE-QUAL-W2 and WASP models, a zooplankton enhanced WASP/EUTRO model, a sediment transport enhanced WASP/TOXI model, a diurnal simulation module of WASP/EUTRO, a sediment diagenesis enhanced WASP/EUTRO, a TMDL tool based on WASP/EUTRO, a linked modeling system with hydrodynamic, water quality, neural network, and genetic algorithm. In addition, he has developed post-processing software for modeling systems such as CE-QUAL-W2, WASP/EUTRO, WASP/TOXI, and EFDC using FORTRAN, Matlab, and Techplot. Dr. Zou's experience in environmental engineering includes serving as environmental engineer for a variety of projects and working as a project manager for international cooperative environmental projects in China. Dr. Zou has produced more than 30 publications in his professional area. He has also served as peer reviewer for several international journals on environmental engineering and management.

Dr. Leslie Shoemaker, Tetra Tech's TMDL Development QC Officer, has more than 20 years' experience in the analysis of watersheds and ecosystems and development of management plans. She has provided project management and oversight for hundreds of work assignments under a variety of federal, state and local contracts. Dr. Shoemaker has been supporting TMDL and related program activities since 1991. She has provided technical and programmatic support to all phases of the TMDL program, from guidance development, technical reviews, TMDL development, to national training and facilitation. Her TMDL-related activities have included review of more than 80 TMDLs; technical oversight for hundreds of TMDL development projects throughout the United States; developing new TMDL course materials and performing highly acclaimed training courses; developing the first TMDL protocols and modeling compendium, recommendations on 303(d) listing, and technical support and facilitation for the development of sediment criteria. She has responded to numerous, quick-response requests for technical review and consultation. Dr. Shoemaker has also directed numerous large-scale, multidisciplinary watershed management projects such as Lake Tahoe, Milwaukee, Clermont County, and Prince George's County. She developed and has provided TMDL training at more than 30 locations and is widely recognized as a national TMDL expert. She has applied both ground and surface water models including HSPF, BASINS, SWMM, GWLF, WASP, CREAMS, GLEAMS, PRZM, MODFLOW, and DRASTIC. Dr. Shoemaker supported the development and testing of the first version of GWLF and the initial design and development of the BASINS modeling system. Dr. Shoemaker manages Tetra Tech's Water Resources Center, which includes more than 60 specialists in modeling, water quality assessment, and systems development throughout the United States.

Dr. Jonathan Butcher, Tetra Tech's Modeling QC Officer, an assistant director and principal engineer in Tetra Tech's Research Triangle Park, North Carolina office, is a registered Professional Hydrologist and environmental engineer with more than 19 years' experience in watershed planning; risk assessment; and the development, application, and communication of hydrologic and water quality models. Dr. Butcher has led technical efforts to support state and local governments in a variety of TMDL, wasteload allocation, watershed modeling, and waterbody restoration and protection studies. He is the technical lead for projects to develop nutrient loading and response models for Jordan Lake (North Carolina) and leads the development of multiple HSPF models for TMDL application over the entire Minnesota River watershed. Dr. Butcher's research interests include development of TMDLs to address narrative criteria for sediment and nutrients. He is experienced in using numerous lake, river, and estuarine hydrodynamic, hydrologic, and water quality models and has conducted flow, sediment, dissolved oxygen, nutrient, algae, and toxics modeling on a variety of river systems ranging from the Santa Margarita River in southern California to the Thames Estuary in Connecticut. Dr. Butcher has been a lead author for several EPA Office of Water guidance documents.

1.6 Documentation and Records

Thorough documentation of all modeling activities is necessary to be able to effectively interpret the results. All records and documents relevant to the application, including electronic versions of data and input data sets, will be maintained at Tetra Tech's offices in the central file. The central repository for the model will be Tetra Tech's Fairfax, Virginia, office. Tetra Tech will deliver a copy of the records and documents in the central file to EPA at the end of the task. Unless other arrangements are made, records will be maintained at Tetra Tech's offices for a maximum of 3 years following task completion.

The Tetra Tech TOLs and designees will maintain files, as appropriate, as repositories for information and data used in models and for preparing reports and documents during the task. Electronic project files are maintained on network computers and are backed up weekly. The Tetra Tech TOLs will supervise the use of materials in the central files. The following information will be included in the hard copy or electronic task files in the central file:

- Any reports and documents prepared
- Contract and task order information
- QAPP and draft and final versions of requirements and design documents
- Electronic copies of models
- Results of technical reviews, internal and external design tests, quality assessments of output data, and audits

- Documentation of response actions during the task to correct problems
- Input and test data sets
- Communications (memoranda; internal notes; telephone conversation records; letters; meeting minutes; and all written correspondence among the task team personnel, suppliers, or others)
- Studies, reports, documents, and newspaper articles pertaining to the task
- Special data compilations

Records of receipt with information on source and description of documentation will be filed along with the original data sheets and files to ensure traceability. Records of actions and subsequent findings will be kept during additional data processing.

All data files, source codes, and executable versions of the computer software will be retained for internal peer review, auditing, or post-task reuse in the electronic task files in the administrative record. These materials include the following:

- Versions of the source and executable code used
- Databases used for model input, as necessary
- Key assumptions
- Documentation of the model code and verification testing for newly developed codes or modifications to the existing model

The Tetra Tech Modeling QC Officer and other experienced technical staff will review the materials listed above during internal peer review of modified existing models or new codes or models. The designated QC Officers will perform QC checks on any modifications to the source code used in the design process. All new input and output files, together with existing files, records, codes, and data sets, will be saved for inspection and possible reuse.

Any changes in this QAPP required during the study will be documented in a memo sent by Tetra Tech QA Officer Esther Peters to each person on the distribution list following approval by the appropriate persons. The memo will be attached to the revised QAPP.

2 MODEL SELECTION, CALIBRATION, AND SUPPORTING DATA ACQUISITION AND MANAGEMENT

This section of the QAPP provides a description of the process that was used to select the model for the Ohio River Bacteria TMDL.

2.1 MODEL SELECTION

Model selection is critical for developing a comprehensive, predictive, and flexible numerical simulator for Ohio River bacteria loads. A comprehensive water quality model for the Ohio River is needed to address the bacteria-related impairments and to develop fecal coliform and *E. coli* TMDLs. Tetra Tech identified the following five model configurations potentially applicable for this task:

- RIV1
- CE-QUAL-W2
- EFDC (two-dimension (2D) configuration)
- EFDC (three dimension (3D) configuration)
- Linked EFDC-WASP system.

Tetra Tech considered the following 11 model selection factors in deciding on a preferred modeling framework and rated on a scale of 1 to 3 the suitability of each model with respect to each model selection factor. A score of 1 indicates the model is not recommended for that selection factor, a score of 2 indicates the model is sufficient, and a score of 3 means the model is highly recommended for that selection factor. Selection factors that were common to each model (e.g., the ability to perform continuous simulations) are not presented.

2.1.1 Selection Factor 1: Simulating Locks and Dams

The model must be capable of representing a riverine system that is interrupted by locks and dams. Because the Ohio River spans a very long distance and is interrupted 20 locks and dams, it is necessary to select a modeling framework that has the capability of representing the impact of locks and dams on hydrodynamics and fate and transport of pollutants. Five different frameworks were considered for representing the locks and dams that interrupt the hydrology of the Ohio River system, as discussed below.

RIV1 can represent the locks/dams in the sense that an individual model could be developed for each impounded section, and the simulated output from upstream of each lock and dam could be configured as the upstream boundary condition to drive the simulation of the downstream reach. Although this is theoretically workable, it would result in a series of models that are linked externally, which is cumbersome and inefficient. Therefore, RIV1 received a score of 1 (not recommended) for this selection factor.

CE-QUAL-W2 (W2) is a laterally averaged 2D modeling framework that is capable of representing a dam/lock interrupted system within a single model. This feature of W2 makes it possible to develop a holistic modeling system for the entire Ohio River. In addition, Tetra Tech's in-house version of W2 has a special function that allows representation of the entire river in one model, while also providing an option to run the model in smaller, distinct segments. This technique has been proven to be extremely efficient in developing TMDL modeling for a dam/lock interrupted river system. Considering its special capability, W2 is highly recommended for this task (score = 3).

EFDC is a general hydrodynamic and water quality model that is applicable to almost all natural water systems. It can also represent the hydraulic function of dams/locks and its impact on hydrodynamics and water quality in a dam/lock interrupted system. However, it does not include a function for segmented simulation. The computational burden would be tremendous if the entire Ohio River could be represented in only one holistic model, making model runs much slower and less efficient than W2. Therefore, EFDC was rated as moderately recommended (score=2).

The linked EFDC-WASP modeling option is possible; however, data storage requirements for the hydrodynamic file could be prohibitive for such a large system, which would limit the simulation period. Also, the linkage of EFDC and WASP may incur numerical instability problems compared to only applying EFDC. Therefore, EFDC-WASP is rated with a score of 2.

2.1.2 Selection Factor 2: Simulating Lateral Inflows and Withdrawals

Representing lateral inflows and withdrawals is essential to modeling the impact from tributaries and CSOs. All the models considered have the capability of representing lateral inflows and withdrawals, so they are all rated as highly recommended, with a rating score of 3.

2.1.3 Selection Factor 3: Representing Vertical Water Quality Conditions

The Ohio River spans a large extent of water that can cover sections where vertical water quality variability might have significant implications for TMDL development. For example, deeper water behind dams can provide areas of reduced light and low oxygen that are conducive to longer survival of bacteria in the environment. Therefore, selecting a modeling framework that has the flexibility to represent vertical variability, if and where necessary, is an important consideration in the model selection process. RIV1 is a one-dimensional modeling framework having no flexibility to be extended to a 2D representation; therefore, it is rated the least desirable option in this task (score = 1). W2, EFDC, and EFDC-WASP all have the capability of readily resolving the vertical resolution of a waterbody, so they are all recommended for this selection factor (score = 3).

2.1.4 Selection Factor 4: Simulating Sediment Transport and Bacteria Interaction

Interactions between bacteria and sediment have been documented in large river systems; therefore, it would be preferred if the modeling framework could fully or partially simulate sediment transport and the associated impacts on fate and transport of bacteria. RIV1 does not have sediment transport capacity and, because it is not a fully open-source modeling framework, there is no way to incorporate any sediment transport and bacterial interaction module. RIV1 therefore received a score of 1 for this selection factor.

W2 has a simple sediment transport function, and a simple sediment-bacteria interaction module can be conveniently incorporated into the model because it is a fully open-source modeling framework. W2 therefore received a score of 2 for this selection factor.

EFDC has the full capability of simulating sediment transport, along with sediment-bacteria interaction module, therefore, it is highly recommended for this task (score = 3). The EFDC-WASP modeling framework is rated as moderately recommended for this task (score = 2) because significant effort would be involved in incorporating sediment transport information into the WASP model.

2.1.5 Selection Factor 5: Simulating Sophisticated Bacterial Kinetics

Bacteria are most often simulated with simple, first-order, die-off kinetics. However, in some occasions, more complex dynamic processes are needed to simulate processes such as light effect, regrowth, settling, resuspension, or nutrient interactions and these are important issues that will need to be addressing during development of the Ohio River TMDL. Both RIV1 and W2 have only first-order decay formulation. However, W2 is an open-source modeling framework to which other bacterial dynamics can be conveniently incorporated into the code, whereas similar code changes could not be made for RIV1. RIV1 is therefore scored low for this selection factor (score = 1), and W2 is moderately recommended (score =2). EFDC and the EFDC-WASP framework both have the capability of representing more sophisticated bacterial kinetics, so they are highly rated for this selection factor (score =3).

2.1.6 Selection Factor 6: Simulating Other Pollutants (Nutrients, Algae, and Dissolved Oxygen)

Because developing a TMDL model for the Ohio River system will involve significant cost and effort, it would be desirable if the model could be readily expanded to model other pollutants so as to address future water quality issues. RIV1 can simulate 10 water quality constituents in addition to fecal coliform. Both RIV1 and EFDC-WASP modeling frameworks are rated as moderate for this selection factor because they do have major capability of simulating other pollutants but at a moderate level of complexity. EFDC and W2 have more advanced water quality structure and formulations, allowing them to simulate more complex system interactions between various pollutants than other models; they both received a score of 3.

2.1.7 Selection Factor 7: Resources and Computational Cost

The cost-effectiveness of each model varies. In terms of resource requirements and computational cost, both RIV1 and W2 require the least effort, so they are rated as highly recommended (score = 3). The EFDC and EFDC-WASP models receive a score of 1 for this selection factor because of the tremendous computational effort that would be involved with such a large river system.

2.1.8 Selection Factor 8: Representing Lateral Variability

Lateral variability in bacteria counts has been documented for the Ohio River. A portion of this variability is likely due to analytical uncertainty, but a portion is also expected to be due to real differences in source inputs (e.g., more significant CSO discharges on one side of the river). An ideal modeling framework would thus include the ability to simulate different bacteria counts laterally across the river.

RIV1 and W2 do not have the capability to directly simulate lateral variability and therefore received a score of 1. EFDC and EFDC-WASP have this capability in their 3D or horizontal 2D configurations, and are therefore received scores of 3.

2.1.9 Selection Factor 9: Availability of Source Code

The capability and suitability of a modeling framework to the Ohio River is partly constrained by the availability of source code. An open source code allows for model customization through incorporation of additional model parameters as the TMDL project evolves. Open source code also enables independent review of embedded assumptions in the model. The current version of RIV1 is not known to be a fully open-source model, although code for obsolete versions of the model might be available, so it is rated as moderately recommended (score = 2). In contrast, W2 and EFDC are fully open-source models whose source code is readily available, so they are highly recommended (score = 3). WASP source code is available for older, pre-Windows-based versions, but the code for current version of WASP, while supported by EPA, is not publicly available, so it is only moderately recommended (score =2).

2.1.10 Selection Factor 10: Model Suitability

To improve the defensibility of the TMDL, the model should be widely accepted among professionals in the water resources discipline. It should also have a history of successful TMDL application. On the basis of these criteria, the RIV1 model is moderately recommended for TMDL modeling because it is infrequently used for TMDL development. All the other models have been widely applied for TMDL development purposes and receive a score of 3.

2.1.11 Selection Factor 11: Data Requirements for Setup and Calibration

Data requirements for model setup and calibration are similar for RIV1, W2, and EFDC 2D. Development of a full scale, 3D model for the entire river would require significantly more data.

2.1.12 Summary and Recommendations

Table 6 summarizes the discussion above, and includes weights that were applied to each selection factor. The weighting factors were initially specified by the Tetra Tech Modeling Lead and Modeling QC Officer and were then modified on the basis of comments received by the Workgroup.

Table 6 indicates that the W2 model scored slightly higher than the second ranked model (EFDC 2D) and is therefore recommend for TMDL development. The major differences between these two models are associated with Resources and Computational Cost and Representing Lateral Variability. EFDC scored better because of its ability to simulate lateral variability, but this was essentially offset by the significantly increased cost (an EFDC 2D application is estimated to cost twice as much as a W2 application). Other considerations taken into account included the following:

- While lateral variability likely exists, many of the sources (such as CSOs and stormwater) are not sufficiently well characterized to accurately represent the time course of concentrations across lateral gradients.
- 3-D mixing patterns are strongly affected by lockages, hydropower releases, and local wind stress. Sufficient details of these measurements are not available to accurately characterize these forcings at the time scales required by the model, which will create significant uncertainty in the simulation of lateral variability. The 2-D representation essentially averages across the lateral, is less affected by these issues, and is more consistent with the level of accuracy in the source forcing.
- The lateral variability appears to be an issue only at locations close to the sources, which suggests a mixing zone type of problem that could be addressed during the allocation of the TMDL as discussed in Section 1.3.5.
- The 2-D configuration of W2 will produce shorter model run times allowing for more extensive iterative calibration.
- The cost required for application of W2 is significantly less (an EFDC 2D application is estimated to cost twice as much as a W2 application).

The selection of W2 as the preferred model for development of the Ohio River bacteria TMDL will be explained to stakeholders during the Task 1 public meetings and, if necessary, can be re-visited by the Workgroup prior to the start of Task 2 (Model Setup). Any changes to the recommended model (or to the modeling approach) will be documented in a revision to this QAPP.

Table 6. Ohio River Bacteria TMDL model selection matrix

Category	Specification	3 = Highly Recommended, 2 = Sufficient, 1 = Not Recommended					
		Weighting Factor	**RIV1**	**CE-QUAL-W2**	**EFDC (2D)**	**EFDC (3D)**	**EFDC-WASP (3D)***
Hydrodynamic	Simulating Lock/Dams	3	1	3	2	2	2
	Simulating lateral inflows and withdrawals	3	3	3	3	3	3
Water Quality	Representing Vertical Water Quality Conditions	2	1	3	3	3	3
	Simulating Sediment Transport and Bacteria Interaction	1	1	2	3	3	2
	Simulating Sophisticated Bacterial Kinetics	1	1	2	3	3	2
	Simulating Other Pollutants (Nutrients, Algae, and Dissolved Oxygen)	1	2	3	3	3	2
Other	Resources and Computational Cost	3	3	3	1	1	1
	Representing Lateral Variability	3	1	1	3	3	3
	Availability of Source Code	3	2	3	3	3	2
	Model Suitability	3	2	3	3	3	3
	Data Requirements for Setup and Calibration	2	3	3	3	1	1
Recommendation: Applicability of the model to this TMDL			**48**	**67**	**66**	**62**	**56**

* Note: EFDC-WASP can also be configured as a 2D model. The 3D ratings are provided for comparison purposes.

2.2 Model Calibration and Validation

2.2.1 Objectives of Model Calibration Activities

The principal study questions for this project address the response of the Ohio River to existing and future bacteria nonpoint sources and permitted bacteria point sources in its watershed. The general objective for model calibration is to create a reliable modeling tool that can be used to evaluate such responses. To create such a tool, it will be necessary to first calibrate and then validate the model.

Calibration consists of the process of adjusting model parameters and the initial estimates of boundary conditions to provide a suitable representation of observed conditions. Calibration is necessary because of the semiempirical nature of water quality models. Although these models are formulated from mass balance principles, most of the kinetic descriptions in the models are empirically derived. These empirical derivations contain a number of coefficients that are usually determined by calibration to data collected in the waterbody of interest. In addition, there is uncertainty associated with the specification of boundary conditions—particularly bacteria loads from tributaries, CSOs, and other sources. These boundary conditions might need to be adjusted within the uncertainty bounds of available data to achieve model calibration.

Calibration tunes the models to represent conditions appropriate to the waterbody and watershed under study. However, calibration alone is not sufficient to assess the predictive capability of the model or to determine whether the model developed via calibration contains a valid representation of cause-and-effect relationships. To help determine the adequacy of the calibration and to evaluate the uncertainty associated with the calibration, the model is subjected to a validation step. In the validation step, the model is applied to a set of data independent from that used in calibration.

ORSANCO *E. coli* and fecal coliform field observations from 2002 to 2006 for the Ohio River mainstem, as well as a subset of major tributaries, are available for calibration and validation purposes. Other field observations from the Ohio River mainstem and tributaries are available from various cooperating state agencies, although these data have much more temporal and spatial variability. These data will be separated into a calibration period (2007) and a second validation period (one year between 2002 and 2006). This will help to ensure construction of a robust predictive tool. Model precision will depend on the level of spatial and temporal detail in available bacteria data. Complete data sets that span the entire modeling domain would allow model developers to calibrate and validate models that provide the best possible representation of bacteria dynamics. Missing data, or data collected with an uneven level of effort across the modeling domain will introduce uncertainty into the calibration and validation process.

While model developers will strive to achieve the highest quality of fit possible during calibration and validation, they must keep in mind the decision purposes of the models. Specifically, the models will be used to evaluate whether the various bacteria-related water quality standards will be met under a variety of future conditions, and to provide a basis for comparison among potential allocation scenarios. As such, some degree of uncertainty in model predictions is acceptable; however, bias—a systematic deviation between model predictions and observations—should be avoided to the extent practicable.

2.2.2 Model Calibration/Validation Procedures

W2 is a 2D, longitudinal/vertical, hydrodynamic, and water quality model. The model solves laterally averaged 2D partial differential equations representing water circulation, thermal dynamics, mass balance and transport of dissolved and suspended particulate constituents, and fate and transport of water quality constituents including bacteria, nutrients, algae, and dissolved oxygen. Because of its full hydrodynamic feature and its capability of simulating multiple arbitrary tracer constituents, W2 is readily usable for evaluating the spatial-temporal distribution and dynamics of bacteria in the entire Ohio River system. In addition, a numerical tag analysis can be implemented when necessary to identify the contribution from different sources to the water quality problem at a special location of concern.

The W2 model is a general modeling framework. To develop a site-specific representation, the general modeling framework of W2 must be customized to the Ohio River system using the bathymetric data and forcing information that characterizes this system. The major forcing data include upstream flow, temperature, and bacteria boundary conditions, lateral tributary flow, temperature, and bacteria boundary conditions, lateral distributed flow, temperature, and bacteria boundary conditions, lateral withdrawal boundary conditions, downstream outflow boundary condition, and atmospheric boundary conditions.

In this study, upstream, and lateral tributary/distributed boundary conditions are expected to be based primarily on observed data. If available, data from a calibrated watershed model might also be used. When only observed data are available a regression or rating curve approach, likely stratified by season, will be used to estimate loads because they are likely to be strongly related to flow. Loads from unmonitored tributaries will be estimated based on finding a suitable *surrogate* monitored tributary and adjusting for drainage area and other appropriate factors (such as land use and the existence of potentially significant bacteria sources). The specification of boundary conditions will inevitably introduce uncertainty into the model output. Sensitivity analyses will be used to evaluate the impacts of boundary condition uncertainty on model results.

The lateral withdrawal and downstream outflow boundary conditions will be configured using observed data. Because locks/dams exist along the river, downstream flow boundary conditions must be specified for each lock/dams to route flow and water quality mass from upstream to downstream. The atmospheric boundary conditions will be configured using information obtained from nearby meteorological stations.

Because there are 20 lock/dams along the river length, the model for the Ohio River will be developed as a multiple-domain system, where each reach of the river between a pair of lock/dams will be configured as a subdomain, which is further segmented into finite-difference segments to resolve spatial variability. The segments will be variably sized to allow for more resolution around large, urban areas and other key locations and less resolution in areas where such resolution is unnecessary. Similarly, the segments can be separated into vertical layers, where necessary, to simulate important vertical hydrodynamic or bacteria gradients and otherwise can be simulated one-dimensionally. In doing so, the entire river can be represented in one holistic modeling system, while the spatial variability in waterbody type and characterization can be effectively considered. Each of the domains is internally linked to each other in an upstream-to-downstream fashion, with the flows through dams or locks to be parameterized as either specified flows or predicted flows depending on the specific configuration of each flow control structures. For any dams that do not impose downstream-to-upstream type of flow reversal, the piece-wise simulation function in Tetra Tech's in house W2 version can be applied to significantly enhance the computational efficiency through splitting the model simulation in pieces during the calibration and scenario analysis process.

Flows from all the incoming tributaries and CSOs will be represented as lateral tributary files with specified time series for flow, temperature, and bacteria concentration. Establishing the flow and concentration time series for the CSOs is expected to be challenging, as many of them are not well characterized. For some of the communities, there are CSO models that would be one source of interpolation, and output from these models will be requested as part of this project. Concentration of pollutants from the CSOs will also be highly variable, both by location and timing, because some CSOs are predominantly stormwater, whereas others have a large sanitary sewage component, which will cause variations in strength.

Bacteria fate and transport can be simulated in W2 using the framework for general constituents. Because W2 allows specifying an arbitrary number of species for general constituents, both fecal coliform and *E. coli* bacteria can be simulated simultaneously in a single model run. In doing so, fecal coliform and *E. coli* will be configured as two different species of general constituents with distinct kinetic parameters. Also, they will be input in all the boundary condition files side by side on the basis of data or watershed model result. The capability of W2 to simulate both *E. coli* and fecal coliform in one single model offers a significant advantage in conducting model calibration and TMDL analysis.

The W2 model for the Ohio River will be calibrated and validated through a sequential process, beginning with hydrodynamics, followed by the water quality. The calibration period will be for a one year period to be defined following a thorough analysis all of the available data (including the scheduled Spring 2008 data). The model will be validated to a separate year. The calibration and validation years will be selected based on a consideration of the following factors:

- Recentness and completeness of data set (including model input data).
- Critical conditions (periods with high bacteria counts throughout the river).

Hydrodynamic and water quality models are often evaluated through visual comparisons, in which the simulated results are plotted against the observed data for the same location and time and are visually evaluated to determine if the model is able to mimic the trend and overall magnitude of the observed conditions. If the model predictions follow the general trend and reproduce the overall magnitude of the observed data, the model is said to represent the dynamics of the system well. The merit of this method is that it is straightforward, taking full advantage of the strength of human intelligence in pattern identification. This method works particularly well when data are limited in quantity and contain significant uncertainty. The limitation of this method is that it relies on the subjective judgment of modelers and lacks quantitative measures to differentiate among sets of calibration result.

An alternative approach aimed at overcoming the limitations of the visual comparison method is to quantify the goodness of fit using a series of statistical measures. Ideally, if there are a large number of data and most of the data are accurate, a quantitative approach can be used to evaluate the model's performance. However, in reality, the amount of water quality data is generally limited, and the available data often contains errors and uncertainties. Therefore, the validity of the quantitative statistical method is often compromised by uncertainties in the observed data. In addition, there is no widely acceptable range of error statistics defined for water quality model calibration. Generally, because of the uncertainty in model boundary conditions and bathymetries, it is generally not expected that a water quality model can reproduce the exact timing of water quality in a dynamic system. For example, if a water quality model has mimicked the time variable feature in the river very well but with a 1-day shift in time, poor error statistics can result. In this case, the error statistic does not make any practical sense unless it is interpreted with the visual comparison of trend and magnitude.

In this study, a dual approach will be adopted to guide the calibration of the W2 model of the Ohio River. The dual approach will be implemented in a two-stage manner. For the first stage, the model calibration will be guided through the visual comparison approach, which would allow the calibration effort to be led toward reproducing the trend and overall dynamics of the river. After the model has been calibrated to the trend and overall dynamics, the second stage involves fine tuning the parameters and then calculating various error statistics to find a most appropriate calibration within the range of state spaces that were found in stage one.

The first step is to calibrate hydrology to ensure mass balance closure for flow volumes. Once this is completed, the model will be calibrated for hydrodynamics. The data needed for hydrodynamic calibration include water surface elevation, flow velocity (if available), temperature time series, and other conservative constituents. Hydrodynamic calibration will be implemented following the standard routine as described in the W2 model users' manual (Cole and Wells 2003), in the order of elevation, velocity, and temperature. The dual approach as described above will be applied to implement the calibration. The key factors that would impact the hydrodynamic calibration include accuracy and availability of bathymetric data, tributary inflow and temperature, accuracy of flow measurement, unaccounted groundwater interaction, dam/lock operation, meteorological condition representation. Calibrating hydrodynamic detail in the Ohio River will be a challenging task, because it is strongly affected by lockages, boat traffic, hydropower generation, and other factors. As such, the goal of the hydrodynamic calibration will be to ensure a close match to daily elevations and velocities. However, the model might not be able to capture subdaily changes very well.

The second step is to calibrate the water quality dynamics. Because the kinetics of indicators for human pathogenic microorganisms such as fecal coliform and *E. coli*, bacteria are relatively simple (compared to simulation of the full nutrient cycle), first-order decay representation will be applied to represent the major loss process. In the calibration process, the major factors that need to be considered include the source loadings, potential groundwater interactions, and the first-order decay parameter. If, however, it is found that the simplified, first-order kinetics are not sufficient to represent fecal coliform and *E. coli* bacteria in the Ohio River, specific model enhancement will be conducted to incorporate more advanced kinetic formulations. A large number of iterations will be conducted to achieve a satisfactory calibration of the model. The dual approach as described above will be used to guide the calibration process.

After both the hydrodynamic and water quality model are calibrated, a separate validation analysis will be evaluated. Model validation is defined as, "subsequent testing of a pre-calibrated model to additional field data, usually under different external conditions, to further examine the model's ability to predict future conditions" (USEPA 1997). Its purpose is to assure that the calibrated model properly assesses all the variables and conditions that can affect model results and demonstrate the ability to predict field observations for periods separate from the calibration effort (Donigian 2003).

To conduct the dual calibration process, a set of basic statistical methods will be used to compare model predictions and observations in the second calibration stage, including the mean error statistic, the absolute mean error, the root-mean-square error, and the relative error.

Mean Error Statistic. The mean error between model predictions and observations is defined as

$$E = \frac{\sum (O - P)}{n},$$

where

E = mean error
O = observations
P = model prediction at the same time as the observations
n = number of observed-predicted pairs

A mean error of zero is ideal. A non-zero value is an indication that the model might be biased toward either over- or under-prediction. However, an important consideration of the mean error approach is that it can severely penalize the model for small phase shifts in timing, which are expected for the Ohio River because of, for example, extremely dynamic CSO inputs. One approach that will be used to address this in the Ohio River model application is to establish a time window, calculate the range of model predictions for the time window, then count a deviation from prediction only if the observation falls outside this range.

Absolute Mean Error Statistic. The absolute mean error between model predictions and observations is defined as

$$E_{abs} = \frac{\sum \left|(O - P)\right|}{n},$$

where

E_{abs} = absolute mean error.

An absolute mean error of zero is ideal. The magnitude of the absolute mean error indicates the average deviation between model predictions and observed data. Unlike the mean error, the absolute mean error cannot give a false zero.

Root-Mean-Square Error Statistic. The root-mean-square error (E_{rms}) is defined as

$$E_{rms} = \sqrt{\frac{\sum (O-P)^2}{n}} \, ,$$

A root-mean-square error of zero is ideal. The root-mean-square error is an indicator of the deviation between model predictions and observations. The E_{rms} statistic is an alternative to (and is usually larger than) the absolute mean error.

Relative Error Statistics. The relative error statistics between model predictions and observations can be calculated through dividing the error statistics as defined in a), b), and c) by the mean of the observations. A relative error statistic of zero is ideal. When it is non-zero, it represents the percentage of deviation between the model prediction and observation.

Coefficient of Model Fit Efficiency. The coefficient of model fit efficiency or Nash-Sutcliffe coefficient (E_{NS}) is particularly useful for evaluating model fit to continuous data, taking into account both the difference between model and observation and the variance of the observations. The statistic is defined as

$$E_{NS} = 1.0 - \frac{\sum_{i=1}^{n} \left(O_i - P_i\right)^2}{\sum_{i=1}^{n} \left(O_i - \overline{O}\right)^2} \, ,$$

where O and P represent observed and predicted values, respectively. The resulting coefficient ranges from minus infinity to 1.0, with higher values indicating better agreement. At a value of zero, the test indicates that the observed mean is as good a predictor as the model, while negative values indicate that the observed mean is a better predictor than the model.

Other Error Statistics: Because a major purpose of this model is to predict the frequency of excursions above the standard, measures directly related to that purpose will also be included. For example, the frequency at which observed concentrations greater than the standard are predicted within 0.5 log values will be reported.

2.2.2.1 Uncertainty Analysis for Calibrated Models

From a decision context, the primary function of the calibrated water quality model is to predict the response of flow, fecal coliform bacteria, and *E. coli* to changes in loadings. As such, an important input to the decision-making process is information on the degree of uncertainty that is associated with model predictions. In some cases, the risks or *costs* of not meeting water quality standards could be substantially greater than the costs of over-protection, creating an asymmetric decision problem in which there is a strong motivation for risk avoidance. Further, if two scenarios produce equivalent predicted results, the scenario that has the smaller uncertainty is often preferable. Additionally, the Clean Water Act requires that TMDLs include an MOS to account for any uncertainty between source loadings and water quality response. However, it is not possible to evaluate how much of an MOS is appropriate without information on the uncertainty associated with model predictions. Therefore, an uncertainty analysis of model predictions is essential.

As with any mathematical approximation of reality, a water quality model is subject to significant uncertainties. Some information on uncertainty in Ohio River model predictions will arise directly from the calibration and validation process. However, a more formal analysis is likely to be appropriate. The major sources of model uncertainty include the following:

- **Mathematical formulation**. A real water system is too complex for a mathematical model to represent all the dynamics; therefore, no matter how sophisticated a mathematical water quality model is, it is based on a simplified mathematical formulation. The simplifications in general neglect processes that are considered to be insignificant, thus the model can catch the general trend of the real system. In other words, a mathematical model is designed to represent the trend, rather than provide exact replication of the real system. Thus, uncertainty exists when those neglected factors start to play some detectable roles.
- **Boundary conditions**. Specification of boundary conditions, particularly loads from tributaries and CSOs, is anticipated to be a key source of uncertainty in the model. The propagation of this uncertainty to model predictions and its potential effect on decisions will be evaluated as part of the model calibration and validation process.
- **Data Uncertainty**. Site-specific data are the basis for developing a water quality model for a specific waterbody. A water quality model requires data from different sources and for a large number of parameters. There is always some level of analytical uncertainty in any reported observation that derives from the inherent imprecision of analytical techniques and, occasionally, from laboratory analysis and reporting errors. Precision is often low for commonly used bacterial measures. Also, data are always limited in both time and space; thus, an interpolation method must be used to represent continuous inputs. Finally, in most cases, monitoring data are not available for all the water quality parameters; thus, they have to be derived based on some empirical method. All these can contribute to uncertainty in the model.
- **Parameter Specification**. In a water quality model, parameters quantify the relationships in the major dynamic processes. The values of parameters are generally obtained through the model calibration process while constrained by a range of reasonable values documented in literature. Because of the sparseness and uncertainty in data used to configure and calibrate a water quality model, the model parameter is also subjected to uncertainty. Actually, the parameter uncertainty can be considered as a direct reflection of the uncertainty from both mathematical formulation and data. In real-world practice, while it is hard to quantify the uncertainty in model formulation and data, uncertainty analysis for model parameters becomes a key method for evaluating the overall uncertainty of model predictions.
- **Sensitivity Analysis.** The most widely applied parameter uncertainty analysis approach is sensitivity analysis. Sensitivity analysis is implemented by perturbing model parameter values one at a time and evaluating the model response. This method is useful in identifying key parameters and processes in a water quality system, and the interpretation of the result is straightforward and meaningful. Sensitivity analysis, however, is limited in that it cannot account for the compound uncertainty of multiple parameters because it is implemented by varying parameter values one at a time. In a water quality model, many if not all of the parameters interact with each other; hence their uncertainties often compound to form an overall parameter uncertainty, which ultimately represents the model uncertainty.
- **Monte Carlo Simulation.** Generally, the evaluation of overall parameter uncertainty has been handled using the Monte Carlo method (Bobba et al. 1995; Duke et al. 1998; Yulianti et al. 1999; Zou et al. 2002). In the Monte Carlo simulation, the model parameters are assumed to be random

variables that are represented by probability density functions (PDFs). However, the applicability of the Monte Carlo method in this study is restricted by the prohibitive computational requirements of full implementation throughout the Ohio River. In addition, it is also unlikely that sufficient data are available to derive the probabilistic distribution through statistical analysis.

- ***Fuzzy* Mathematics.** Another alternative is to apply fuzzy mathematics to evaluate the compound uncertainty in a water quality model because water quality parameters can often be perceived in terms of possibilities rather than probabilities in management context. For example, although it is hard to define a PDF for a water quality model parameter, it can often be expressed more vaguely as, "the value of parameter X is about 0.25, and can vary between 0.1 to 0.4." This kind of linguistic judgment can be automatically transformed into mathematical language using mathematical operations. This approach has the advantage over the Monte Carlo method in that it directly handles the uncertainty in parameters caused by vagueness in definitions, and it does not require derivation of detailed PDFs (Dou et al. 1995; Zou and Lung 2002). However, although the computational requirement for implementing a fuzzy approach can be lower than the Monte Carlo method, it can still be prohibitive because the solution of a series of nonlinear optimization problems will be required given the complexity in transport and kinetics in the Ohio River model.

After performing initial sensitivity analyses, the potentially most applicable method for analyzing the compound uncertainty in the Ohio River model is to apply an interval parameter method, in which Tetra Tech will replace a few (fewer than 5) key single value parameters in the model with interval numbers which characterize the estimated range of the parameters and then apply a simulation-based optimization algorithm to solve the minimization and maximization equations to obtain the possible range of model prediction on the basis of the interval parameters. In doing so, the decision maker can obtain information about the most optimistic and pessimistic consequences of the model prediction, which can then provide a range to use for making decisions on development and environmental management. It should be noted that this method, although subject to significantly lower computational burden than the fuzzy method, still needs complicated computer implementation and can be time consuming. Therefore, whether there is a need to implement this type of compound uncertainty analysis in addition to the sensitivity analysis will be determined according to feedback from the Workgroup.

2.2.3 Acceptance Criteria for Model Calibration

The acceptance criteria for model calibration are related to the project quality objectives and have been developed in conjunction with the needs of the regulatory decision makers. Because the principal study questions are all in terms of meeting standards and allocations, the most fundamental acceptance criteria are in terms of the frequency of excursions. Other key acceptance criteria relate to ensuring an adequate representation of flow to properly simulate the frequency of excursions. The acceptance criteria are listed below and are based on generally accepted values in the literature and from previous TMDL projects (Bicknell et al. 1996; Donigian 2000):

- The relative error between observed and simulated flows will be less than the following:
  - Error in total volume—10 percent
  - Error in recreation season volume—30 percent
  - Error in 50 percent lowest flows—10 percent
  - Error in 10 percent highest flows—15 percent

- The frequency at which observed concentrations greater than the applicable standards are predicted within 0.5 log values will be at least 80 percent.
- A standard t-test will be used to test the null hypothesis of equality between the observed and simulated geometric mean of *E. coli* and fecal coliform observations over the entire calibration period and the entire validation period. (There are not sufficient data to adequately evaluate performance on individual seasons or years, particularly given the presence of analytical and sampling uncertainty.) In these tests, the equality of observed and sample geometric means on paired daily average data is taken as the null hypothesis or a rebuttable proposition. That is, model performance is judged acceptable unless the statistical analysis proves otherwise.

Additional statistical tests will be performed and reported as part of model calibration and validation but are not characterized as fundamental acceptance criteria.

It should be noted that the acceptance criteria will not be the sole arbiter of the usefulness of the model. Instead, meeting the Acceptance Criteria will mean that the model is proven to perform well enough. However, if some or all of the acceptance criteria are not met, the model can still be usable, for instance through an increased MOS, but decision makers need to be clearly informed about the increased level of uncertainty. In cases where the Acceptance Criteria are not met, Tetra Tech will provide a discussion summarizing the most likely reasons why the model did not perform as well as desired.

2.2.4 Frequency of Model Calibration Activities

The current project will include calibration to observed data collected from the ORSANCO and state water quality monitoring records. This calibration will reflect existing land use and management in the watershed and current permitted point source discharges. As land uses change over time, it might be necessary to undertake another iteration of model calibration. Such future activities are not, however, within the scope of the QAPP for the current project.

2.3 NONDIRECT MEASUREMENTS (SECONDARY DATA ACQUISITION REQUIREMENTS)

Nondirect measurements (also referred to as secondary data) are data previously collected under an effort outside this contract that are used for model development and calibration. Details regarding how relevant secondary data will be identified, acquired, and used for this task are provided below.

2.3.1 Meteorology

Meteorological data are a critical component of any hydrologic model. Appropriate representation of precipitation, wind speed, potential evapotranspiration, cloud cover, temperature, and dew point is required to develop a valid model. Meteorological data will be obtained from a number of sources in an effort to develop the most representative data set for the Ohio River watershed. In general, hourly precipitation data are recommended for nonpoint source modeling, but sometimes weather stations with only daily data must be used to develop a representative data set. Long-term hourly precipitation data available from National Climatic Data Center (NCDC) weather stations distributed throughout the watershed will be the first source of weather data, followed by daily precipitation data available from National Weather Service weather stations.

2.3.2 River Geometry

Modelers will rely on data from existing Ohio River bathymetry and stream morphology studies published in scientific literature to develop necessary model parameters for river channel geometry.

2.3.3 Flow

Reliable streamflow data are also important to hydrologic model calibration and validation. The U.S. Army Corps of Engineers (USACE) and the U.S. Geological Survey (USGS) maintains streamflow gages along the Ohio River and many of its tributaries. The period of record and completeness vary among gages, but most gages have daily average streamflow data available dating back to the early 1980s or earlier, sometimes to the 1940s. A period of record of 20 years or more is usually adequate for model calibration and validation. USGS data are readily available through the USGS National Water Information System Web Interface, accompanied by useful background information on the gage site and drainage area. The USACE flow data will be accessed by contacting the appropriate USACE personnel. Flow in ungaged or partially gaged tributaries will be estimated by relating to available gages and accounting for issues such as precipitation, land uses, significant point sources, and such. Flow estimates from calibrated watershed models will also be used if determined to be acceptable.

2.3.4 Water Quality Observations

Water quality observations are critical for modeling bacteria inputs from nonpoint sources. Because nonpoint bacteria sources can vary widely, field observations help modelers capture the relative contributions of bacteria loading from known residential, agricultural, and forested areas. ORSANCO comprehensive bacteria field sampling data on the Ohio River and selected tributaries are available from 2003 to 2006, and additional data are being collected in 2007. Several state agencies, including West Virginia and Kentucky, also have field data available for approximately the past 5 years. It will be important to obtain information on analytical precision related to all water quality measurements.

2.3.5 Tributary Loadings

Impaired tributaries can deliver significant bacteria loads to the Ohio River mainstem. Tributary loads will need to be incorporated into the Ohio River TMDL model, even if tributary watershed loading dynamics are summarized to simplify the modeling process. As explained in Section 2.2.2, existing loadings from impaired tributaries are expected to be based primarily on observed sampling data. If available, data from a calibrated watershed model might also be used. When only observed data are available a regression or rating curve approach, likely stratified by season, will be used to estimate loads because they are likely to be strongly related to flow. Loads from unmonitored tributaries will be estimated based on finding a suitable *surrogate* monitored tributary and adjusting for drainage area and other appropriate factors (such as land use and the existence of potentially significant bacteria sources). During TMDL development activities the loads from tributaries will be reduced to meet the applicable water quality standards.

2.3.6 CSO and SSO Loadings

Significant effort will be necessary to quantify CSO and SSO loadings in the Ohio River watershed. CSO data are not readily available because CSO reporting requirements are not uniform from state to state. Even if overflow frequency is known, the flow and bacteria concentration are largely unknown. CSO overflows often occur during high precipitation events, and sometimes localized flooding can make conditions difficult or hazardous for CSO field sampling. It is highly likely that supplementary analysis will be necessary to characterize CSO loadings to the Ohio River. Some municipalities could have existing models developed to predict overflow volumes and pollutant loads from CSOs. In addition, responsible entities might have useful information incorporated into their CSO LTCPs. The information and data collected from existing CSO models and LTCPs will be used to characterize the CSO bacteria loading contribution to the Ohio River in the following order of priority:

1. Time series of flows from existing calibrated CSO/SSO models will be used wherever they are made available by the community. Similarly, model-predicted bacteria loads will be used where available; otherwise, data on typical bacteria counts in CSO effluent will be used for each community when it is available.
2. When a model is not available but historical reporting of overflow timing and volumes is available for the entire modeling period, the reported overflows will be input to the model.
3. When some historical reporting is available but it does not cover the entire modeling period, a relationship between precipitation and observed overflows will be used to estimate CSO discharges.
4. When neither a model nor observed data are available, a community's CSO discharges will be estimated using a surrogate community taking into account the size, age, and type of the combined sewer system.
5. The following literature values will be used to estimate bacteria counts from CSOs if site-specific data for a community does not exist:
    a. Fecal coliform—215,000 counts/100 mL (USEPA 2004)
    b. *E. coli*—134,375 counts/100 mL (Fecal coliform count multiplied by 0.625 conversion factor)

All these approaches are subject to considerable uncertainty, which will be quantified to the extent possible.

2.3.7 Point Sources

Most point sources permitted under NPDES with bacteria effluent limits (e.g., wastewater treatment facilities) will have bacteria loading data available in DMRs. DMR data is available either from STORET databases or directly from state agencies. There are more than 800 permitted discharges to the Ohio River (more than 180 are municipal wastewater discharges). Robust data management protocols will become critical for managing the potentially enormous volume of data. Literature values based on wastewater treatment efficiencies will be used to characterize point sources without effluent discharge data.

2.3.8 Water Management

The Ohio River is a highly managed system with hydrology affected by a number of human activities such as locks and dams, hydropower discharges, etc. An important part of Task 1 will therefore be to identify, compile, and assess all of the relevant information on water management so that it can be adequately used to set up and calibrate the model. Tetra Tech will work closely with each state agency, ORSANCO, and the USACE to contact the appropriate personnel with access to this information.

2.3.9 Quality Control for Nondirect Measurements

The majority of the nondirect measurements will be obtained from ORSANCO, which has a QA program in place. As an extra safeguard, Tetra Tech will perform a review of the ORSANCO data to check for any potentially spurious outliers, and the like. Other nondirect data are expected to be provided by a variety of federal and state agencies that also should have been screened and meet specified measurement performance criteria but will still be reviewed. Tetra Tech will also perform general quality checks on the transfer of data from any source databases to another database, spreadsheet, or document.

Where data are obtained from nongovernment sources and lack quality documentation (e.g., a report indicating the data were collected according to specific methods and were checked to verify or validate that the values met specified requirements), Tetra Tech will evaluate data quality of such secondary data before use. Additional methods that might be used to determine the quality of secondary data include the following:

- Verifying values and extracting statements of data quality from the raw data, metadata, or original final report.
- Comparing data to a checklist of required factors (e.g., analyzed by an approved laboratory, used a specific method, met specified DQOs, validated).
- Comparing data collection process to any *credible data* rules or guidelines established by one of the participating states. Members of the Workgroup have agreed that any such rules or guidelines will apply to any data submitted by the public for this project even if the data are from a state without such a rule or guideline.

If it is determined that such searches are not necessary or that no quality requirements exist or can be established, however these data must be used in the task, Tetra Tech will add a disclaimer to the deliverable indicating that the quality of the secondary data is unknown. No data of unknown quality will be used if the use of such data will have a significant or disproportionate impact on the TMDL results.

A special note is appropriate regarding precipitation data. The precipitation data supplied by NCDC can vary widely in terms of QC, from carefully controlled observations at first-order weather stations, to data of uncertain quality reported by volunteer observers. Data from volunteer Cooperative Summary of the Day stations will be carefully evaluated for potential quality problems. An important issue for many precipitation series is attribution of missing data. Rainfall for model input will be processed using the MetADAPT weather data processing tool. The tool was developed with the Normal Ratio Method patching routine to fill gaps in rainfall records on an hourly basis.

The records will be reviewed to consider unreasonable or extreme values. This will be performed by inspection of the patched record against a regional record that has no impaired periods or a very small number of impaired periods, such as an airport station. Furthermore, the patched record will be reviewed against the original record and the index stations.

2.4 Data Management and Hardware/Software Configuration

No sampling (primary data collection) will be conducted for this task. Secondary data collected as part of this task will be maintained as hard copy only, both hard copy and electronic, or electronic only, depending on their nature.

Software to be used for this project includes publicly available code for CE-QUAL-W2 v 3.2 provided by the U.S. Army Corps of Engineers and Portland State University at http://www.ce.pdx.edu/~scott/w2/ and spreadsheet analysis tools created by Tetra Tech for similar projects.

The software used for the project operates on standard Pentium-class microcomputers under the Windows (2000/XP) operating system. The recommended hardware configuration varies depending on the complexity of the model. For CE-QUAL-W2, minimum requirements are anticipated to include a 600-megahertz processor, 512-megabyte random access memory (RAM), 10-gigabyte disk drive, and compact disc (CD) reader.

Tetra Tech Modeling Lead Dr. Rui Zou will provide the final version of the model input, output, and executables, to USEPA for archiving at the completion of the task. Electronic copies of the data, GIS, and other supporting documentation will be supplied to EPA with the final report. Tetra Tech will maintain copies in a task subdirectory (subject to regular system backups) and on disk for a maximum period of 3 years after task termination, unless otherwise directed by the client.

Most work conducted by Tetra Tech for this task requires the maintenance of computer resources. Tetra Tech's computers are either covered by on-site service agreements or serviced by in-house specialists. When a problem with a microcomputer occurs, in-house computer specialists diagnose the problem and correct it if possible. When outside assistance is necessary, the computer specialists call the appropriate vendor. For other computer equipment requiring outside repair and not currently covered by a service contract, local computer service companies are used on a time-and-materials basis. Routine maintenance of microcomputers is performed by in-house computer specialists. Electric power to each microcomputer flows through a surge suppressor to protect electronic components from potentially damaging voltage spikes. All computer users have been instructed on the importance of routinely archiving work assignment data files from hard drive to compact disc or floppy disk storage. The office network server is backed up on tape nightly during the week. Screening for viruses on electronic files loaded on microcomputers or the network is standard company policy. Automated screening systems have been placed on all of Tetra Tech's computer systems and are updated regularly to ensure that viruses are identified and destroyed. Annual maintenance of software will be performed to keep up with evolutionary changes in computer storage, media, and programs.

3 ASSESSMENTS AND RESPONSE ACTIONS

3.1 Assessment and Response Actions

The QA program under which this task order will operate includes surveillance and internal and external testing of the software application. The essential steps in the QA program are as follows:

- Identify and define the problem
- Assign responsibility for investigating the problem
- Investigate and determine the cause of the problem
- Assign and accept responsibility for implementing appropriate corrective action
- Establish the effectiveness of and implement the corrective action
- Verify that the corrective action has eliminated the problem

Many technical problems can be solved on the spot by the staff members involved; for example, by modifying the technical approach, correcting errors in input data, or correcting errors or deficiencies in documentation. Immediate corrective actions are part of normal operating procedures and are noted in records for the task. Problems not solved this way require formalized, long-term corrective action. If quality problems that require attention are identified, Tetra Tech will determine whether attaining acceptable quality requires short- or long-term actions. If a failure in an analytical system occurs (e.g., performance requirements are not met), the appropriate QC Officer will be responsible for corrective action and will immediately inform the Tetra Tech PM or QA Officer, as appropriate. Subsequent steps taken will depend on the nature and significance of the problem.

The Tetra Tech TOLs (or designees) have primary responsibility for monitoring the activities of this task and identifying or confirming any quality problems. Significant quality problems will also be brought to the attention of the Tetra Tech QA Officer, who will initiate the corrective action system described above, document the nature of the problem, and ensure that the recommended corrective action is carried out. The Tetra Tech QA Officer has the authority to stop work if problems affecting data quality that will require extensive effort to resolve are identified.

Corrective actions may include the following:

- Reemphasizing to staff the task objectives, the limitations in scope, the need to adhere to the agreed-upon schedule and procedures, and the need to document QC and QA activities
- Securing additional commitment of staff time to devote to the task
- Retaining outside consultants to review problems in specialized technical areas
- Changing procedures

The assigned QC Officers will perform or oversee the following qualitative and quantitative assessments of model performance to ensure that models are performing the required tasks while meeting the quality objectives:

- Data acquisition assessments
- Secondary data quality assessments
- Model testing studies

- Model evaluations
- Internal peer reviews

3.1.1 Model Development Quality Assessment

This QAPP and other supporting materials will be distributed to all personnel involved in the work assignment. Designated QC Officers will ensure that all tasks described in the work plan are carried out in accordance with the QAPP. Tetra Tech will review staff performance throughout each development phase of each case study to ensure adherence to task protocols.

Quality assessment is defined as the process by which QC is implemented in the model development task. All modelers will conform to the following guidelines:

- All modeling activities including data interpretation, load calculations, or other related computational activities are subject to audit or peer review. Thus, the modelers are instructed to maintain careful written and electronic records for all aspects of model development.
- If historical data are used, a written record on where the data were obtained and any information on their quality will be documented in the final report. A written record on where this information is on a computer or backup media will be maintained in the task files.
- If new theory is incorporated into the model framework, references for the theory and how it is implemented in any computer code will be documented.
- All modified computer codes will be documented, including internal documentation (e.g., revision notes in the source code), as well as external documentation (e.g., user's guides and technical memoranda supplements).

A QC Officer will periodically conduct surveillance of each modeler's work. Modelers will be asked to provide verbal status reports of their work at weekly internal modeling work group meetings. Tetra Tech Modeling Lead Dr. Rui Zou or his assigned deputy will make detailed modeling documentation available to members of the modeling work group on a monthly basis.

3.1.2 Software Development Quality Assessment

QC Officers will also conduct surveillance on any needed software development activities to ensure that all tasks are carried out in accordance with the QAPP and satisfy user requirements. Staff performance will be reviewed throughout the life cycle to ensure adherence to task procedures and protocols. All task staff will conform to the following guidelines:

- All software development activities, including data compilation, processing, and analysis, are subject to audit or peer review. Thus, the programmers are instructed to maintain careful written and electronic records for all aspects of software development.
- As computer programs are modified, (e.g., hand calculation checks, checks against other models) the code will be checked and a written record made as to how the code is known to work.
- If historical data are used, a written record of where the data were obtained and any information on the quality of the data will be documented in the final report. A written record of where this information is on a computer or backup medium will be maintained in the task files.
- All new and modified computer codes will be documented, including internal documentation (e.g., revision notes in the source code) as well as external documentation (e.g., user guides and technical memoranda supplements).

- The QC Officer or his designee will conduct periodic surveillance of each programmer’s work. Programmers will also adhere to a variety of practices and protocols in addition to the guidelines listed above. Programmers will follow development practices and use a software testing plan that includes internal testing, error tracking, and external testing.

Depending on the scale of the software task, one or more developers might need to collaborate or concurrently work with the same software source code. In these situations, it is important that all changes to the code be tracked and easily reconstructed as the various versions are reassembled into the single, monolithic code base. To assist with version control and management, Tetra Tech uses a concurrent version control system (CVS) during development. CVS is a *source control* or *revision control* tool designed to keep track of source changes made by groups of developers working on the same files, allowing them to stay in sync. Version control and tracking also enables a particular *snapshot* of a development process to be recovered at some stage in the future (after the development has moved beyond the snapshot).

3.1.3 Surveillance of Project Activities

Internal peer reviews will be documented in the project file and QAPP file. Documentation will include the names, titles, and positions of the peer reviewers; their report findings; and the project management’s documented responses to their findings. The Tetra Tech TOLs may replace a staff member if it is in the best interest of the task to do so.

Performance audits are quantitative checks on different segments of task activities. The Tetra Tech QC Officer or his designees will be responsible for overseeing work as it is performed and for periodically conducting internal assessments during the data entry and analysis phases of the task. The Tetra Tech TOLs will perform surveillance activities throughout the duration of the task to ensure that management and technical aspects are being properly implemented according to the schedule and quality requirements specified in the data review and technical approach documentation. These surveillance activities will include assessing how task milestones are achieved and documented, corrective actions are implemented, budgets are adhered to, peer reviews are performed, and data are managed, and whether computers, software, and data are acquired in a timely manner.

3.2 Reports to Management

The TOLs (or designee) will provide monthly progress reports to EPA. As appropriate, these reports will inform EPA of the following:

- Adherence to project schedule and budget
- Deviations from approved QAPP, as determined from project assessment and oversight activities
- The impact of these deviations on model application quality and uncertainty
- The need for and results of response actions to correct the deviations
- Potential uncertainties in decisions based on model predictions and data
- Data Quality Assessment findings regarding model input data and model outputs

4 OUTPUT ASSESSMENT AND MODEL USABILITY

4.1 DEPARTURES FROM VALIDATION CRITERIA

The models developed for the Ohio River bacteria TMDL project will be used to assess a series of study questions, as summarized in Section 1.4, associated with the project goals and objectives. Acceptance criteria for each of the modeling components are described in Section 2.2.3.

Written documentation will be prepared under the direction of the relevant QC Officer addressing each calibrated model’s ability to meet the specified acceptance criteria and provided to the TOLs and QA Officer for review. If a model does not meet acceptance criteria, the QC Officer will first direct efforts to bring the model into compliance. If, after such efforts, the model still fails to meet acceptance criteria, a thorough exposition of the problem and potential corrective actions (e.g., additional data collection or modification of model code) will be provided to EPA.

4.2 VALIDATION METHODS

The water quality model proposed for the Ohio River bacteria TMDL will be rigorously validated using data separate from those used in model calibration, as described in Section 2.2.2. Results of model validation will be documented in writing and provided to EPA.

4.3 RECONCILIATION WITH USER REQUIREMENTS

Quality objectives for modeling are addressed in Section 1.3.1. Acceptance criteria for model calibration (Section 2.2.2) were selected to ensure achievement of the quality objectives. If there are unresolvable departures from validation criteria, the ability of the models to achieve quality objectives and provide answers to the principal study questions might be compromised. If such circumstances occur, Tetra Tech will consult with EPA (and the Policy Advisory Council and Technical Advisory Council, as appropriate) as to whether the levels of uncertainty present in the models can allow user requirements to be met, and, if not, the actions needed to address the issue.

A detailed evaluation of the ability of the modeling tools to meet user requirements will be provided in the modeling report.

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