Quality Assurance Project Plan: Modeling QAPP

EPA Contract EP-C-12-052 Order No. 0002

Illinois River Watershed Nutrient Modeling Development

Prepared for:

Environmental Protection Agency
Region 6
Dallas, TX 75202

Prepared by:

Michael Baker Jr., Inc.
3601 Eisenhower Avenue,
Alexandria, VA 22304

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Approvals:

_____ _____
Quang Nguyen Date
Task Order Project Officer/Quality Assurance Officer
EPA Region 6

_____ _____
Henry Manguerra, Ph.D., P.E. Date
Project Manager
Michael Baker Jr., Inc.

_____ _____
Turgay Dabak, Ph.D., P.E Date
Quality Assurance Officer
Michael Baker Jr., Inc.

This document is the Modeling QAPP for the development of the Illinois River Watershed Nutrient Model under EPA Contract EP-C-12-052 Order No. 0002. The Modeling QAPP is consistent with EPA Guidance for Quality Assurance Plans for Modeling (EPA QA/G-5M, 2002); EPA Manual 5360 A1 (EPA, 2000); and EPA Order 5360.1 A2 (EPA, 2000). Michael Baker Jr., Inc., and its subcontractors, AQUA TERRA Consultants and Dynamic Solutions, LLC will conduct work following the QA/QC procedures described in the Modeling QAPP and in conformance with the approved Quality Management Plan for the contract.

This Modeling QAPP is used to communicate to all interested parties the QA/QC procedures that will be followed to ensure that the quality objectives for this project are achieved throughout the period of performance. EPA's intention is to develop a scientifically robust model of the Illinois River watershed, upon which regulatory and non-regulatory decisions can be confidently based. To ensure that the model will be as representative of the watershed as possible, EPA has and will continue to both solicit and encourage active participation from State partners and stakeholders in the development of this modeling project. Future project deliverables will be shared with both States and stakeholders for technical peer review and comment. Throughout this process, EPA will continue to inform and engage States and stakeholders about project developments by conducting informational meetings to update and to solicit inputs useful for refining and improving the watershed model.

TABLE OF CONTENTS

TABLE OF CONTENTS I

FIGURES III

TABLES III

PREAMBLE 1

SECTION 1.0 PROJECT ORGANIZATION 2

SECTION 2.0 PROBLEM DEFINITION/BACKGROUND 4

SECTION 3.0 PROJECT DESCRIPTION AND SCHEDULE 5

3.1 Calibration/Validation EFDC Lake Modeling and Modeling Report Development 5
3.2 Sensitivity Analysis of The Lake Modeling 7
3.3 Uncertainty Analysis of The Lake Modeling 8
3.4 Nutrient Load Reduction Scenario Modeling 8
3.5 Addressing Stakeholder/Public/Peer Reviewer Comments 9
3.6 Stakeholder Meetings 9
3.7 Schedule 9

SECTION 4.0 QUALITY OBJECTIVES AND CRITERIA FOR MODEL INPUTS/OUTPUTS 11

SECTION 5.0 DOCUMENTATION AND RECORDS 13

SECTION 6.0 MODELING APPROACH AND MODEL CALIBRATION/VALIDATION 15

6.1 Modeling Approach 15
6.1.1 Overview of HSPF and Rationale for Selection 16
6.1.2 Overview of EFDC and Rationale for Selection 17
6.1.3 Model Application 18
6.2 Model Calibration and Validation Procedures 26
6.2.1 Watershed Model Calibration and Validation 28
6.2.2 Hydrologic Calibration and Key Calibration Parameters 29
6.2.3 Hydraulic Calibration 31
6.2.4 Specific Comparisons to be Performed - Hydrology 31
6.2.5 Sediment Erosion Calibration and Key Calibration Parameters 32
6.2.6 Specific Comparisons to be Performed - Sediment Loadings 33
6.2.7 Nonpoint Source Calibration and Key Calibration Parameters 33
6.2.8 Potency Factor Approach for Simulating Nonpoint Source Loadings 33
6.2.9 Detailed Process Approach for Simulation of Nonpoint Source Nutrients 34
6.2.10 Specific Comparisons to be Performed - Nonpoint Loadings 35
6.2.11 Water Temperature Calibration 35
6.2.12 Instream Sediment Calibration 36
6.2.13 Instream Water Quality Calibration 37
6.2.14 Lake Model Calibration and Validation 37
6.3 Model Performance Criteria 41
6.3.1 Watershed Model Performance Criteria 41
6.3.2 Proposed Model Calibration and Validation Targets 43
6.3.3 Lake Model Performance Criteria 44
6.4 Model Parameter Sensitivity 46
6.4.1 Sensitivity Analysis Procedures 46
6.4.2 Example Metrics and Results 47

6.4.3 Sensitivity Analysis of the EFDC Lake Model 48
6.5 Model Uncertainty 49
6.5.1 Uncertainty Analysis of the EFDC Lake Model 50
6.6 Model Linkage 51
6.7 Nutrient Load Reduction Scenario Modeling 54

SECTION 7.0 DATA ACQUISITION 56

7.1 Review of Secondary Data 56
7.2 Data Sources Performance and Acceptance Criteria 56

SECTION 8.0 HARDWARE/SOFTWARE CONFIGURATION 59

SECTION 9.0 REFERENCES 60

APPENDIX A. STAKEHOLDER RESPONSE RECORDS 66

FIGURES

Figure 1.1 Project Organization Chart 3
Figure 3.1 Deliverable Schedule 10
Figure 6.1 Pervious Land Simulation (PERLND) Module in HSPF 19
Figure 6.2 Soil Phosphorus Cycle in HSPF AGCHEM....19
Figure 6.3 Instream Phosphorus Processes in HSPF RCHRES....20
Figure 6.4 Computational Grid with 195 Cells for Previous EFDC Model of Lake Tenkiller (DSLLC, 2006) 22
Figure 6.5 Updated Computational Grid with 277 Cells for Current EFDC Model of Lake Tenkiller. Station locations are the OWRB BUMP monitoring program sites. 23
Figure 6.6 Comparison of Grid Resolution for 195 Cell and 277 Cell Models. 23
Figure 6.7 Summary of OWRB station data for Lake Tenkiller 24
Figure 6.8 Lake Sediment Bed Locations (LKTSED-01,LKT SED-02,LKT SED-03,LKT SED-04, LKT SED-05) during 2005 Survey of Lake Tenkiller (Fisher et al., 2009). 25
Figure 6.9 CDM/USGS Station Locations in Lake Tenkiller 26
Figure 6.10 Model versus Natural System: Inputs, Outputs, and Errors 28
Figure 6.11 Anoxic Volume of Lake Tenkiller on 15-August-1993 at 12:00 (DSLLC, 2006) 40
Figure 6.12 R and R^2 Value Ranges for Model Performance 43
Figure 6.13 Example Tornado Diagrams at New Lenox Road (Donigian and Love (2007) *(Conversion Factors: 1 in = 2.54 cm; 35.3 cfs = 1 cms; 1 short ton = 0.907 metric tons)* ...48
Figure 6.14 HSPF-EFDC Linkage for Illinois River and Lake Tenkiller Model Framework ...52
Figure 6.15 Linkage of Total Organic Carbon from HSPF to EFDC....54

TABLES

Table 6.1 General Calibration/Validation Targets or Tolerances for HSPF Application (Donigian, 2000)....42
Table 6.2 Proposed Model Calibration and Validation Target Tolerances....44

PREAMBLE

This document has been designated as the "Modeling QAPP" for the EPA Region 6 project entitled Illinois River Watershed Nutrient Modeling Development under EPA Contract EP-C-12-052 Order No. 0002. This document updates the Modeling QAPP submitted by AQUA TERRA Consultants to EPA on June 12, 2013 under EPA-11-6-000023). The updates reflect the new project organization, its revised technical scope (i.e., technical tasks), and corresponding changes in the Quality Assurance/Quality Control (QA/QC) procedures as a result of the new project organization.

The project is the latest in a series of projects which began in September 2009 to develop the Illinois River Watershed Nutrient Total Maximum Daily Load (TMDL). The objectives of this particular project are primarily to calibrate/validate the EFDC lake model, and in linkage with the HSPF watershed model, develop phosphorous load reduction scenarios that will be used as a basis for developing one or more nutrient TMDLs for the Illinois River Watershed. Note that due to limited budget, the current scope of this project does not include the development of the TMDL. This project may be amended or a follow-on project created for the development of the TMDL when additional funding becomes available. It should be also noted that the calibration/validation of the HSPF watershed model including the development of watershed load reduction scenarios is being completed under another contract.

This Modeling QAPP is a stand-alone document and supplements the initial project QAPP that was developed by AQUA TERRA in 2010. The document was organized to accommodate the full body of information required for a modeling project. It includes all the heading topics that are suggested by EPA's "Guidance for Quality Assurance Project Plans for Modeling (EPA QA/G-5M) (EPA, 2002). The readers are also encouraged to refer to another planning document entitled Model Simulation Plan that includes detailed description of the model application process such as collection and development of time series data, characterization and segmentation of the watershed and lake, and calibration and validation of the models.

SECTION 1.0

PROJECT ORGANIZATION

The project team is composed of individuals from EPA and the Contractor's project team. The Contractor's project team, hereinafter referred as the Baker Team includes Michael Baker Jr., Inc (Baker) as the prime contractor and its subcontractors, Dynamic Solutions, LLC (DSLLC) and AQUA TERRA Consultants (AQUA TERRA). The key individuals for ensuring that the project meets all QA and QC objectives are Quang Nguyen from EPA Region 6; Henry Manguerra and Turgay Dabak from Baker, Anthony Donigian, Jr., and John Imhoff from AQUATERRA; and Christopher Wallen, Silong Lu, and William McAnally from DSLLC.

Quang Nguyen will provide the overall project oversight as the Task Order Project Officer (TOPO). He will be responsible for the review and final approval of all deliverables. Mr. Nguyen's responsibilities include reviewing and approving the Modeling QAPP, all other contractor deliverables. Mr. Nguyen will also serve as the Quality Assurance Officer (QAO) for this project. His responsibilities as a QAO will include reviewing and approving the Modeling QAPP and ensuring that the QA/QC practices and requirements specific to EPA Region 6 are achieved.

Henry Manguerra is the Project Manager (PM) for Baker, responsible for managing all tasks and deliverables according to the project schedule and budget and is ultimately accountable for the quality of services and deliverables of the Baker Team. He will be the primary contact of the Baker Team for the EPA TOPO. Because all technical tasks are being performed by the subcontractors, Dr. Manguerra will serve also as the Task Order QA/QC manager. He will coordinate the timely and quality performance of all technical tasks with the subcontractors, DSLLC and AQUA TERRA.

Turgay Dabak is the QAO for Baker, responsible for maintaining Baker's EPA-approved QMP for this contract and ensuring that the modeling QAPP is consistent with the QMP. He will provide QA management oversight.

Anthony Donigian, Jr. is the Subcontractor's Project Manager and Technical Lead for AQUA TERRA, responsible for directing and coordinating technical work of AQUA TERRA and completing all tasks and deliverables on schedule and within budget and according to the QA/QC requirements as defined in the Modeling QAPP.

John Imhoff is the Task Order QA/QC Manager for AQUA TERRA. Mr. Imhoff is responsible for overseeing all QA/QC activities that AQUA TERRA performs for this project.

Christopher Wallen is the Subcontractor's Project Manager for DSLLC. He is responsible for directing and coordinating technical work of DSLLC and completing all tasks and deliverables on schedule and within budget and according to the QA/QC requirements as defined in the modeling QAPP.

William McAnally is the Task Order QA/QC Manager for DSLLC. He is responsible for overseeing all QA/QC activities that DSLLC performs for this project. He will conduct the review of technical QA material and data related to the surface water model system design and analytical techniques and he will implement, or ensure, implementation of corrective actions needed to resolve non-conformances noted during QA assessments.

Silong Lu is the Technical Lead for DSLLC. He will lead data management and all Lake Tenkiller modeling activities for the project and will coordinate all technical tasks. He will perform data quality assurances prior to transmission of data and all model input/output files,

and reports. He is the point of contact to resolve issues related to project data and assumes responsibility for the correction of any data/model errors.

Figure 1.1 shows the organizational diagram for both technical and QA lines of communication between EPA and the Baker Team. It should be noted that the Project Management and Technical Coordination (PMTC) Team, with the Baker PM as the primary point of contact, will directly interact as a team with the EPA TOPO on management, technical, and quality aspects of the project. The QA/QC Team will interact directly with the PMTC Team on all quality matters including the performance of the following tasks:

- Initiating, reviewing, and following-up on corrective actions as necessary to address quality issues
- Provide a written summary of QA activities that can be included as part of monthly progress reports and Quality Assurance Report (QAR) section of technical deliverables.

The Baker QAO who oversees the QA program for the contract will provide quality oversight by interacting directly in an advisory role and on an as-needed basis with the Baker Task Order QA/QC Manager. When appropriate or if requested, he will communicate directly with the EPA QAO to report QA matters about the project and the program in general.

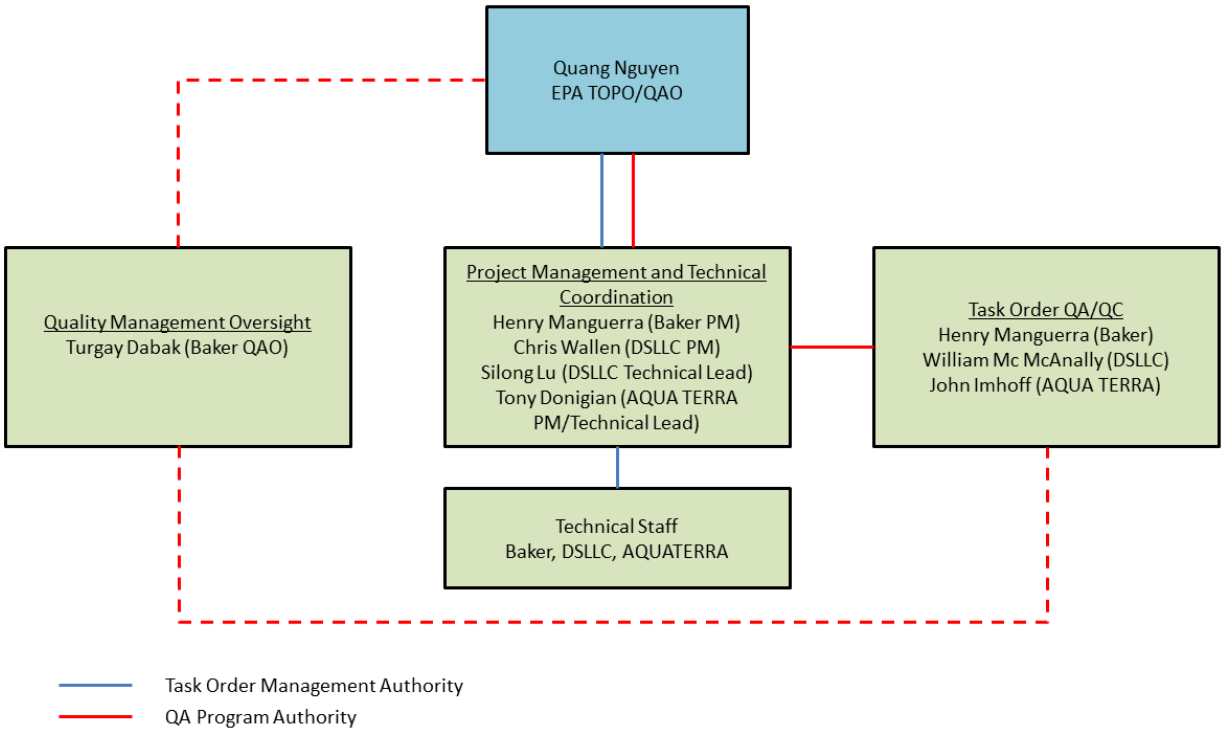


Figure 1.1 Project Organization Chart

SECTION 2.0

PROBLEM DEFINITION/BACKGROUND

The Illinois River is a multi-jurisdictional tributary of the Arkansas River, approximately 160 miles long, in the states of Arkansas and Oklahoma. The Illinois River begins in the Ozark Mountains in the northwest corner of Arkansas, and flows for 50 miles west into northeastern Oklahoma. The Arkansas portion of the Illinois River Watershed is characterized by fast growing urban areas and intensive agricultural animal production. It includes Benton, Washington and Crawford Counties and according to the US Census Bureau, the population of Benton and Washington Counties increased by 45% between 1990 and 2000. Arkansas ranked second in the nation in broiler production in 1998. Benton and Washington Counties ranked first and second respectively in the state. Other livestock production such as turkey, cattle and hogs are also all significant in this area. Upon entering Oklahoma, the river flows southwest and then south through the mountains of eastern Oklahoma for 65 miles until it enters Lake Tenkiller. The upper section of the Illinois River in Oklahoma is a designated scenic river and home to many native species of bass with spring runs of white bass. The lower section, below Tenkiller dam flows for 10 miles to the Arkansas River, and is a designated year-round trout stream, stocked with rainbow and brown trout.

Several segments of the Illinois River are currently on the State of Oklahoma's 303(d) list for Total Phosphorus (TP), while the mainstem Illinois River in Arkansas is not listed for TP. However, three tributaries to the Illinois River in Arkansas (Osage Creek, Muddy Fork, and Spring Creek) are designated as Phosphorus-impaired and included by EPA in the State's Clean Water Act 303(d) list.

The Illinois River Watershed is a complex watershed with a large drainage area with multiple land uses, and multiple contaminant sources contributing to numerous impaired waterbodies. The watershed consists of a large network of streams, channels, rivers and lake systems. As noted above, there are a number of waterbodies in the watershed that are on each state's 303(d) list for the general pollutant category of "nutrients". The EPA project goals are to develop a model as representative of the Illinois River Watershed as possible for use in developing one or more TMDLs for the watershed. These TMDLs will set waste load allocations and load allocations needed to attain the Oklahoma scenic river water quality standards at the state line and at Lake Tenkiller. Therefore, at a minimum, the OK standard for Total P at the state line (0.037 mg P/l), and at Lake Tenkiller for Water Quality Standards for DO, chlorophyll-a, and Carlson's Trophic State Index will be considered for the TMDL development. Specifically, the TMDL development for the IRW will be performed through a series of models runs, or "scenarios", representing alternative conditions on the watershed. Through an iterative process, the impacts of each individual proposed scenario through-out the watershed will be assessed. Impacts due to proposed Phosphorus load reductions at the state line, Lake Tenkiller and impaired water-bodies will be assessed and used as a basis to develop one, or more, TMDLs for the watershed.

From a regulatory perspective, the central problem that this project addresses is evaluating point and nonpoint source reduction scenarios needed to meet the State of Oklahoma scenic river in-stream total phosphorus criterion of 0.037 mg P/l that will also result in compliance with water quality criteria for DO, Chlorophyll-a and the Trophic State Index for Lake Tenkiller.

SECTION 3.0

PROJECT DESCRIPTION AND SCHEDULE

This project includes the following tasks:

- Calibration/validation EFDC lake modeling and modeling report development
- Sensitivity Analysis of the EFDC lake modeling
- Uncertainty Analysis of the EFDC lake modeling
- Nutrient Load Reduction Scenario Modeling
- Addressing Stakeholder/Public/Peer Reviewer Comments
- Stakeholder Meetings

Completed tasks from the previous project under AQUATERRA contracts namely EPA Purchase Order #EP-11-000023, and Work Assignments #33-36, #4-36, and 5-36 -- Water Quality Modeling and TMDL Development for the Illinois River Watershed -- under EPA's BASINS contract (# EP-C-06-029) include the following:

- Data compilation and assessment
- Development of a GIS data base

Other tasks that are being completed under another project under AQUA TERRA EPA contract EP-G126-00097 include the following:

- Calibration and validation of the Illinois river watershed model (HSPF)
- Sensitivity and uncertainty analyses of the Illinois river watershed model
- Development of watershed load reduction scenarios

The reader is referred to the project QAPP developed by AQUA TERRA in 2010 to obtain additional details for the other tasks.

Note that due to limited budget, the current scope of this project does not include the development of the TMDL. This project may be amended or a follow-on project created for the development of the TMDL when additional funding becomes available.

This Modeling QAPP defines the QA/QC procedures that will be followed for the development of the Illinois River watershed model. Note that the purpose of this section (Section 3) is to describe the technical needs of the work effort related to the EFDC lake modeling, not the QA/QC procedures that will be used in satisfying these needs. Different aspects of the QA/QC procedures that will be used to ensure the quality of the work that is performed to accomplish the tasks are described in Sections 4 (Quality Objectives), 5 (Documentation), 6 (Modeling Approach and Calibration/Validation) and 7 (Data Acquisition).

3.1 Calibration/Validation EFDC Lake Modeling and Modeling Report Development

In the previous EFDC model for the Lake Tenkiller, bottom elevation data was digitized from historical USGS quadrangle maps that represented the topography of the area before construction of the dam in the early 1950s (DSLLC, 2006). Detailed contemporary bathymetric data is now available from a 2005 survey that was conducted to support the collection of sediment cores (Fisher, 2008; Fisher et al., 2009) and the development of a laterally-averaged hydrodynamic and water quality model of Lake Tenkiller (Wells et al., 2008). Setup of the lake model has incorporated the new bathymetry data collected in 2005 and linkage of the Illinois

River watershed HSPF model for input to the EFDC lake model. The primary data sources that will be used for calibration and validation of the lake model include water quality data collected by the Oklahoma Water Resources Board (OWRB) and CDM/USGS during 2005-2007 (Olsen, 2008), sediment bed data collected in 2005 by Fisher et al. (2009), lake level and release flow data obtained from the Corps of Engineers (COE) Tulsa District, and atmospheric forcing data obtained from Oklahoma Mesonet. Based on our review and evaluation of hydrologic conditions, lake data and sediment bed data, the period from 2005-2006 has been identified for lake model calibration and validation and the availability of the above described data sets are considered to be adequate for lake model calibration and validation. The EFDC model will be calibrated to 2005 and validated to 2006 data sets. The choice of the calibration and validation years will be reviewed in consultation with EPA Region 6 to ensure that the calibration and validation periods selected represent a sufficient range of hydrologic conditions. Flow boundary conditions used for input to the current lake model have been updated to account for the new data linkage from the current HSPF model results. In order to provide reliable flow and loading data from the watershed for input to the lake model, significant efforts have been expended to ensure that the HSPF watershed model is well calibrated and meets the stringent model performance criteria established in the modeling QAPP. Calibration of the lake model will not be initiated without satisfactory calibration of the watershed model.

Calibration of the lake model will be based on the following sequence of steps:

a) develop flow balance to calibrate lake volume and stage height;
b) add water temperature to represent lake stratification;
c) add sediment loading with cohesive parameters for critical shear stress, deposition and resuspension;
d) add water quality loading with kinetic coefficients for organic carbon, nutrients, and algae; and finally
e) add sediment diagenesis to couple organic matter deposition with sediment oxygen demand and internal loading of nutrients.

In calibrating the lake model, we will first assess the overall accuracy of external flows, loadings and forcing functions in relation to model results. We will then direct our attention to adjusting key kinetic coefficients and model input parameters to improve model performance. Coefficients and parameters for the lake model will initially be taken from the existing literature for EFDC (Park et al., 1995; Ji, 2008) and the sediment flux model (Di Toro, 2001) as well as coefficients assigned for previous models of Lake Tenkiller (Wells et al., 2008; DSLLC, 2006). Model coefficients will be adjusted, within a reasonable range of values reported in the literature, to achieve calibration of the model against observed data sets collected in 2005. Following model calibration, validation of the model will be performed for 2006 data sets using the assigned set of model parameters and coefficients developed for model calibration. Model validation will be performed to confirm that the calibrated model can represent the lake water quality response under different hydrologic conditions.

Calibration and validation of the lake model will be accomplished by comparison of model results to observed data collected during 2005-2006 by CDM/USGS and OWRB. Model-data comparisons will be presented for water level, water temperature, TSS, dissolved oxygen, nutrients (N,P), and algae biomass (as chlorophyll-a). Lake model results will also be post-processed to evaluate compliance with water quality targets for dissolved oxygen, the anoxic volume of the lake, chlorophyll-a, and Carlson's Trophic State Index (TSI). EFDC_Explorer (Craig, 2012) was upgraded for our previous Lake Tenkiller modeling project (DSLLC, 2006) to support the display of TSI and anoxic volume of Lake Tenkiller. Model variables will be displayed as (a) time series plots to show surface layer and near bottom layer results; (b)

vertical profiles for selected time snapshots matching sampling dates; and (c) spatial maps of surface layer and bottom layer results for selected time snapshots and/or animation of simulation results as Audio Video Interleave (AVI) files. As described in Section 6.3.3, lake model performance will be evaluated to determine the endpoint for model calibration using a "weight of evidence" approach that has been adopted for many water quality modeling studies.

Sediment-water fluxes for sediment oxygen demand and nutrients will be simulated with the sediment diagenesis model. Direct measurements of sediment flux rates for nutrients and dissolved oxygen are not available for Lake Tenkiller to support calibration of the sediment flux model. The CDM/USGS water quality data collected in Lake Tenkiller during 2005-2006 was, however, used to derive indirect estimates of internal loading rates for phosphorus from the sediment bed for stations located in the lacustrine, transition and riverine zones (Cooke et al., 2011). The derived sediment flux rate estimates for phosphorus for the 2005-2006 calibration and validation period will be used for comparison to the sediment flux rates simulated with the EFDC sediment diagenesis model. In addition to the derived estimates of phosphorus release from the sediment bed for Lake Tenkiller, measured sediment flux rates reported in the literature for other reservoirs, including Lake Eucha (Haggard et al., 2005), Wister Lake (Corral et al., 2011), and Beaver Reservoir in northwest Arkansas (Sen et al., 2007) and a composite of measured sediment phosphorus flux rates from 17 oligotrophic, mesotrophic and eutrophic reservoirs in the Central Plains (Dzialowski and Carter (2011), will be used as supplemental information to determine if the sediment diagenesis model is producing reasonable results. Sediment oxygen demand measurements, available from Veenstra and Nolen (1991) for four reservoirs in Oklahoma characterized by hypolimnetic oxygen depletion, will be used to support calibration of the sediment flux model for sediment oxygen demand. A review of sediment phosphorus release and the interaction with bottom water dissolved oxygen in lakes by Hupfer and Lewandowski (2008) may also provide important insight for the calibration of the sediment flux component of the lake model.

The Lake Tenkiller, Oklahoma Modeling Report (i.e., EFDC lake model report) will provide an overview of the key technical features, data sources, model setup and assumptions of the hydrodynamic, sediment transport, water quality and sediment diagenesis models used for the Lake Tenkiller model. The report will present model calibration and validation results, model performance statistics and the report will present, the methodologies used, and results obtained, for Sensitivity Analysis, Uncertainty Analysis and Nutrient Load Reduction Scenarios as separate appendices.

3.2 Sensitivity Analysis of The Lake Modeling

A sensitivity analysis is typically conducted to better understand how adjustments to the model input parameters, both for historical conditions and hypothetical scenarios, affect modeling results. It provides useful information regarding the physical, chemical and biological processes represented in a model and identify the most influential parameters for improving model accuracy. Specifically, sensitivity analysis is a procedure to determine the changes in model output with respect to changes in model input parameters. This analysis will provide useful information on the model responses to changes in different model input parameters and coefficients. During the model calibration process a series of iterative adjustments are typically made to selected model coefficients to determine how changes in model input will affect model results. Based on this iterative approach to model calibration, one set of model coefficients are identified to achieve overall acceptable model results. It is

important to note that the parameter values assigned during model calibration must be within an accepted low to high range of the parameter where such data is available from the literature. The model calibration process thus provides important information to the modeling team about the sensitivity of key model parameters and coefficients. Calibration and validation results of the EFDC model of Lake Tenkiller will be reviewed and evaluated to identify those model input parameters and kinetic coefficients to be considered for the sensitivity analyses. Key kinetic coefficients (e.g., algae growth rate) and model input parameters (e.g., settling velocity) expected to have the greatest effect on the water quality response of the calibrated EFDC lake model will be selected for review and approval in consultation with EPA Region 6. Procedures and methodologies used to perform the sensitivity analysis will be documented in a technical appendix to the lake modeling report.

3.3 Uncertainty Analysis of The Lake Modeling

Uncertainty analysis is a procedure to determine the confidence limits or reliability of model predictions with respect to the errors associated with observations and a model. The uncertainty analysis of the EFDC lake model will be developed using lake model runs, including, but not limited to, the baseline calibration run and pooled results of the sensitivity analysis to determine 90% confidence intervals around the baseline model results for each model input parameter evaluated under the Sensitivity Analysis described above. Procedures and methodologies used to perform the uncertainty analysis will be documented in a technical appendix to the lake modeling report. The documentation, at the minimum, will include, but is not limited to, time series plots aggregated to daily summary statistics (i.e., 95% confidence interval around the baseline results) and data tables based on time aggregated summary statistics over the entire simulation period to define the 90% confidence interval around the overall mean value for key state variables (e.g., dissolved oxygen or chlorophyll-a) or derived model parameters (e.g., hypoxic volume).

3.4 Nutrient Load Reduction Scenario Modeling

The HSPF-EFDC model framework for this study will, after the models are calibrated and validated, be used to assess the effectiveness of alternative load reduction scenarios and compliance with Oklahoma water quality criteria for (a) Total Phosphorus (TP) in streams and (b) water quality targets in Lake Tenkiller. The calibrated HSPF-EFDC model framework will be used to assess the effectiveness of alternative load reduction scenarios of TP, TN and/or TSS and compliance with (a) Arkansas/Oklahoma stateline water quality criteria for TP in streams and (b) water quality targets in Lake Tenkiller. Based on 2005-2006 (OWRB, 2011a) OWRB assessments of compliance with criteria for the lake, water quality targets include hypolimnetic dissolved oxygen, chlorophyll-a and Trophic State Index (TSI). Lake Tenkiller is designated as a Nutrient Limited Water (NLW) by the State of Oklahoma and compliance with the designated use for aesthetics is defined by the Trophic State Index where TSI is computed from chlorophyll-a (OWRB, 2011b; 2011c).

The load reduction scenarios will be primarily focused on changes to the IRW watershed model, through changes to the HSPF model inputs, while the EFDC model of Lake Tenkiller will be used to assess lake impacts of the HSPF watershed load reduction scenarios. Based on a uniform percent reduction of TP, TN, and/or TSS (i.e., across the board), up to ten (10) scoping scenarios for load reduction will be developed with the watershed HSPF model. The modeling team will review the watershed load reduction scenarios and coordinate with EPA Region 6 to identify the load reduction scenarios selected for input to the Lake Tenkiller EFDC model for an

assessment of the lake impacts. If further refinements to the selected scoping scenarios for load reduction are needed, the modeling team will coordinate with EPA Region 6 for the selection of no more than five (5) additional refinements of HSPF load reduction scenarios. This process will be completed progressively as a means of assessing and identifying the appropriate number of load reduction scenarios for evaluation with the lake model. Prior to conducting EFDC modeling to assess the impacts of the additional selected scenarios on Lake Tenkiller, the modeling team will coordinate with EPA Region 6 on the selection of up to ten (10) additional EFDC load reduction scenarios. The total number of EFDC load reduction scenarios to be simulated shall be no more than ten (10) model runs including those chosen from the initial scoping scenarios and the HSPF refinement scenarios.

3.5 Addressing Stakeholder/Public/Peer Reviewer Comments

EPA will make the final draft lake modeling report Task 3 deliverables available to stakeholders, the public and peer reviewers for their review. The Baker Team proposes that EPA shares the final draft versions of the report deliverables (i.e., reports that have incorporated EPA's comments) instead of the draft version. This plan is already reflected in the proposed schedule.

EPA will be the primary point of contact for the stakeholder/public/peer reviewers including soliciting/collecting comments of the peer-reviewers during the duration of the review for each report deliverable. The Baker Team understands that the duration of the review of each report deliverable is 30 days. After receiving comments, EPA will send the comments to the Baker PM. The Baker Team will then compile the comments in a MS Word document. The Baker PM will work with EPA to determine which questions the Baker Team should prepare the response for. In general, the Baker Team will be responsible for addressing comments related to the technical approaches and EPA will be responsible for comments related to policy or programmatic concerns. It is our understanding that approximately 30 comments may be received from the Stakeholders during the review process. The Baker Team will submit to EPA a technical memorandum as a consolidated summary of the all comments and responses.

3.6 Stakeholder Meetings

Representatives from AQUA TERRA and DSLCC will attend one peer-review meeting in person in Dallas, Texas, and one informational public meeting at an AR/OK location in the Illinois River watershed. The Baker PM and other support personnel, as needed will participate by telephone. The peer review meeting is anticipated to be a 2-day meeting (including travel), and the informational public meeting is anticipated to be 3-days (including travel). The Baker Team will present modeling information (i.e., input preparation, assumptions, approaches, results, etc.) at the meetings. The Baker Team will submit to EPA for review the information and materials that will be presented during the meetings.

3.7 Schedule

The planned schedule for performance of tasks and deliverables is shown in Figure 3.1.

	EPA RFP PR-OW-13-00426 Illinois River Watershed Nutrient Modeling Project	Date	Period of Performance (2013-2014)												
	Description		Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Task 1	Project Management														
	Milestone: Kickoff Meeting	19-Sep-13	X												
	Monthly Progress Report	End of Month	X	X	X	X	X	X	X	X	X	X	X	X	
Task 2	QAPP & WorkPlan														
	Milestone: Draft QAPP and Simulation Plan	30-Sep-13	X												
	Milestone: Comments Received from EPA	22-Oct-13		X											
	Milestone: Final QAPP and Simulation Plan	30-Oct-13		X											
Task 3	Calibration/Validation/Report														
	Hydrodynamics/WaterTemp (assuming QAPP is approved by Nov 1, 2013)	Nov 1 - Nov 30, 2013													
	Sediment - TSS (assuming HSPF TSS loads available by Nov 30, 2013)	Dec 1 - Dec 31, 2013													
	Water Quality (assuming HSPF water quality loads available by Jan 1, 2014	Jan 1 2014 - Mar 15, 2014													
	Milestone: Draft Lake Modeling Report	17-Mar-14							X						
	Milestone: Comments Received from EPA	24-Mar-14							X						
	Milestone: Final Draft Lake Modeling Report	7-Apr-14								X					
Task 3A	Sensitivity Analysis														
	Milestone: Draft TM Sensitivity Analysis	14-Apr-14								X					
	Milestone: Comments Received from EPA	21-Apr-14								X					
	Milestone: Final Draft TM Sensitivity Analysis	28-Apr-14								X					
Task 3B	Uncertainty Analysis														
	Milestone: Draft TM Uncertainty Analysis	12-May-14									X				
	Milestone: Comments Received from EPA	19-May-14									X				
	Milestone: Final Draft TM Uncertainty Analysis	26-May-14									X				
Task 3C	Phosphorus Load Reduction														
	Milestone: Draft TM Scenario Modeling	9-Jun-14										X			
	Milestone: Comments Received from EPA	16-Jun-14										X			
	Milestone: Final Draft TM Scenario Modeling	30-Jun-14										X			
Task 5	Address Review/Comments														
	Milestones: EPA Submits Deliverables for Peer/Public/Stakeholder Review	Multiple Dates*								X	X	X	X		
	Milestone: Final Comments Received from Reviewers	Multiple Date**									X	X	X	X	
	Milestone: TM Comments and Responses Documentation	Multiple Dates***										X	X	X	X
	Milestone: Final Reports	Multiple Dates***										X	X	X	X
Item F	Travel/Meetings														
	Peer Reviewer Meeting	April 2014								X					
	Informational Public Meeting	June 2014										X			

*** Dates coincide with due dates of the final draft reports (Lake Modeling, Sensitivity TM, Uncertainty TM, Scenario Modeling)**
**** due at the end of 30-day comment/review period by peer/public/stakeholders**
***** due 30 days after receipt of final comments from peer/public/stakeholders**
Additional note: Schedule reflects adjustment due to government shutdown from October 1-17, 2013

Figure 3.1 Deliverable Schedule

SECTION 4.0

QUALITY OBJECTIVES AND CRITERIA FOR MODEL INPUTS/OUTPUTS

Data Quality Objectives (DQOs) are qualitative and quantitative statements that clarify the intended use of data, define the types of data needed to support a decision, identify the conditions under which the data should be collected, and specify tolerable limits on the probability of making a decision error because of uncertainty in the data.

Data of known and documented quality are essential to the success of any water quality modeling study which will be used to generate information for use in decision making. Model calibration will be accomplished using data available from other studies in addition to these companion investigations. All data used in this modeling effort will be reviewed for quality and consistency with other relevant data and for reasonableness in representing known conditions of the study area (see Section 7.2 for further discussion).

The QA/QC goals for this project are:

- Objectivity—all work should be based on a methodology and utilize a set of evaluation criteria that can be explicitly stated and applied.
- Thoroughness—all elements of the study should be carried out and documented in a thorough manner.
- Consistency—all work should be performed and documented in a consistent manner.
- Transparency—the documentation will make it clear the sources of the data used, the assumptions used in the modeling, and the results obtained.

USEPA (2000, 2002) emphasizes a systematic planning process to determine the type and quality of output needed from modeling projects. This begins with a Modeling Needs and Requirements Analysis, which includes the following components:

- Assess the need(s) of the modeling project
- Define the purpose and objectives of the model and the model output specifications
- Define the quality objectives to be associated with model outputs

The first item (needs assessment) is covered in EPA's Statement of Work (SOW). In essence, simulation models are needed to develop a scientifically robust and defensible watershed model to develop one or more TMDL for the Illinois River Watershed. The existing watershed simulation model HSPF and lake simulation model EFDC are believed to be sufficient for this purpose, and creation of new models (i.e., model code) is not required.

EPA recognizes the value of performing holistic modeling of the Illinois River Watershed that includes consideration of Lake Tenkiller. Hence, the need exists for a linked modeling system that includes a lake simulation model. The quality objectives for the model(s) follow directly from the purposes and objectives. In general, the modeling effort needs to be designed to achieve an appropriate level of accuracy and certainty in achieving the principal study need.

The quality assurance process for this type of study consists of using appropriate data, data analysis procedures, modeling methodology and technology, administrative procedures, and auditing. To a large extent, the quality of the modeling study is determined by the expertise of the modeling and quality assessment teams, in addition to the available data. The ultimate test of quality for this study, however, is that the model output is a sufficiently accurate representation of the natural system to address the site-specific study objectives/data quality objectives listed below.

The proposed modeling study design was developed to (1) represent the full range of physical, chemical, and biological processes of concern for phosphorus fate and transport in the Illinois River Watershed, and (2) address each of the following specific study objectives, which also serve as the DQOs for the model output:

- Develop at least ten nutrient load reduction scenarios that can be used as a basis for developing one of more TMDL to meet water quality standards in the Illinois River Watershed in both Arkansas and Oklahoma.
- Develop a technically defensible hydrodynamic and water quality model of Lake Tenkiller to represent in-lake response to existing watershed flow and pollutant loading;
- Use calibrated and validated lake model to determine in-lake responses to alternative management scenarios;

The determination of whether the DQOs have been achieved is less straightforward for a modeling study than for the more typical sampling and analysis type of study. The usual data quality indicators (e.g., completeness, accuracy, precision) are difficult to apply and in many cases do not adequately characterize model output. Nonetheless, HSPF contains operational state-of-the-art science algorithms for representing nutrient dynamics including phosphorus dynamics. We have confidence that the model can accurately represent very low instream phosphorus concentrations. The sensitivity and uncertainty analyses that will be performed for this study will provide further insight into the relative impact that various washoff and instream model parameters exert on achieving accurate fate and transport results. There are a number of objective techniques that will be used to evaluate the quality of the model performance and output. These methods and the proposed performance expectations are discussed in Section 6.3.

SECTION 5.0

DOCUMENTATION AND RECORDS

A **document** is any written or pictorial information describing, defining, specifying, reporting, or certifying activities, requirements, procedures, or results. A **record** is a document that furnishes objective evidence of the items or activities and that has been verified and authenticated as technically complete and correct. Records may include photographs, drawings, magnetic tape, and other data-recording material. Generally speaking, *documents* comprise efforts that are complete and organized to describe the results of a significant element of the project effort, whereas *records* are more specific and limited data elements that often lack contextual explanation. Recognizing this distinction, products considered to be records will be archived at Baker and/or Subcontractors' premises unless specifically requested by EPA Region 6. Products considered to be documents will be delivered to EPA Region 6 to be included in EPA's project archive.

The Baker PM will be responsible for ensuring that all project-related documents and records are managed in accordance with the procedures described below and elaborated upon in the Baker QMP. Project-specific documents or records will be clearly identified by:

- Title
- Author or responsible person
- Date
- Report or document number (if applicable)
- Project-related information (i.e., contract number, project number, task or sub-task number, if applicable, and project code)

Documents and records that will be collected and archived for the Illinois River Watershed Modeling study include, but are not limited to:

Documents

- Project quality plans (e.g., modeling QAPP)
- Significant interim drafts and all review drafts and final drafts of all established deliverables
- Internal working papers, e.g. technical memos, spreadsheet analyses, GIS documents
- Peer review documents (if developed)

Records

- Interview notes
- Working notes and calculations
- Assessment results and findings
- Calibration data
- Data usability results
- Field notes
- Other records required for statutory or contract-specific compliance

All documents will be subject to review by the Baker PM and Subcontractors' Project Managers to ensure their conformance with technical requirements and quality system requirements. Documents will be released to EPA Region 6 following authorization by the Baker PM and, when required, the QAO. The Baker PM and the Subcontractors' Project Managers shall ensure that records are developed, authenticated, and maintained to reflect the achievement of quality goals. Through adoption of these document-specific quality control procedures, Baker intends to

ensure that records and documents reflect completed work, in keeping with specifications of Section 3.6 of EPA QA/R-2 (EPA, 2001).

Throughout the course of the project, the project-specific indexing and filing system will meet the following minimum performance specifications:

- All documents and records will be physically or electronically retrievable.
- Primary copies of all physical documents and records will be stored in filing cabinets or other appropriate storage space on Baker and/or Subcontractors' premises. Any backup copies of physical documents and records will be stored separately.
- Any documents subject to confidential business information (CBI) restrictions will be stored in strict accordance with Baker CBI plan.

All documents and records will be listed and identified with respect to retention schedules. All documents in the first list above (e.g., work plans; QAPPs) are subject to an automatic disposition schedule that requires their retention for 10 years, unless a longer time is required by the particular contract under which they were created or is required for other purposes. Within one month of their creation, all other documents and records will be classified for retention/disposition.

Upon completion of this project, a complete set of all the documents and records will be appropriately filed for long-term storage.

The Baker Team will save on an external hard drive all modeling output data from both models as digital computer files in a file directory using a file-naming convention. In addition, the Baker Team will save on an external hard drive all scripts, project files, calibration data, and other information used to conduct watershed and lake modeling. Baker will deliver these external hard drives to EPA within 2 weeks of the conclusion of the project. Baker will maintain a copy of the project files at the Alexandria, Virginia office for at least 3 years (unless otherwise directed by the EPA TOPO). The EPA TOPO, Baker PM, and Subcontractors' PMs will maintain files, as appropriate, as repositories for information and data used in models and for preparing any reports and documents during the project. Electronic project files are maintained on networked computers and are backed up daily.

SECTION 6.0

MODELING APPROACH AND MODEL CALIBRATION/VALIDATION

6.1 Modeling Approach

EPA guidance defines the role of a QAPP as integrating the "technical and quality aspects of a project" (EPA, 1999). The need to do this has perhaps one of its strongest focuses in describing the modeling approach, and then defining the QA/QC procedures that correspond to the approach. The level of detail provided in the QAPP related to the modeling approach is critical to 'grounding' these procedures.

This modeling effort encompasses both watershed and reservoir model development, includes both the flow quantity and water quality capabilities in both models, and linkage of the models so that the watershed model provides flow and loading of constituents to the reservoir model. Each of these components will be summarized in turn below.

In order to develop a scientifically sound modeling system to represent the entire IRW, including the land areas, the stream channels and Lake Tenkiller, models must be selected to represent each of these components. If the selected models are not already integrated within a single modeling system, the models must be linked to provide a comprehensive tool that addresses the watershed hydrology, generation of pollutants, fate/transport within the stream system, and ultimately dynamics and impacts on Lake Tenkiller.

As part of the study effort, a model selection task was performed and produced a Draft Model Selection Technical Memorandum dated November 22, 2010 (Donigian and Imhoff, 2010). This model comparison and selection process resulted in the recommendation that the US EPA HSPF (Hydrological Simulation Program – FORTRAN (Bicknell et al., 2005)) watershed model and the US EPA EFDC (Environmental Fluid Dynamics Code (Hamrick 1992, 1996; Tetra Tech, 2007) lake model be used in a linked application to provide the necessary modeling framework for performing this study. Following review and comments from project stakeholders, EPA subsequently agreed to the model recommendations and selected the HSPF watershed model and the EFDC lake model for this TMDL development effort (M. Flores, personal communication, email to Project Stakeholders dated January 13, 2011).

As discussed by Donigian and Imhoff (2010), since the prior modeling studies applied well-known, widely-used, and respected public-domain models for both the Illinois River watershed and the Lake Tenkiller, a detailed, comprehensive review of all available and relevant models was not considered necessary, nor the best use of project resources. Consequently, the approach in model selection was to review the applications and published reviews and comparisons of the HSPF and USDA SWAT models, for the watershed, and the EFDC and US EPA AQUATOX models for the lake simulation. As noted above, all these models have had a prior history of model application to the IRW and Lake Tenkiller, respectively.

HSPF was selected for the watershed because it provides a strong dynamic (i.e. short time step, hourly) hydrologic and hydraulic model simulation capability, and a moderately complex instream fate/transport simulation of sediment and phosphorus, both of which are linked to soil nutrient and runoff models; this combination provides a strong and established capability to relate upstream watershed point and nonpoint source contributions to downstream conditions and impacts at both the AR/OK state line and to Lake Tenkiller.

EFDC was selected because it allows a more mechanistic modeling of thermal stratification and is capable of a high level of spatial resolution in Lake Tenkiller, both of which are essential to support water quality compliance issues in OK, particularly time- and space-varying anoxic

conditions. EFDC also provides moderately complex *biochemical* process representation that enables modeling and evaluation of chlorophyll *a* concentrations expressed as Carlson's Trophic State Index (TSI). Oklahoma statutes use TSI values to determine whether or not water bodies are threatened by nutrients. The EFDC water quality model is internally coupled to a sediment diagenesis model (Di Toro, 2001) so that the effect of external nutrient loading on organic matter production and settling to the bed, decomposition within the bed, sediment oxygen demand and benthic release of nutrients to the lake can be simulated within a consistent mass balance model framework. The sediment diagenesis model is the only lake model methodology available to provide a simulated cause-effect link between watershed loading, nutrient enrichment, eutrophication, sediment oxygen demand and internal release of nutrients from the lake bed back to the water column.

For those readers not familiar with the HSPF and EFDC models, brief summaries are provided in the sections below. The HSPF summary is taken essentially verbatim from a recent modeling review by Borah and Bera (2003) to provide descriptions from relatively unbiased, non-developers of these models. Note that minor revisions and additions to the original descriptions are shown underlined.

6.1.1 Overview of HSPF and Rationale for Selection

HSPF, the Hydrological Simulation Program – Fortran (Bicknell et al., 2005; Donigian et al., 1995), first publicly released in 1980, was put together by Hydrocomp, Inc. (Johanson et al., 1980) under contract with the U.S. Environmental Protection Agency (US EPA). It is a continuous watershed simulation model that produces a time history of water quantity and quality at any point in a watershed. HSPF is an extension and reformulation of several previously developed models: the Stanford Watershed Model (SWM) (Crawford and Linsley, 1966), the Hydrologic Simulation Program (HSP) including HSP Quality (Hydrocomp, 1977), the Agricultural Runoff Management (ARM) model (Donigian and Davis, 1978), and the Nonpoint Source Runoff (NPS) model (Donigian and Crawford, 1977). HSPF uses many of the software tools developed by the U.S. Geological Survey (USGS) for providing interactive capabilities on model input, data storage, input-output analyses, and calibration. … HSPF has been incorporated …. into the US EPA's Better Assessment Science Integrating Point and Nonpoint Sources (BASINS), which was developed initially by Tetra Tech, Inc. (Lahlou et al., 1998), under contract with the US EPA, and has been maintained and enhanced by AQUA TERRA Consultants since 1998. The main purpose of BASINS is to analyze … and develop TMDL standards and guidelines nationwide. The most recent version is BASINS4 (US EPA, 2007; Duda et al., 2003) which is based on an open-source code concept and includes a number of models as plug-in components, including both HSPF and SWAT.

Based on our model review and selection effort as described in the Model Selection Technical Memorandum, prior knowledge of currently available watershed models, and the specific needs for the IRW TMDL study, the HSPF model was selected as the preferred framework for the IRW model, for the following reasons:

a. HSPF is a widely used, well-known, and respected, public domain watershed model with extensive experience and use across the country for TMDL development. It is considered a premier, complex high-level model among those currently available for watershed assessment, and it has received development support over the years from the US EPA, USGS, ACOE, and numerous states and regional water agencies.

b. The HSPF hydrology model with its hourly (or less) simulation provides a strong and comprehensive representation of the dynamic hydrology of the IRW, and is well suited for a robust short time step linkage with the detailed hydrodynamic and water quality model of

Lake Tenkiller based on EFDC.

c. The HSPF soil nutrient models provide a complete mass-balance approach for simulating nitrogen and phosphorus balances and runoff components, with detailed nutrient cycling of both organic and inorganic nutrient forms. This capability allows a direct connection between nutrient application rates from chemical fertilizers, manure, and poultry litter, and subsequent soil buildup and potential runoff to rivers and streams, from applied pasture lands, subject to limitations of the available data.

d. The sediment transport and instream water quality capabilities of HSPF provide a moderately complex process-based representation of the fate and transport processes for nutrients, including phosphorus, along with sediment-nutrient interactions, scour/deposition impacts with the sediment bed, and combined uptake/cycling of phosphorus by algae and DO/BOD processes.

e. The combined capabilities of HSPF with well-established instream fate/transport simulation of sediment and phosphorus, linked to the soil nutrient and runoff models, is expected to provide a scientifically sound simulation of both watershed point and nonpoint source contributions of phosphorus to downstream impacts both to the OK/AR state line and to Lake Tenkiller.

6.1.2 Overview of EFDC and Rationale for Selection

EFDC, the Environmental Fluid Dynamics Code was originally developed at the Virginia Institute of Marine Science (VIMS) and School of Marine Science of The College of William and Mary, by Dr. John Hamrick (Hamrick, 1992). Subsequent support for EFDC development at VIMS was provided by the U.S. Environmental Protection Agency and the National Oceanic and Atmospheric Administration's Sea Grant Program. Tetra Tech, Inc. became the first commercial user of EFDC in the early 1990's and upon Dr. Hamrick's joining Tetra Tech in 1996, the primary location for the continued development of EFDC (Tetra Tech, 2007). Primary external support of both EFDC development and maintenance and applications at Tetra Tech has been provided by the U.S. Environmental Protection Agency including the Office of Science and Technology, the Office of Research and Development, and Regions 1 and 4. The ongoing evolution of the EFDC modeling system has to a great extent been application driven by a diverse group of EFDC users in the academic, governmental, and private sectors.

EFDC has evolved over the last two decades to become one of the most widely used and technically defensible multidimensional hydrodynamic models in the world (see http://www.epa.gov/athens/wwqtsc/html/efdc.html). For the Illinois River study, EFDC will be implemented using the Dynamic Solutions' version of EFDC_DS source code that is available from the Dynamic Solutions website (www.efdc-explorer.com). The full version of the EFDC_Explorer software, available from the Dynamic Solutions website, will be used as the pre-and post-processor software interface for model setup and calibration of the EFDC model of Lake Tenkiller.

Based on the evaluation performed in support of the aforementioned Model Selection Memo, EFDC was selected as the lake model for the Illinois River TMDL project. EFDC offers the following capabilities:

a. EFDC provides an effective spatial framework and process representation scheme that will allow the mechanistic modeling of thermal stratification phenomena in Lake Tenkiller. This capability is deemed essential to one of the two most important evaluation endpoints, i.e., the identification of time-varying anoxic conditions.

b. By offering a more mechanistically based simulation of stratification, EFDC in turn offers a

capability to model the *physica*l component (i.e., vertical movement of the biotic and chemical materials within reservoir) of the eutrophication process.

c. The spatial resolution and the physical detail achieved by the EFDC flow simulation provides significant benefit to a water quality simulation performed at the same level of spatial resolution as the EFDC hydrodynamics simulation.

d. The high spatial resolution that is inherent in EFDC applications (and results) offers advantages in applications that are intended to support compliance with water quality standards. The planned application for this project has that objective.

e. EFDC provides appropriate *biochemical* process representation to model and evaluate chlorophyll a concentrations expressed as Carlson's Trophic State Index. Further, EFDC enables accurate spatial mapping of observed data using its detailed grid system.

f. The EFDC sediment diagenesis model is the only lake model methodology available to provide a simulated cause-effect link between watershed loading, nutrient enrichment, eutrophication, sediment oxygen demand and internal release of nutrients from the lake bed back to the water column.

g. Previous applications of EFDC to Lake Tenkiller provide significant opportunities for leveraging.

6.1.3 Model Application

HSPF represents a watershed as comprised of two primary components: land areas and stream channels or lakes and reservoirs. Each is represented by a different module(s) within HSPF: the land areas are represented with the PERLND and IMPLND modules for pervious and impervious areas, respectively, while the waterbodies, whether a free-flowing stream or a lake/reservoir, are represented with the RCHRES module.

Figure 6.1 shows the various components and capabilities of the PERLND module of HSPF. Each of the boxes in Figure 6.1 identifies a capability used by HSPF to model the corresponding process, or processes, that occur on each category of land; thus, the PWATER subroutine models the water budget, SEDMNT models soil erosion and delivery to the stream, PSTEMP models soil temperatures, etc. For runoff loadings of water quality constituents, HSPF provides alternative methods, among which the user can select, to calculate loadings either with simple, empirical build-up and washoff algorithms used in the PQUAL subroutine, or the detailed mass balance formulations used within the group of subroutines within the dashed-line box marked as AGCHEM. The PQUAL (and IQUAL for impervious surfaces) are commonly used for urban land uses, as the buildup/washoff formulations have traditionally been applied for urban runoff quality models, and for applications that are primarily focused on impacts of urbanization and a general assessment of land use changes. For watersheds that are dominated by agriculture, and agricultural practices and impacts are key element of the assessment, the AGCHEM module may be required as it allows a more process, and mass-balance based, evaluation of land management practices including nutrient application practices.

For the IRW application of HSPF, we will utilize the AGCHEM subroutines for the pasture lands that are the primary recipients of fertilizer, manure, and litter applications, and then use the simpler PQUAL routines for all other land uses. The data requirements and calibration effort associated with using the AGCHEM routines is much greater than for the PQUAL routine, but the end result is a capability to quantify the impacts of changes in nutrient application rates on the resulting runoff, and subsequently assess scenarios of alternative management practices and their impacts on water quality.

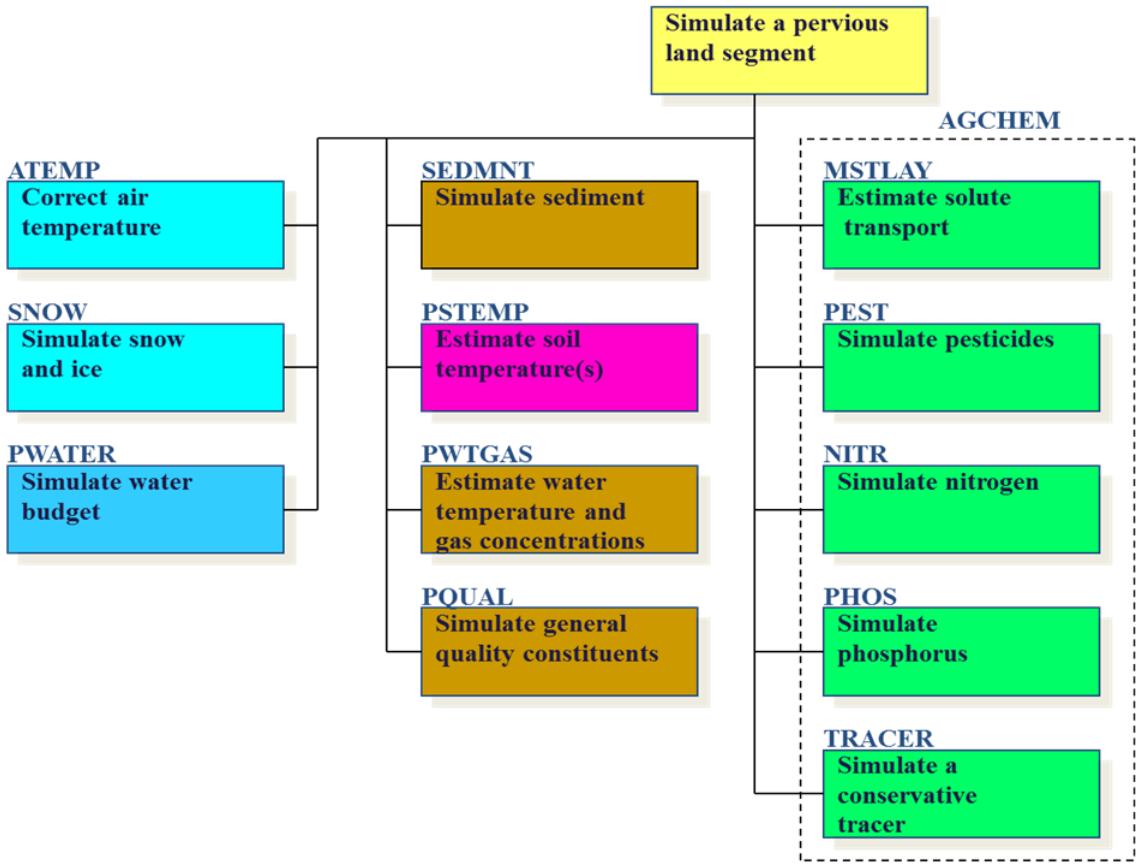


Figure 6.1 Pervious Land Simulation (PERLND) Module in HSPF

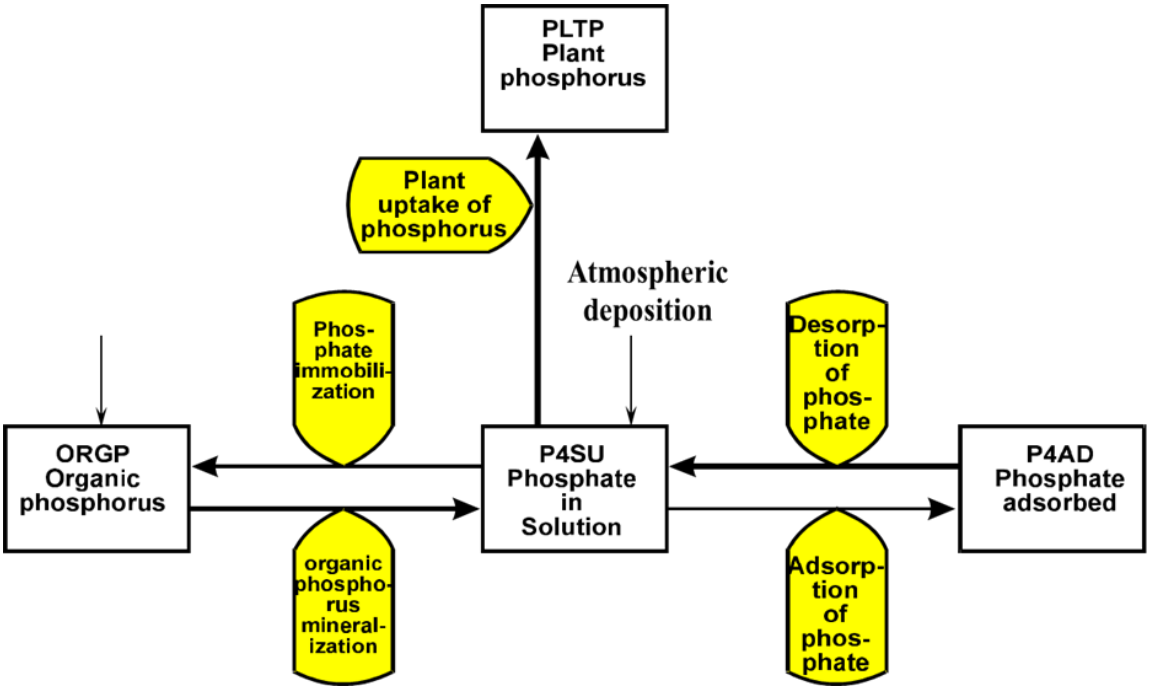


Figure 6.2 Soil Phosphorus Cycle in HSPF AGCHEM

Figure 6.2 shows the phosphorus cycling capability and processes simulated with the AGCHEM routines; these process simulations are performed within each soil layer and then utilize the simulated flow and sediment fluxes to calculate the associated dissolved and sorbed phosphorus contributions to the stream channel. For the channel system, Figure 6.3 shows phosphorus fate and transport processes that are modeled to calculate concentrations of the various forms of phosphorus and it subsequent downstream transport. Complete descriptions of the HSPF modules and algorithms are available in the HSPF User Manual (Bicknell et al., 2005) and the other references cited above.

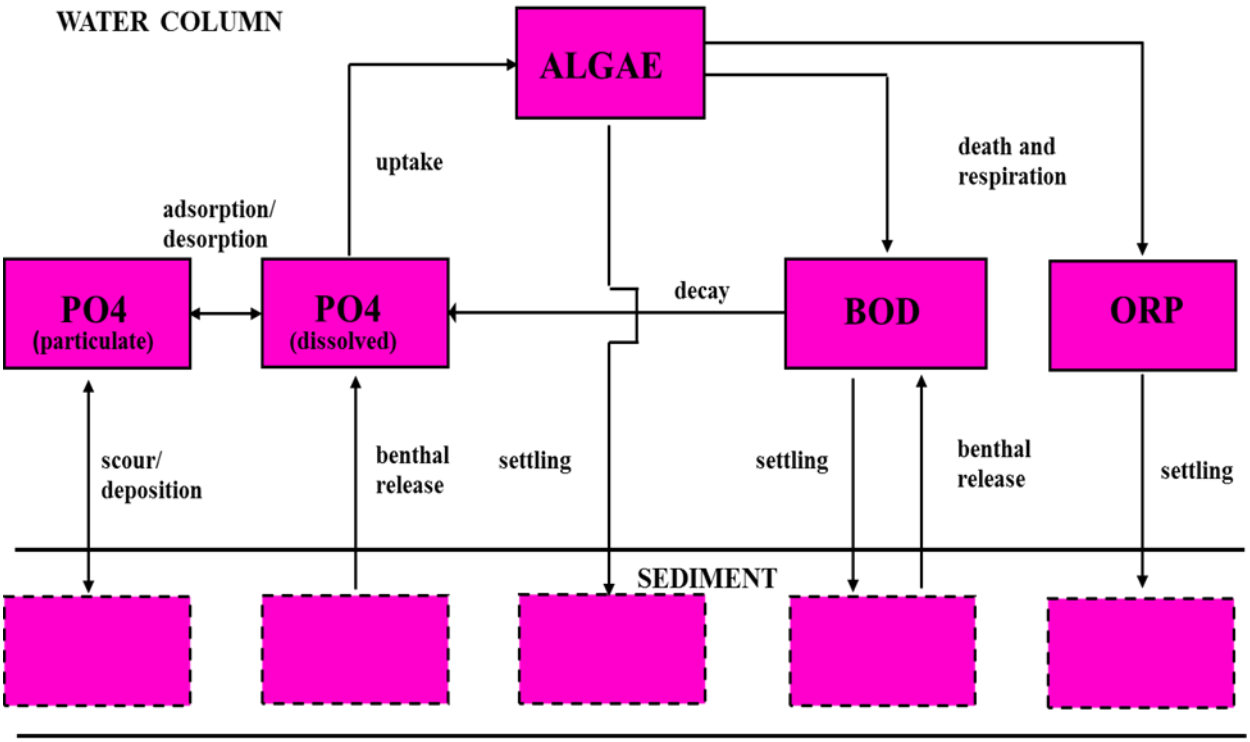


Figure 6.3 Instream Phosphorus Processes in HSPF RCHRES

The distinction between the HSPF simulation modules for the land area and channels within the IRW, noted above, is also important for the linkage interface between HSPF and EFDC. For Lake Tenkiller, the local drainage that enters the Lake directly without first entering a modeled stream channel will be provided by the PERLND and IMPLND modules for all relevant land use categories within the local area, whereas the HSPF RCHRES module will provide the loadings entering from all the major tributary streams including the Illinois River, downstream from its confluence with Baron Fork, and Caney Creek. In addition, a few other selected smaller tributaries are modeled with a channel reach either due to their size or due to being listed as impaired.

As previously stated, modeling of hydrodynamics and water quality processes in Lake Tenkiller will be performed using the Environmental Fluid Dynamics Code (EFDC) (Hamrick, 1992,1996; Tetra Tech, 2007). EFDC is a state-of-the-art hydrodynamic and water quality model that can be used to simulate surface water systems in one, two, and three dimensions. EFDC uses stretched, or a sigma bottom following vertical coordinate system, and Cartesian or curvilinear, orthogonal horizontal coordinates to represent the physical characteristics of a waterbody. EFDC solves three-dimensional, vertically hydrostatic, free surface, turbulent averaged

barotropic and baroclinic equations of motion for a variable-density fluid. Dynamically-coupled transport equations for turbulent kinetic energy, turbulent length scale, salinity and water temperature are also solved. The EFDC model allows for drying and wetting in shallow areas using a mass conservation scheme and includes capabilities to model flushing time, age of water and Lagrangian particle tracking.

The hydrodynamic model of EFDC is equivalent to other 3D finite difference models such as the Estuarine Coastal and Ocean Model (ECOM) (Blumberg and Mellor, 1987), and the Curvilinear Grid Hydrodynamics Model in 3-Dimensions (CH3D) model (Sheng, 1987, 1990). EFDC, unlike most surface water models, is a single source code model that internally links sub-models for the smooth interface of hydrodynamics with sediment transport, water quality and sediment diagenesis sub-models. Any technical issues related to the linkage of EFDC hydrodynamic results for input to water quality models are eliminated with the full EFDC model. Sediment transport of cohesive and non-cohesive solids internally links hydrodynamics with deposition and resuspension and wind-driven resuspension processes.

The water quality model includes organic carbon, nutrients, dissolved oxygen and eutrophication processes that can represent up to three classes of phytoplankton and benthic macroalgae. The water quality model includes internal coupling with a sediment diagenesis model to provide sediment fluxes of nutrients and oxygen to the water column. Wet and dry atmospheric deposition of nutrients can be represented. The EFDC model that Dynamic Solutions developed previously for Oklahoma DEQ (DSLLC, 2006) and the laterally averaged CE-QUAL-W2 model developed by Wells and Berger (2008) will be used to support development of the updated model for Lake Tenkiller for this project. The previously developed EFDC lake model consisted of 195 horizontal cells and 10 vertical layers to represent the effect of seasonal stratification on hypolimnetic oxygen depletion. Figure 6.4 shows a plan view map of the previous 195 cell computational grid where the lake shoreline is defined by the normal conservation pool elevation of 632.0 ft (192.63 m). This previous EFDC model of the lake was calibrated with data collected by the Clean Lakes Program in 1992-1993. In this current project, the grid resolution of the lake model has been made finer to resolve technical issues related to grid resolution identified in the previous study (DSLLC, 2006). Using software for grid generation (Delft, 2007), grid resolution has been increased in areas of the lake characterized by steep bottom slopes such as the Forebay area. This refinement of the grid is expected to minimize numerical diffusion errors caused by the bottom following vertical layers. Grid resolution has also been increased in the upper riverine and transition zones of the reservoir where the previous model grid represented a laterally averaged channel. Figure 6.5 shows a plan view map of the new 277 cell grid that will be used for developing the current model for Lake Tenkiller. In the increased resolution grid, the shoreline of the lake is defined by the normal conservation pool elevation of 632.0 ft (192.6 m). A comparison of the existing and current grid resolution is shown in Figure 6.6 for the central area of the lake. In this map, the previous 195 cell grid is shown with red lines and the new current grid is shown with grey lines.

In the previous model for the lake, bottom elevation data was digitized from historical USGS quadrangle maps that represented the topography of the area before construction of the dam in the early 1950s (DSLLC, 2006). Contemporary detailed bathymetric data is now available from a 2005 survey that was conducted to support the collection of sediment cores (Fisher, 2008; Fisher et al., 2009) and the development of a laterally-averaged 2D hydrodynamic and water quality model of Lake Tenkiller (Wells et al., 2008). The new refined lake model grid (Figure 6.5) has been updated with the new bathymetry data collected in 2005. The updated model grid will be setup and calibrated with more recent data sets that have been identified in an assessment of available data for the Illinois River basin and Lake Tenkiller (AQUA TERRA, 2010). Data sets have been identified from the USACE Tulsa District, Oklahoma OWRB, USGS, and EPA

Modern STORET. In addition to these data sets, additional lake water quality data was collected for the State of Oklahoma from 2005-2007 by CDM and the USGS as a component of an extensive monitoring program of the watershed and the lake (Olsen, 2008). The CDM/USGS data was used analyses of the effects of watershed nutrient loading on eutrophication in the lake (Cooke and Welch, 2008; Cooke et al., 2011; Welch et al., 2011).

The CDM/USGS database has been reviewed and evaluated and it has been determined that these data sets will be used with the OWRB data sets for calibration and validation of the lake model. As a component of the Beneficial Use Monitoring Program (BUMP) surveys in Oklahoma lakes, OWRB has maintained a long-term data collection effort in Lake Tenkiller at 7 station sites (Figure 6.5) with water quality data available from 1994 through 2012 (Figure 6.7). Based on our review and evaluation of hydrologic conditions, lake data and sediment bed data, the period from 2005-2006 has been identified for lake model calibration and validation. The availability of the OWRB and CDM/USGS data sets are considered to be adequate for lake model calibration and validation. The EFDC model will be calibrated to 2005 and validated to 2006. The choice of the calibration and validation years will be reviewed in consultation with EPA Region 6 to ensure that the calibration and validation periods selected represent a sufficient range of hydrologic conditions. Flow boundary conditions used for input to the current lake model have been updated to account for the new data linkage from the current HSPF model results. Station data sets from the OWRB and CDM/USGS data sources for water quality data have been compiled as time series and vertical profiles for comparison of model results.

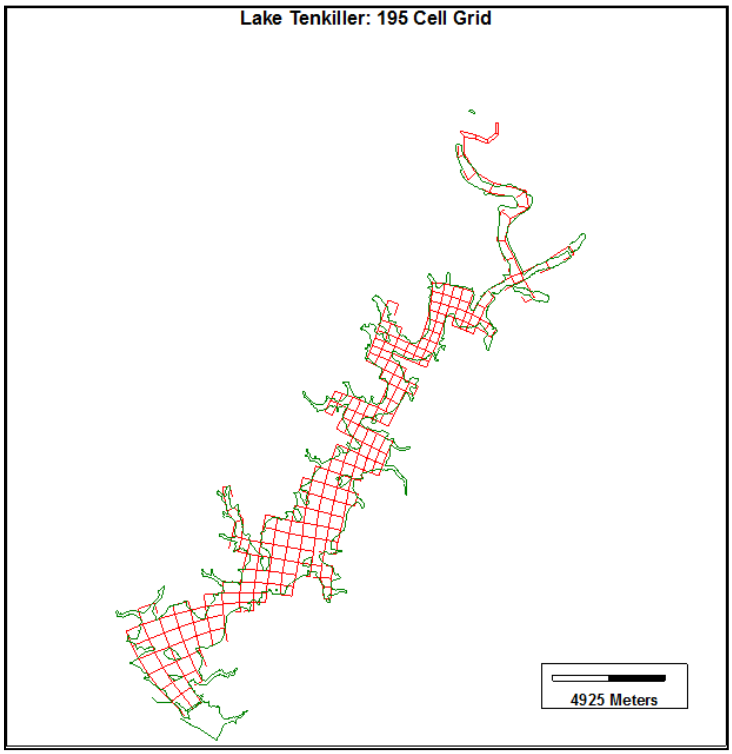


Figure 6.4 Computational Grid with 195 Cells for Previous EFDC Model of Lake Tenkiller (DSLLC, 2006)

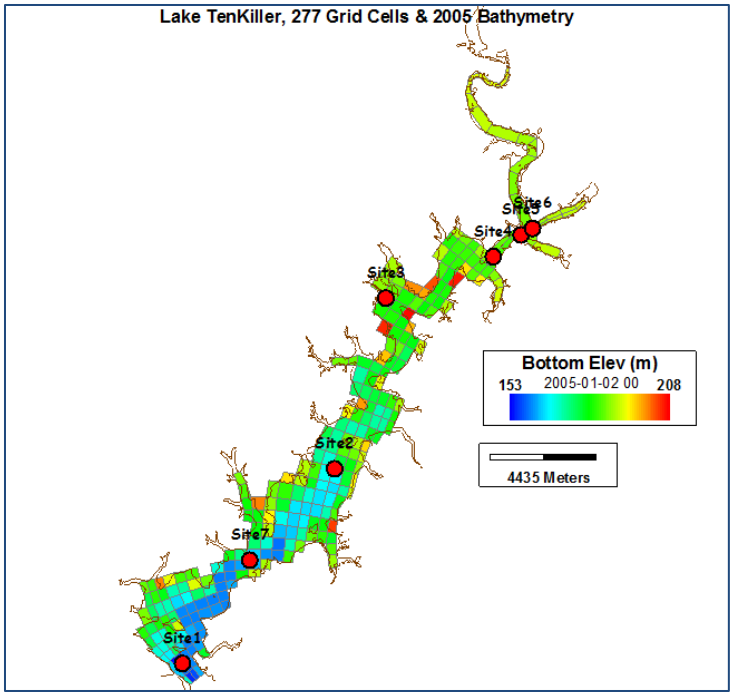


Figure 6.5 Updated Computational Grid with 277 Cells for Current EFDC Model of Lake Tenkiller. Station locations are the OWRB BUMP monitoring program sites.

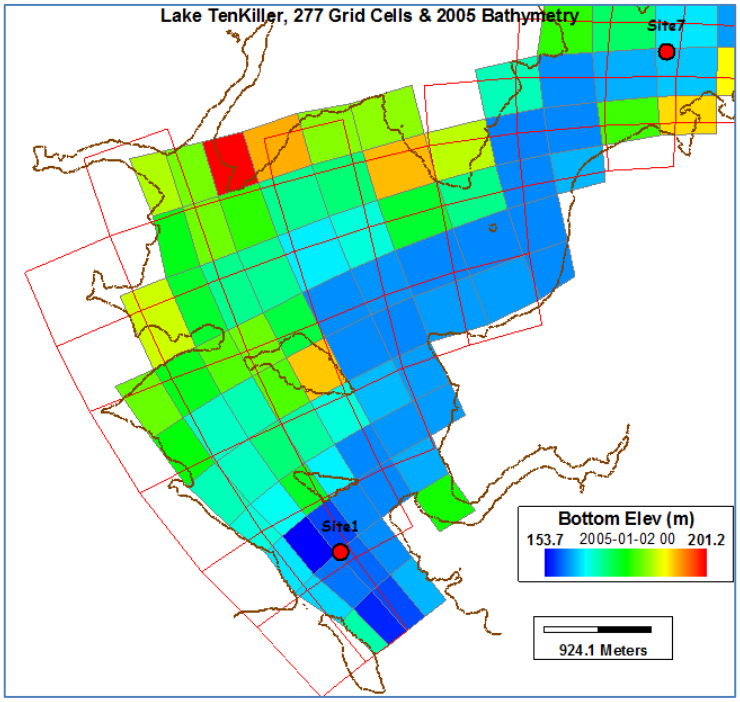
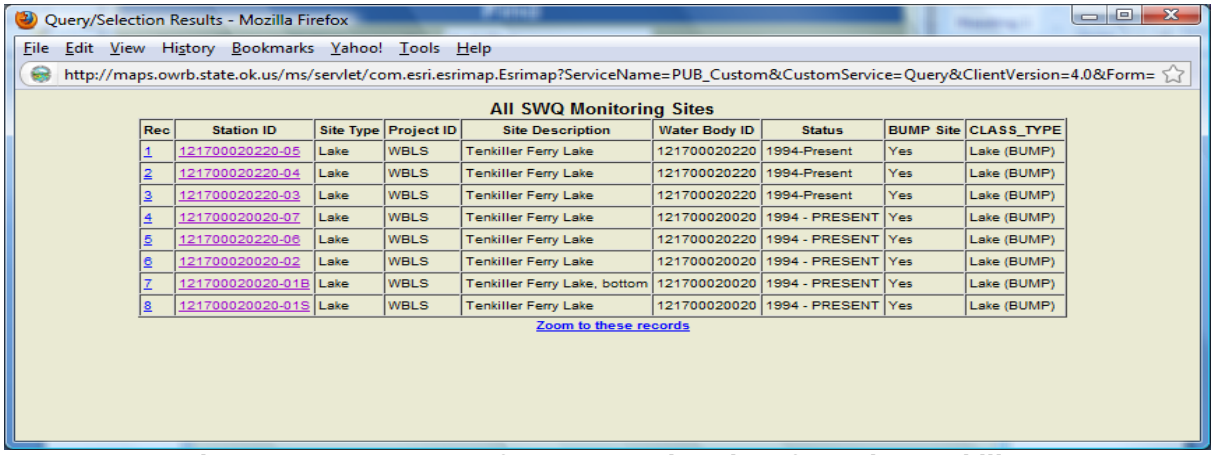


Figure 6.6 Comparison of Grid Resolution for 195 Cell Model (red line) and 277 Cell Model (gray line).



Rec	Station ID	Site Type	Project ID	Site Description	Water Body ID	Status	BUMP Site	CLASS_TYPE
1	121700020220-05	Lake	WBLS	Tenkiller Ferry Lake	121700020220	1994-Present	Yes	Lake (BUMP)
2	121700020220-04	Lake	WBLS	Tenkiller Ferry Lake	121700020220	1994-Present	Yes	Lake (BUMP)
3	121700020220-03	Lake	WBLS	Tenkiller Ferry Lake	121700020220	1994-Present	Yes	Lake (BUMP)
4	121700020020-07	Lake	WBLS	Tenkiller Ferry Lake	121700020020	1994 - PRESENT	Yes	Lake (BUMP)
5	121700020220-06	Lake	WBLS	Tenkiller Ferry Lake	121700020220	1994 - PRESENT	Yes	Lake (BUMP)
6	121700020020-02	Lake	WBLS	Tenkiller Ferry Lake	121700020020	1994 - PRESENT	Yes	Lake (BUMP)
7	121700020020-01B	Lake	WBLS	Tenkiller Ferry Lake, bottom	121700020020	1994 - PRESENT	Yes	Lake (BUMP)
8	121700020020-01S	Lake	WBLS	Tenkiller Ferry Lake	121700020020	1994 - PRESENT	Yes	Lake (BUMP)

Figure 6.7 Summary of OWRB station data for Lake Tenkiller

Dynamic Solutions has been involved in a number of surface water modeling projects where HSPF and EFDC have been selected as the watershed and hydrodynamic/water quality models to build a linked surface water model framework. To facilitate the data processing needed for the HSPF-EFDC linkage, we have developed custom software to provide a systematic approach for the linkage of flow boundary conditions from HSPF and boundary conditions obtained from other data sources (e.g., lake withdrawals) to provide a set of boundary condition files formatted for input to the EFDC model. The updated calibration of the HSPF watershed model will provide streamflow, water temperature, inorganic solids (TSS), inorganic and organic nutrients (N,P), dissolved oxygen, BOD and algae biomass for input to the EFDC lake model. Details of the HSPF-EFDC data linkage methodology are presented in a separate section of this QA Plan.

With the refined grid completed with the new 2005 bathymetry data for the current model, setup of the lake model will be completed with the assignment of initial conditions, external forcing functions and flow boundary conditions. Initial conditions will be assigned for water column and sediment bed state variables to represent conditions at the beginning of the calibration and validation periods. Station data from OWRB (Figure 6.5) and CDM/USGS (Figure 6.9) data sources will be used to estimate spatial distributions of water temperature, TSS and water quality constituents for the water column. Data needed to characterize sediment bed initial conditions includes sediment bed concentrations of organic carbon and nutrients (N,P). Initial conditions for solids content and organic matter content (C,N,P) of the sediment bed will be estimated from a sediment core survey conducted in Lake Tenkiller in 2005 by Fisher et al. (2009). Figure 6.8 shows the locations of the sediment core stations collected by Fisher et al. The 2005 sediment bed data from Lake Tenkiller may be supplemented, as needed, with sediment bed data collected in other lakes and reservoirs in NW Arkansas and NE Oklahoma (Haggard and Soerens, 2006; Haggard and Smith, 2007; Haggard et al., 2005; Sen et al., 2007; Corral et al., 2011).

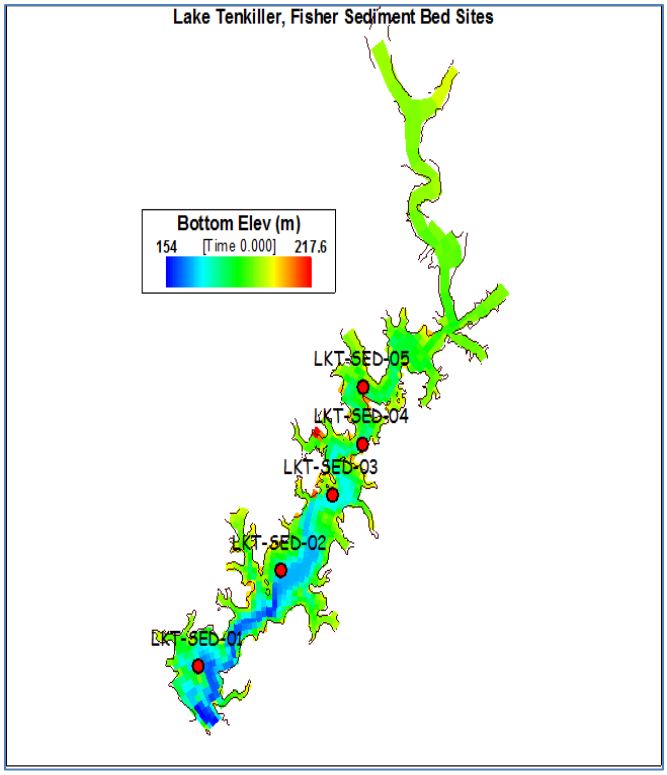


Figure 6.8 Lake Sediment Bed Locations (LKTSED-01,LKT SED-02,LKT SED-03,LKT SED-04, LKT SED-05) during 2005 Survey of Lake Tenkiller (Fisher et al., 2009).

Sediment core data collected by Fisher et al. (2009) in 2005 will be reviewed and, if acceptable, will allow specification of sediment bed initial conditions for the sediment transport and sediment diagenesis models. Station data available from the BUMP data collected by OWRB during 2005-2006 in addition to data that may be used from the CDM/USGS surveys collected during 2005-2006, will allow specification of initial conditions for the water column. These data sets will also provide time series and vertical profile observations for calibration and validation of the lake model.

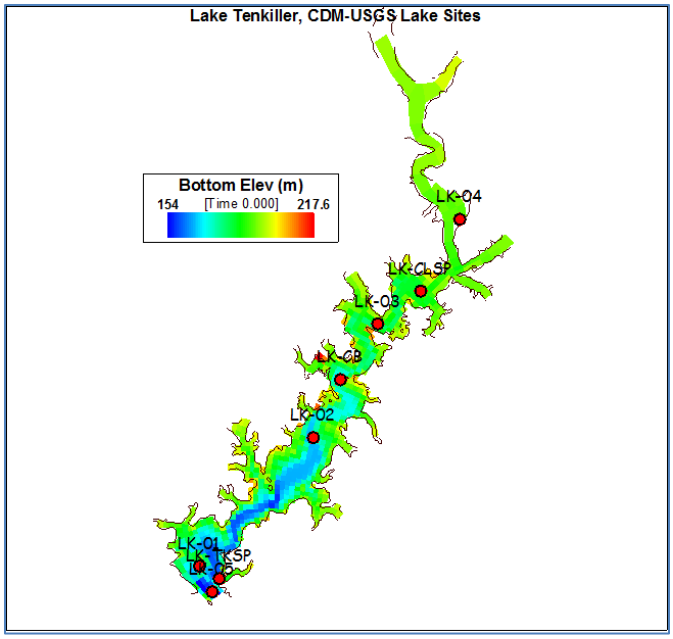


Figure 6.9 CDM/USGS Station Locations in Lake Tenkiller

AQUA TERRA's staff and consultant will have ultimate responsibility for the development of model input data sets, development and testing of the model reach/grid system, preliminary and supplemental model analyses, model calibration, model validation, analysis of alternative load allocation scenarios, and writing of intermediate and final reports and other documentation. AQUA TERRA Consultants will provide the technical expertise necessary to perform the watershed modeling for the Illinois River Watershed, and AQUA TERRA's consultant Dynamic Solutions, LLC will provide the technical expertise necessary to perform the modeling for Lake Tenkiller. AQUA TERRA Consultants is a premier firm in providing services for the HSPF model, and the firm has previous experience in applying the model to the Illinois River Watershed. Dynamic Solutions is one of a handful of firms with the highest level of expertise in applying EFDC, and the firm has previously applied the model to Lake Tenkiller.

6.2 Model Calibration and Validation Procedures

Calibration and validation have been defined by the American Society of Testing and Materials, as follows:

- Calibration: a test of the model with known input and output information that is used to adjust or estimate factors for which data are not available.
- Validation: comparison of model results with numerical data independently derived from experiments or observations of the environment.

Model calibration is the process of adjusting model inputs within acceptable limits until the resulting predictions give good correlation with observed data. Commonly, calibration begins with the best estimates for model input based on measurements and subsequent data analysis. Results from initial simulations are then used to modify the values of the model input parameters. Models are often calibrated through a subjective trial-and-error adjustment of model input data because a large number of interrelated factors influence model output. However, the experience and judgment of the modeler are a major factor in calibrating a model accurately and

efficiently. Further, the model should meet pre-specified quantitative measures of accuracy to establish its acceptability in answering the principal study questions (Tetra Tech, 2009).

Model validation is in reality an extension of the calibration process. Its purpose is to assure that the calibrated model properly assesses all the variables and conditions which can affect model results. While there are several approaches to validating a model, perhaps the most effective procedure is to use only a portion of the available record of observed values for calibration; once the final parameter values are developed through calibration, simulation is performed for the remaining period of observed values and goodness-of-fit between recorded and simulated values is reassessed. However, model credibility is also based on the ability of a single set of parameters to represent the entire range of observed data. Therefore, if a single parameter set can reasonably represent a wide range of events, then this is a form of validation.

Calibration and validation of the Illinois River Watershed models will be achieved by considering qualitative *and* quantitative measures, involving both graphical comparisons and statistical tests. For flow simulations where continuous records are available, all these techniques will be employed, and the same comparisons will be performed during both the calibration and validation phases. Comparisons of values for simulated and observed state variables will be performed for daily, monthly, and annual values, in addition to flow-frequency duration assessments. Statistical procedures will be applied as appropriate, including error statistics, correlation and model-fit efficiency coefficients, and goodness-of-fit tests. For water quality constituents, model performance will be based primarily on visual and graphical presentations as the frequency of observed data will likely be inadequate for accurate statistical measures.

The model calibration/validation process can be viewed as a systematic analysis of errors or differences between model predictions and field observations. Figure 6.10 schematically compares the model with the 'natural system', i.e. the watershed, and identifies various sources of potential errors to be investigated. These types of analysis require evaluation of the accuracy and validity of the model input data, parameter values, model algorithms, calibration accuracy, and observed field data used in the calibration/validation. The modelers have responsibility for searching for the causes of the errors or differences, and potential remedies to improve the agreement and reduce the errors. A more complete discussion of these error sources is provided in Donigian and Rao (1990).

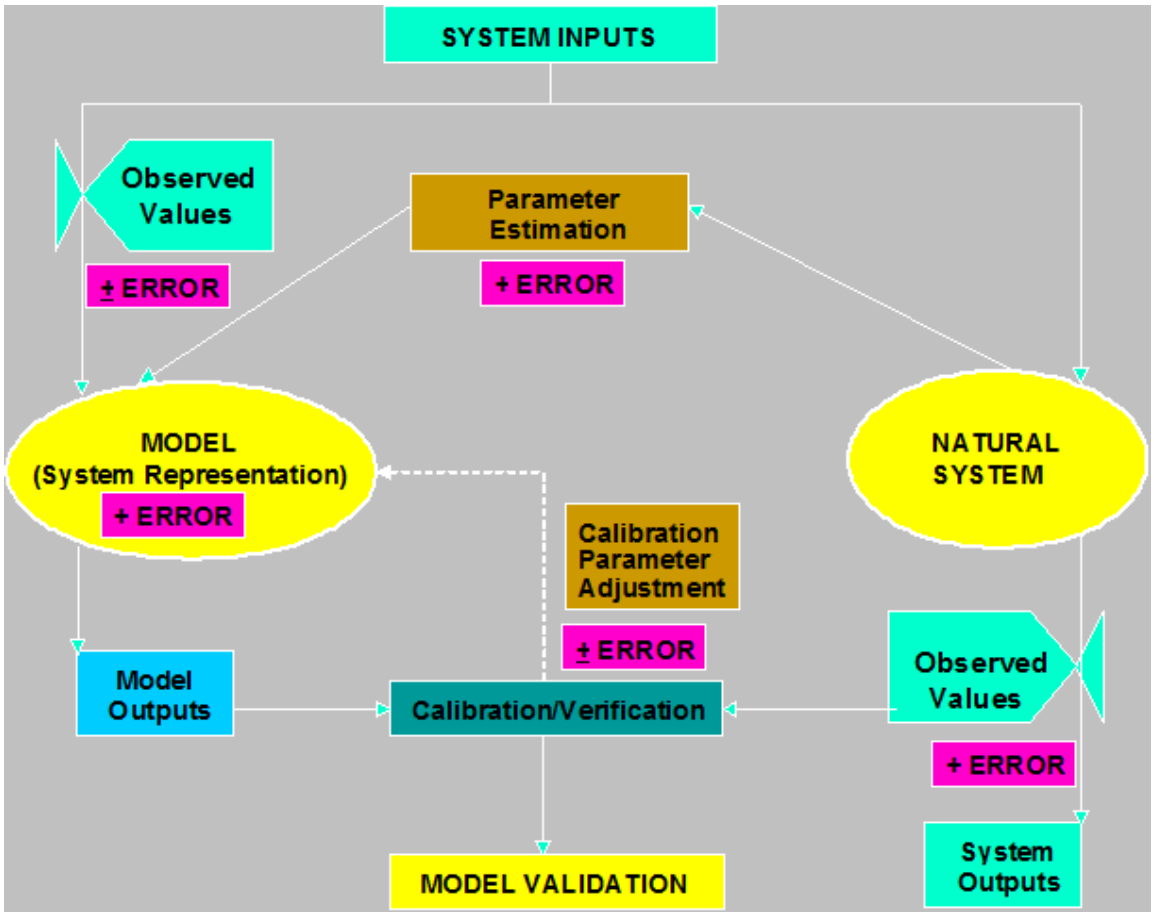


Figure 6.10 Model versus Natural System: Inputs, Outputs, and Errors

6.2.1 Watershed Model Calibration and Validation

As noted above, model calibration and validation are necessary and critical steps in any model application. For HSPF, calibration is an iterative procedure of parameter evaluation and refinement, as a result of comparing simulated and observed values of interest. Calibration is required for parameters that cannot be deterministically, and uniquely, evaluated from topographic, climatic, edaphic, or physical/chemical characteristics of the watershed and constituents of interest. Fortunately, the large majority of HSPF parameters do not fall in this category. Calibration is based on several years of simulation (at least 3 to 5 years) in order to evaluate parameters under a variety of climatic, soil moisture, and water quality conditions. The objective of the calibration effort for the Illinois River Watershed HSPF model is to establish parameter values that produce the best overall agreement between simulated and observed values throughout the calibration period.

Calibration will include the comparison of both monthly and annual values, and individual storm events, whenever sufficient data are available for these comparisons. All of these comparisons will be performed for a proper calibration of hydrology and water quality parameters. In addition, when a continuous observed record is available, such as for streamflow, simulated and observed values will be analyzed on a frequency basis and their resulting cumulative distributions (e.g. flow duration curves) compared to assess the model behavior and agreement over the full range of observations.

Calibration of the watershed model is a hierarchical process beginning with hydrology calibration of both runoff and streamflow, followed by sediment erosion and sediment transport calibration, and finally calibration of nonpoint source loading rates and water quality constituents. When modeling land surface processes hydrologic calibration must precede sediment and water quality calibration since runoff is the transport mechanism by which nonpoint pollution occurs. Likewise, adjustments to the instream hydraulics simulation must be completed before instream sediment and water quality transport and processes are calibrated. Each of these steps is discussed below with the emphasis on the key calibration parameters;

The application of HSPF to the Illinois River Watershed will follow the standard model application procedures as described in the HSPF Application Guide (Donigian et al., 1984), in numerous watershed studies over the past 25 years (e.g. Donigian et al., 1984), summarized by Donigian (2002).

Model application procedures for HSPF include database development, watershed segmentation, and hydrology, sediment, and water quality calibration and validation. Each of these steps is discussed in the Illinois River Watershed Simulation Plan (AQUA TERRA Consultants, in progress), with additional details provided in this section for the QA-related steps of calibration and validation.

Because parameter evaluation is a key precursor to the calibration effort, a valuable source of initial values for many of the key calibration parameters are the previous model applications to the watershed (e.g., Donigian et al., 2009; Storm et al., 2006; Storm et al., 2009). Initial values for other parameters will be obtained directly or derived from various data sources reported in the Illinois River Data Report (AQUA TERRA Consultants, 2010b).

6.2.2 Hydrologic Calibration and Key Calibration Parameters

Hydrologic simulation combines the physical characteristics of the watershed and the observed meteorologic data series to produce the simulated hydrologic response. All watersheds have similar hydrologic components, but they are generally present in different combinations; thus different hydrologic responses occur on individual watersheds. HSPF simulates runoff from four components: surface runoff from impervious areas directly connected to the channel network, surface runoff from pervious areas, interflow from pervious areas, and groundwater flow. Because the historic streamflow is not divided into these four units, the relative relationship among these components must be inferred from the examination of many events over several years of continuous simulation.

A complete hydrologic calibration involves a successive examination of the following four characteristics of the watershed hydrology, in the order shown: (1) annual water balance, (2) seasonal and monthly flow volumes, (3) baseflow, and (4) storm events. Simulated and observed values for reach characteristic are examined and critical parameters are adjusted to attain acceptable levels of agreement (discussed further below).

The annual water balance specifies the ultimate destination of incoming precipitation and is indicated as:

Precipitation - Actual Evapotranspiration - Deep Percolation - Soil Moisture = Runoff

HSPF requires input precipitation and potential evapotranspiration (PET), which effectively “drive” the hydrology of the watershed; actual evapotranspiration is calculated by the model from the input potential and ambient soil moisture conditions. Thus, both inputs must be accurate and representative of the watershed conditions; it is often necessary to adjust the input data derived from neighboring stations that may be some distance away in order to reflect conditions on the watershed. HSPF allows the use of factors (referred to as MFACT) that

uniformly adjust the input data to watershed conditions, based on local isohyetal and evaporation patterns. The Simulation Plan describes the numerous rainfall stations available within and surrounding the Illinois River Watershed, whereas evaporation is calculated and available from BASINS. Fortunately, evaporation does not vary as greatly with distance, and use of evaporation data from distant stations (e.g., 50 to 100 miles away) is common practice.

In addition to the input meteorological data series, the critical parameters that govern the annual water balance are as follows:

LZSN - lower zone soil moisture storage (inches).
LZETP - vegetation evapotranspiration index (dimensionless).
INFILT - infiltration index for division of surface and subsurface flow (inches/hour).
UZSN - upper zone soil moisture storage (inches).
DEEPFR - fraction of groundwater inflow to deep recharge (dimensionless).

Thus, from the water balance equation, if precipitation is measured on the watershed, and if deep percolation to groundwater is small or negligible, actual evapotranspiration must be adjusted to cause a change in the long-term runoff component of the water balance. Changes in LZSN and LZETP affect the actual evapotranspiration by making more or less moisture available to evaporate or transpire. Both LZSN and INFILT also have a major impact on percolation and are important in obtaining an annual water balance. Whenever there are losses to deep groundwater, such as recharge, or subsurface flow not measured at the flow gage, DEEPFR is used to represent this loss from the annual water balance.

In the next step in hydrologic calibration, after an annual water balance is obtained, the seasonal or monthly distribution of runoff can be adjusted with use of INFILT, the infiltration parameter defined above. This seasonal distribution is accomplished by INFILT by dividing the incoming moisture among surface runoff, interflow, upper zone soil moisture storage, and percolation to lower zone soil moisture and groundwater storage. Increasing INFILT will reduce immediate surface runoff (including interflow) and increase the groundwater component; decreasing INFILT will produce the opposite result.

The focus of the next stage in calibration is the baseflow component. This portion of the flow is often adjusted in conjunction with the seasonal/monthly flow calibration (previous step) because moving runoff volume between seasons often means transferring the surface runoff from storm events in wet seasons to low-flow periods during dry seasons. By increasing INFILT, runoff is delayed and occurs later in the year as an increased groundwater or baseflow. The shape of the groundwater recession; i.e., the change in baseflow discharge, is controlled by the following parameters:

AGWRC - groundwater recession rate (per day).
KVARY - index for nonlinear groundwater recession.

AGWRC is calculated as the rate of baseflow (i.e., groundwater discharge to the stream) on one day divided by the baseflow on the previous day; thus AGWRC is the parameter that controls the rate of outflow from the groundwater storage. Using hydrograph separation techniques, values of AGWRC are calculated as the slope of the receding baseflow portion of the hydrograph; these initial values are then adjusted as needed through calibration. The KVARY index allows users to impose a nonlinear recession so that the slope can be adjusted as a function of the groundwater gradient. KVARY is usually set to zero unless the observed flow record shows a definite change in the recession rate (i.e., slope) as a function of wet and dry seasons.

In the final stage of hydrologic calibration, after an acceptable agreement has been attained for annual/monthly volumes and baseflow conditions, simulated hydrographs for selected storm events can be effectively adjusted with UZSN and the following parameters:

INTFW - Interflow inflow parameter (dimensionless).
IRC - Interflow recession rate (per day).

Both INTFW and IRC are used to adjust the shape of the hydrograph to better agree with observed values; both parameters are evaluated primarily from past experience and modeling studies, and then adjusted in calibration. Also, minor adjustments to the INFILT parameter can be used to improve simulated hydrographs; however, adjustments to INFILT should be minimal to prevent disruption of the established annual and monthly water balance. Examination of both daily and short-time interval (e.g., hourly) flows may be included, depending on the purpose of the study and the available data.

The hydrology calibration process has been facilitated with the aide of HSPEXP, an expert system for hydrologic calibration, specifically designed for use with HSPF, developed for the U.S. Geological Survey (Lumb, et al., 1994). This package gives calibration advice, such as which model parameters to adjust and/or input to check, based on predetermined rules, and allows the user to interactively modify the HSPF Users Control Input (UCI) files, make model runs, examine statistics, and generate a variety of plots.

6.2.3 Hydraulic Calibration

The major determinants of the routed flows simulated by section HYDR are the hydrology results from pervious land segments and/or impervious land segments and the physical data contained in the FTABLE; i.e., the stage-discharge function used for hydraulic routing in each reach. The FTABLE specifies values for surface area, reach volume, and discharge for a series of selected average depths of water in each reach. This information is part of the required User's Control Input and is obtained from cross-section data, channel characteristics (e.g., length, slope, roughness), and flow calculations. Since the FTABLE is an approximation of the stage-discharge-volume relationship for relatively long reaches, calibration of the values in the FTABLE is generally not needed.

6.2.4 Specific Comparisons to be Performed - Hydrology

As discussed in the Simulation Plan, hydrologic calibration will be performed for the time period of 2001 to 2009, whereas the period of 1992 to 2000 will be used for validation. The available flow data include continuous flow records at ten USGS gage sites that are identified in the SImulation Plan for the entire time period.

The same comparisons will be performed for both the calibration and validation periods.

Following the steps discussed above, the following specific comparisons of simulated and observed values will be performed:

For the all gage sites:

- Annual and monthly runoff volumes (inches)
- Daily time series of flow (cfs)
- Flow frequency (flow duration) curves (cfs)
- Storm hydrographs (flow, cfs) for selected storm events

In addition to the above comparisons, the water balance components (input and simulated) will be reviewed for consistency with expected literature values for the Illinois River Watershed

Region. This effort involves displaying model results for individual land uses for the following water balance components:

- Precipitation
- Total Runoff (sum of following components)
  - Overland flow
  - Interflow
  - Baseflow
- Total Actual Evapotranspiration (ET) (sum of following components)
  - Interception ET
  - Upper zone ET
  - Lower zone ET
  - Baseflow ET
  - Active groundwater ET
- Deep Groundwater Recharge/Losses

Although observed values are not available for each of the water balance components listed above, the average annual values must be consistent with expected values for the region, as impacted by the individual land use categories. This is a separate consistency, or reality check with data independent of the modeling (except for precipitation) to insure that land use categories and overall water balance reflect local conditions in the Illinois River Watershed.

6.2.5 Sediment Erosion Calibration and Key Calibration Parameters

Sediment calibration follows the hydrologic calibration and must precede water quality calibration. Calibration of the parameters involved in simulation of watershed sediment erosion is more uncertain than hydrologic calibration, due to the comparably smaller number of sediment simulations that have been performed in different regions of the country. The process is analogous; the major sediment parameters are modified to increase agreement between simulated and recorded monthly sediment loss and storm event sediment removal. However, observed monthly sediment loss is often not available, and the sediment calibration parameters are not as distinctly separated between those that affect monthly sediment and those that control storm sediment loss. In fact, annual sediment losses are often the result of only a few major storms during the year.

Sediment loadings to the stream channel are estimated by land use category from literature data, local Extension Service sources, or procedures like the Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1978) and then adjusted for delivery to the stream with estimated sediment delivery ratios. Model parameters are then adjusted so that model calculated loadings are consistent with these estimated loading ranges. The loadings are further evaluated in conjunction with instream sediment transport calibration (discussed below) that extends to a point in the watershed where sediment concentration data are available. The objective is to represent the overall sediment behavior of the watershed, with knowledge of the morphological characteristics of the stream (i.e., aggrading or degrading behavior), using sediment loading rates that are consistent with available values and providing a reasonable match with instream sediment data.

In HSPF, the erosion process is represented as the net result of detachment of soil particles by raindrop impact on the land surface, and then subsequent transport of these fine particles by overland flow. The primary sediment erosion parameters are as follows:

KRER - Coefficient in soil detachment equation.
KSER - Coefficient in sediment washoff equation.

Although a number of additional parameters are involved in sediment erosion calibration, such as those related to vegetal cover, agricultural practices, rainfall and overland flow intensity, etc., KRER and KSER are the primary ones controlling sediment loading rates. KRER is usually estimated as equal to the erodibility factor, K, in the USLE (noted above), and then adjusted in calibration, while KSER is primarily evaluated through calibration and past experience.

6.2.6 Specific Comparisons to be Performed - Sediment Loadings

The sediment erosion calibration period for the Illinois River simulation will coincide with the hydrology calibration and extend from 2001 through 2009; the available historical data prior to 2001 will be reserved for validation. Observed storm concentrations of TSS will be compared with model results, and the sediment loading rates by land use category will be compared with the expected ranges, as noted above.

6.2.7 Nonpoint Source Calibration and Key Calibration Parameters

HSPF enables simulation of nonpoint source pollutants by utilizing two different schemes:

- a generalized scheme for any pollutant whereby the pollutant washoff from the land surface is expressed as a potency factor in relation to sediment washoff or as a function of the runoff rate, or
- a more detailed behavior of soil nutrients (i.e., nitrogen and phosphorus) and non-reactive tracer chemicals (e.g., chloride).

The strategy that will be used to simulate nutrients for the Illinois River Watershed study will utilize both schemes, with BOD, nitrate and ammonia simulated as a function of runoff rate and phosphate simulated using the potency factor approach in all land use segments defined for watershed simulation. For pasture (with and/or without poultry litter application), the more detailed algorithms for nutrient processes will be utilized. First the calibration procedures for the potency factor approach are discussed.

Calibration procedures and parameters for simulation of nonpoint source pollutants will vary depending on whether constituents are modeled as sediment-associated or flow-associated. This refers to whether the loads are calculated as a function of sediment loadings or as a function of the overland flow rate. Nonpoint source loads will be provided for DO, BOD, NO_x, NH_4, and PO_4. Because of its affinity for sediment, PO4 will be modeled as sediment-associated, and DO, BOD, NOx, and NH_4 will be modeled as flow-associated.

6.2.8 Potency Factor Approach for Simulating Nonpoint Source Loadings

Calibration of sediment-associated pollutants begins after a satisfactory calibration of sediment washoff has been completed. At this point, adjustments are performed in the contaminant potency factors, which are user-specified parameters for each contaminant, defined as follows:

POTFW - mass of pollutant per mass of sediment washoff (lb pollutant/100 lb sediment)
POTFS - mass of pollutant per mass of sediment scour (lb pollutant/100 lb sediment)

Potency factors are used for highly sorptive contaminants that can be assumed to be transported with the sediment in the runoff. Generally, monthly and annual contaminant loss will

not be available, so the potency factors will be adjusted by comparing simulated and recorded contaminant concentrations, or mass removal, for selected storm events. For nonpoint pollution, mass removal in terms of contaminant mass per unit time (e.g., gm/min) is often more indicative of the washoff and scour mechanisms than instantaneous observed contaminant concentrations.

Calibration procedures for simulation of contaminants associated with overland flow are focused on the adjustment of following three key parameters:

ACQOP - the daily accumulation rate (lb/acre/day).
SQOLIM - the maximum contaminant storage on the land surface (lb/acre).
WSQOP - the washoff factor parameter (in/hr) which is the runoff intensity that produces 90% removal in 1 hour.

As was the case for sediment-associated constituents, calibration is performed by comparing simulated and recorded contaminant concentrations, or mass removal, for selected storm events. In most cases, proper adjustment of SQOLIM, WSQOP, and ACQOP can be accomplished to provide a good representation of the washoff of flow-associated constituents; the HSPF Application Guide (Donigian et al., 1984) includes guidelines for calibration of these parameters, and the HSPFParm Database (Donigian et al., 1999) includes representative values for selected model applications for most conventional constituents. In areas where pollutant contributions are also associated with subsurface flows, such as BOD or nitrate from agricultural croplands, contaminant concentration values are assigned for both interflow and active groundwater. The key parameters are simply the user-defined concentrations in interflow and groundwater/baseflow for each contaminant, as follows:

IOQC - Concentration of contaminant in interflow discharge (mg/L).

AOQC - Concentration of contaminant in groundwater discharge (mg/L).

HSPF includes the functionality to allow monthly values for all these nonpoint loading parameters in order to better represent seasonal variations in the resulting loading rates.

6.2.9 Detailed Process Approach for Simulation of Nonpoint Source Nutrients

These capabilities have been referred to as the AGCHEM module because their primary use to date has been for modeling the mass balance and runoff of agricultural chemicals. First, storages and fluxes of moisture in four user-defined soil layers are estimated—surface, upper, lower, groundwater. The moisture storage and flux scheme used for modeling the hydrologic cycle must be modified to effectively simulate solute transport through the soil. Estimates of solute flux are computed based on the assumption that the concentration of solute being transported is the same as that for storage; uniform flow through the layers and continuous mixing of solutes is also assumed. Leaching retardation factors are computed to modify the solute fluxes from the top three soil layers based on user-defined model parameters.

For the pasture areas of the Illinois River Watershed, the AGCHEM module will be used to simulate the transport and soil reactions of nitrate, ammonia, and four forms of organic nitrogen. Nitrate and dissolved ammonium are transported as a function of water flow; organic nitrogen and adsorbed ammonium are removed from the surface layer storage by association with sediment scour and washoff; nitrate and ammonium in the soil water are transported according to the fractions calculated in the soil moisture estimations; and computations are performed that compute the movement of adsorbed organic nitrogen and ammonium associated with removal of sediment from the topsoil surface layer. First-order kinetics or a Freundlich isotherm can be used to model adsorption/desorption. Nitrogen transformation processes (denitrification,

nitrification, plant uptake, immobilization, mineralization, volatilization, plant nitrogen return to organic nitrogen) are modeled using temperature-corrected, first-order kinetics with separate rate constants defined for each soil layer.

Transport and reaction of phosphate and organic phosphorus in pasture areas will be simulated using methods parallel to those used for nitrogen species. Transport mechanisms for phosphate parallel those modeled for ammonium, and those for organic phosphorus parallel organic nitrogen. Like ammonium, phosphate adsorption/desorption can be modeled using either first-order kinetics or a Freundlich isotherm. Phosphorus transformation processes (plant uptake, immobilization, mineralization) are modeled using temperature-corrected, first-order kinetics with separate rate constants defined for each soil layer.

6.2.10 Specific Comparisons to be Performed - Nonpoint Loadings

The nonpoint loading calibration will be performed in a manner directly analogous to the sediment loading calibration. The calibration period will be 2001 through 2009. The historical data in the period from 1992 through 2000 will be used for validation. Observed stormwater concentrations for each contaminant will be compared with model results, and the pollutant loading rates by land use category will be compared with the expected ranges available from the literature and past modeling studies, in a manner analogous to the sediment loading calibration.

6.2.11 Water Temperature Calibration

To model the instream water temperature, HSPF calculates the heat loadings to a stream reach from all sources, including the runoff components, and then performs a balance of the heat fluxes across the reach boundaries to arrive at the reach water temperature in each model time step. Heat sources/sinks to a reach include upstream or tributary reaches, nonpoint runoff (i.e. surface runoff, interflow, and baseflow) or point sources, heat exchange with the atmosphere, and conduction from the streambed. Heat outputs from a reach include downstream advection, losses to the atmosphere, and conduction to the streambed.

In order to estimate heat inputs to a reach from local land segments, it is necessary to estimate the temperature of the runoff flow components (i.e., surface runoff, interflow, and baseflow) originating from these areas. The fluxes are a function of the user supplied meteorological data, model parameters, and the estimated stream temperature. The meteorological data required includes: 1) shortwave solar radiation; 2) cloud cover; 3) air temperature; 4) dewpoint temperature; and 5) wind speed. The transfer of heat across the streambed and the water column interface is driven by temperature gradients between the assumed three layer system (i.e., a water layer, a streambed or mud layer, and a ground layer) within each reach. The temperature of the ground layer (TGRND) is supplied by the user, while the temperature of the streambed and the water column are calculated at every interval by the model. The temperatures of the three layers are then used to calculate the heat transfer rates between the layers as a function of the temperature gradients and input parameters KGRND and KMUD.

There are few calibration parameters within HSPF for water temperature, and as long as the meteorological inputs are relatively accurate, the default values for the parameters are usually adequate to produce reasonable simulations and comparisons with data. Most of the calibration parameters within HSPF are typically set at, or very near, their default values, with the exception of CFSAEX that is set based on site-specific, and reach-specific, information. CFSAEX is the fraction of the reach that is exposed (i.e., not shaded by riparian vegetation or topographical obstructions). Reach specific values of CFSAEX for shading will be set using a combination of colored orthophotos, pictures from site visits, calibration process, and professional judgment.

In situations where point loadings contribute a significant volume of water to the reach system, the water temperature values assigned to the point loading may become the dominant factor in water temperature simulation. If reasonable adjustments to the calibration parameters cannot produce an acceptable calibration, input data for point loads or meteorology are most likely unrepresentative of the study reaches and will be re-examined.

6.2.12 Instream Sediment Calibration

Once the sediment loading rates are calibrated to provide the expected input to the stream channel, the sediment calibration will focus on the channel processes of deposition, scour, and transport that determine both the total sediment load and the outflow sediment concentrations to be compared with observations. The initial steps in instream calibration involve dividing the input sediment loads into appropriate size fractions, estimating initial parameter values and storages for all reaches, and a preliminary model run to calculate shear stress timeseries in each reach to estimate critical scour and deposition values.

The eroded material is fractionated into sand, silt, and clay prior to entering a model reach using available soils information; typically, a single fractionation scheme is used for all reaches unless soils and land surface variations within the watershed support use of reach-specific fractions. The fractions should reflect the relative percent of the surface material (i.e., sand, silt, clay) available for erosion in the surrounding watershed, but also should include an enrichment factor of silt and clay to represent the likelihood of these finer materials reaching the channel.

Initial sediment parameters, such as particle diameter, particle density, settling velocity, bed depth and composition, and beginning calibration parameter values will be evaluated from local/regional data, past experience, handbook values, etc., and then adjusted based on available site specific data and calibration. Bed composition data are especially important so that the model results can be adjusted to reflect localized aggradation (deposition) or degradation (scour) conditions within the stream system.

As part of the sediment parameterization, the model is run with the initial parameter estimates and shear stress values are output for each stream reach. For the silt and clay size particles, the critical shear stress parameters (one for scour and one for deposition) for each size are adjusted so that the model calculates scour during high flow events, deposition and settling during low flow periods, and transport with neither scour nor settling for moderate flow rates.

The shear stress values are then adjusted more carefully in calibration so that scour occurs during storm periods and deposition occurs at low flows. Once the timing of scour and deposition processes is correct, the rate of scour is adjusted in an attempt to match either expected behavior within each reach, and/or the observed concentrations. During high flow periods, the amount of scour is adjusted with an erodibility factor for each reach that controls the rate of scour whenever the actual shear stress is greater than the critical shear stress value for scour. During low flow periods the silt/clay fall velocity parameter can be adjusted slightly to improve the agreement.

The calibration procedure generally involves comparison of model simulations (concentrations and loads) to available observed data. This is often limited to event mean concentrations of total suspended solids (TSS) for selected storm events and nonstorm (baseflow) periods, or pollutographs of TSS concentrations throughout a few events. However, other types of comparisons are also possible, such as load estimates and sediment rating curves. A complete discussion of HSPF sediment calibration is provided by Donigian and Love (2003).

6.2.13 Instream Water Quality Calibration

Calibration of instream water quality is complicated by two factors. First, the interrelationships of the various constituents result in changes in simulated concentrations for numerous constituents by adjustment of a parameter value specific to only one constituent. For example, if one increases the value for the algal respiration rate parameter in order to reduce simulated plankton populations, the modification will also result in increased values for nutrients and inorganic carbon and a decreased value for dissolved oxygen. Thus, the final calibration of any one water quality constituent cannot be completed until all adjustments have been made to associated constituents. The calibration is complete when the best overall fit to data is achieved for all constituents which are simulated.

The second factor which complicates the instream water quality calibration is the wide range of values which have been reported for certain model parameters. The variability of literature values for many of these parameters results from the complexity of the physical, chemical, and biological factors which influence the ultimate biochemistry of each individual stream.

Given the potential complexity of instream water quality calibration, as well as the flexibility allowed in constituents/processes simulated, it is not possible to define a detailed calibration procedure at the onset of a specific model application. Nonetheless, the parameters identified below are generally considered to be the most useful for calibration of the various constituents that may be modeled:

Oxygen	BENOD	benthal oxygen demand rate
BOD	BRBOD	benthal release rate for BOD
	KBOD20	decay rate of BOD
Nutrients	BRCON (I)	benthal release rates for nitrate and orthophosphorus
	KNH320	oxidation rate of ammonia
	KNO220	oxidation rate of nitrite
	DEBAC	fraction of denitrifying bacteria
Algae	CFSAEX	correction factor for surface area exposed to sunlight
	LITSED	light extinction factor to account for suspended sediment
	EXTB	base extinction coefficient for light
	MARGR	maximal unit algal growth rate
	ALR20	algal unit respiration rate
	ALDH	high algal death rate
	ALDL	low algal death rate
Zooplankton	MZOEAT	maximum zooplankton unit ingestion rate
	ZFIL20	zooplankton filtering rate
	ZRES20	zooplankton unit respiration rate
	ZD	zooplankton unit death rate

6.2.14 Lake Model Calibration and Validation

Dynamic Solutions has acquired and compiled bathymetry data that was collected in 2005 to update and refine the computational grid used for the lake model. Data has been acquired from the USACE and compiled for water levels, storage volume and release flow at the dam. Water quality data has been acquired and compiled for the OWRB and CDM/USGS lake stations and sediment bed data has been acquired from Fisher et al. (2009). Sediment core data collected by Fisher et al. (2009) in 2005 will allow specification of sediment bed initial conditions for the sediment transport and sediment diagenesis models. Station data available from the OWRB BUMP (Figure 6.5) and CDM/USGS (Figure 6.9) data sets during 2005-2006, will allow

specification of initial water quality conditions for the water column. OWRB BUMP and CDM/USGS station data sets will also provide time series and vertical profile observations for calibration and validation of the lake model. When the HSPF calibration results for flow, water temperature, suspended sediment and water quality loading become available for linkage to the EFDC model, the lake model will be calibrated and validated to data collected during 2005-2006. In order to provide reliable flow and loading data from the watershed for input to the lake model, significant efforts have been expended to ensure that the HSPF watershed model is well calibrated and meets the stringent model performance criteria established in the QAPP. Calibration of the lake model will not be initiated without satisfactory calibration of the watershed model.

To efficiently calibrate the lake model we will use the following sequence of steps: (a) test hydrodynamic model water balance to calibrate lake volume and stage height; (b) add heat and density effects (i.e. water temperature) to test the ability of the hydrodynamic model to represent lake stratification; (c) add sediment loading and in-lake sediment transport with cohesive parameters for critical shear stress, deposition velocity and resuspension rate; (d) add nutrient loading and water quality; and finally (e) add sediment diagenesis to couple organic matter deposition from the water column to sediment-water fluxes of nutrients and oxygen. In calibrating the hydrodynamic, sediment transport and water quality model, we will first assess the accuracy of external flows, loadings and forcing functions in relation to lake model results. We will then direct our attention to adjusting various kinetic coefficients to improve model performance. Coefficients for the hydrodynamic, sediment transport, water quality eutrophication and sediment flux model will initially be taken from the existing literature for EFDC (Park et al., 1995; Ji, 2008) and the sediment flux model (Di Toro, 2001) as well as coefficients assigned for our previous EFDC model of Lake Tenkiller (DSLLC, 2006) and the laterally averaged model (Wells and Berger, 2008). Model coefficients will be adjusted, as needed, within a reasonable range of reported values, to achieve calibration of the Lake Tenkiller model against observed data sets collected in 2005. Following model calibration, validation of the model will be performed for data collected in 2006 using the assigned set of model parameters and coefficients developed for model calibration. Model validation will be performed to confirm that the calibrated model can represent the lake water quality response under different hydrologic conditions.

Calibration of the lake model will be accomplished by comparison of model results to observed data extracted from grid cells matching the OWRB and CDM/USGS station locations in Lake Tenkiller. Model-data comparisons will be presented and analyzed for water level, water temperature, TSS, dissolved oxygen, total-N and total-P, and algae biomass (as chlorophyll-a). Model variables will be displayed as (a) time series plots to show surface layer and near bottom layer results; (b) vertical profiles for selected time snapshots matching sampling dates; and (c) spatial maps of surface layer and bottom layer results for selected time snapshots and/or animation of simulation results as AVI files. Model performance will be evaluated to determine the endpoint for model calibration using a “weight of evidence” approach that has been adopted for many water quality modeling studies. As detailed in Section 6.3.3 of this revised QAPP document, the proposed “weight of evidence” approach includes the following steps: (a) visual inspection of plots of model results compared to observed data sets (e.g., station time series or vertical profiles); and (b) analysis of model-data performance statistics such as the Root Mean Square (RMS) Error and the Relative RMS Error. Model performance statistics will be used, not as absolute criteria for acceptance of the model, but rather, as guidelines to supplement our visual inspection of model-data plots to determine the appropriate endpoint for calibration of the lake model. The “weight of evidence” approach thus acknowledges the approximate nature of a model and the inherent uncertainty in input data and observed data. The EFDC_Explorer pre- and post-processor software will be an essential tool for calibration and validation of the lake

model since this software supports the capability to extract EFDC model results for comparison to observed data sets for time series, longitudinal transects and/or vertical profile plots, compute model performance statistics, and edit values of adjustable parameters (Craig, 2012).

Sediment-water fluxes for sediment oxygen demand and benthic nutrient (N,P) fluxes will be simulated with the sediment diagenesis sub-model of the EFDC model. Direct measurements of sediment flux rates for nutrients and dissolved oxygen are not available for Lake Tenkiller to support calibration of the sediment flux model. The CDM/USGS water quality data collected in Lake Tenkiller during 2005-2006 was, however, used to derive indirect estimates of internal loading rates for phosphorus from the sediment bed for stations located in the lacustrine, transition and riverine zones (Cooke et al., 2011). The derived sediment flux rate estimates for phosphorus for the 2005-2006 calibration and validation period will be used for comparison to the sediment flux rates simulated with the EFDC sediment diagenesis model. In addition to the derived estimates of phosphorus release from the sediment bed for Lake Tenkiller, measured sediment flux rates reported in the literature for other reservoirs in similar ecoregions with similar agricultural loading characteristics in the watershed, including Lake Eucha (Haggard et al., 2005), Wister Lake (Corral et al., 2011), and Beaver Reservoir in northwest Arkansas (Sen et al., 2007) and a composite of measured sediment phosphorus flux rates from 17 oligotrophic, mesotrophic and eutrophic reservoirs in the Central Plains (Dzialowski and Carter (2011), will be used as supplemental information to determine if the sediment diagenesis model is producing reasonable results. Sediment oxygen demand measurements, available from Veenstra and Nolen (1991) for four reservoirs in Oklahoma characterized by hypolimnetic oxygen depletion, will be used to support calibration of the sediment flux model for sediment oxygen demand. A review of sediment phosphorus release and the interaction with bottom water dissolved oxygen in lakes by Hupfer and Lewandowski (2008) may also provide important insight for the calibration of the sediment flux component of the lake model. Following calibration of the lake model to 2005 data, the model will be validated against data collected in 2006. The choice of the calibration and validation years will be reviewed in consultation with EPA Region 6 to ensure that the calibration and validation periods selected represent a sufficient range of hydrologic conditions.

As a result of several decades of nutrient and organic matter loading from wastewater facilities and agricultural and other land use-related activities in the Illinois River watershed, the sediment bed of Lake Tenkiller may represent a storage reservoir of nutrients that can recycle nutrients back into the water column to support algal production and eutrophication of the lake. The sediment flux sub-model component of the HSPF-EFDC model framework will be a very powerful tool to quantify the cause-effect interactions between watershed loading, organic matter production, particulate matter deposition to the lake bed, decomposition in the sediment bed, benthic release of nutrients to the water column, sediment oxygen demand (SOD) and hypolimnetic oxygen depletion. When the calibration effort is completed, the lake model will be used to determine the “spin-up” time needed for the sediment flux model to attain quasi-equilibrium conditions driven by the existing watershed loads used for input to the lake model. Based on the literature and our experience modeling other waterbodies, we anticipate that a time scale of ~5-15 years may be needed to attain new equilibrium conditions in Lake Tenkiller. Spin-up runs will be performed only for final calibration of the lake model since several days will be required to execute the series of multiple restart runs. The restart run conditions will be used to define water column and sediment bed initial conditions for the final calibration run.

In addition to the analysis of model-data results as described above, lake model results will also be post-processed to evaluate water quality targets for dissolved oxygen, the anoxic volume of the lake, chlorophyll-a, and Carlson’s Trophic State Index (TSI) (OWRB, 2008; OWRB, 2011a).

EFDC_Explorer (Craig, 2012) was upgraded for our previous Lake Tenkiller modeling project (DSLLC, 2006) to support the display of the TSI and anoxic volume of Lake Tenkiller. An example of the anoxic volume display extracted from the EFDC model results for the 1992-1993 calibration is shown in Figure 6.11.

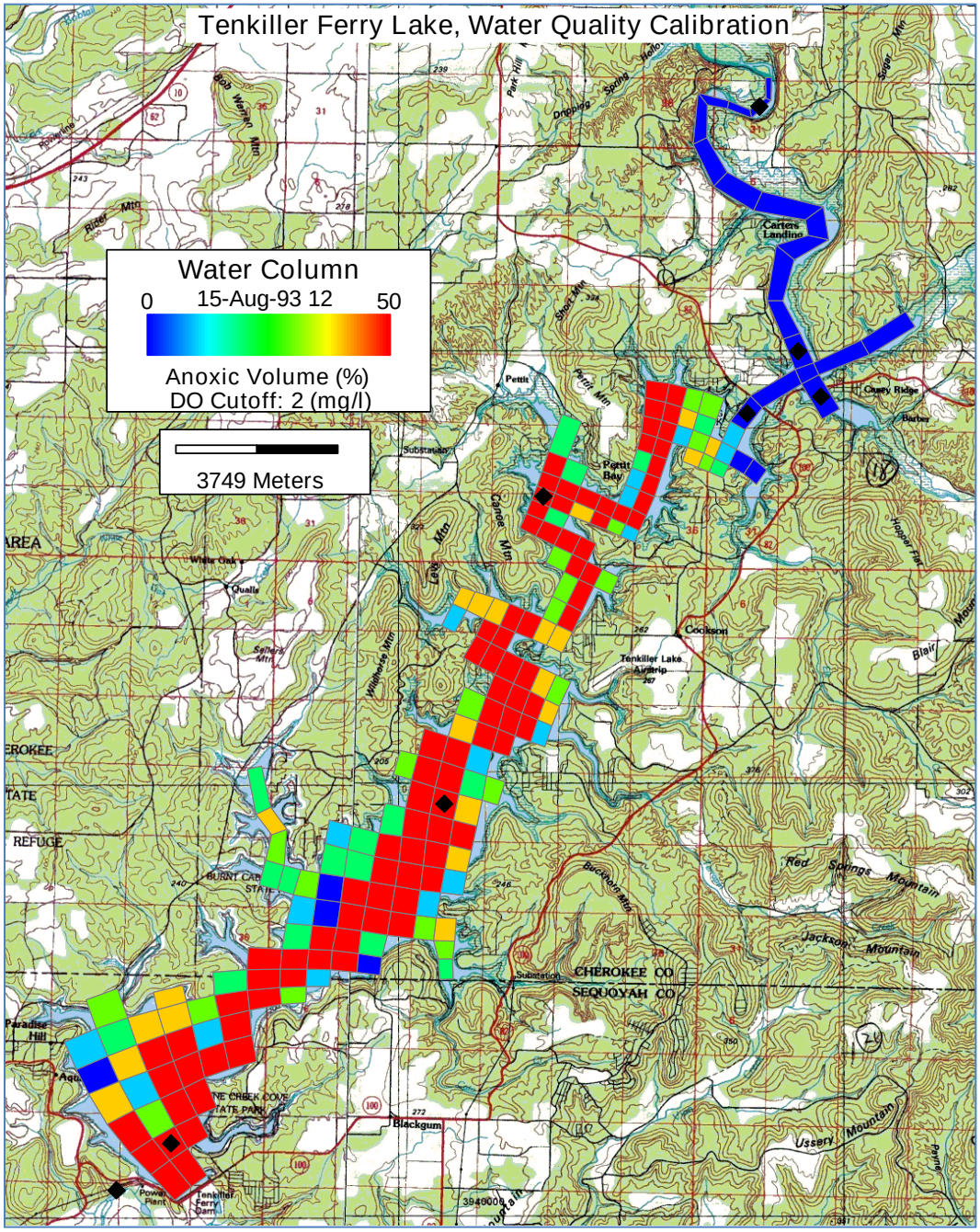


Figure 6.11 Anoxic Volume of Lake Tenkiller on 15-August-1993 at 12:00 (DSLLC, 2006)

6.3 Model Performance Criteria

This section focuses on the model performance criteria, which are the basis by which judgments will be made on whether the model results are adequate to support the decisions required to address the study objectives. In essence, the model performance criteria provide the numerical basis for answering the question, "Are the model results, as reflected in the calibration and validation comparison, of sufficient quality to be used in decision making for this study?"

Model performance assessment is a necessary and critical element in the application of both watershed and lake models. Assessment of watershed model performance entails evaluation of how well a model is able to simulate observed data that describe the watershed's hydrologic and water quality response to its forcing functions (e.g., meteorology, land disturbance activities, point and nonpoint source loadings). Assessment of lake model performance is a similar process; however, many of the forcing functions for the lake model are provided as output from the watershed model simulation.

Model performance criteria have been contentious topics for more than 30 years. The issues inherent in measuring performance have in recent years been thrust to the forefront in the environmental arena as a result of the need for, and use of modeling for exposure/risk assessments, TMDL determinations, and environmental assessments. Despite a lack of consensus on how they should be evaluated, in practice, environmental models are being applied, and their results are being used, for assessment and regulatory purposes. Although no **complete** consensus on model performance criteria is apparent from the past and recent model-related literature, a number of 'basic truths' are evident and are likely to be accepted by most modelers in modeling natural systems:

- Models are approximations of reality; they cannot precisely represent natural systems.
- There is no single, accepted statistic or test that determines whether or not a model is validated
- Both graphical comparisons and statistical tests are required in model calibration and validation.
- Models cannot be expected to be more accurate than the errors (confidence intervals) in the input and observed data.

All of these 'basic truths' must be considered in the development of appropriate procedures for model performance and quality assurance of modeling efforts. A **'weight of evidence'** approach is most widely used and accepted when models are examined and judged for acceptance. Simply put, the weight-of-evidence approach embodies the above 'truths', and demands that multiple model comparisons, both graphical and statistical, be demonstrated in order to assess model performance, while recognizing inherent errors and uncertainty in both the model, the input data, and the observations used to assess model acceptance.

6.3.1 Watershed Model Performance Criteria

Although individual watershed models will utilize different types of graphical and statistical procedures, they will generally include a subset of the following:

Graphical Comparisons**:**

1. Timeseries plots of observed and simulated values for fluxes (e.g. flow) or state variables (e.g. stage, sediment concentration, biomass concentration)
2. Observed vs. simulated scatter plots, with a 45° linear regression line displayed, for fluxes or state variables
3. Cumulative frequency distributions of observed and simulated fluxes or state variable (e.g. flow duration curves)

Statistical Tests**:**

1. Error statistics, e.g. mean error, absolute mean error, relative error, relative bias, standard error of estimate, etc.
2. Correlation tests, e.g. linear correlation coefficient, coefficient of model-fit efficiency, etc.
3. Cumulative distribution tests, e.g. Kolmogorov-Smirnov (KS) test

These comparisons and statistical tests are fully documented in a number of comprehensive references on applications of statistical procedures for biological assessment (Zar, 1999), hydrologic modeling (McCuen and Snyder, 1986), and environmental engineering (Berthouex and Brown, 1994).

Time series plots are generally evaluated visually as to the agreement, or lack thereof, between the simulated and observed values. Scatter plots usually include calculation of a correlation coefficient, along with the slope and intercept of the linear regression line; thus the graphical and statistical assessments are combined. For comparing observed and simulated cumulative frequency distributions (e.g. flow duration curves), the KS test can be used to assess whether the two distributions are different at a selected significance level. Unfortunately, the reliability of the KS test is a direct function of the population of the observed data values that define the observed cumulative distribution. Except for flow comparisons at the major USGS gage sites, there is unlikely to be sufficient observed data (i.e. more than 50 data values per location and constituent) to perform this test reliably for most water quality and biotic constituents. Moreover, the KS test is often quite easy to 'pass', and a visual assessment of the agreement between observed and simulated flow duration curves, over the entire range of high to low flows, may be adequate and even more demanding in many situations.

In recognition of the inherent variability in natural systems and unavoidable errors in field observations, the USGS provides the following characterization of the accuracy of its streamflow records in all its surface water data reports (e.g. Socolow et al., 1997):

Excellent Rating	95 % of daily discharges are within 5 % of the true value
Good Rating	95 % of daily discharges are within 10 % of the true value
Fair Rating	95 % of daily discharges are within 15 % of the true value

Records that do not meet these criteria are rated as 'poor'. Clearly, model results for flow simulations that are within these accuracy tolerances can be considered acceptable calibration and validation results, since these levels of uncertainty are inherent in the observed data.

Table 6.1 lists general calibration/validation tolerances or targets that have been provided to model users as part of HSPF training workshops over the past 10 years (e.g. Donigian, 2000). The values in the table attempt to provide some general guidance, in terms of the percent mean errors or differences between simulated and observed values, so that users can gage what level of agreement or accuracy (i.e. very good, good, fair) may be expected from the model application.

Table 6.1 General Calibration/Validation Targets or Tolerances for HSPF Application (Donigian, 2000).

	% Difference Between Simulated and Recorded Values		
	Very Good	Good	Fair
Hydrology/Flow	< 10	10 - 15	15 - 25
Sediment	< 20	20 - 30	30 - 45
Water Temperature	< 7	8 - 12	13 - 18
Water Quality/Nutrients	< 15	15 - 25	25 - 35
Pesticides/Toxics	< 20	20 - 30	30 - 40

CAVEATS: Relevant to monthly and annual values; storm peaks may differ more
Quality and detail of input and calibration data
Purpose of model application
Availability of alternative assessment procedures
Resource availability (i.e. time, money, personnel)

The caveats at the bottom of the table indicate that the tolerance ranges should be applied to **mean** values, and that individual events or observations may show larger differences, and still be acceptable. In addition, the level of agreement to be expected depends on many site and application-specific conditions, including the data quality, purpose of the study, available resources, and available alternative assessment procedures that could meet the study objectives.

Figure 6.12 provides value ranges for both correlation coefficients (R) and coefficient of determination (R^2) for assessing model performance for both daily and monthly flows. The figure shows the range of values that may be appropriate for judging how well the model is performing based on the daily and monthly simulation results. As shown, the ranges for daily values are lower to reflect the difficulties in exactly duplicating the timing of flows, given the uncertainties in the timing of model inputs, mainly precipitation.

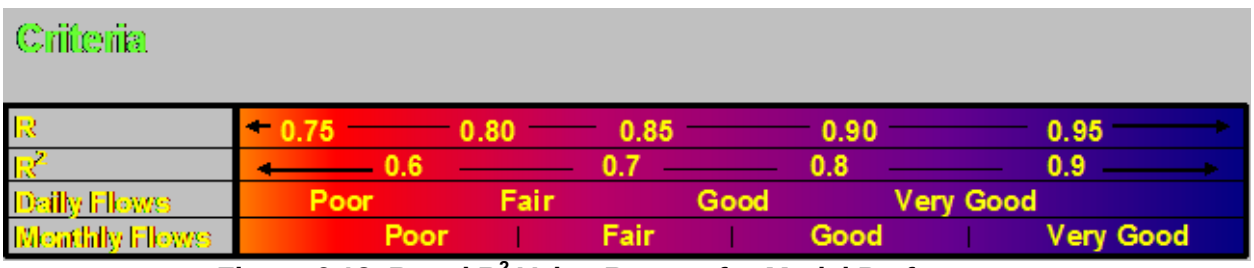


Figure 6.12 R and R^2 Value Ranges for Model Performance

Given the uncertain state-of-the-art in model performance criteria, the inherent errors in input and observed data, and the approximate nature of model formulations, **absolute** criteria for watershed model acceptance or rejection are not generally considered appropriate by most modeling professionals. And yet, most decision makers want definitive answers to the questions - 'How accurate is the model ?', 'Is the model good enough for this evaluation ?', 'How uncertain or reliable are the model predictions ?'. Consequently, we propose that targets or tolerance ranges, such as those shown above, be defined as general targets or goals for model calibration and validation for the corresponding modeled quantities. These tolerances should be applied to comparisons of simulated and observed mean flows, stage, concentrations, and other state variables of concern in the IRW TMDL effort, with larger deviations expected for individual sample points in both space and time. The values shown above have been derived primarily from HSPF experience and selected past efforts on model performance criteria; however, they do reflect common tolerances accepted by many modeling professionals.

6.3.2 Proposed Model Calibration and Validation Targets

Because of the uncertain state-of-the-art in model performance criteria, the inherent error in input and observed data, and the approximate nature of model formulations, absolute criteria for model acceptance or rejection are not appropriate for this effort. Consequently, the tolerance ranges shown in Table 6.2 are proposed as general targets or goals for model calibration and validation for the corresponding modeled quantities. These tolerances will be applied to comparisons of simulated and observed mean flows, stage, concentrations, and other state

variables (listed below), with larger deviations expected for individual sample points in both space and time.

There are a variety of ways to compare simulated and observed mean values. The sporadic observed data can be aggregated over annual, seasonal, or monthly timeframes and compared to the full range of simulated values. Alternatively, the simulated time series can be sampled to include only the time periods when samples were gathered, and then limiting the model-data comparisons to those sampled time periods. Clearly, both approaches have advantages and disadvantages. Both of these approaches and others will be explored as part of the model performance evaluation.

The values shown in Table 6.2 are derived from extensive past experience with HSPF and the selected past efforts on model performance criteria discussed above. If preliminary model results do not satisfy the target tolerances listed in Table 6.2, additional efforts will be required to investigate all possible errors in, and the accuracy of, input data, model formulations, and field observations. If adjustments in these tolerances are needed, they will be fully investigated and documented, and revisions to this QAPP will be issued.

Table 6.2 Proposed Model Calibration and Validation Target Tolerances

Model/Modeled Quantity	Calibration/Validation Target Tolerances
Watershed Model	
Hydrology/Flow	± 15 %
Sediment Loadings/Concentrations	± 30 %
Water Temperature	± 10 %
Nutrient Loadings/Concentrations	± 25 %

6.3.3 Lake Model Performance Criteria

Previously established performance and acceptance methods for EFDC will be utilized. The approach includes both (a) visual inspection of plots of model results compared to observed data sets (e.g., station time series or vertical profiles) and (b) analysis of model-data performance statistics. The “weight of evidence” approach recognizes that, as a numerical model approximation of a lake, perfect agreement between observed data and model results is not expected and is not specified as a performance criterion for model calibration and validation. Model performance statistics are used, not as absolute criteria for acceptance of the lake model, but rather, as guidelines to supplement our visual inspection of model-data plots, and to determine appropriate endpoints for calibration and validation of the lake model.

In evaluating the results obtained with the EFDC hydrodynamic model, a Relative RMS Error performance measure of $\pm 20\%$ is adopted for evaluation of the comparison of the model predicted results and observed measurements of water surface elevation of the lake. For the hydrographic state variables simulated with the EFDC hydrodynamic model, a Relative RMS Error performance measure of $\pm 20\%$ is adopted for evaluation of the comparison of the predicted results and observed measurements of water temperature. For the water quality state variables simulated with the EFDC water quality model, a Relative RMS Error performance measure of $\pm 20\%$ is adopted for dissolved oxygen; $\pm 50\%$ for nutrients and suspended solids; and $\pm 100\%$ for algal biomass for the evaluation of the comparison of the predicted results and

observed water quality measurements for model calibration. These targets for hydrodynamic, sediment transport and water quality model performance are consistent with the range of model performance targets established for previous EFDC applications. Any model performance comparison of model results versus observed measurement yielding differences greater than the relative RMS errors listed above triggers a re-evaluation of all data used to construct the lake model to determine if (a) the input data is valid and needs to be revised or (b) the observed data sets are valid. If the input data requires revision, or if the observed data sets require modification, then the model input files and/or observed data files are revised, as needed, and the model re-run with the objective of achieving an acceptable comparison of model vs. observed data.

The Relative RMS Error, expressed as a percentage, is computed as the ratio of the RMS Error normalized to the observed range of each water quality constituent (Blumberg et al., 1999; Ji, 2008). The equations for the RMS Error and the Relative RMS Error are given as:

$$RMS_Error = \sqrt{\frac{1}{N}\Sigma(O-P)^2}$$

$$\mathrm{Re}\,lative_RMS_Error = \frac{RMS_Error}{(O_{range})}x100$$

where:

N is the number of paired records of observed measurements and model results

O is the observed lake water quality measurement

P is the predicted lake model result

O_{range} is the range of observed from maximum to minimum values

Sediment-water fluxes for sediment oxygen demand and internal loading of nutrients from the sediment bed will be simulated with the EFDC sediment diagenesis model. Direct measurements of sediment flux rates for nutrients and dissolved oxygen are not available for Lake Tenkiller to support calibration of the sediment flux model**.** The CDM/USGS water quality data collected in Lake Tenkiller during 2005-2006 was, however, used to derive indirect estimates of internal loading rates for phosphorus from the sediment bed for stations located in the lacustrine, transition and riverine zones (Cooke et al., 2011). As part of the QA/QC procedure of the sediment flux rate model, the derived indirect sediment flux rate estimates for phosphorus for the 2005-2006 calibration and validation period will be compared to the sediment flux rates simulated with the EFDC sediment diagenesis model. In addition to the derived estimates of phosphorus release from the sediment bed for Lake Tenkiller, measured sediment flux rates reported in the literature for other reservoirs**,** including Lake Eucha (Haggard et al., 2005), Wister Lake (Corral et al., 2011), and Beaver Reservoir in northwest Arkansas (Sen et al., 2007) and a composite of measured sediment phosphorus flux rates from 17 oligotrophic, mesotrophic and eutrophic reservoirs in the Central Plains (Dzialowski and Carter (2011), will be used as supplemental QA/QC check to determine if the sediment diagenesis model is producing reasonable results. Sediment oxygen demand measurements, available from Veenstra and Nolen (1991) for four reservoirs in Oklahoma characterized by hypolimnetic oxygen depletion, will be used to support calibration of the sediment flux model for sediment oxygen demand. A review of sediment phosphorus release and the interaction with bottom

water dissolved oxygen in lakes by Hupfer and Lewandowski (2008) may also provide important insight for the calibration of the sediment flux component of the lake model.

6.4 Model Parameter Sensitivity

Long term experience with the HSPF model and predecessor models has provided a strong foundation for identifying the most sensitive model parameters for most climatic, edaphic, and physiographic watershed settings. However, sensitivity of model results to parameters varies from watershed to watershed, with relative sensitivity in a given watershed depending on the combined impacts of climate and watershed conditions. In other words, sensitivity for a specific watershed is a function of the specific combination of parameter values that reflect climate and watershed characteristics which control the hydrologic response, along with the sediment and water quality behavior. Below we discuss the parameter sensitivity analysis techniques that are applicable to the Illinois River Watershed HSPF application. For clarity, example results from a previous study are provided.

The sensitivity to variations in input parameter values is an important characteristic of a model. Sensitivity analysis is used to identify the most influential parameters in determining the accuracy and precision of model predictions. Sensitivity analysis quantitatively or semi-quantitatively defines the dependence of the model's performance on a specific parameter or set of parameters. Sensitivity analysis can also be used to establish strategies for improving the efficiency of the calibration process.

Model sensitivity can be expressed as the relative rate of change of selected output caused by a unit change in the input. If the change in the input causes a large change in the output, the model is considered to be sensitive to that input parameter. Sensitivity analysis methods are mostly nonstatistical or even intuitive by nature. Sensitivity analysis is typically performed by changing one input parameter at a time and evaluating the effects on the distribution of the dependent variable. Nominal, minimum, and maximum values are specified for the selected input parameter.

It should be noted that informal sensitivity analyses (iterative parameter adjustments) provide the basis for model calibration and ensure that reasonable values for model parameters will be obtained and will in turn result in acceptable model results. The degree of allowable adjustment of any parameter is usually directly proportional to the uncertainty of its value and is limited to its expected range of values (Tetra Tech, 2009).

6.4.1 Sensitivity Analysis Procedures

In a paper reporting the results of modeling and assessing model performance in simulating flow, sediment and water temperature in the Housatonic River (MA), Donigian and Love (2007) recently outlined a generally applicable procedure for performing a sensitivity analysis for parameters used in HSPF calibration. They described the following steps:

1. Identify the critical model input and parameters, based either on past experience or specific calibration experience for the watershed.
2. Identify reasonable percent perturbations from the calibration values, increases and decreases, for each model input and parameter.
3. Assess the resulting changes to ensure the absolute differences in input and parameters are reasonable and appropriate. Perform a long-term model run (e.g., 25 years) using the calibration parameters as a baseline simulation.

4. Perform additional model runs for the entire period, with each run representing a single input/parameter change.
5. Process the model sensitivity run results to calculate the percent difference from the baseline and the sensitivity factor, defined as the percent change in model output divided by the percent change in input/parameter value.
6. Rank the model input and parameters by the sensitivity metric to establish those with the greatest impact on model results.

6.4.2 Example Metrics and Results

Sensitivity factors can be calculated as the ratio (expressed as a percentage) of the average absolute percent change in model output for the two model runs to the average absolute percent change in input/parameters. Values near 100% indicate a 1:1 sensitivity with the model producing a result in direct proportion to the input/parameter change; e.g., a 10% change in input/parameter produces a 10% change in model results. In a similar fashion, values of the sensitivity factor near 200% indicate a highly sensitive response of 2:1, whereas a value of 10% indicates relative model insensitivity of 0.1:1, where a 10% input/parameter change produces only a 1% model response.

Sensitivity results are displayed in graphics such as Figure 6.13, referred to as “tornado diagrams.” Within each diagram, the input/parameters are shown on the left ordinate, ranked by the sensitivity factor (highest to lowest) which is listed on the right ordinate. The bottom horizontal scale shows the “percent difference” from the baseline values, while the top horizontal scale shows the absolute values of the model results. Within the figures, the vertical center line is the mean value from the baseline run, with the width of the horizontal line for each model input/parameter representing the model results from the parameter perturbations. One variable that is of particular importance in the Illinois River Watershed is the application rate of poultry litter as fertilizer. This variable will be among those included in the sensitivity analysis.

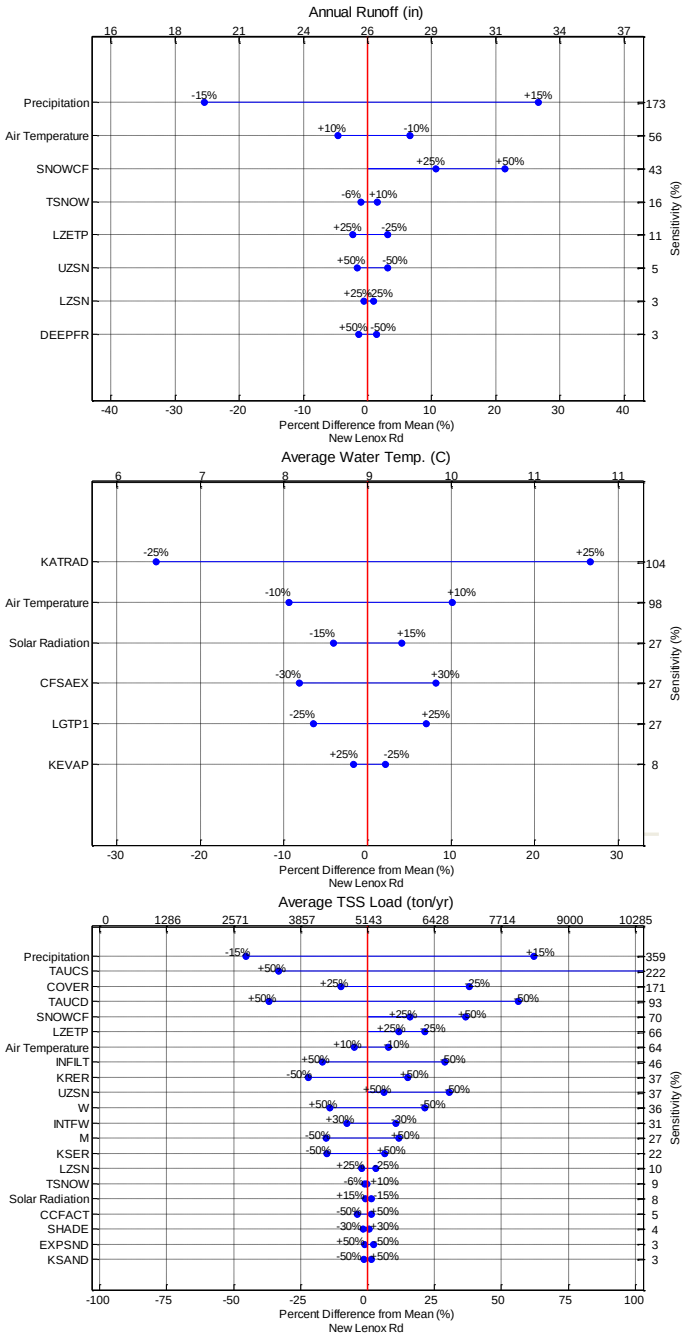


Figure 6.13 Example Tornado Diagrams at New Lenox Road (Donigian and Love (2007)
(Conversion Factors: 1 in = 2.54 cm; 35.3 cfs = 1 cms; 1 short ton = 0.907 metric tons)

6.4.3 Sensitivity Analysis of the EFDC Lake Model

Sensitivity analysis is a procedure to determine how lake model output changes with respect to changes in lake model input parameters. This analysis will provide information on the model response to changes in different model input parameters and coefficients. During the model calibration process a series of iterative adjustments are typically made to selected model coefficients to determine how changes in model input will affect model results. Based on this

iterative approach to model calibration, one set of model coefficients are identified to achieve overall acceptable model results. It is important to note that the parameter values assigned during model calibration must be within an accepted low to high range of the parameter where such data is available from the literature. The model calibration process thus provides important insight to the modeling team that informs the modeling team about the sensitivity of key model parameters and coefficients. Calibration and validation results of the EFDC model of Lake Tenkiller will be reviewed and evaluated to identify those model input parameters and kinetic coefficients to be considered for the sensitivity analyses. Key kinetic coefficients (e.g., algae growth rate) and model input parameters (e.g., settling velocity) expected to have the greatest effect on the water quality response of the calibrated EFDC lake model will be selected for review and approval in consultation with EPA Region 6. The sensitivity analyses (SA) of the EFDC lake model will be performed using accepted modeling practice by setting up a series of model runs based on a systematic low and high adjustment of selected key model coefficients and parameters. The baseline model calibration results are compared to the model results obtained for the low and high adjustment of model inputs to identify model sensitivity to the input variable. One model input variable that is of particular importance in the Illinois River Watershed and Lake Tenkiller is watershed loading of TP to the lake. Low and high ranges of HSPF watershed TP loading conditions will be provided as input for one of the variables selected for sensitivity analysis of the lake model.

Sensitivity analysis runs for the lake model will be constrained to changes in input data for watershed model TP loads and three (3) other EFDC model input parameters and kinetic coefficients. A total of four (4) model input parameters and eight (8) EFDC runs will be used for the sensitivity analyses. EFDC results will be compiled to evaluate sensitivity to state variables (e.g., dissolved oxygen, chlorophyll, TP) and derived output variables (e.g., TSI) that can be compared to water quality targets. EFDC results will be extracted for two (2) station locations identified as either impaired or located within the riverine, transition and lacustrine zones of the lake. EFDC sensitivity runs will be post-processed to provide time series, summary statistics (number of records, mean, and standard deviation) and frequency distributions reported for 5th, 25th, 50th, 75th and 95th percentile data. The EFDC sensitivity runs will be post-processed to compute sensitivity metrics to rank the relative impacts of changes to model inputs on changes to model results between the baseline calibration run and the sensitivity runs. The sensitivity metrics will be used to identify those model inputs determined to have the greatest impact on changes in model results, relative to the baseline set of results for model calibration, for each selected station location.

QA/QC procedures that will be followed for the Sensitivity Analysis will include visual inspection of time series plots, frequency distributions and tables of summary statistics prepared as part of the Sensitivity Analysis. Careful inspection and review of data products generated for the Sensitivity Analysis should help to identify any errors that may be introduced either in the setup of model input data or post-processing of the numerous files associated with the model results.

Procedures and methodologies used to perform the Sensitivity Analysis will be documented in a technical appendix to the lake modeling report.

6.5 Model Uncertainty

The funding of the Illinois River Watershed TMDL Development project includes the resources necessary for performance of uncertainty analysis.

When calibration and parameter sensitivity analysis are completed, the uncertainty in the calibrated model caused by uncertainty in the estimates of the model input parameters will be assessed. Formal uncertainty analyses for watershed model applications have not historically been done, largely due to the complexity and computational demands of most watersheds that are modeled. To address the need for uncertainty analyses while recognizing such restrictions when complex codes are involved, a previously used approach is to identify key parameters using a sensitivity analysis and then to focus on the model uncertainty associated with those parameters identified as most "sensitive." Typically in cases where uncertainty analysis is performed on watershed model applications, a Monte Carlo approach is utilized, and the same approach will be utilized for this project. An upper limit for model runs to support such an analysis in previous efforts has been approximately 600 runs, with a simulation span of ten years. To address the issue of parameter correlation, major parameters will be identified, and related parameters will be grouped and correlated in terms of any perturbation performed as part of the uncertainty analysis, and an appropriate correlation structure will be incorporated into the parameter perturbations generated for each model run. After confidence has been gained in the Monte Carlo methodology and procedures that have been established for a specific project, uncertainty in the model predictions will be expressed by calculating the 5th and 95th percentiles of the ranked output, representing the range for 90 percent of the model results. The differences between the mean value and the 5th and 95th percentiles values will be calculated, divided by the mean and expressed as percentages, and averaged to express uncertainty as the percent deviation from the mean. Normalizing to the mean allows for uncertainty comparisons to be made between the output variables.

A Draft Technical Memo on the proposed sensitivity and uncertainty analysis procedures has been developed and is currently being revised in response to EPA comments (Mishra and Donigian, 2013). The Tech Memo describes the proposed sensitivity and uncertainty analysis procedures in more detail, with specific reference to the sites and parameterization of the IRW model.

6.5.1 Uncertainty Analysis of the EFDC Lake Model

Uncertainty analysis is a procedure to determine the confidence limits or reliability of model predictions with respect to the errors associated with observations and a model. The uncertainty analysis of the EFDC lake model will be developed using a selected set of lake model runs, including, but not limited to, the calibration run and results of the sensitivity analysis to determine 90% confidence intervals around the calibration model results. In order to derive robust statistics for the uncertainty analysis, two additional sets of model runs will be setup based on middle-low and middle-high values for each model input parameter. Summary statistics (number of records, mean, and standard deviation) of model results will be time aggregated (e.g., stratified summer conditions) and used to derive the 90% confidence interval around the model calibration results to determine model uncertainty based on the four (4) model input parameters evaluated for the Sensitivity Analysis. Time aggregated summary statistics and the 90% confidence interval around the model calibration results will be developed to identify the uncertainty response of key model state variables (e.g., dissolved oxygen, TP, chlorophyll) to the range of input values (low, middle low, middle high and high) for each model parameter evaluated at the two (2) station locations for the Sensitivity Analysis.

The overall joint uncertainty of the EFDC lake model will be evaluated for the combined set of four (4) model input parameters (watershed TP load + 3 other model input parameters) using results of the calibration run, the sensitivity runs based on the low and high values, and the additional runs based on the middle low and middle high values. Pooled model results will be

used to compute summary statistics and 90% confidence intervals around the model calibration results. Summary statistics (number of records, mean, and standard deviation) and the 90% confidence interval for key variables of the lake model will be aggregated over time (e.g., stratified summer conditions) for the two (2) station locations selected for the Sensitivity Analysis.

Uncertainty in the lake model results will be expressed as the combined plus and minus uncertainty bounds about model outputs to a 90% confidence level. Uncertainty in the model predictions will be quantified by the 5th and 95th percentiles of the ranked model output, representing the range for 90 percent confidence of the pooled model results. The differences between the mean value and the 5th and 95th percentiles values will be calculated, divided by the mean value and expressed as percentages, and averaged to express uncertainty as the percent deviation from the mean. Normalizing to the mean value will allow for uncertainty comparisons to be made between the output variables (Donigian and Love, 2007).

QA/QC procedures that will be followed for the Uncertainty Analysis will include visual inspection of time series plots, frequency distributions and tables of summary statistics prepared as part of the Uncertainty Analysis. Careful inspection and review of data products generated for the Uncertainty Analysis should help to identify any errors that may be introduced either in the setup of model input data or post-processing of the numerous files associated with the model results.

Procedures and methodologies used to perform the Uncertainty Analysis will be documented in a technical appendix to the lake modeling report. The documentation, at the minimum, will include, but is not limited to, time series plots aggregated to daily summary statistics (i.e., 95% confidence interval around the baseline results) and data tables based on time aggregated summary statistics over the entire simulation period to define the 90% confidence interval around the overall mean value for key state variables (e.g., dissolved oxygen or chlorophyll-a) or derived model parameters (e.g., TSI).

6.6 Model Linkage

An integrated modeling framework using HSPF and EFDC will be used because no single model is capable of representing all the physical, biogeochemical, and biological processes that are relevant to the Illinois River Watershed study. The modeling framework consists of a watershed model (HSPF) that simulates runoff, sediment and nutrient washoff linked to a lake model (EFDC) that simulates detailed lake hydrodynamics, as well as sediment transport, nutrient fate and transport, oxygen depletion and eutrophication. The linkage between the models requires accommodation of both spatial and temporal issues since each model simulates different processes at different time and space scales. The physical domains of each model and the resulting transfer of information (i.e., model results) must be closely integrated to allow for the efficient operation and effective representation of the Illinois River Watershed study. Figure 6.14 illustrates an overview of the linkage of the outputs from the watershed model (HSPF) as water inflows and constituent loads from nonpoint sources (drainage basin runoff) and point sources (tributaries and wastewater dischargers), to the instream hydraulic, sediment transport and nutrient fate and transport submodel of HSPF, and finally to the lake hydrodynamic, sediment transport, and water quality model (EFDC). HSPF will provide EFDC with inputs for streamflow, water temperature, and loads for total suspended solids, inorganic

nutrients, dissolved oxygen, BOD, algae biomass and organic matter as carbon, nitrogen and phosphorus.

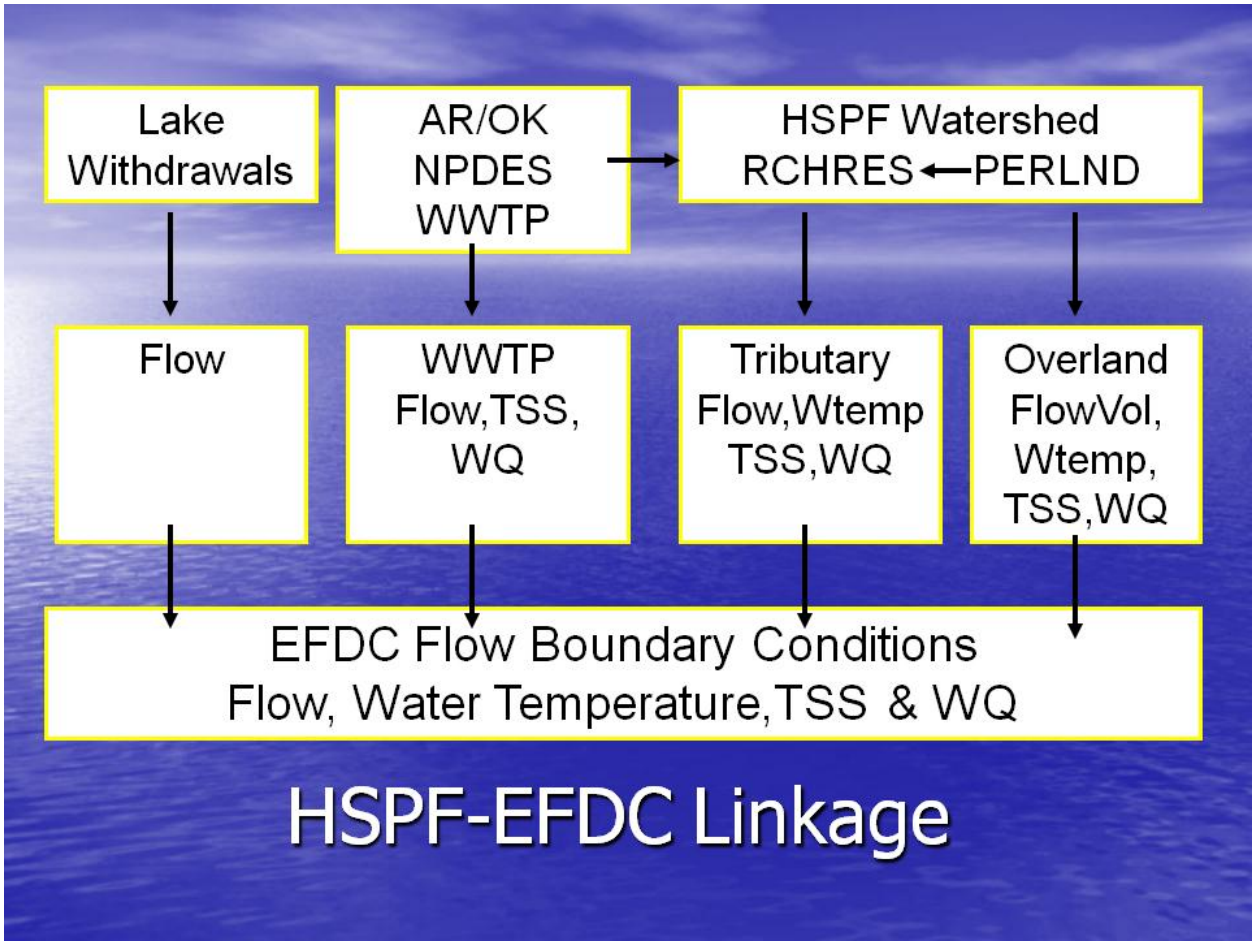


Figure 6.14 HSPF-EFDC Linkage for Illinois River and Lake Tenkiller Model Framework

The Simulation Plan (AQUA TERRA Consultants, 2013) presents a detailed description of the methodology and assumptions used to construct the data linkages for the model framework consisting of HSPF and EFDC. A brief overview of the methodology that is described in the Simulation Plan is as follows:

Using streamflow, water temperature, sediment, organic mattter and nutrient loadings provided by the watershed runoff model (HSPF), EFDC will simulate surface water elevation and water temperature with the hydrodynamic model. The EFDC sediment transport model will include one (1) class of inorganic solids as cohesive sediments since any sediment that remains suspended in the lake for any length of time is typically cohesive silts and clays. Bottom velocities will be internally linked from the hydrodynamic model to provide bottom stresses for deposition and resuspension processes. The EFDC water quality and eutrophication model will include organic carbon, inorganic and organic nutrients, algae, and dissolved oxygen. The water quality model includes internal coupling with a state-of-the-art sediment diagenesis model (Di Toro, 2001) to link *in situ* organic matter production and deposition with sediment fluxes of nutrients and oxygen.

A relevant scheme and software for linking the HSPF simulation of the Illinois River Watershed with the EFDC simulation of Lake Tenkiller has been previously developed and tested (DSLLC, 2006). Since the linkage between the models is complex, it was essential to design procedures to ensure that the linkages maintained proper mass balances of constituents. Although the QA/QC tests that were performed to ensure that the linkages between HSPF (Illinois River Watershed) and EFDC (Lake Tenkiller) perform correctly were not extensively documented in the previous study, the guiding principle was the strict requirement to maintain a mass balance of water volume, heat content, inorganic solids, organic matter, and nutrients provided by HSPF to EFDC. The nature and approach of QA/QC testing that was performed evolved from the approach used in a similar collaboration of AQUA TERRA Consultants and Dynamic Solutions for HSPF-EFDC linkage for the Housatonic River PCB Modeling Study (Beach et al., 2000).

Since completion of the Housatonic River project and the previous Illinois River watershed and Lake Tenkiller modeling study, Dynamic Solutions has been involved in a number of surface water modeling projects where HSPF and EFDC have been selected to build linked surface water model frameworks. To facilitate data processing needed for the HSPF-EFDC linkage, Dynamic Solutions has developed custom software, including an interface for EFDC_Explorer (Craig, 2012), to provide a systematic approach for the linkage of flow boundary conditions from HSPF and boundary conditions obtained from other data sources (e.g., wastewater dischargers, lake withdrawals) to provide boundary condition files formatted for input to the EFDC model. Using time series data for flow and loads provided by the HSPF model, the data linkage software maps HSPF state variables to the corresponding EFDC state variables. Once the HSPF output data is mapped as EFDC input data, the linkage software generates a mass balance inventory of flows and loads for each HSPF boundary location. The mass balance generated with the linkage software will be checked against an independent mass balance accounting of HSPF boundary flows and loads. The independent mass balance check is used to either confirm that the EFDC boundary loading data matches the input HSPF data or that a discrepancy in the data transformation needs to be resolved before data is accepted for input to the EFDC model.

Linkage of the results generated by the HSPF model for input to EFDC requires that the AQUA TERRA and Dynamic Solutions modeling teams work closely together to ensure a clear understanding of the state variables used in both models so that the HSPF output can be correctly mapped for input to the EFDC model. For watersheds represented by a tributary reach, the HSPF model will simulate flow, water temperature, TSS, algae biomass, CBOD, dissolved oxygen, ammonia-N, nitrate+nitrite-N,refractory organic-N, orthophosphate-P,refractory organic-P, and refractory organic-C. For watersheds represented as overland flow and loads, the HSPF model will simulate runoff flow, water temperature, TSS, dissolved oxygen, ammonia-N, nitrate+nitrite-N, orthophosphate-P, and total organic matter. Total organic matter will then be split to derive labile organic matter (as equivalent CBOD) and refractory organic matter (as equivalent C,N,P) using appropriate stoichiometric ratios for labile and refractory fractions of total organic matter, carbon-to-dry weight, oxygen-to-carbon, carbon-to-nitrogen and carbon-to-phosphorus. The output results from HSPF will be written in the standard ASCII file (*.PLT) file format available as an output option for HSPF. In the HSPF model, CBOD accounts for labile organic matter and total organic matter (as carbon, nitrogen and phosphorus) accounts for refractory organic matter. Linkage of labile organic matter (as CBOD) and refractory organic matter from HSPF to total organic matter in EFDC is accomplished by assigning stoichiometric ratios for CBOD(Ultimate)-to-CBOD5 (U/5) and oxygen-to-carbon (2.67 mg C/mg O2), carbon-to-nitrogen (5.7 mg C/mg N) and carbon-to-phosphorus (41.1 mg C/mg P) to convert CBOD (Ultimate) to equivalent forms of labile organic matter (as C,N,P). The labile organic C,N,P is added to refractory organic C,N,P to compute the combined labile and refractory components of

TOC, TON and TOP. The schematic diagram (Figure 6.15) shows the linkage procedure that will be used for total organic carbon. A similar procedure will be used for the linkage of organic phosphorus and organic nitrogen by assigning carbon-to-nitrogen and carbon-to-phosphorus stoichiometric ratios to convert labile BOD to the equivalent organic nutrient form. Fractional splits, representative of watershed runoff for the Illinois River Basin, will be assigned to transform TOC, TON and TOP to obtain dissolved and particulate labile/refractory components for input to EFDC. Linkage of HSPF state variables for streamflow, water temperature, suspended solids, dissolved oxygen, ammonia-N, nitrate+nitrite-N and orthophosphate-P from HSPF to EFDC is straightforward with no transformations needed other than conversions of runoff volume and flow to cubic meters/sec and water temperature to Deg-C. Linkage of HSPF algae biomass to EFDC algae biomass as organic carbon will be performed using stoichiometric ratios for carbon-to-dry weight (0.45 mg C/mg DW) and a carbon-to-chlorophyll ratio appropriate for watershed derived algal biomass. The carbon-to-chlorophyll ratio will be based either on site-specific Illinois River watershed data sets or on data identified in the literature for similar ecoregion watersheds in northwest Arkansas and northeast Oklahoma.

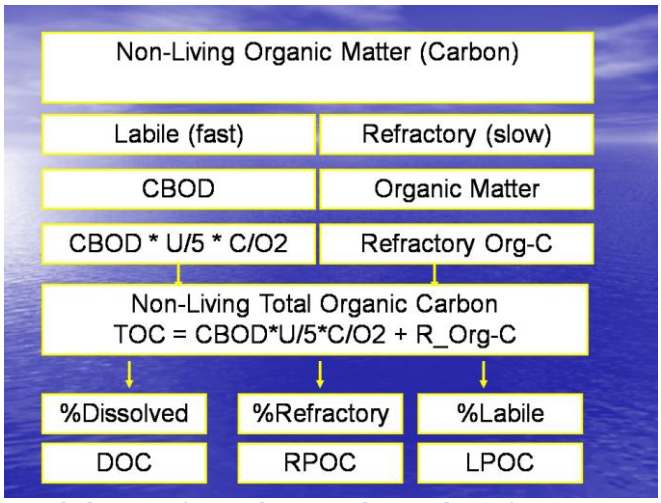


Figure 6.15 Linkage of Total Organic Carbon from HSPF to EFDC

6.7 Nutrient Load Reduction Scenario Modeling

The HSPF-EFDC model framework for this study will, after the models are calibrated and validated, be used to assess the effectiveness of alternative load reduction scenarios and compliance with Oklahoma water quality criteria for (a) Total Phosphorus (TP) in streams and (b) water quality targets in Lake Tenkiller. The calibrated HSPF-EFDC model framework will be used to assess the effectiveness of alternative load reduction scenarios of TP, TN and/or TSS and compliance with (a) Arkansas/Oklahoma stateline water quality criteria for TP in streams and (b) water quality targets in Lake Tenkiller. Based on 2005-2006 (OWRB, 2011a) OWRB assessments of compliance with criteria for the lake, water quality targets include hypolimnetic dissolved oxygen, chlorophyll-a and Trophic State Index (TSI). Lake Tenkiller is designated as a Nutrient Limited Water (NLW) by the State of Oklahoma and compliance with the designated use for aesthetics is defined by the Trophic State Index where TSI is computed from chlorophyll-a (OWRB, 2011b; 2011c).

The load reduction scenarios will be primarily focused on changes to the IRW watershed model, through changes to the HSPF model inputs, while the EFDC model of Lake Tenkiller will be used to assess lake impacts of the HSPF watershed load reduction scenarios. Based on a uniform percent reduction of TP, TN, and/or TSS (i.e., across the board), up to ten (10) scoping

scenarios for load reduction will be developed with the watershed HSPF model. The modeling team will review the watershed load reduction scenarios and coordinate with EPA Region 6 to identify the load reduction scenarios selected for input to the Lake Tenkiller EFDC model for an assessment of the lake impacts. If further refinements to the selected scoping scenarios for load reduction are needed, the modeling team will coordinate with EPA Region 6 for the selection of no more than five (5) additional refinements of HSPF load reduction scenarios. This process will be completed progressively as a means of assessing and identifying the appropriate number of load reduction scenarios for evaluation with the lake model. Prior to conducting EFDC modeling to assess the impacts of the additional selected scenarios on Lake Tenkiller, the modeling team will coordinate with EPA Region 6 on the selection of up to ten (10) additional EFDC load reduction scenarios. The total number of EFDC load reduction scenarios to be simulated shall be no more than ten (10) model runs including those chosen from the initial scoping scenarios and the HSPF refinement scenarios.

QA/QC procedures that will be followed for the Nutrient Load Reduction evaluations will include visual inspection of time series plots, frequency distributions and tables of summary statistics prepared as part of the Nutrient Load Reduction Scenarios. Careful inspection and review of data products generated for the Nutrient Load Reduction Scenarios should help to identify any errors that may be introduced either in the setup of model input data for a load scenario or post-processing of the numerous files associated with the model results.

SECTION 7.0

DATA ACQUISITION

To perform watershed and lake modeling, the Baker Team will use necessary secondary data collected from other sources including Baker Team member, AQUA TERRA's in-house databases. From previous projects, a large amount of data, reports, and information has been provided to EPA Region 6 for use in this study as a result of initial data requests and acquisition efforts, and subsequent responses from the State and federal agencies and other stakeholders. This includes both time-variable (e.g. meteorological data, stream flow, water quality, point sources) and GIS data (e.g., land use, topography, hydrography), along with an extensive array of reports and studies performed on or within the Illinois River Watershed. In addition, this information has also provided citations for other supplemental reports and studies identified through online searches and investigations. The data available to support the project has been summarized in a report entitled "Preliminary Data Review and Analysis for Water Quality Modeling and TMDL Development for the Illinois River Watershed (AQUA TERRA Consultants, 2010).

7.1 Review of Secondary Data

Data sources have undergone final review as a part of the completed data quality assessment under the previous project. On an as- needed basis, new data sources will be reviewed as part of the modeling tasks. When quality objectives are provided with data sets from EPA and other agency sources, the corresponding data have been assumed to have met those quality objectives. That is to say, it has been assumed that these data have been subject to the standard QA/QC procedures of the source agency, unless there is evidence to the contrary. In consultation with the EPA TOPO, the Baker Team will continue to evaluate the secondary data and corresponding quality objectives received from EPA and other sources to determine whether the data are acceptable for use in performing watershed and/or lake modeling to support development of TMDLs.

Data used in the project are predominantly available in electronic form. Raw data received in hard copy format will be entered into the project data base. Baker Team personnel will compare all entries to the original hard copy data sheets. As is the protocol with already existing electronic, data sets, screening methods will be used to scan through the data set and flag data that are outside typical ranges for the data type. The Baker Team will not use values outside typically observed ranges to develop model calibration data sets or model kinetic parameters. Data quality will be further assessed by performing the data and model evaluations described in Sections 4.0 and 6.0 to determine whether to accept, reject or qualify the data. Results of the review and validation processes will be reported to the EPA TOPO.

7.2 Data Sources Performance and Acceptance Criteria

EPA's Guidance QA/QC guidance document *Guidance on Systematic Planning Using the Data Quality Objective Process* (QA/G-4) (EPA, 2006) differentiates two different sets of DQO Process guidelines: one for data used directly for making *decisions* and one for data used for *estimation*. The body of data that we are screening for the Illinois River Watershed modeling project falls within the category of *estimation* data, since the collective function of the data is to estimate watershed characteristics and conditions.

QA/G-4 identifies the causes of bias for environmental sampling and analysis:

1. Non-representative sampling (or application of sampling results)
2. Instability or contamination of samples between sampling and analysis
3. Interferences and matrix effects in analysis
4. Inability to determine the relevant forms of the parameter being measured
5. Calibration (machine)
6. Failure to blank correct

The list above provides a useful reference in understanding and establishing an approach to screening the data that have been collected for this study. For our purposes the list of six items above can be lumped into three data screening issues:

- Issue #1: Is a data set (or certain values within a data set) appropriate for consideration/inclusion in the process of characterizing one or more environmental forcing functions or model parameters used for watershed characterization *or* for model calibration and validation?
- Issue #2: Does the available metadata or documentation indicate appropriate protocol was followed in the sampling effort that generated the data set?
- Issue #3: Does the available metadata or documentation indicate that laboratory analyses that generated the data values were performed by certified personnel and accredited laboratories?

Regarding Issues #2 and #3 above, the Baker Team is dependent upon the detail and accuracy of the QA/QC information that accompanies the individual data sets collected to potentially support this study. The Baker Team routinely examines the supporting information and metadata for data sets for evidence that appropriate sampling and analysis protocols have been used.

Issue #1, however, requires additional comment. It is important to note that the Illinois River Watershed modeling effort will utilize data that are representative of the calibration period in the initial effort to calibrate and validate the model. Subsequently data representative of *current watershed conditions* will be used to simulate and evaluate alternative management strategies superimposed against the current conditions. For each of these conditions there are an additional layer of spatial considerations that must be addressed. Watershed modeling always entails using a combination of analysis and professional judgment to interpret and integrate available data so that the landscape can be represented by sets of parameter values that describe current conditions within each of the modeling areas (land segments, channel reaches). QA/G-4 refers to this issue as “defining the scale of inference” for data collected and used for estimation. Necessary to this process is using a “weight of evidence” approach that inherently places a higher level of confidence/representativeness on certain data sets than on others. The Model Simulation Plan will provide additional description of this process and will serve as the documentation of its application to the study.

Data to be used as input to the modeling effort will be judged acceptable for their intended use if they meet acceptance criteria. As described above, the Baker Team, in consultation with the EPA TOPO, will determine the factors to be evaluated to determine whether the data provided in secondary sources are acceptable for use in developing, calibrating, or testing the models for this project. Acceptance criteria that will be used for this project will include data reasonableness, completeness, representativeness, and comparability.

- Data reasonableness: Data sets will be checked for reasonableness. Flow gaging data obtained from USGS have undergone quality review for reasonableness. This is not always the case for water quality data and graphical methods will be used to evaluate potential anomalous entries that may represent data entry or analytical errors. In addition, all dates will be checked through queries to ensure that no

mistyped dates (e.g., 8/24/1900) and corresponding information are loaded into the models without clarification from the agency from which the data were collected.

- Data completeness: Data sets will be checked to determine if any data are missing. In any complex model study, it is inevitable that there will be some data gaps. These data gaps and the assumptions used in filling the gaps will be documented for inclusion in the technical reports.
- Data representativeness: Sampling station data will be checked through queries and mapping to ensure that no mistyped geospatial data (e.g., locations outside the watershed in question) and corresponding information are loaded into the models without clarification from the agency from which the data were collected. In addition, acceptance criteria will be obtained from any existing QAPPs, sampling and analysis plans, standard operating procedures (SOPs), laboratory reports, and other correspondence for a given source of measurement data, if available. The data assessment and quality guidelines associated with a given type of measurement will be developed from these sources and included in the documentation.
- Data comparability: Data sets will be checked with respect to variables of interest, commonality of units of measurement, and similarity in analytical and QA procedures. The Baker Team will ensure additional comparability of data by similarity in geographic, seasonal, and sampling method characteristics.

SECTION 8.0

HARDWARE/SOFTWARE CONFIGURATION

The majority of the work conducted by the Baker Team for performing watershed and lake modeling will involve acquiring and processing data and generating reports and documents, all of which require maintaining computer resources. The Baker Team computers are either covered by on-site service agreements or serviced by in-house specialists. When there is a problem, in-house computer specialists diagnose the trouble and correct it if possible. When outside assistance is necessary, the computer specialists call the appropriate vendor. In-house computer specialists perform routine maintenance on computers. Electric power to each computer flows through a surge suppressor to protect electronic components from potentially damaging voltage spikes. The Baker Team network servers are backed up nightly during the week. Screening for viruses on electronic files loaded on computers or the network is a standard protocol for both firms. Automated screening systems are updated on a regular schedule to ensure that viruses are identified and destroyed promptly.

HSPF will be implemented through the WinHSPF version available within the US EPA BASINS Modeling System.

EFDC will be implemented using DSLLC version of EFDC_DS source code that is available from the DSLLC website (www.efdc-explorer.com). The full version of the EFDC_Explorer software, available from the DSLLC website, will be used as the pre-and post-processor software interface for model setup and calibration of the EFDC model of Lake Tenkiller.

It is essential that version control on model executables be strictly maintained to ensure reproducibility of results. Any modifications that may be needed to the publicly available executable versions of these models are expected to address only data storage/array size or data input/output formats for automation. If such modifications are implemented, they will be subject to detailed code verification, as described in CREM (2009) and USEPA (2002). If needed, specific tests will be proposed and documented in a revision to this QAPP. Currently, it is not anticipated that either HSPF or EFDC will need to be modified in order to accommodate the necessary modeling efforts for this project.

SECTION 9.0

REFERENCES

AQUA TERRA Consultants. 2010a. Quality Assurance Project Plan for Water Quality Modeling and TMDL Development for the Illinois River Watershed. Prepared for US EPA Region 6, Dallas, TX and US EPA Office of Science and Technology, Washington DC. EPA Contract #EP-C-06-029 with AQUA TERRA Consultants, Work Assignments #3-36 and #4-36.

AQUA TERRA Consultants. 2010b. Preliminary Data Review and Analysis for Water Quality Modeling and TMDL Development for the Illinois River Watershed. Prepared for US EPA Region 6, Dallas, TX and US EPA Office of Science and Technology, Washington DC. EPA Contract #EP-C-06-029 with AQUA TERRA Consultants, Work Assignments #3-36 and #4-36.

AQUA TERRA Consultants. 2013, Quality Assurance Project Plan: Modeling QAPP. Prepared for Us EPA Region 6, Dallas, TX, EPA PO # EP-11-6-000023. Submitted June 12, 2013.

AQUA TERRA Consultants. 2013. Simulation Plan for Water Quality Modeling and TMDL Development for the Illinois River Watershed. Prepared for US EPA Region 6, Dallas, TX. EPA PO # EP-11-6-000023. Submitted May 24, 2013.

AQUA TERRA Consultants. 2007. AQUA TERRA Consultants Quality Management Plan Version 1.0. March, 20, 2007. Available from AQUA TERRA Consultants for review.

Beach, R.B., J. S. Clough, P. M. Craig, A.S. Donigian, R.A. McGrath, R.A. Park, A. Stoddard, S.C. Svirsky, and C.M. Wallen. 2000. Quality Assurance Project Plan - Modeling Study of PCB Contamination in the Housatonic River. DCN:GE-100500-AADY. Prepared by R. F Weston, Inc, for the U.S. Army Corps of Engineers, New England District, Concord MA, (USACE Contract No. DACW33-00-D-0006) and U.S. EPA, Region I, Boston, MA (EPA Contract No. 68-C-98-010 with AQUA TERRA Consultants)

Berthouex, P. M. and L. C. Brown. 1994. Statistics for Environmental Engineers. Lewis Publishers, CRC Press, Boca Raton, FL. 335 p.

Bicknell, B.R., J.C. Imhoff, J.L. Kittle Jr., T.H. Jobes, and A.S. Donigian, Jr. 2005. Hydrological Simulation Program - Fortran (HSPF). User's Manual for Release 12.2. U.S. EPA National Exposure Research Laboratory, Athens, GA, in cooperation with U.S. Geological Survey, Water Resources Division, Reston, VA.

Blumberg, A.F. and G.L. Mellor. 1987. A description of a three dimensional coastal ocean circulation model. In: Three Dimensional Coastal Ocean Models, Coastal and Estuarine Science, Vol. 4, Heaps, N.S., Ed. American Geophysical Union, pp. 1 19.

Blumberg, A.F., L.A. Khan and J. St. John 1999. Three-dimensional hydrodynamic model of New York Harbor Region. Jour. Hydraulic Engineering Div. , Proc. ASCE, 125(8):799-816, August.

Bora, D.K. and M. Bera. 2003. Watershed-scale hydrologic and nonpoint-source pollution models: Review of mathematical bases. Trans. of ASABE, 46(6):1553-1566.

Carlson, R.E. (1977). A trophic state index for lakes. Limnol. Oceanogr. 22:361-369.

Cooke, D.B. and E.B. Welch. 2008. Eutrophication of Tenkiller Reservoir, Oklahoma and Effects on Water Quality and Fisheries. Expert Report of Dr. G.D. Cooke and Dr. E.B. Welch.

Prepared for State of Oklahoma in Case No. 05-CU-329-GKF-SAJ State of Oklahoma v. Tyson Foods, et al. (in the United States District Court for the Northern District of Oklahoma).

Cooke, D.B., E.B. Welch, and J.R. Jones. 2011. Eutrophication of Tenkiller Reservoir,Oklahoma, from nonpoint agricultural runoff. Lake and Reservoir Management, 27:3, 256-270.

Corral, J., B. Haggard, T. Scott and S. Patterson (2011). Potential alum treatment of reservoir bottom sediments to manage phosphorus release. Poster presentation at Arkansas Water Resources Center 2011 Annual Watershed and Research Conference, July 6-7, 2011, Fayetteville, Arkansas.

Council for Regulatory Environmental Modeling (CREM), EPA/100/K-09, March 2009, "Guidance on the Development, Evaluation, and Application of Environmental Models." (EPA 2009). http://www.epa.gov/crem/library/cred_guidance_0309.pdf

DSLLC, P.M. 2006 Tenkiller Ferry Lake Water Quality Modeling Analysis in Support of TMDL Development for Tenkiller Ferry Lake and the Illinois River Watershed in Oklahoma. EFDC Model Calibration. Draft Letter Report prepared by Dynamic Solutions, LLC, Knoxville, TN for Oklahoma DEQ, Oklahoma City, OK.

Craig, P.M. 2012. User's Manual for EFDC_Explorer7: Pre/Post-Processor for the Environmental Fluid Dynamics Code (Rev 00), Dynamic Solutions, LLC, Knoxville, TN.

Crawford, N. H., and R. K. Linsley. 1966. Digital simulation on hydrology: Stanford Watershed Model IV. Stanford University Tech. Rep. No. 39. Palo Alto, Cal.: Stanford University.

Delft. 2007. Delft3D-RGFGRID Generation and Manipulation of Curvilinear Grids for FLOW and WAVE. User Manual. Delft Hydraulics, Rotterdamseweg, Netherlands.

Di Toro, D.M. 2001. *Sediment Flux Modeling*. Wiley-Interscience, John Wiley & Sons, Inc., New York, NY, 624 pp.

Donigian, A. S., Jr., and H. H. Davis. 1978. User's Manual for Agricultural Runoff Management (ARM) Model. Report No. EPA-600/3-78-080. Athens, Ga.: U.S. EPA Environmental Research Lab.

Donigian, A. S., R. A. Park, and J. S. Clough. 2009. Tenkiller Ferry Lake Modeling Case Study - HSPF and AQUATOX. Office of Water/Office of Science and Technology, U.S. Environmental Protection Agency, Washington DC.

Donigian, A.S. Jr. and J.C. Imhoff. 2010. Model Selection for the Illinois River TMDL in AR/OK. Technical Memorandum prepared by AQUA TERRA Consultants for EPA Region 6. EPA Contract No. EP-C-06-29, Work Assignment No. 4-36. November 22, 2010. pp. 33.

Donigian, A.S. Jr. and J.T. Love 2007. The Housatonic River Watershed Model: Model Application and Sensitivity/Uncertainty Analysis. 7th International IWA Symposium on System Analysis and Integrated Assessment in Water Management, May 7-9, 2007. Washington, DC. WATERMATEX Proceedings on CD-ROM.

Donigian, A.S. Jr. and P.S.C. Rao. 1990. Selection, Application, and Validation of Environmental Models. Proceedings of International Symposium on Water Quality Modeling of Agricultural Nonpoint Sources. Part 2. June 19-23, 1988. Logan, UT. USDA-ARS Report No. ARS-81. D. G. Decoursey (ed). pp 577- 604

Donigian, A.S. Jr. 2002. Watershed Model Calibration and Validation: The HSPF Experience. WEF National TMDL Science and Policy 2002, November 13-16, 2002. Phoenix, AZ. WEF Specialty Conference Proceedings on CD-ROM.

Donigian, A.S. Jr., B.R. Bicknell, A.S. Patwardhan, L.C. Linker, C.H. Chang, and R. Reynolds. 1994. Chesapeake Bay Program - Watershed Model Application to Calculate Bay Nutrient Loadings: Final Findings and Recommendations (FINAL REPORT). Prepared for U.S. EPA Chesapeake Bay Program, Annapolis, MD. 283 p.

Donigian, A.S. Jr., B.R. Bicknell, and J.C. Imhoff. 1995. Hydrological Simulation Program - FORTRAN (HSPF). Chapter 12. In: Computer Models of Watershed Hydrology. V.P. Singh (ed). Water Resources Publications. Littleton, CO. pp. 395-442.

Donigian, A.S., J.T. Love. 2003. Sediment Calibration Procedures and Guidelines for Watershed Modeling. WEF TMDL 2003, November 16-19, 2003. Chicago, Illinois. WEF Specialty Conference Proceedings on CD-ROM.

Donigian, A.S., Jr., J.C. Imhoff, B.R. Bicknell and J.L. Kittle, Jr. 1984. Application Guide for the Hydrological Simulation Program - FORTRAN EPA 600/3-84-066, Environmental Research Laboratory, U.S. EPA, Athens, GA.

Donigian, Jr., A.S. 2000. HSPF Training Workshop Handbook and CD. Lecture #19. Calibration and Verification Issues, Slide #L19-22. EPA Headquarters, Washington Information Center, 10-14 January, 2000. Presented and prepared for U.S. EPA, Office of Water, Office of Science and Technology, Washington, D.C.

Donigian, Jr., A.S., J.C. Imhoff, and J.L. Kittle, Jr. 1999. HSPFParm, An Interactive Database of HSPF Model Parameters. Version 1.0. EPA-823-R-99-004. Prepared for U.S. EPA, Office of Science and Technology, Washington, DC. 39 p.

Duda, P.B., J.L. Kittle, M.H. Gray, P.R. Hummel, R.S.Kinerson, P. Cocca, D. Wells, M. Wellman, E. Partington, L. MacWilliams. 2003. BASINS 4.0 - Flexible Integration of Components and Data for Watershed Assessment and TMDL Development. WEF TMDL 2003, November 16-19, 2003. Chicago, Illinois. WEF Specialty Conference Proceedings on CD-ROM.

Dzialowski, A.R. and L. Carter 2011. Predicting internal nutrient release rates from Central Plains reservoirs for use in TMDL development. Final Report, Project Number: X7 97703801, Dept. Zoology, Oklahoma State University, Stillwater, OK, Submitted to U.S. Environmental Protection Agency, Region 7, TMDL Program, Water Quality Management Branch, Kansas City, KS.

EPA. 2001. EPA Requirements for Quality Management Plans, EPA QA/R-2. EPA/240/B-01/002. U.S. EPA Office of Environmental Information, Washington, DC.

EPA. 2006. Guidance on Systematic Planning Using the Data Quality Objectives Process – EPA QA/G-4. U.S. EPA Office of Environmental Information, Washington, DC.

EPA. 1999. EPA Requirements for Quality Assurance Project Plans – EPA QA/R-5. U.S. EPA Office of Environmental Information, Washington, DC.

EPA. 2002. Guidance for Quality Assurance Project Plans for Modeling - EPA QA/G-5M. EPA/240/R-02/007. U.S. EPA Office of Environmental Information, Washington, DC.

Fisher, J.B. 2008. Expert Report. Prepared for State of Oklahoma in Case No. 05-CV-329-GKF-SAJ State of Oklahoma v. Tyson Foods, et al. (in the United States District Court for the Northern District of Oklahoma).

Fisher, J.B., R.L. Olsen, F. M Soster, B. Engle and M. Smith 2009. The history of poultry waste contamination in the Illinois River watershed as determined from sediment cores collected from Tenkiller Ferry Reservoir (Oklahoma, United States). Proc. 2009 International Symposium Environmental Science and Technology, Shanghai, China, June 2-5.

Haggard, B.E. and T.S. Soerens. 2006. Sediment phosphorus release at a small impoundment on the Illinois River, Arkansas and Oklahoma, USA. Ecol. Eng'r. 28:280-287.

Haggard, B.E., D.R. Smith and K.R. Brye. 2007. Variations in stream water and sediment phosphorus among select Ozark catchments. J. Environ. Qual. 36(6):1725-1734.

Haggard, B.E., P.A. Moore and P.B. DeLaune. 2005. Phosphorus flux from bottom sediments in Lake Eucha, Oklahoma. J. Environ. Qual. 34:724-728.

Hamrick, J.M., 1992. "A Three-Dimensional Environmental Fluid Dynamics Computer Code: Theoretical and Computational Aspects," Special Report No. 317, Applied Marine Science and Ocean Engineering, Virginia Institute of Marine Science, Gloucester Point, VA. 64 pg.

Hamrick, J.M., 1996. User's Manual for the Environmental Fluid Dynamics Computer Code. Special Report No. 331 in Applied Marine Science and Ocean Engineering, Virginia Institute of Marine Science, Gloucester Point, VA.

Hupfer, M. and J. Lewandowski. 2008. Oxygen controls the phosphorus release from lake sediments- a long-lasting paradigm in limnology. Internat. Rev. Hydrobiol. 93(4-5):415-432.

Hydrocomp, Inc. 1977. Hydrocomp Water Quality Operations Manual. Hydrocomp, Inc., Palo Alto, CA.

Ji, Z-G. (2008). Hydrodynamics and Water Quality Modeling Rivers, Lakes and Estuaries. Wiley Interscience, John Wiley & Sons, Inc., Hoboken, NJ, 676 pp.

Johanson, R. C., J. C. Imhoff, and H. H. Davis, Jr. 1980. User's Manual for Hydrologic Simulation Fortran Program-FORTRAN (HSPF). Research Grant No. R804971-01. Office of research and development. U.S. Environmental Protection Agency, Athens, GA

Lahlou, M., L. Shoemaker, S. Choudhury, R. Elmer, A. Hu, H. Manguerra, and A. Parker. 1998. Better assessment science integrating point and nonpoint sources: BASINS Version 2.0. EPA-823-B98-006. Washington, D.C.: U.S. EPA. Available at www.epa.gov/OST/BASINS. Accessed 3 October 2002.

Lumb, A.M., R.B. McCammon, and J.L. Kittle. 1994. User's manual for an expert system (HSPEXP) for calibration of the Hydrologic Simulation Program–Fortran. Water Resources Investigation Report 94-4068. USGS, 1994.

McCuen, R. H. and W. M. Snyder. 1986. Hydrologic Modeling: Statistical Methods and Applications. Prentice-Hall, Englewood Cliffs, NJ. 568 p.

Mishra, A. and A.S. Donigian, Jr. 2013. Methodology andProcedures for Sensitivity and Uncertainty Analyses of the Illinois River Watershed (IRW) model. Prepared by AQUA TERRA Consultants, Mountain View, CA. Technical Memo submitted to Quang Nguyen, EPA Region 6, Dallas TX. September 24, 2013.

Olsen, R.B. 2008. Expert Report. Prepared for State of Oklahoma in Case No. 05-CV-329-GKF-SAJ State of Oklahoma v. Tyson Foods, et al. (in the United States District Court for the Northern District of Oklahoma).

OWRB 2008. 2007-2008 Oklahoma's Lakes Report. Beneficial Use Monitoring Program. Oklahoma Water Resources Board, Oklahoma City, OK. http://www.owrb.ok.gov/quality/monitoring/bump.php

OWRB 2011a. *2010 - 2011 Oklahoma's Lakes Report. Beneficial Use Monitoring Program*. Oklahoma Water Resources Board, Oklahoma City, OK http://www.owrb.ok.gov/quality/monitoring/bump/pdf_bump/archives/2010-2011_LakesBUMPReport.pdf

OWRB 2011b. Oklahoma Water Resources Board. Oklahoma's Water Quality Standards. Title 785, Chapter 45. July 1, 2011.

OWRB 2011c. Implementation of Oklahoma's Water Quality Standards. Title 785, Chapter 46. July 1, 2011.

Park, K., A.Y. Kuo, J. Shen and J.M. Hamrick. 1995. A Three-Dimensional Hydrodynamic-Eutrophication Model (HEM-3D): Description of Water Quality and Sediment ProcessSubmodels(EFDC Water Quality Model). Special Report in Applied Marine Science and Ocean EngineeringNo. 327, School of Marine Science, Virginia Institute of Marine Science, College of William and Mary, Gloucester Point, VA.

Sen, S., B.E. Haggard, I. Chaubey, K.R. Brye, T.A. Costello and M.D. Matlock. 2007. Sediment phosphorus release at Beaver Reservoir, northwest Arkansas, USA, 2002-2003: a preliminary investigation. Water, Air & Soil Pollution 179:67-77.

Sheng, Y. P. 1987. On modeling three-dimensional estuarine and marine hydrodynamics. In: Three-Dimensional Models of Marine and Estuarine Dynamics. New York: Elsevier Oceanography Series, Elsevier, pp. 35–54.

Sheng, Y. P. 1990. Evolution of a three dimensional curvilinear-grid hydrodynamic model for estuaries, lakes and coastal waters: CH3D. In: Proceedings of the First International Conference on Estuarine and Coastal Modeling. (ASCE, Newport, Rhode Island), pp. 40–49.

Socolow, R.S., C. R. Leighton, J. L. Zanca, and L. R. Ramsey 1997. Water Resources Data, Massachusetts and Rhode Island: Water Year 1997. Water-Data Report MA-RI-97-1. U.S.G.S Water Resources Division, Marlborough, MA.

Storm, D. E., M. J. White, and M. D. Smolen. 2006. Illinois River Upland and In-stream Phosphorus Modeling Final Report. Pages 74 + Appendices. Department of Biosystems and Agricultural Engineering, Oklahoma State University, Stillwater OK.

Storm, D. E., P. R. Busteed, A. R. Mittelstet, M. J. White. 2009. Hydrologic Modeling of the Oklahoma/Arkansas Illinois River Watershed Using SWAT 2005. Submitted to Oklahoma Department of Environmental Quality. Biosystems and Agricultural Engineering Department, Division of Agricultural Sciences and Natural Resources, Oklahoma State University. 208 pp.

Tetra Tech, 2007. The Environmental Fluid Dynamics Code User Manual, US EPA Version 1.01, Tetra Tech, Inc., Fairfax, VA.

Tetra Tech 2009. Quality Assurance Project Plan for Watershed Modeling to Evaluate Potential Impacts of Climate and Land use Change on the Hydrology and Water Quality of Major U.S. Drainage Basins. Prepared for U.S. EPA Office of Research and Development Global Climate Research Program, Washington DC.

Veenstra, J.N. and S. L. Nolen 1991. In-situ sediment oxygen demand in five southwestern U.S. lakes. Water. Research, 25(3):351-354.

Welch, E.B., G.D. Cooke, J.R. Jones, and T.C. Gendusa. 2011. DO-Temperature habitat loss due to eutrophication in Tenkiller Reservoir, Oklahoma. Lake and Reservoir Management, 27:271-285.

Wells, S.A, V.I. Wells and C. J. Berger 2008. Water Quality and Hydrodynamic Modeling of Tenkiller Reservoir.Expert report prepared for State of Oklahoma in Case No. 05-CU-329-GKF-SAJ State of Oklahoma v. Tyson Foods, et al. (in the United States District Court for the Northern District of Oklahoma).

Wischmeier, W.H. and D.D. Smith. 1978. Predicting Rainfall-Erosion Losses: A Guide to Conservation Planning. Agricultural Handbook No.537. U.S. Department of Agriculture, Agricultural Research Service, Washington, DC. 58 p.

Zar, J.H. 1999. Biostatistical Analysis. 4th Edition. Prentice Hall, Upper Saddle River, NJ.

APPENDIX A. STAKEHOLDER RESPONSE RECORDS

This section, the contents of which was prepared by AQUA TERRA from other projects under EPA Contract EP-11-15-000023 and EP-G126-00097 contracts, documents AQUA TERRA's responses to stakeholders' comments on the project's Modeling QAPP (June 2012). It is included in this version of the Modeling QAPP for the current project to serve as a reference only and provide additional historical background. It should be noted that some of the responses may not be relevant anymore with respect to the context of the current project because of changes in the project's team, scope, and schedule.

Additional Explanatory Note from AQUA TERRA: The 'response records' provide a one-to-one record of stakeholder comments and contractor response/actions. In some cases a comment resulted in an elaboration in the Modeling QAPP, and if this is the case that fact and the nature of the change are noted in the response record. In other cases it was mutually agreed upon with EPA Region 6 that it was inappropriate to incorporate or respond to a comment in the Modeling QAPP itself. Accordingly, a response is noted in the record, but not in the QAPP.

The comments and responses are organized according to the following:

A. Arkansas Department of Environmental Quality

B. Oklahoma Department of Environmental Quality

C. Rogers Utility District

D. City of Siloam Springs

E. Dr. Karen Mills

A. Arkansas Department of Environmental Quality Comments Dated 11/10/11)

1. Section 2.0 Problem Definition/Background: This paragraph describes changes that have occurred in Arkansas related to "fast-growing urban areas" and "intensive agricultural animal production." There have been changes in Oklahoma that should be similarly described. Further the geomorphological characteristics of the Illinois River in Arkansas are vastly different than that of the Illinois River in Oklahoma. These differences should be characterized.

   We don't believe that this request is falls within the charge that we have been given.

2. Page 8 notes that 1992 and 2001 land use data will be used. Even though the model will be calibrated and a sensitivity analysis performed conditions in the area have changed significantly from those dates and ADEQ questions the usefulness or appropriateness of the data.

   Since the draft version of the modeling QAPP was written, the modeling team has gained access to 2006 NLCD land use data, and it will be used in the modeling effort.

3. Modeling QAPP Section 6.1.3: The draft appears to indicate that simplified soil erosion and municipal runoff subroutines will be used. ADEQ staff questions whether the simplified subroutines are appropriate and representative of conditions in Northwest Arkansas and Northeast Oklahoma given the potential TP contributions from soil erosion.

   There is simply not enough data available, or resources to support the use of the more detailed HSPF AGCHEM formulations for land use types other than pasture.

B. Oklahoma Department of Environmental Quality Comments Dated 10/20/11

- The project timeline seems a bit ambitious: modeling and scenarios by Nov 2011 and establishment of TMDL by May 2012. How confident are we in meeting those dates and what if we can't?
  EPA has revised the project timeline to accommodate these concerns, and a revised schedule has been integrated into the Modeling QAPP. The new timeline allows greater opportunity for stakeholder involvement, as well as external peer review.

- There are no descriptions on the TMDL end points, i.e., what the water quality goals are in the lake and in the stream, and how the TMDL will use the models to design load reduction scenarios to achieve these goals? The simulation plan briefly describes the end points issue (last four paragraphs of Section 6.4). Will there be a separate QAPP for

the TMDL process to more comprehensively address this issue? If not, the current QAPP should do so.

The Illinois River Watershed is a complex watershed with a large drainage area and with multiple land uses and multiple contaminant sources contributing to each impaired waterbodies. The watershed consists of a large network of lake, channel, stream and river systems. There are a number of waterbodies in the watershed that are on each state's 303(d) list for the general pollutant category of "nutrients". The EPA project goals are to develop a model as representative of the Illinois River Watershed as possible for use in developing one or more TMDLs for the watershed. These TMDLs will set waste load allocations and load allocations needed to attain the Oklahoma standards at the state line and at the Lake Tenkiller. Therefore, at the minimum, the OK standard of the state line (0.037 mg/l), and Lake Tenkiller Water Quality Standards for DO, Chl a, and Carlson's Trophic State Index will be considered for the TMDL development. Specifically, the TMDL development for the IRW will be performed through a series of models runs, or "scenarios", representing alternative conditions on the watershed. Through an iterative process, the impacts of each individual proposed scenario through-out the watershed will be assessed. Impacts due to proposed Phosphorus load reductions at the state line, Lake Tenkiller and impaired water-bodies will be assessed and used as a basis to develop one or more TMDLs for the watershed (Please see Section 6.4 of the Simulation Plan for details).

- Second to the last line of Page 4, what is a "WAL"? And the third line of the last paragraph on Page 15, what is a "WAM"?

  The WAL (Work Assignment Leader) and WAM (Work Assignment Manager) titles are inconsistent with the funding mechanism used for this work. These terms have been replaced with "Project Leader" and "Project Manager" throughout the document.

C. Rogers Water Utilities Comments Dated 10/21/11

1. Page 10 states: "It is worth noting that supplemental data quality assessment will be achieved within the context of the initial model simulations. It is common practice to identify and correct problems associated with various data sets and data types when potential problems are revealed by unexpected or unrealistic simulation results during the early stages of model setup and calibration." Comment We have some concerns about modifying a data set in order to match model simulation results. Please explain the types of changes to the data that would be made at this stage of the process. We would like more information on the nature of the corrections that may be made as part of this process and how these corrections will be documented.
   The process of 'data correction' as it is described here is not directed at attempting to 'match' simulation results. Initial simulations offer an opportunity to detect problems such as (1) using data expressed in improper units, (2) using data

that mistakenly offer a significant misrepresentation of reality (e.g., point sources with zero values for temperature), or (3) using time series data that has missing values that must be filled in using best professional judgment and techniques.

2. Page 11. Section 3.6. Table 3.1 lists the deliverables schedule for various reports and the modeling effort. Comment: The table does not identify when stakeholder comments will be addressed. All final documents, including QAPP's and the Data Report were scheduled for completion in September 2011; however, most documents are still in draft form. Is the deliverables schedule being re-evaluated and will consideration be given for additional time for Aqua Terra to address stakeholders' comments prior to model development?

   EPA has revised the project timeline to accommodate this concern, and a revised schedule has been integrated into the Modeling QAPP. The new timeline allows greater opportunity for stakeholder involvement and response to stakeholder comments, as well as an external peer review.

3. Page 17, "To a large extent the quality of the modeling study is determined by the expertise of the modeling and quality assessment teams, in addition to the available data. The ultimate test of quality for this study, however, is that the model output is a sufficiently accurate representation of the natural system to address the site-specific study objectives/data quality objectives listed below." Comment: We agree that this is one of the fundamental questions for the project: "are the data and model sufficiently accurate to estimate the reductions in loads that are necessary to achieve such a low phosphorus standard? We have interest in the level of confidence achievable for the model results and believe that a thorough uncertainty analysis is needed for this purpose.

   We agree. EPA has subsequently provided funding to the modeling team to perform uncertainty analysis. The description in the Modeling QAPP has been updated to reflect this.

4. Page 17. "The proposed modeling study design was developed to (1) represent the full range of physical, chemical, and biological processes of concern for phosphorus fate and transport in the Illinois River Watershed.... The determination of whether the DQOs have been achieved is less straightforward for a modeling study than for the more typical sampling and analysis type of study. The usual data quality indicators (e.g., completeness, accuracy, precision) are difficult to apply and in many cases do not adequately characterize model output..." Question: Are the model representations of these processes and model outputs sufficiently accurate to simulate very low instream phosphorus concentrations?

   HSPF contains operational state-of-the-art science algorithms for representing nutrient dynamics, including phosphorus dynamics. We have confidence that the model can accurately represent very low instream phosphorus concentrations.

5. Page 20. "HSPF was selected for the watershed because it provides a strong dynamic (i.e. short time step, hourly) hydrologic and hydraulic model simulation capability, and a moderately complex instream fate and transport simulation of sediment and phosphorus, both of which we linked to soil nutrient and runoff models..." Comment: We

have some questions about how well HSPF simulates the land-based generation of pollutants, their entrainment into the runoff, transport to the receiving water, and the removal of these pollutants by BMPs.

Please continue to ask them – we'll do our best to answer. We note that the sensitivity and uncertainty analyses that will be performed for this study will provide further insight into the relative impact that various washoff and instream model parameters exert on achieving accurate fate and transport results.

6. Page 22 bullet list

"c. The HSPF soil nutrient models provide a complete mass-balance approach for simulating nitrogen and phosphorus balances and runoff components, with detailed nutrient cycling of both organic and inorganic nutrient forms. This capability allows a direct connection between nutrient application rates from chemical fertilizers, manure, and poultry litter, and subsequent soil buildup and potential runoff to rivers and streams, from applied pasture lands, subject to limitations of the available data."

"d. The sediment transport and instream water quality capabilities of HSPF provide a moderately complex process-based representation of the fate and transport processes for nutrients, including phosphorus, along with sediment-nutrient interactions, scour/deposition impacts with the sediment bed, and combined uptake/cycling of phosphorus by algae and DO/BOD processes."

Comments on c & d: How accurate are these capabilities, particularly with regard to characterizing inter-storm and intra-storm processes?

Based on the modeling results achieved by previous use of HSPF capabilities for very similar modeling applications to the Illinois River application, we believe that the algorithms will provide appropriate results for both inter-storm and intra-storm components of the current application.

7. Page 4. "For runoff loadings of water quality constituents, HSPF provides alternative methods, among which the user can select, to calculate loadings either with simple, empirical build-up and washoff algorithms used in the PQUAL subroutine, or the detailed mass balance formulations used within the group of subroutines within the dashed-line box marked as AGCHEM." and Page 24: "For the IRW application of HSPF, we plan to utilize the AGCHEM subroutines for the pasture lands that are the primary recipients of fertilizer, manure, and litter applications, and then use the simpler PQUAL routines for all other land uses." Comment We have some concerns about buildup-washoff algorithms because it is not clear whether they adequately simulate the intra-event storm load from a watershed.

Based on the modeling results achieved by previous use of the buildup-washoff functions for very similar modeling applications to the Illinois Rive application, we believe that the algorithms will provide appropriate results for the current application.

8. Page 33. "For water quality constituents, model performance will be based primarily on visual and graphical presentations as the frequency of observed data will likely be

inadequate for accurate statistical measures." Comment: This is important to keep in mind with regard to the accuracy of simulated water quality results and reinforces the need for uncertainty analysis.

We agree. Again, EPA has subsequently provided funding to the modeling team to perform uncertainty analysis.

9. Page 34. "The objective of the calibration effort for the Illinois River Watershed HSPF model is to establish parameter values that produce the best overall agreement between simulated and observed values throughout the calibration period." Comment: How will "best" be determined, especially in light of the fact that "the frequency of observed data will likely be inadequate for accurate statistical measures."

Common modeling practice is to define the 'best' calibration as the one that is most consistent with the 'weight of evidence'. The weight of evidence approach is elaborated in the following paper:

Donigian, A.S. Jr. and J.C. Imhoff. 2009. Evaluation and Performance Assessment of Watershed Models. WEF TMDL 2009, August 9 - 12, 2009. Minneapolis, MN. WEF Specialty Conference Proceedings on CD-ROM.

10. Page 35. "A complete hydrologic calibration involves a successive examination of the following four characteristics of the watershed hydrology, in the order shown: (1) annual water balance, (2) seasonal and monthly flow volumes, (3) baseflow, and (4) storm *events.* Simulated and observed values for reach characteristic are examined and critical parameters are adjusted to attain acceptable levels of agreement (discussed further below)." Comment: What parameters are adjusted if the simulated storm hydrology does not produce the measured runoff?

The parameters that represent infiltration, interflow, upper zone storage and lower zone storage are critical to calibrating runoff volume.

The watershed is very large; how will spatial variation in storm precipitation *be* handled? This area of the country gets severe local thunderstorms that will produce heavy runoff from some areas and not from other areas. We think this is important in calculating the spatial variation of the pollutant mass washed into the receiving waters.

In Oklahoma, where traditional rain gage data were used, representation of thunderstorms depends on the density of the gage network as compared to the spatial characteristics of the thunderstorms. The Simulation Plan identifies the rain gage network used for modeling. In Arkansas gridded NEXRAD data were used; in theory these data offer a higher likelihood of capturing localized differences in rainfall; however, our analysis of the NEXRAD data suggested that at least some of the data provided for the watershed may be in error.

11. Page 38. "Sediment calibration follows the hydrologic calibration and must precede water quality calibration. Calibration of the parameters involved in simulation of watershed sediment erosion is more uncertain than hydrologic calibration, due to the comparably smaller number of sediment simulations that have been performed in different regions of the country."...and..."In HSPF, the erosion process is represented as

the net result of detachment of soil particles by raindrop impact on the land surface, and then subsequent transport of these fine particles by overland flow." Comment: These processes are important potential sources of error that warrant careful attention. How is instream bank erosion calculated and how is the difference between channel erosion and watershed erosion distinguished? Instream water quality results reflect the sum of these two sources.

Bank erosion is not explicitly represented in HSPF, as a separate channel process. However, it is implicitly included in the channel scour processes as the shear stress and scour is calculated on the wetted perimeter of the stream reach, including both the channel bed and banks. For each modeled channel reach, mass loading summaries of eroded watershed sediment from each land use type (or their sum) are computed, and a mass balance is performed showing nonpoint and point sediment loads, upstream inflow loads, downstream outflow loads, and net deposition or scour. Data sources and studies in the IRW are being investigated to identify, locate and quantify bank erosion so that the model can accommodate and represent this source.

12. Page 39. "The strategy that will be used to simulate nutrients for the Illinois River Watershed study will utilize both schemes, with BOD, nitrate and ammonia simulated as a function of runoff rate and phosphate simulated using...." Comment: How will organic nitrogen, i.e. Kjeldahl N be simulated?

The organic materials that are represented as watershed washoff entities are essentially lumped surrogates. The edge-of-stream washoff loadings are fractionated into commonly modeled and monitored instream nutrient constituents using stoichiometric relationships, and these nutrient constituents are then introduced into the channel network where their fate and transport are estimated using algorithms that are specific to each nutrient form.

13. Page 41. "Observed stormwater concentrations for each contaminant will be compared with model results, and the pollutant loading rates by land use category will be compared with the expected ranges available from the literature and past modeling studies, in a manner analogous to the sediment loading calibration." Comment: Will the "expected ranges from literature and past modeling studies" be focused on those conducted in the Illinois River Watershed and/or comparable watersheds in geographic proximity?

Professional judgment will be exercised in selecting the most representative and most reliable source(s) of available data. It would be ideal if extensive efforts (with a high degree of documented QA/QC) had been made within the modeled watershed to develop pollutant loading rates for its many land uses, but this is rarely the case. Some information will be available locally, but realistically we expect there will be a need to use loading rate information from outside the watershed for some of the land uses.

14. Page 54. "The current scope and funding of the Illinois River Watershed TMDL Development project does not include performance of uncertainty analysis. However, if the scope is subsequently expanded..." As stated at the beginning of this comment letter, this is a fundamental issue. Only uncertainty analysis can tell what impact the uncertainty in a model parameter or estimate of pollutant loading will have on the certainty of the simulated in-stream quality.

EPA has subsequently provided funding to the modeling team to perform uncertainty analysis. The description in the Modeling QAPP has been updated to reflect this.

D. City of Siloam Springs Comments Dated 10/24/11

1. Sections 3.5 and 3.6 of the QAPP discuss the public comment opportunities and deliverable schedule. There will be a draft TMDL provided for stakeholder review somewhere around December 2011. The OWRB is in the process of reviewing their scenic rivers phosphorus standard (0.037 mg/L) and **are** not expected to conclude the process for approximately six months (April 2012). Should the TMDL proceed with the potential for the standard at the State line to change in about six months? This issue needs to be addressed and the Simulation Plan and QAPP amended.

   EPA has revised the project timeline to accommodate this concern as well as other time-sensitive issues. A revised schedule has been integrated into the Modeling QAPP. The new timeline will allow an opportunity for the OWRB decision on this matter to be reflected in the phosphorus load reduction scenarios that are modeled and the TMDLs that are established.

2. Section 6.2 discusses model calibration. Considerable effort is expended in describing how soil (sediment) and associated nutrients will leave an agricultural site in an HRU and enter the stream channel. How will the original source of the nutrients leaving the site be determined? Will it be assessed as a ratio of pounds applied per acre per source type? The different composition of manures (cattle, hog, poultry, etc.) and commercial fertilizers provide for a different integration into the soils and ultimately a different rate of export into the stream channel. How this issue will be addressed in the modeling should be addressed in the Simulation Plan and the QAPP.

   There is little discussion of how sediment and nutrient loads from urban land uses will be applied in the model. It is of significant importance that accurate storm loading from urban areas be included as a source in the TMDL. Urban areas have been shown to contribute high levels of nutrients (higher than some agricultural watersheds) to stream systems and to contribute unnaturally high peak flows that have a dramatic affect on channel scour and bank erosion.

   Collectively, the set of questions above seek a description of (1) how nutrient source terms for agriculture will be established and (2) how nutrient source terms for urban land use will be established and the resulting loadings modeled. These questions fall outside the scope of the modeling QAPP. As of September 2013 final decisions have not been made; when they are made they will be answered in a revised version of the Simulation Plan or a technical memorandum.

   This section also discusses in-stream sediment transport calibration as it relates to particle size and channel shear. The calibration will evaluate sediment loading overall and during storm event hydrographs. In order to accurately represent sediment transport from a storm event it is necessary to have in-stream data, during that event, for water quality, flow, velocity, and cross sectional measurements so that shear stress can be calculated accurately. It is unlikely that such storm specific data is available from

the existing historical data being used to develop this model. Therefore, the data should be collected in the field for use in the calibration.

Based on modeling experience elsewhere, in situations where we have comparable supporting data to that already available for the Illinois River, the modeling team believes that we can satisfactorily establish critical shear stress through calibration.

There is no discussion of the data source for stream shading to be used in the algal routines in the HSPF model. Stream shading is a key element for determination of benthic algae biomass, and its use should be discussed thoroughly in the Simulation Plan.

This question falls outside the scope of the modeling QAPP. This will be discussed in the Simulation Plan as suggested by the above comment.

3. Section 6.4 of the QAPP describes the sensitivity analysis that will be completed as part of the TMDL modeling. A complete list of parameters that will be varied for the sensitivity analysis is not included in the QAPP or in the Simulation Plan. Therefore, a list of critical parameters that must be evaluated for sensitivity is included below. This list is not all inclusive but should be considered a critical starting point.

   a. shear stress (scour potential and deposition potential)
   b. channel depth
   c. velocity (or slope)
   d. algal growth rate
   e. shading
   f. erosion rate from pasture
   g. urban land use loading
   h. poultry litter application rate
   i. cattle manure application rate
   j. BMP effectiveness
   k. POTW loading
   l. Rainfall run-off rate
   m. Addition of an unknown source representing at least 25% of the annual load to Lake Tenkiller (to account for bank erosion if it is not integrated into the model).

The modeling team appreciates this list and will certainly give it careful consideration in establishing the final list of parameters that will be subjected to sensitivity analysis. EPA has not yet decided on future procedures for providing documentation of modeling details such as the above. Either additional revisions of the Simulation Plan will be made available for review, or perhaps one or more technical memoranda will be released for comment.

4. Section 4.3 discusses model performance criteria and sums up the key question that should be carefully considered before the TMDL is completed. "Are the model results, as reflected in the calibration and validation comparison, of sufficient quality to be used in decision making for this study?" Or, should the modeling be put on hold until sufficient data/information can be collected to ensure the results are of "sufficient quality". Further

discussion and consideration of these fundamental questions must be brought forward in the public participation process.

Both EPA and the modeling team agree with this comment.

E. Dr. Karen Miles Comments Dated 11/10/11

- The preface made it sound as if this is a new QAPP. If the previous one was accepted by EPA that is problematic since errors in the previous draft are still in this one. Is EPA Region 6 not mandating that AQUA TERRA follow the requirements outlined in R5? [EPA Requirements for Quality Assurance Project Plans (http://www.epa.gov/quality/qs-docs/r5-final.pdf).] For example, AQUA TERRA is still using numbers instead of letters (R5 is dated 2001 so the outline format has been in place for a long time), there is no distribution list, and an unacceptable document control format in the header (See section 3.2.2 of R5 of what is supposed to be in Section A2, Table of Contents).

  We can understand the source of confusion regarding these formatting questions. During the first two years of the Illinois River TMDL project, the funding mechanism was a longstanding contract that AQUA TERRA had with EPA Office of Water, Office of Science and Technology. The conventions that we used for the Project QAPP that preceded this Modeling QAPP are those that were agreed upon with OST's QAPP Coordinator and used over the 13 years that we held this contract. The relationship of the Modeling QAPP to the Project QAPP is explained in the Preamble to the Modeling QAPP. A few notes specific to issue mentioned in this comment:

  - **Although a final decision has not been made, it is our understanding that the Modeling QAPP will in its final form be adopted as an appendix to the Project QAPP. It was necessary for the Project QAPP to be developed and implemented at an earlier stage than could have been achieved by waiting until the model selection process was completed. It is for this reason that the Modeling QAPP does not include a repetitive distribution list – the distribution list is already a component of the Project QAPP.**

  - **Given that the Project QAPP was developed using a number, rather than a letter organizational scheme and that the intent is to combine the two documents, we opted to avoid confusion by preserving the number scheme in the Modeling QAPP.**

  - **The control format header that we have used was again consistent with that adopted for all the QAPPs that we developed for the OW OST contract.**

  - **We also preserved the OW OST convention of omitting sections of the R5 guidance that we did not believe were relevant to the scope of work that was being performed for the Illinois River Project – perhaps this needs to be clarified in the Preamble.**

- R5 says that Section A5 (Problem definition/Background) is supposed to, "Include sufficient background information to provide a historical, scientific, and **regulatory** perspective for this particular project." Though the AQUA TERRA QAPP in 2.0 says segments of the Illinois River are on the 303(d) list for TP, the QAPP gives neither the regulatory citation nor the regulatory limit here. The limit isn't given until page 8.

The suggestion to introduce text that addresses the regulatory perspective has been implemented in the revised Modeling QAPP.

- There is no mention about the actual PROBLEM in the Problem Definition Section. It talks about various animals (the word "chicken" is not used anywhere in this 67-page document), about rivers in the area, and about Oklahoma having a TP limit that is not given. Nothing in here about nutrients or NPS pollution.

  Different stakeholders have different perspectives on the magnitude and impact of various point and nonpoint sources to the resulting nutrient concentrations in the Illinois River. The modeling effort will offer clarification. The addition to the section made to address the comment directly preceding this one introduces the existence of nutrient impairments.

- There is supposed to be a section *A6 - Project/Task Description* which provides maps or tables that show or state the geographic locations of field tasks. A map showing the study area, including impaired/unimpaired areas, should have been included.

  Part of the confusion in this review originates from misunderstanding of the division of information between the Modeling QAPP and the Simulation Plan. Maps of the type that are identified as missing from the Modeling QAPP are included in the Simulation Plan. It should be noted, however, that there are no "field tasks" associated with this project. Perhaps this misconception is tied to a preconception that primary data are being collected.

- In the last QAPP, it said, "AQUA TERRA Quality Assurance Officer develops the QAPP." I commented that was a problem since the QAPP is supposed to be generated by those who generate the data since a QA Officer cannot be objective if they are developing the QAPP. This time they just omitted completely who wrote the QAPP.

  This appears to be a minority opinion, and one that originates from familiarity with writing QAPPs for collection of primary data, not modeling studies. This project does not require generation of data. Regarding the issue of company QA officers writing QAPPs for modeling projects, our experience for well over a decade has been that this is the rule rather than the exception. The primary authors of modeling QAPPs in both small and very large consulting firms are the QA Officers.

- In Section 3.0 on Page 6, the QAPP says, "*Five technical tasks **have either been completed**, or remain to be completed for **this** project*." QAPPs are supposed to describe what the project is going to be, not what has been done.

  Our experience in recent years is that various QA personnel within EPA are favoring QAPPs that are "living documents". For Office of Water we have developed QAPPs for multi-year projects that required us to summarize the accomplishments and activities of each previous year as we developed the QA/QC requirements for a new set of activities in the current year. For an EPA OW/ORD project completed last year the EPA WAMs and QA Officers agreed that the most useful product for the agency was a living QAPP that was actually the only written product for the project – all technical documentation was provided as appendices to the QAPP. Our experience is that EPA is growing smarter as an agency in terms of allowing flexibility that

results in more useful products. They are moving past trivial concerns such as whether letters or numbers are used to organize QAPP contents.

- Section 4 is supposed to be A7, Quality Objectives and Criteria. But the meat of what is supposed to be in this section is missing. For example, **there is no acceptance criteria** even though the title of this section included in it, "The Criteria for Model Inputs/Outputs". In a secondary data QAPP like this, the acceptance criteria needs to be specified to insure that there is quality data going into the project. According to G5-M[1], Section A7 is to include "Acceptance criteria focus on whether data generated outside of the project are acceptable for their intended use on the project (e.g., as input to a model)." This has to identify the secondary sources that will be used in the model and what criteria are being used to decide if that data is acceptable or not.

  We believe that this comment has merit. Part (but not all) of the concern is attributable to the fact that three documents were developed for this project, each of which contains information relevant to this subject: the Project QAPP, the Modeling QAPP and the Simulation Plan. For example, the Project QAPP provides a table that identifies the types of secondary environmental data that need to be assembled for watershed and water quality modeling in the Illinois River Basin. The Simulation Plan contains many pages of detail that identify most (but not all) secondary data that will be used by the models. It has been our goal to avoid repeating an excessive amount of the information that these three documents provided; at the same time not doing so requires stakeholders to read multiple documents in order to locate the full body of information that is provided.

  There is a second issue embedded in this comment, that issue being how determinations will be made of whether to include certain potentially relevant data sets as part of the Illinois River Watershed Model. As noted in the Preamble to the Modeling QAPP, the information it contains is supplemental to that contained in the Project QAPP. The Project QAPP provides the primary description of the procedures that have been used to assess the quality of candidate data.

  Most data used in the project will have been collected or developed by a variety of sources commonly used for watershed model development. Often these data will be available in electronic format and will include metadata that will be valuable for assessing the QA/QC imposed on the data collection and processing. In cases where multiple sources of data are available, the team will use the best available data with the highest quality. Data of unknown quality will be incorporated into the model only if approved by the EPA project manager, and the data's inclusion status will be documented. If there is no information available regarding the data, the data will either not be used or qualified with, "The quality of this specific secondary data set used in developing the watershed model could not be determined."

  Finally, to the best of our knowledge a comprehensive set of explicit decision criteria for the many data types used in complex watershed modeling has neither been developed nor applied. There is simply too much professional judgment involved in understanding the context and purpose for which individual data sets are potentially

[1] G5-M is the EPA Guidance document based in R5 but specific for modeling projects. See: http://www.epa.gov/quality/qs-docs/g5m-final.pdf

being used in a specific modeling effort to allow consistent protocols for making such decisions. Even the most detailed QAPPs that we have seen developed by other highly reputable firms for high visibility projects do not contain explicit decision criteria for specific types of data.

- Since the acceptance criteria is not addressed then the following are also not addressed which must be included in A7 according to G5-M,

    - *The statistical criteria (e.g., limits on decision error) to be used in the model-building process to identify those variables considered statistically important to the prediction process and included as input to the model;*

    - *desired limits placed on the probability of making a certain type of decision error due to the uncertainty associated with the model output (if a decision is to be made) and/or criteria to demonstrate the model performs adequately (e.g., as well or better than a previously accepted model for a given situation);*

    - *how the parameter, input, calibration, and test data necessary for this project are acquired and evaluated for use in model development and/or in producing output;*

    - *requirements associated with the hardware/software configuration (e.g., run time or processing capabilities) for those studies involving software evaluation.*

  Regarding the first two bullets, we would welcome examples of realistic and effective establishment, application and documentation of such criteria and limits for a complex watershed modeling project. Armed with successful examples, we would be in a position to provide cost estimates to our client for carrying out the process – our initial impression is that this would be cost prohibitive, explaining the absence of documentation of such activities in any literature that we've reviewed.

  We feel we've satisfied the third bullet. Granted, there are hundreds of model parameters, and we have not provided the basis for establishing value for many of them. That would be another exercise that many clients are not willing to fund.

  The Modeling Team is comprised of firms that are very experienced in running and configuring the model software with appropriate hardware to achieve effective model applications. The hardware/software configuration plan is included in Section 8 of the Modeling QAPP.

- This is one of the most important sections of the QAPP because as G5-M states, "While DQOs state the user's data needs relative to a given decision, corresponding criteria need to be placed on the data to determine whether the data have satisfied these needs. For modeling projects, such quality criteria can be placed on outcomes such as software performance (e.g., run time or processing capabilities) and model prediction (e.g., acceptable level of uncertainty associated with model prediction, relative to decision error). This element of the QA Project Plan links the DQOs with appropriate *data quality indicators (DQIs)*, which measure features of data quality such as precision (i.e., variability in data

under prescribed similar conditions), bias (i.e., systematic error), accuracy, representativeness, completeness, and comparability. Although the level of rigor with which this is done and documented within the QA Project Plan can vary widely depending on the particular type of modeling project, this linkage represents an important advancement in implementing quality assurance."

Section 7.2 addresses these issues.

- Instead of these requirements for DQO and DQI, this QAPP just had vague language. The DQOs in this QAPP consisted of just these seven lines :

  Objectivity—all work should be based on a methodology and utilize a set of evaluation criteria that can be explicitly stated and applied.
  Thoroughness—all elements of the study should be carried out and documented in a thorough manner.
  Consistency—all work should be performed and documented in a consistent manner.
  Transparency—the documentation will make it clear the sources of the data used, the assumptions used in the modeling, and the results obtained.

  This section had other vague language such as, "Data of known and documented quality." What data? Known by whom? How was the quality documented? In looking at what were called DQOs above, it said that the "documentation" would make clear the sources and assumptions used in the modeling. That is supposed to be here in this QAPP.

  For this project we followed the same convention that we have for other intensive modeling efforts for EPA, particularly those that required extensive documentation: we included the identification and discussion of the data sources and use assumptions in the Simulation Plan, not the QAPP.

- Section 4 said, "The quality assurance process for this type of study consists of using appropriate data, data analysis procedures, modeling methodology and technology, administrative procedures, and auditing." How is "appropriate" defined? Nothing here about that. All these items are supposed to be addressed - not just mentioned.

  Collectively the Project QAPP, the Modeling QAPP, the Simulation Plan and the Model Selection Memorandum comprise 226 pages of front-end description of our dedication to "using appropriate data, data analysis procedures, modeling methodology and technology, administrative procedures and auditing." All of this precedes setting up and running the models. Afterwards the evaluation process includes sensitivity and uncertainty analyses. We do not feel that we have "just mentioned" the quality assurance process. We welcome and will respond to direction from EPA to further develop any area(s) of our front-end documentation.

- Since the next section in the IR Modeling QAPP is "Documents and Records", that means that the information that is supposed to be in A8 is missing. According to R5 3.2.8, "***A8 - Special Training/Certification:*** *Identify and describe any specialized training or certifications needed by personnel in order to successfully complete the project or task. Discuss how such training will be provided and how the necessary skills will be assured and documented*.

As the Preamble to the Modeling QAPP describes, the document provided *supplemental* information to that provided in the Project QAPP. It is intentional that this section is missing – it is already contained in the Project QAPP.

- From text in the QAPP, consideration was given to which model would be used. Because of that, these records should be included according to G5-M: *If candidate models are assessed as part of a model selection process, certain documentation (e.g., code verification, testing results, user's guide, application examples) are needed to ensure that the model selected meets necessary acceptance criteria, such as criteria placed on hardware/software configuration*.

  This comment introduces a fourth relevant document: AQUA TERRA's model selection memorandum dated 11/22/10. This memo provides extensive (36 pages) rationale and documentation of the model selection process. Perhaps EPA will opt to include the memorandum as an additional appendix to the Project QAPP. If so we will revise the Modeling QAPP to include reference to the appendix.

- Because the proper format wasn't used, the QAPP's Section 6.2 is supposed to be B7. In Section 6.2 it says, "*Calibration and validation of the Illinois River Watershed models will be achieved by considering qualitative and quantitative measures, involving both graphical comparisons and statistical tests… Statistical procedures will be applied as appropriate, including error statistics, correlation and model-fit efficiency coefficients, and goodness-of-fit tests*." The problem here is that the statistical level that would be considered "acceptable" in these tests was never specified in the data quality objectives. As a result, any result with this undefined, fuzzy language could be considered "acceptable' according to this section.

  Formatting decisions have already been addressed elsewhere. The comment is correct in stating that statistical levels that are considered "acceptable" are not defined. This is because watershed modeling experience has shown that pre-defining acceptability for statistical test results is a tricky business. It is established professional practice to consider the results of statistical tests in conjunction with the other evaluation techniques that are listed, and a "weight of evidence" approach is used to judge the acceptability of the model calibration/validation.

- Section 6.2 discusses many inputs that will go into the model with no discussion whatsoever of the sources of that data, why that particular data source was chosen, and why that data source collected the data in the first place. In a secondary data QAPP like this one, the primary element of the QAPP is supposed be, according to Table 9, Chapter 3, of G5 (http://www.epa.gov/quality/qs-docs/g5-final.pdf), Section B9 which contains information on existing data, their intended uses, and their limitations. This section is also supposed to include the acceptance criteria **for <u>specific</u> data sources** that were supposed to be introduced in A7 - Quality Objectives and Criteria.

  <u>Many hundreds</u> of parameters and data sets will be used to develop the watershed and lake models. We believe that discussion of why each data component was selected is an unjustified expectation, given how labor intensive the effort would be. It is our understanding that EPA intends to make the model input available to both the Peer Review Panel and to the stakeholders (upon request). This mechanism should

provide ample opportunity for answering and documenting questions related to specific data components.

Again, to the best of our knowledge a comprehensive set of explicit acceptance criteria for the many data types used in complex watershed modeling has neither been developed nor applied. There is simply too much professional judgment involved in understanding the context and purpose for which individual data sets are potentially being used in a specific modeling effort to allow consistent protocols for making such decisions. Even the most detailed QAPPs that we have seen developed by other highly reputable firms for high visibility projects do not contain explicit decision criteria for specific types of data.

- The information on Page 57 was supposed to be in Section A7.

Note that we already referred readers of Section 'A7' to Section 7.2 (including page 57) for further discussion.