Quality Assurance Project Plan:

Modeling QAPP

EPA PO # EP-11-6-000023

AQUA TERRA Project # 21004

TMDL Development for the Illinois River Watershed in Arkansas and Oklahoma

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This document is a Modeling QAPP that is a companion document to the general Illinois River Water Quality and TMDL Development quality assurance project plan (QAPP) (AQUA TERRA Consultants, 2010a). 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). AQUA TERRA Consultants and its subcontractors will conduct work in conformance with the quality assurance program described in the Quality Management Plan for the contract and with the procedures detailed in the general project QAPP and this Modeling QAPP.

This Modeling QAPP is one of the contractor requirements and is used to communicate to all interested parties the QA/QC procedures that will be followed to ensure that the quality objectives for the Illinois River watershed modeling project are achieved throughout this multi-year project. The Modeling QAPP is a commitment by AQUA TERRA Consultants that must be approved by EPA Region 6. 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. Besides the Modeling QAPP, 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.

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PREAMBLE

This document has been designated as the "Modeling QAPP" for the EPA Region 6 Illinois River water quality modeling and TMDL development effort that began in September 2009 and is scheduled for completion no later than summer 2012. The first two years of support that AQUA TERRA Consultants provided to EPA Region 6 for this project was performed under EPA Office of Water's BASINS contract (EP-C-06-029). One element of this work was developing an initial project QAPP (AQUA TERRA Consultants, 2010a) that was approved this past August. The QAPP noted the need and intention to expand the specification of QA/QC procedures related to water quality modeling after the models that will be used for watershed and lake analysis had been selected. The HSPF and EFDC models were selected in January 2011. Region 6 has adopted the August 2010 project QAPP to govern the relevant QA/QC procedures for the remaining work that will be performed under the current funding mechanism to complete the Illinois River modeling and TMDL development project.

The contents of this document require explanation in terms of their relationship to the already-existing project QAPP, as well as to another product that is being produced concurrently for the modeling effort, i.e., the Model Simulation Plan.

As is the case in most environmental modeling projects, a need existed to put into effect an initial project QAPP that identified the organization of QA/QC for the project; defined the study objectives; described the project tasks; and set initial guidelines for data acquisition, modeling activities and documentation practices. The initial project QAPP performed these functions. 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). However, it was noted in the initial project QAPP that specifying the QA/QC procedures needed to support certain project activities (i.e., heading topics) depended on efforts, decisions and deliverables that had not yet been developed at the time the initial QAPP was written and approved. The need to provide additional information for such topics by means of an addendum to the QAPP was noted.

This Modeling QAPP is specifically focused on the quality assurance (QA) aspects of the modeling that will be performed for the *TMDL Development Project for the Illinois River Watershed Basin in Arkansas and Oklahoma.* Since the initial project QAPP is organized according to QA/G-5M, it is also essentially a *modeling QAPP*, albeit one that lacks sufficient details on QA/QC procedures for the modeling effort. At this stage in project development (August 2011), the necessary decisions and deliverables have been achieved that enable developing and documenting these additional QA/QC procedures.

In organizing and presenting the supplemental QA/QC procedures, there is a need to do so using a stand-alone format that will enable straightforward review by EPA Region 6 and stakeholders. In this document we have re-addressed, and enhanced where necessary, a subset of the topics identified in G-5M. In doing so, we have imposed the following structure to them:

Preamble

PROJECT MANAGEMENT

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MEASUREMENT AND DATA ACQUISITION

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For those interested in considering the supplemental information contained in this Modeling QAPP within the structure of the general project QAPP, a mapping is provided [in brackets] to the corresponding section numbers for the parallel discussion sections in the previous QAPP document (AQUA TERRA Consultants, 2010a).

Finally, it is useful to note the relationship of this Modeling QAPP to the Model Simulation Plan that is being developed concurrently. The Model Simulation Plan identifies and describes the watershed and lake characteristics and types of data required/available for the models, and presents the approach to be followed in constructing and calibrating the models. The major steps in the model application process consist of collection and development of time series data; characterization and segmentation of the watershed and lake; and calibration and validation of the models. As can be seen from this description, the Modeling QAPP and the Model Simulation Plan share many common topics. The focus of discussions in the Modeling QAPP is restricted to defining QA/QC procedures. For a more robust discussion of the technical details of the modeling effort, readers are encouraged to consult the Model Simulation Plan (AQUA TERRA Consultants, 2011).

SECTION 1.0

PROJECT ORGANIZATION

The key individuals for ensuring that the project meets all QA and QC objectives are Quang Nguyen and Curry Jones from EPA Region 6; Anthony Donigian, Jr., Brian Bicknell and John Imhoff from AQUA TERRA Consultants; and Christopher Wallen, William McAnally and Andrew Stoddard from Dynamic Solutions.

Quang Nguyen will provide the overall project oversight as the Project Manager (PM). He will be responsible for the review and final approval of all deliverables. Mr. Nguyen's responsibilities include reviewing and approving the WA work plan, the Project QAPP and the Modeling QAPP, and reviewing and approving all contractor deliverables.

Curry Jones is the Approving Quality Assurance Official at Region 6. His responsibilities include reviewing and approving the Modeling QAPP and ensuring that the QA/QC practices and requirements specific to Region 6 are achieved.

Anthony Donigian, Jr. is the Project Leader for AQUA TERRA, responsible for directing and coordinating technical work and interaction with the EPA WAM. He will also track the budget, prepare monthly progress reports and perform administrative functions.

Brian Bicknell is the Deputy Project Officer for AQUA TERRA. In this capacity he will serve as the Technical Monitor for the project.

John Imhoff is the Quality Assurance Officer for AQUA TERRA. Mr. Imhoff is the individual responsible for maintaining AQUA TERRA's official Quality Management Plan. He will also be responsible for overseeing all QA/QC activities that AQUA TERRA performs for this project.

Christopher Wallen is the Project Manager for Dynamic Solutions. He is responsible for executing the tasks and other requirements of the contract on time, within budget and with the quality assurance/quality control requirements as defined by the contract and in the project QAPP.

William McAnally is the Quality Assurance Officer for Dynamic Solutions. He is responsible for coordinating with the AQUA TERRA QA officer to resolve any QA-related issues and he notifies the AQUA TERRA Project Manager of particular circumstances which may adversely affect the quality of the products provided by Dynamic Solutions. He conducts the review of technical QA material and data related to the surface water model system design and analytical techniques and he implements, or ensures, implementation of corrective actions needed to resolve non-conformances noted during QA assessments.

Andrew Stoddard is the Project Leader for Dynamic Solutions. He is responsible for the acquisition, verification, and transfer of applicable data and/or model inputs and outputs to the AQUA TERRA Project Leader. He will oversee data management and all Lake Tenkiller modeling activities for the project and he will perform data quality assurances prior to transfer of data and all model input and output files to AQUA TERRA. He is the point of contact for the AQUA TERRA Project Leader to resolve issues related to project data and assumes responsibility for the correction of any data errors.

Figure 1.1 shows the organizational diagram for both technical and QA lines of communication between EPA and the AQUA TERRA Team. Similarly, the diagram indicates the dual communication lines between Dynamic Solutions and the appropriate technical and QA points of contact at AQUA TERRA.

AQUA TERRA and Dynamic Solutions will conduct work for this project in conformance with the Quality Assurance (QA) program described in the currently active EPA BASINS Quality Management Plan (QMP) (AQUA TERRA Consultants, 2007) and with the procedures detailed in the Project QAPP and this Modeling QAPP.

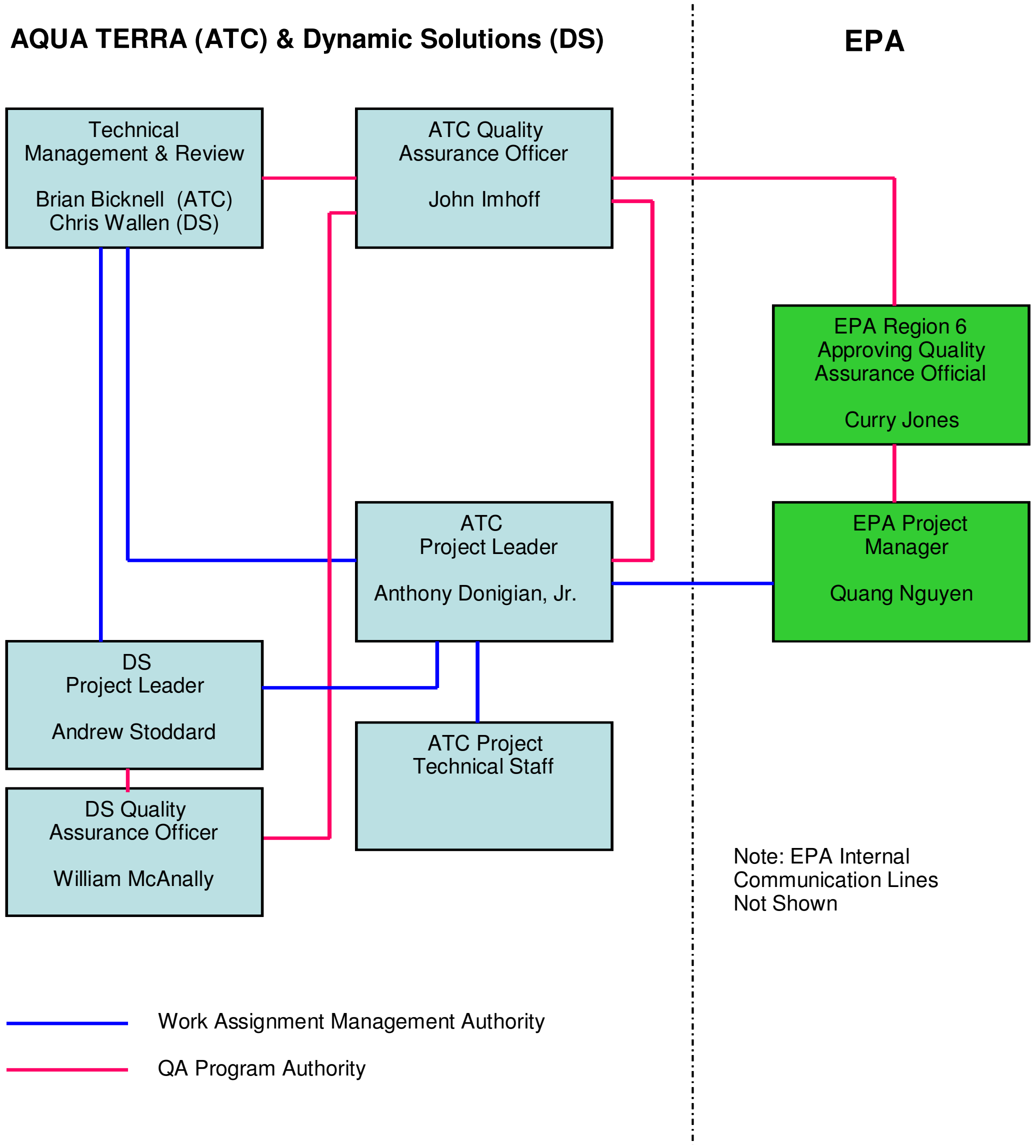


Figure 1.1 Project Organization Chart

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 in the State's Clean Water Act 303(d) list.

SECTION 3.0

PROJECT DESCRIPTION AND SCHEDULE

Five technical tasks have either been completed, or remain to be completed for this project:

- Data compilation and assessment
- Development of a GIS data base
- Development of water quality models
- Development of TMDL(s)
- Public comment response and TMDL amendment

This Modeling QAPP defines the QA/QC procedures that will be followed to perform the final three tasks; these three tasks comprise the remaining technical effort for the work effort and are described in Sections 3.3 through 3.5. Note that the purpose of this section (Section 3) is to describe the technical needs of the work effort, not the QA/QC procedures that will be used in satisfying these needs. For the sake of completeness a summary of the work that has been performed for the first two tasks is provided first. Different aspects of the QA/QC procedures that will be used to ensure the quality of the work that is performed to accomplish the latter three tasks are described in Sections 4 (Quality Objectives), 5 (Documentation), 6 (Modeling Approach and Calibration/Validation) and 7 (Data Acquisition).

3.1 DATA COMPILATION AND ASSESSMENT

This task entailed compiling all existing data and information applicable to the Illinois River and Lake Tenkiller. The complied data were assessed and data gaps critical to model development were identified in the report entitled "Preliminary Data Review and Analysis for Water Quality Modeling and TMDL Development for the Illinois River Watershed" (AQUA TERRA Consultants, 2010b). This Data Report was distributed to EPA and stakeholder reviewers. Much of the work for this task is now complete. The report is being finalized to reflect stakeholders' comments and to include description of additional data that is being provided by the public. This new data continues to undergo evaluation using the approach established in Section 9 of the general QAPP and refined in Section 7 of this document.

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.

3.2 DEVELOPMENT OF A GIS DATABASE OF LAND USES AND OTHER RELEVANT GEOSPATIAL DATA

The Illinois River Watershed (IRW) GIS database was produced as a companion to the Data Report cited in Section 3.1. This data base has been made available for review by the Lead Agencies from Arkansas and Oklahoma, as well as other interested stakeholders, so that all available sources of relevant GIS data are identified and acquired for use in this study.
The GIS data in the current version of the data base were obtained from three main sources: the US EPA BASINS system data download capability, a previous modeling effort by Storm et al., (2009) using the SWAT model, and a previous HSPF modeling effort by Donigian et al

(2009). The Data layers, or coverages, were placed into separate directories, or folders, from each of these three sources, plus a fourth directory for those coverages downloaded from other sources. The folders/directories in the data base are briefly described below.

- **BASINS:** These layers were downloaded from BASINS. Some may have been modified by clipping to the Illinois River Watershed
- **Downloaded:** these layers were downloaded from various sources such as Geospatial One Stop (http://gos2.geodata.gov/wps/portal/gos), USGS's seamless server (http://seamless.usgs.gov/), and from both Oklahoma and Arkansas Department of Environmental Quality web sites.
- **SWAT:** These layers are from the previous study conducted by Storm et al from Oklahoma State University for the Oklahoma Department of Environmental Quality.
- **Tenkiller_CD:** These layers are from the previous study done by AQUA TERRA Consultants and Eco Modeling.

Within each of these folders are subfolders that help to describe the type of data available from each source. These folders are:

- **Boundaries:** contains data relating to state and county boundaries, roads, and cities etc.
- **Elevation:** contains elevation data
- **Hydro:** contains information relating to hydrography and hydrology such as USGS gage location and stream layers etc.
- **Landuse:** contains data relating to land use such as NLCD raster layers etc.
- **Meteorological:** contains meteorological station locations.
- **Misc:** miscellaneous layers such as poultry house locations, litter applications, karst features, etc.
- **Water quality:** contains layers such as USGS water quality stations, point source location layers, etc.

The directory structure is summarized in Figure 3.1. Following each folder (boundaries, elevation etc.) are examples of data layers that are in the folder; not all layers are included in the folder schematic. For a more detailed description of the data see Appendix B of the Data Report (AQUA TERRA Consultants, 2010b).

IRW GIS DATA

- BASINS
  - Boundaries -state boundaries, EPA region boundaries etc
  - Elevation - elevation DEMs
  - Hydro -stream shapefile, NHD shapefiles
  - Landuse -2001 NLCD landcover
  - Meteorological - meteorological stations
  - Waterquality -water quality stations, point sources
- Downloaded
  - Boundaries -city locations
  - Elevation -elevation downloaded from the seamless server
  - Landuse -1992 NLCD landcover
  - Waterquality -303(d) listed streams, EPA point source locations
- SWAT
  - Hydro -stream coverages
  - Landuse -state soil type
  - Misc -poultry house locations
  - Waterquality -point sources, USGS gages
- Tenkiller_CD
  - Hydro -subbasins
  - Meteorological -meteorological stations

Figure 3.1 Directory Structure for the IRW GIS Database

AQUA TERRA ensured that metadata are compliant with the *Content Standard for Digital Geospatial Metadata* (FGDC-STD-001-1998) approved by the Federal Geographic Data Committee.

3.3 DEVELOPMENT OF WATER QUALITY MODELS

This task entails developing a robust model for the Illinois River Watershed, including Lake Tenkiller. Region 6 identified the need for a straightforward yet scientifically defensible modeling approach that incorporates the data compilation/assessment and GIS work products produced by the effort identified in Sections 3.1 and 3.2, respectively. The model must be developed with the necessary level of detail to serve as a basis of evaluating point and nonpoint source reduction scenarios needed to meet the State of Oklahoma in-stream total phosphorus criterion of 0.037 mg P/liter. A necessary first step to developing the water quality models for the Illinois River Watershed was undertaking and completing a focused model evaluation and selection process. As a result of this process (Donigian and Imhoff, 2010), the EPA's Hydrological Simulation Program – FORTRAN (HSPF) and Environmental Fluid Dynamics Code (EFDC) simulation models were selected for use in this project.

The Illinois River Watershed will be modeled using the Hydrological Simulation Program-FORTRAN, known as HSPF (Bicknell et al., 2005). HSPF is a mathematical model developed under EPA sponsorship for use on digital computers to simulate hydrologic and water quality processes in natural and man-made water systems. It is an analytical tool that has application in the planning, design, and operation of water resources systems. The model enables the use of probabilistic analysis in the fields of hydrology and water quality management. HSPF uses such information as the time history of rainfall, temperature, evaporation, and parameters related to land use patterns, soil characteristics, and agricultural practices to simulate the processes that occur in a watershed. The initial result of an HSPF simulation is a time history of the quantity and quality of water transported over the land surface and through various soil zones down to the groundwater aquifers. Runoff flow rate, sediment loads, nutrients, and other water quality constituent concentrations will be predicted. The model will use these results and stream channel information to simulate instream processes. From this information, HSPF will produce a time history of water quantity and quality at many points of concern within the IRW stream and lake network.

Modeling of hydrodynamics and water quality processes in Lake Tenkiller will be performed using the Environmental Fluid Dynamics Code (EFDC) (Hamrick, 1992; 1996; Hamrick 2007). EFDC, supported by the USEPA Office of Water, is an open source, public domain model that has a strong track record of use and acceptance as demonstrated by peer reviewed river, lake, estuary and coastal modeling studies worldwide (Ji, 2008) including a previous modeling study of Lake Tenkiller (Craig, 2006). 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. It has evolved over the past two decades to become one of the most widely used and technically defensible surface water models in the world. 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 is represented with the same data used in the HSPF model. In order to remedy some of the complexities associated with EFDC, Dynamic Solutions has enhanced the original EFDC source code by adding dynamic time stepping algorithms to increase model execution time and input file driven dynamic allocation of arrays. The public domain FORTRAN source code for the Dynamic Solutions version of EFDC is available from the Dynamic Solutions website. Dynamic Solutions has also developed EFDC_Explorer as a software interface to support pre- and post-processing tasks for the EFDC model (Craig, 2010). EFDC_Explorer will be used for the Lake Tenkiller project to support model setup; visualization of model calibration results as time series, vertical profiles, vertical sections, horizontal maps; calculation of model performance statistics.

This task encompasses both watershed and lake 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 lake model.

Concurrent with the development of this Modeling QAPP, AQUA TERRA is developing a Model Simulation Plan that describes **how** the recommended models will be applied to the Illinois River and Lake Tenkiller. The Simulation Plan provides a roadmap and a communication tool for both the EPA WAM and stakeholders as it describes the study objectives, the available data, water quality and land uses, calibration/validation procedures and targets, and potential scenarios for assessment.

Following technical review and approval of the Simulation Plan by EPA, AQUA TERRA and Dynamic Solutions will proceed to develop the watershed and reservoir models and their linkage for the Illinois River Watershed and Lake Tenkiller. Following the model calibration and validation, and in consultation with the EPA WAM, the Project Team will develop various point and nonpoint source scenarios to meet applicable water quality criteria.

3.4 DEVELOPMENT OF TMDLS

This task entails coordination with EPA Region 6 in developing a scientifically sound and stake-holder-supported TMDL for the Illinois River, including Lake Tenkiller. AQUA TERRA will identify alternative point and nonpoint source reduction strategies, using the models to assess their impacts and abilities to meet TMDL requirements. Interacting with the States and other stakeholders AQUA TERRA and Region 6 will communicate the results and explore adjustments to the strategies that have already been evaluated as well as the possibility of additional alternative strategies. The phosphorus TMDL for the Illinois River will include load allocations (LA), wasteload allocations (WLA), margin of safety (MOS) and will consider seasonal variation and future growth.

3.5 PUBLIC COMMENT RESPONSES AND TMDL AMENDMENT

AQUA TERRA will support Region 6 throughout the process of soliciting, receiving, compiling, and responding to public comments on the final draft TMDL document, as well as amending the TMDL as deemed appropriate. AQUA TERRA will provide and/or support the following specific efforts and products:

- A draft final TMDL document suitable for distribution to EPA and stakeholder reviewers
- A compilation of review comments

- Responses to comments (developed in conjunction with EPA). AQUA TERRA's focus will be on the technical approach embodied in the TMDL.
- Revised draft TMDL(s)
- Final TMDL report(s)

3.6 SCHEDULE

The planned schedule for remaining deliverables is provided in Table 3.1.

Table 3.1 Deliverable Schedule.

Project Milestone	Date for Completion
Draft Simulation Plan	August 2011
Draft Modeling QAPP	August 2011
Final Simulation Plan	September 2011
Final Modeling QAPP	September 2011
Final GIS Database	September 2011
Final Data Report	September 2011
Water Quality Model Setup, Calibration, Validation	Sep-Nov 2011
Water Quality Modeling Scenarios	Oct/Nov 2011
TMDL Proposal and Establishment	Dec 2011/May 2012

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 for further discussion).

The Quality Assurance/Quality Control (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 a Phosphorus 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 one or more scientifically-sound Total Maximum Daily Loads (TMDLs) to determine reductions in phosphorus loads needed 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 developed to support TMDL determinations;

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, there are objective techniques that can 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 AQUA TERRA Consultants 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 AQUA TERRA Project Leader, Tony Donigian, 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 AQUA TERRA's QMP (AQUA TERRA Consultants, 2007). 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 modeling study include, but are not limited to:

Documents
- Work plan
- Project quality plans (e.g., the general project QAPP and the 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 AQUA TERRA WAL to ensure their conformance with technical requirements and quality system requirements. Documents will be released to

EPA Region 6 following authorization by the WAL and, when required, the Quality Assurance Officer. The WAL 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, AQUA TERRA 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 AQUA TERRA's 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 AQUA TERRA's 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 AQUA TERRA 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 specified by the EPA WAM. In addition, the AQUA TERRA Team will save on an external hard drive all scripts, project files, calibration data, and other information used to conduct watershed and lake modeling. AQUA TERRA will deliver these external hard drives to EPA within 2 weeks of the conclusion of the project. AQUA TERRA will maintain a copy of the project files at the Mountain View, California, office for at least 3 years (unless otherwise directed by the EPA WAM). The EPA WAM and AQUA TERRA WAL 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, 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 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.

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 (Hamrick, 2005). 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 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 *physical* 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. 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 6.1shows the various components and capabilities of the PERLND module of HSPF. Each of the boxes in Figure 6.1identifies 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 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. 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 6.2 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 6.3Figure 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.

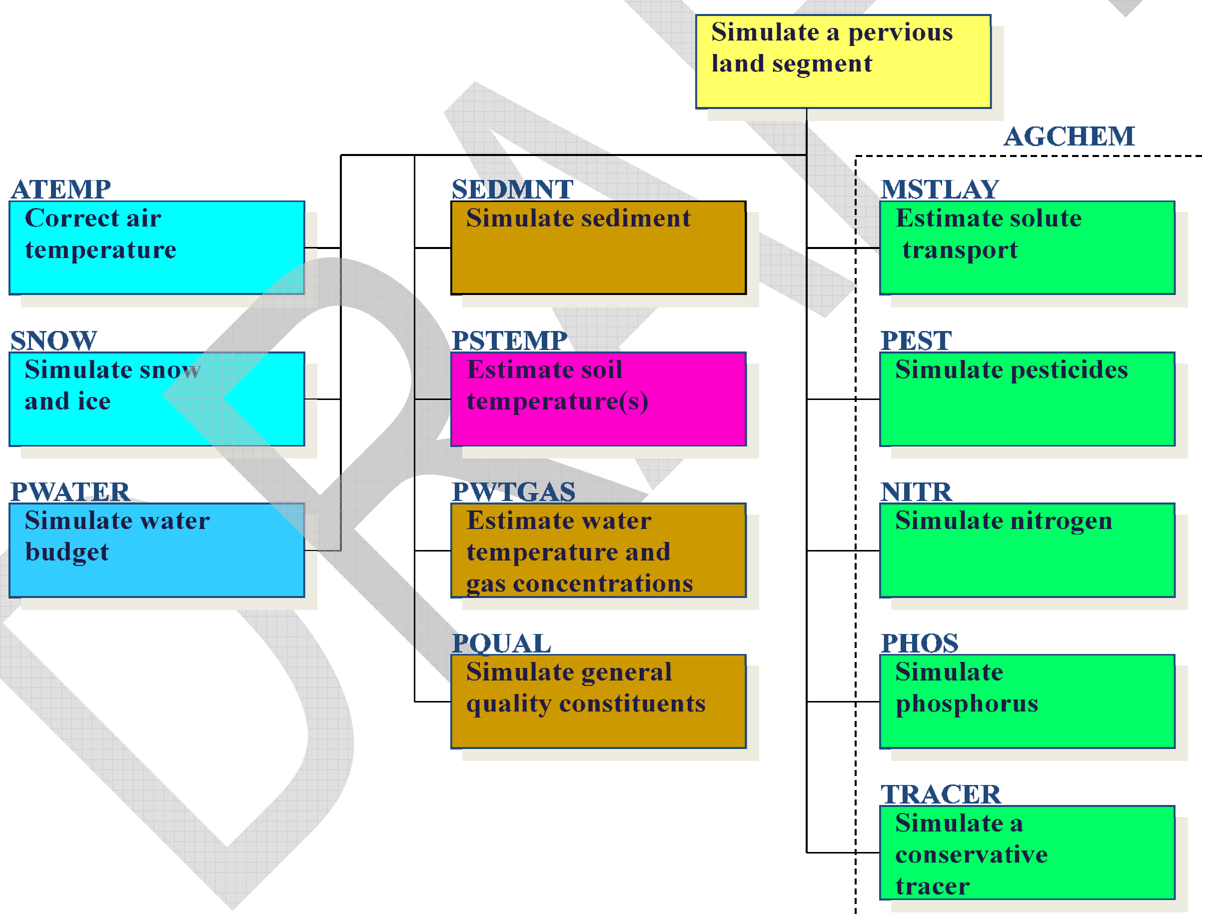


Figure 6.1 Pervious Land Simulation (PERLND) Module in HSPF

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; Hamrick 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.

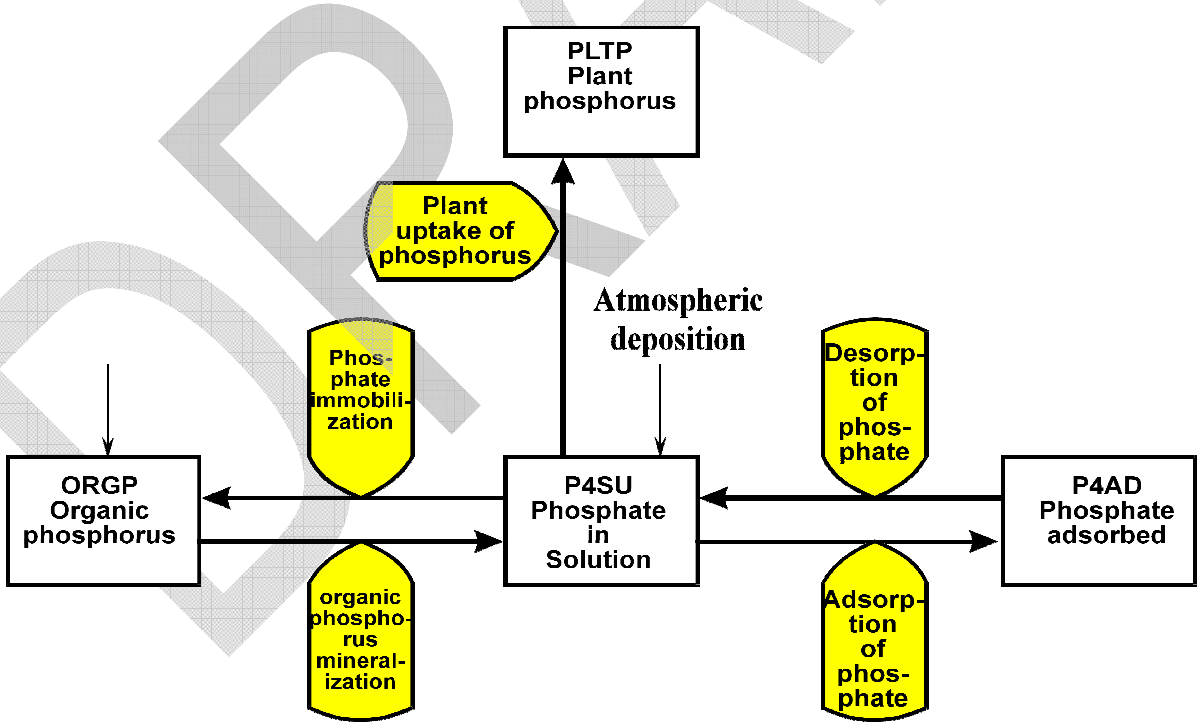


Figure 6.2 Soil Phosphorus Cycle in HSPF AGCHEM

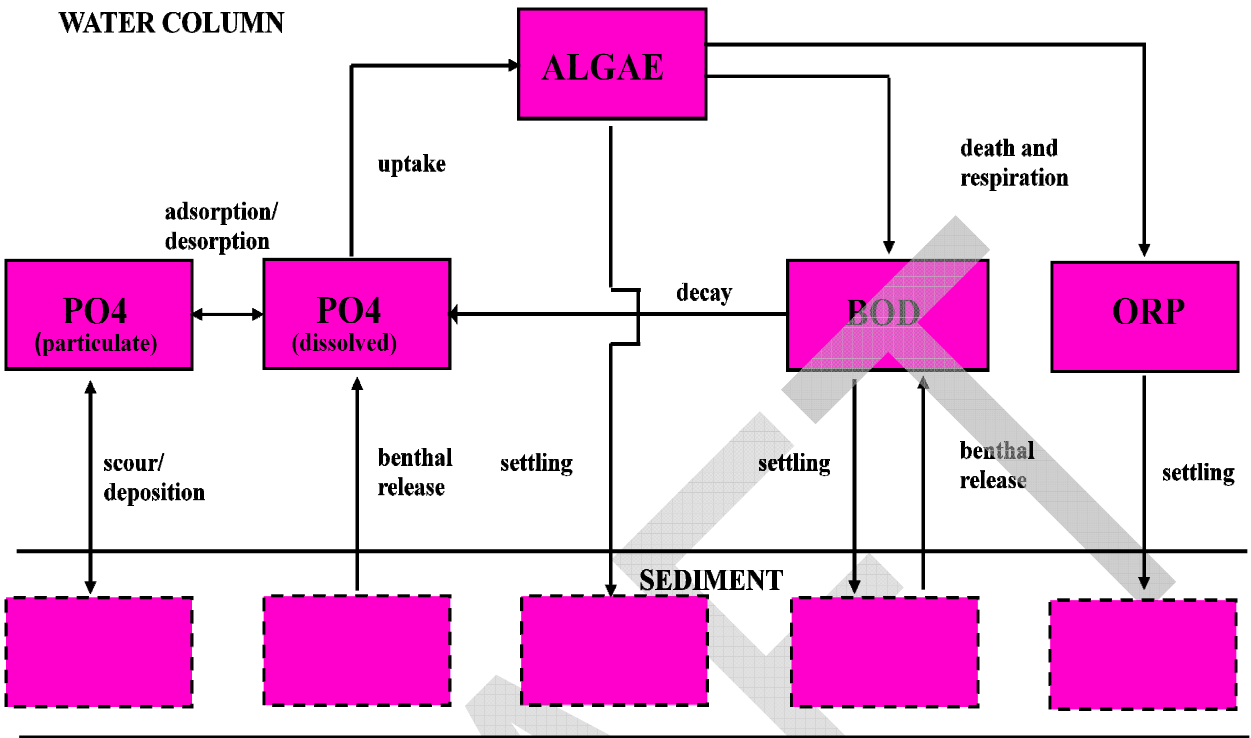


Figure 6.3 Instream Phosphorus Processes in HSPF RCHRES

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 is represented with the same data used in the HSPF model.

The EFDC model that Dynamic Solutions developed previously for Oklahoma DEQ (Craig, 2006) will be used as the foundation for this project. The existing lake model consists 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 existing 195 cell computational grid where lake shoreline is defined by the normal conservation pool elevation of 632.0 ft (192.63 m). This existing EFDC model of the lake has been calibrated with data collected by the Clean Lakes Program during the 1992-1993 time period. In this project, the grid resolution of the lake model will be made finer to resolve technical issues related to grid resolution that were identified in the previous study. Using software for grid generation (Delft, 2007), grid resolution will be increased in areas of the lake characterized by steep bottom slopes such as the Forebay area; this will minimize numerical diffusion errors caused by the bottom following vertical layers. Grid resolution will also be increased in the upper reservoir and transition zone where the existing grid represents a laterally averaged channel. Figure 6.5 shows a plan view map of the new 679 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 flood pool elevation of 667.0 ft (203.3 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 existing grid is shown with dashed red lines and the new current grid is shown with grey lines.

In the existing 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 (Craig, 2006). Detailed bathymetric data is now available from a 2005 survey that was conducted to support the collection of sediment cores (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 revised lake model grid (Figure 6.5) will be updated with the bathymetry data collected in 2005. The model will then 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 (AQUATERRA, 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 from 2005-2007 by CDM and the USGS to support litigation by the Oklahoma Attorney General. The CDM/USGS database will be reviewed and evaluated to determine if these data sets will be used to supplement the OWRB data sets for re-calibration 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 with water quality data available from 1994 through 2010 (Figure 6.7). Based on our review and evaluation of hydrologic conditions, and the availability of lake data and sediment bed data for 2005-2007, a 1-year period will be selected for re-calibration of the model and a 1-year period will be selected for validation of the EFDC lake model. The period from 2005-2007 has been tentatively identified for model re-calibration and validation. Flow boundary conditions used for input to the lake model will be updated to account for the new data linkage from the updated HSPF model results. Station data sets will be compiled as time series and vertical profiles for comparison of model results.

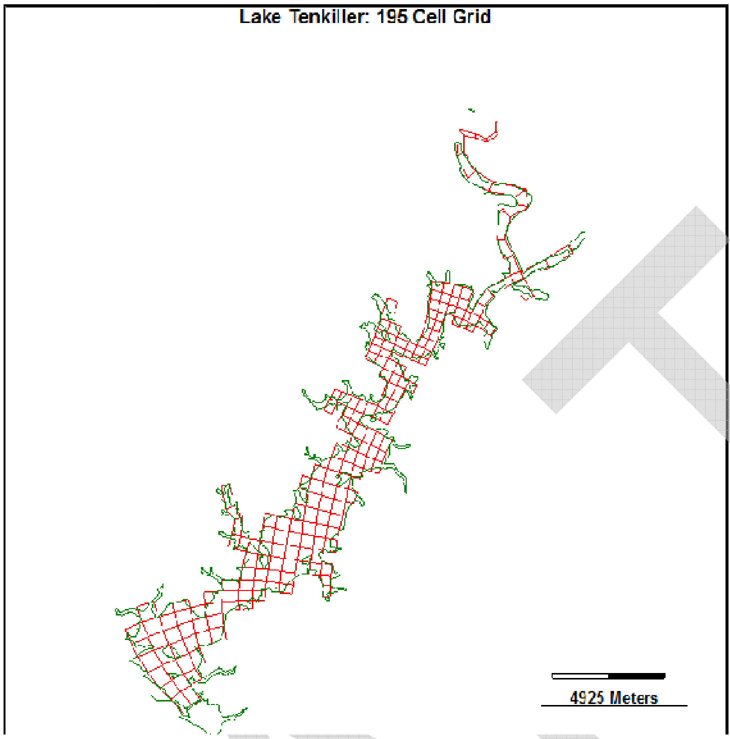


Figure 6.4 Computational Grid with 195 Cells for Existing EFDC Model of Lake Tenkiller (DSLLC, 2006)

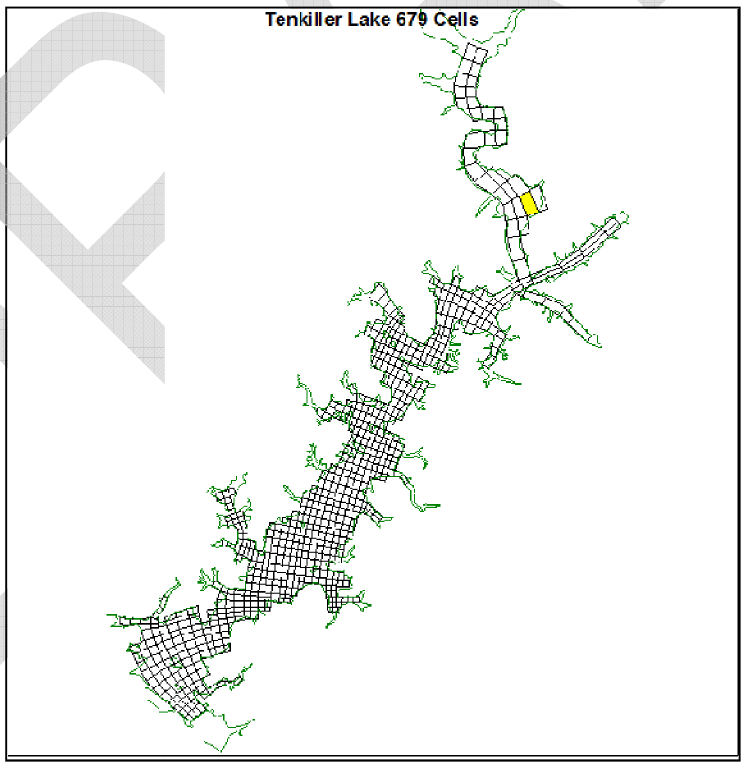


Figure 6.5 Updated Computational Grid with 679 Cells for Current EFDC Model of Lake Tenkiller

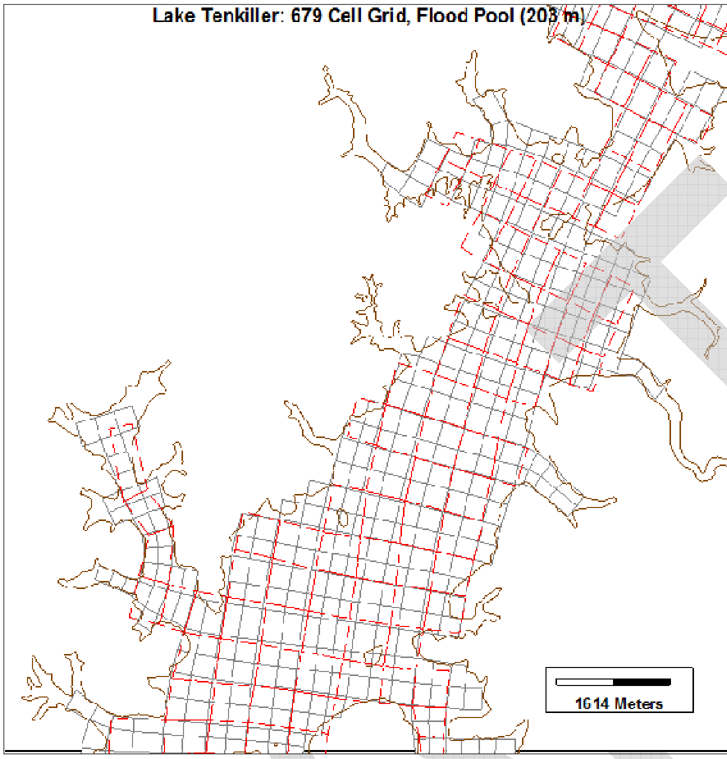
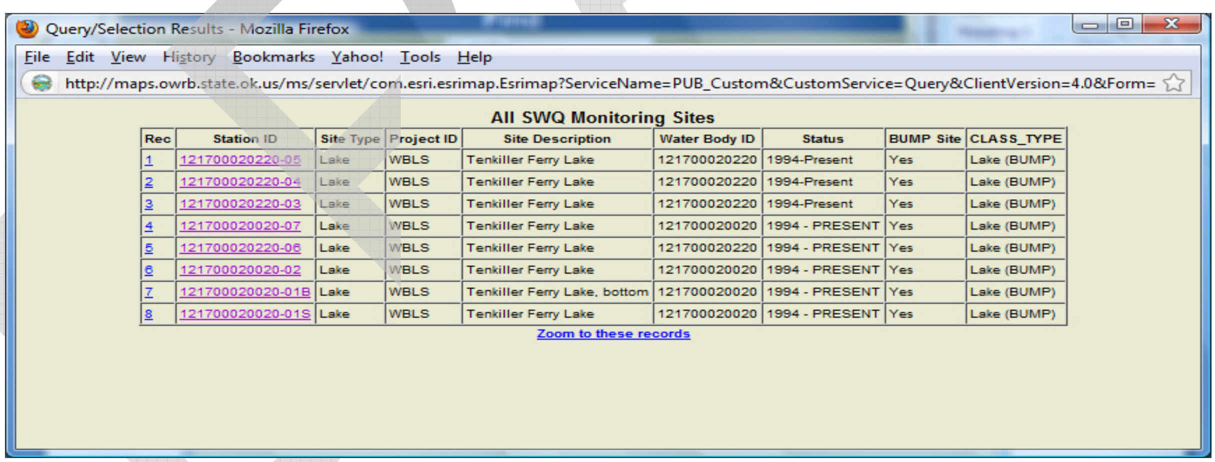


Figure 6.6 Comparison of Grid Resolution for 195 Cell and 679 Cell Models.



All SWQ Monitoring Sites

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)

Zoom to these records

Figure 6.7 Summary of OWRB station data for Lake Tenkiller

Flow boundary conditions used for input to the lake model will be revised from the existing lake model setup to account for the new data linkage that will be provided by the updated HSPF model results for the Illinois River watershed. 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 linked surface water model frameworks. To facilitate data processing needed for the HSPF-EFDC linkage, Dynamic

Solutions has developed custom software programs 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 a set of boundary condition files written for input to the EFDC lake model. The updated 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.

After refinement of the computational grid, 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 re-calibration period. Station data from OWRB and other data sources will be used to estimate spatial distributions of water temperature, TSS and water quality constituents for the water column. Depending on the results of our evaluation of the database, data collected by USGS and other stakeholders may also be used for model setup. 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 surface water and 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).

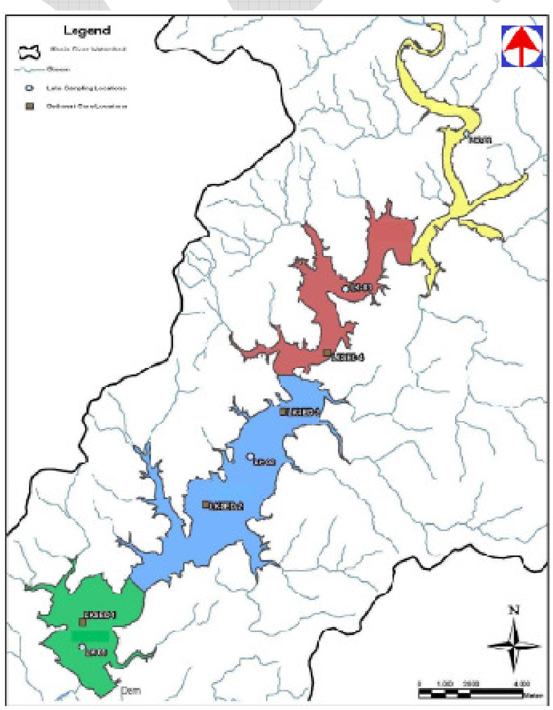


Figure 6.8 Lake Water Column Station Locations (LK-01,LK-02,LK-03,LK-04) and Sediment Core Station Locations (LKSED-1,LKSED-2,LKSED-3,LKSED-4) during 2005 Survey of Lake Tenkiller (Fisher et al., 2009).

After refinement of the computational grid and model setup, preliminary lake model results will be obtained with the 1992-1993 data sets that were compiled for the previous HSPF-EFDC modeling effort (Craig, 2006). When the new HSPF results become available for linkage to the EFDC model, the lake model will be re-calibrated to data collected during 2005-2006. 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 USGS and other stakeholder surveys collected during 2005-2007, will allow specification of initial conditions for the water column. These data sets will also provide time series and vertical profile observations for re-calibration of the lake model.

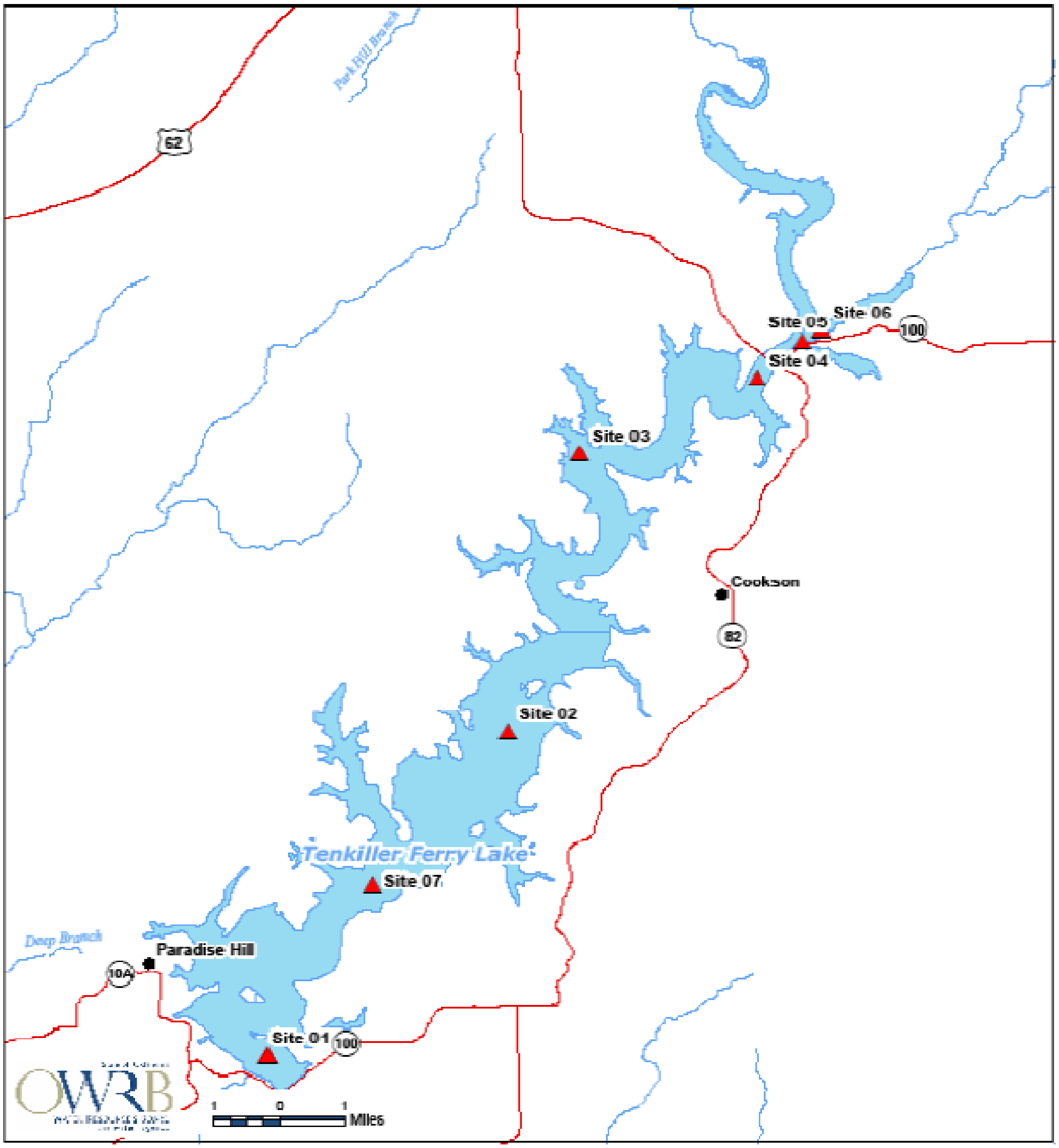


Figure 6.9 OWRB BUMP Station Locations in Lake Tenkiller

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).

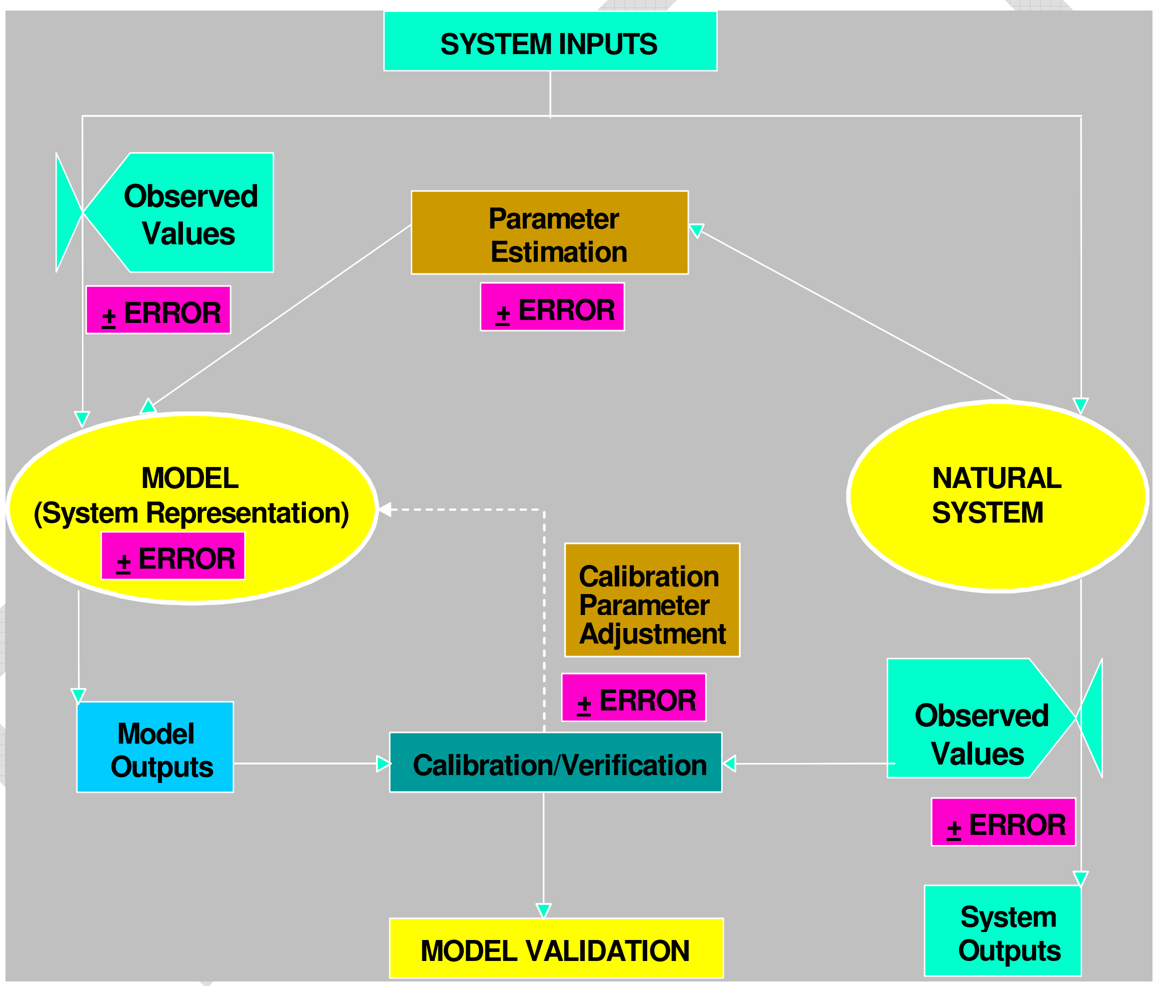


Figure 6.10 Model versus Natural System: Inputs, Outputs, and Errors

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).

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.

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.

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.

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.

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.

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 is 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.

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.

Detailed Process Approach for Simulation 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.

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.

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.

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 HSF sediment calibration is provided by Donigian and Love (2003).

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

Lake Model Calibration and Validation

To efficiently re-calibrate the lake model, the following sequence of steps will be followed:

1. refine the computational grid to improve representation of physical processes in the lake;
2. test hydrodynamic model water balance to re-calibrate lake volume and water level;
3. add heat loading to represent density effects (i.e. water temperature) to test ability of hydrodynamic model to represent lake stratification;
4. add TSS loading and in-lake sediment transport with cohesive parameters for critical shear stress, deposition velocity and resuspension rate;
5. add nutrient loading, algae production and water quality; and finally
6. add sediment diagenesis to couple organic matter deposition from the water column to sediment-water fluxes of nutrients and oxygen.

In re-calibrating the hydrodynamic, sediment transport and water quality model, the accuracy of external flows, loadings and forcing functions in relation to lake model results will first be assessed. Coefficients for the hydrodynamic, sediment transport, water quality, eutrophication and sediment flux sub-models 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 the previous EFDC model of Lake Tenkiller (Craig, 2006). Many of the kinetic coefficients and parameters needed for the sediment flux model can be defined with a robust set of parameter values that have been successfully applied for many sediment flux models (Di Toro, 2001). Key kinetic coefficients, such as solids settling rates, critical stresses for deposition and erosion; organic matter decay rate; phytoplankton growth rate; and the porewater exchange rate that controls sediment-water release of nutrients and SOD, will be adjusted within reasonable and accepted ranges, to achieve re-calibration of the Lake Tenkiller model for the observed data collected during 2005-2006.

Re-calibration of the lake model will be accomplished by comparison of model results to observed data extracted from grid cells matching the OWRB database, and possibly other sources, and station locations in Lake Tenkiller. Model-data comparisons will be presented for water level, water temperature, salinity (specific conductance), TSS, dissolved oxygen, total organic carbon, nitrogen, phosphorus, and algae biomass (as chlorophyll-a). Model output 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. The EFDC_Explorer pre- and post-processor software (Craig, 2010) will be an essential tool for re-calibration of the lake model since this software supports the capability to extract model results for comparison to observed data sets for time series, longitudinal transects and/or vertical profile plots, compute model performance statistics, and change values of adjustable parameters.

Sediment-water fluxes for sediment oxygen demand and benthic nitrogen and phosphorus fluxes will be simulated with the sediment diagenesis model. Since sediment flux data is not available for Lake Tenkiller for calibration of the sediment diagenesis model, sediment flux rates reported in the literature for other lakes and reservoirs in similar ecoregions with similar agricultural loading characteristics (i.e., poultry and other livestock farms) in the watershed will be used to determine if the sediment diagenesis model is producing reasonable results. Sediment flux measurements for phosphorus, for example, have been reported for Lake Frances in the Illinois River basin (Haggard and Soerens, 2006) and sediment bed data for phosphorus is available for selected Ozark catchments (Haggard and Smith, 2007). Sediment flux data for phosphorus under aerobic and anaerobic conditions is available from investigations in Lake Eucha (Haggard et al., 2005) and Sen et al. (2007) have reported sediment phosphorus release rates from Beaver Reservoir in northwest Arkansas. Sediment oxygen demand measurements are summarized by Veenstra and Nolen (1991) for four reservoirs in Oklahoma characterized by hypolimnetic oxygen depletion. 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 re-calibration of the sediment flux component of the lake model. Following re-calibration of the lake model to a 1-year data set selected from the database available for 2005-2007, a different 1-year data set will be identified and used for validation of the lake model. Specific time periods will be identified on the basis of an inventory and evaluation of the water quality data available for Lake Tenkiller.

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 re-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 re-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 re-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, Carlson's Trophic State Index (TSI) and water clarity. EFDC_Explorer (Craig, 2010) was upgraded for our previous Lake Tenkiller modeling project (Craig, 2006) to support the display of the TSI and the 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. In addition to the typical time series plots showing the concentration of simulated chlorophyll, oxygen and the TSI for comparison to target criteria, model results will also be presented as frequency distribution plots to identify how often chlorophyll, dissolved oxygen and the TSI may exceed target criteria for the lake. Because of the importance of the lake for recreational activities water clarity in Lake Tenkiller is defined by a water quality target of 25 NTU's for turbidity. Although the EFDC water quality model does not simulate turbidity as a state variable, the components of water clarity are simulated by TSS, particulate organic carbon (POC) and algae (as chlorophyll-a) to compute light extinction in the water column. Light extinction can be processed in EFDC_Explorer to display estimates of secchi depth and the percentage of surface light available at the bottom. Model results will be compared to observed secchi depth station data to evaluate how well the water quality model is able to represent water clarity in the lake as a composite metric derived from simulated TSS, POC and chlorophyll-a.

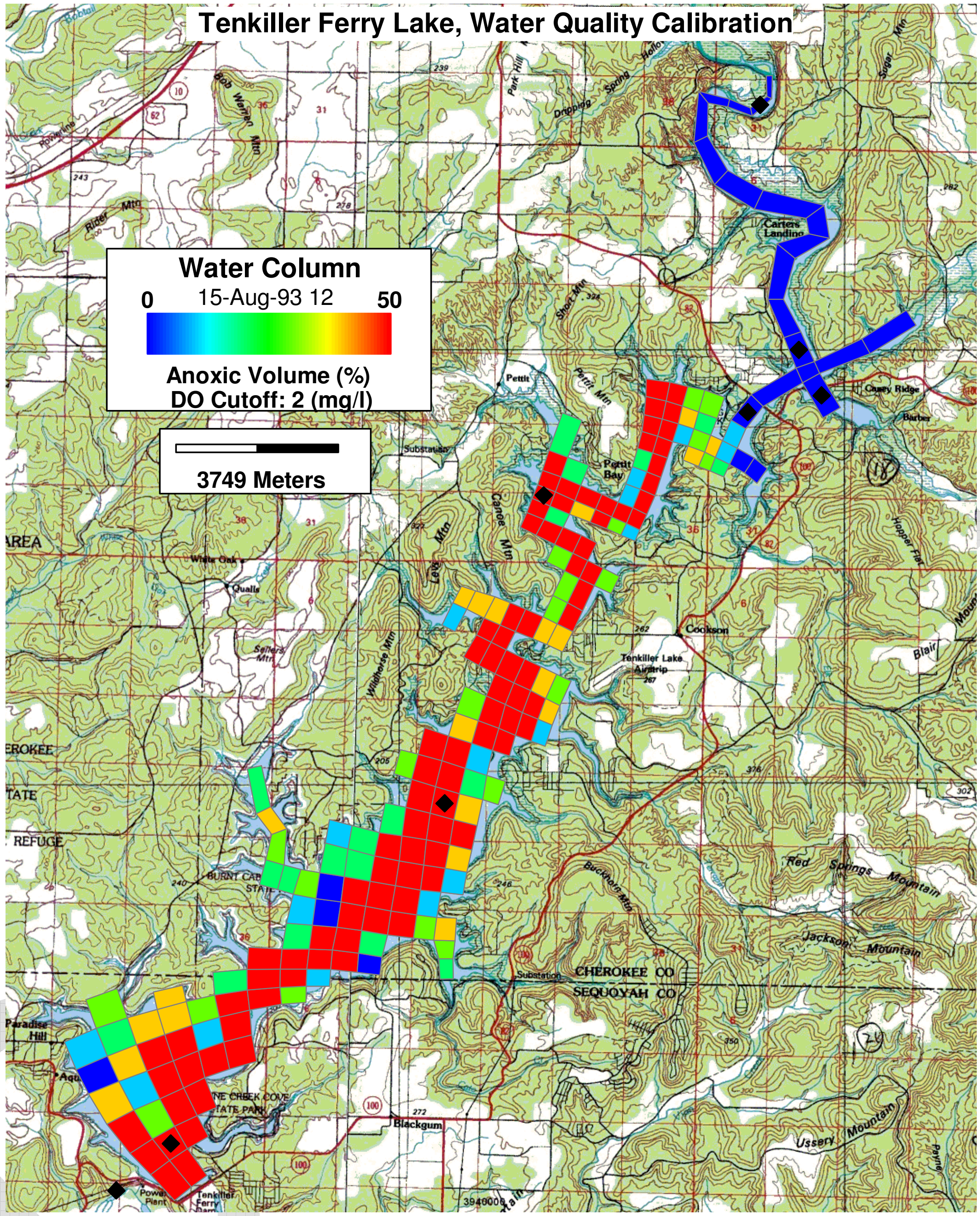


Figure 6.11 Anoxic Volume of Lake Tenkiller on 15-August-1993 at 12:00 (Craig, 2006)

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.

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^{o} 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.

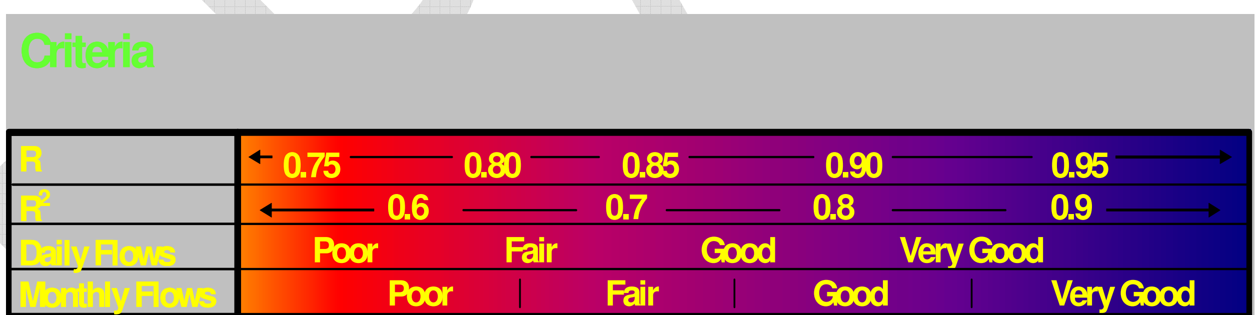


Figure 6.12 R and R^2 Value Ranges for Model Performance

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.

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 %

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:

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

$$Relative\_RMS\_Error = \frac{RMS\_Error}{(O_{range})} x100$$

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

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).

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

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.

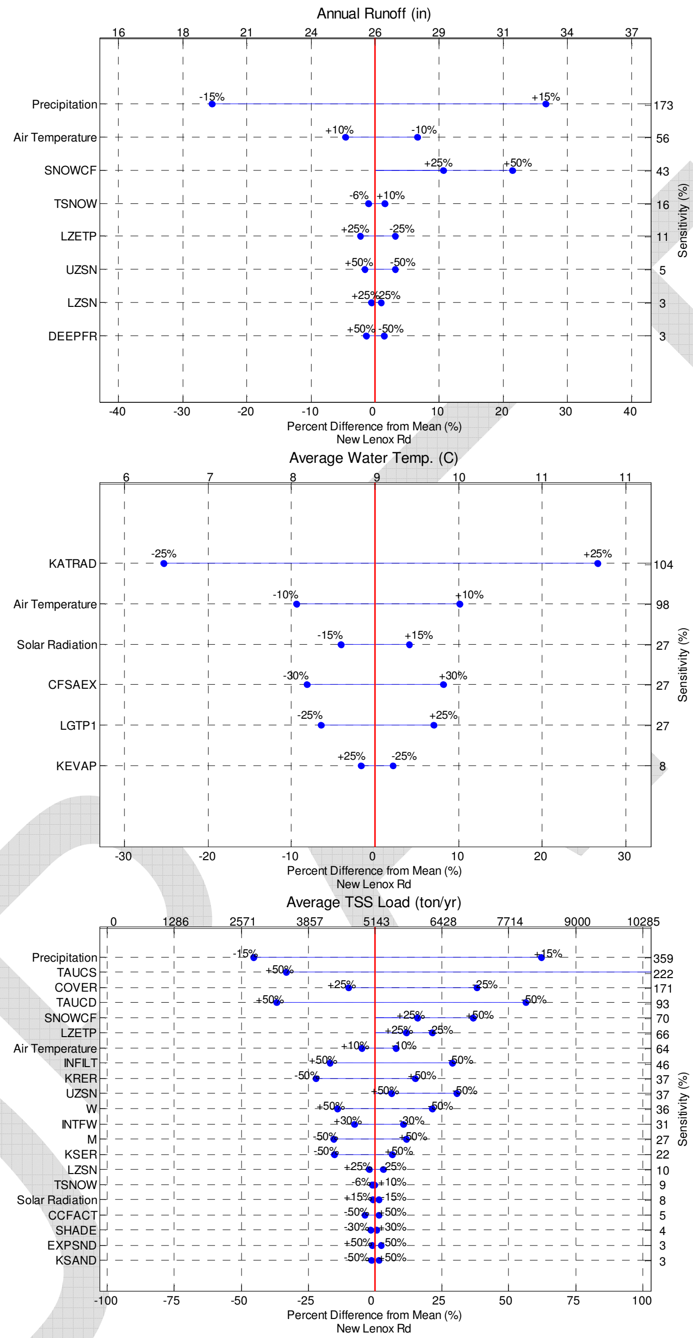


Figure 6.13 Example Tornado Diagrams at New Lenox Road (Donigian and Love (2007)
(Conversion Factors: 1 in = 2.54 cm; 35.3 cfs = 1 cms; 1 short ton = 0.907 metric tons)

6.5 MODEL UNCERTAINTY

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, procedures for performing such an analysis have been established in a few prior studies on other watersheds.

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 can 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. 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 can be identified, and related parameters can be grouped and correlated in terms of any perturbation performed as part of the uncertainty analysis, and an appropriate correlation structure can 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 can 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 can 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.

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.

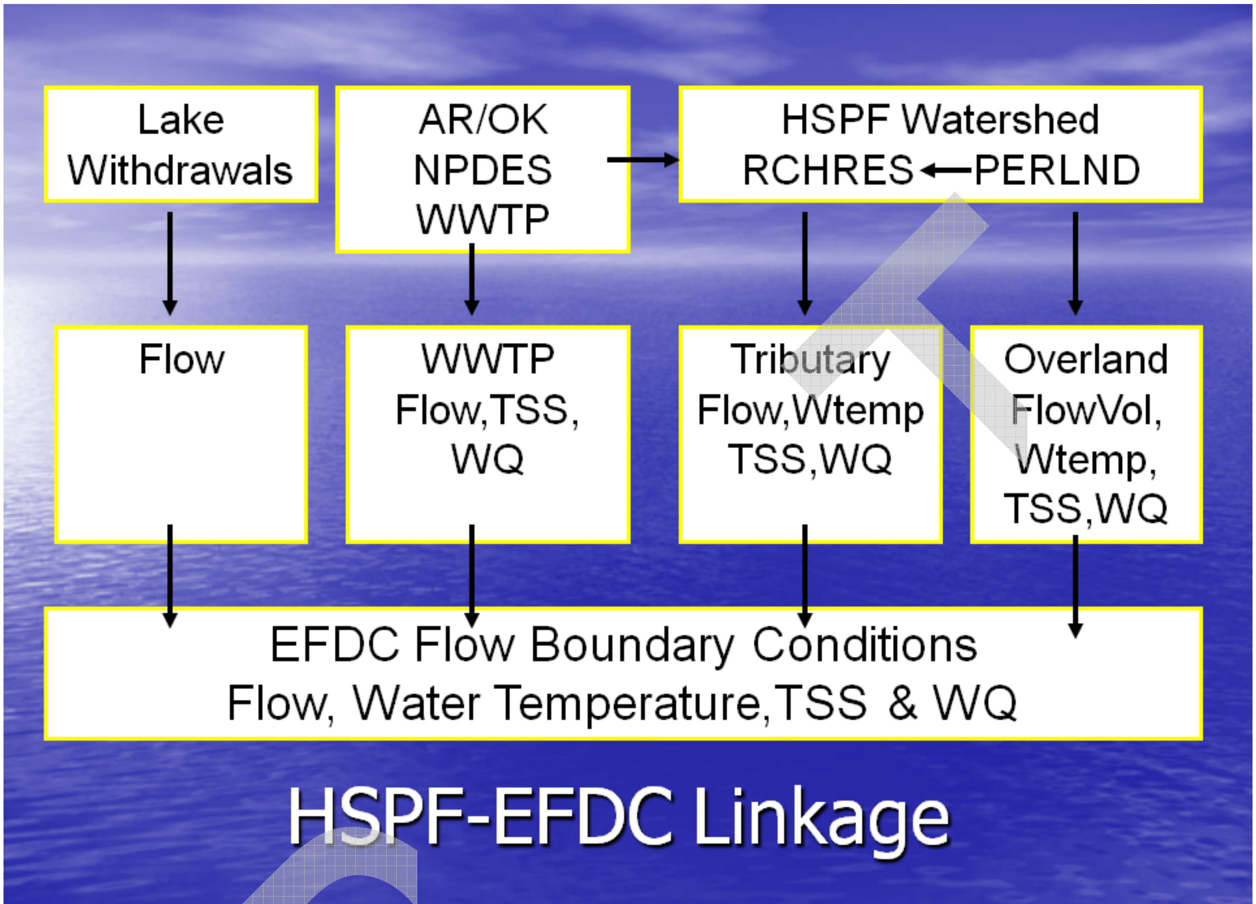


Figure 6.14 HSPF-EFDC Linkage for Illinois River and Lake Tenkiller Model Framework

The Simulation Plan (AQUA TERRA Consultants, in progress) 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 (Craig, 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, 2010), 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.

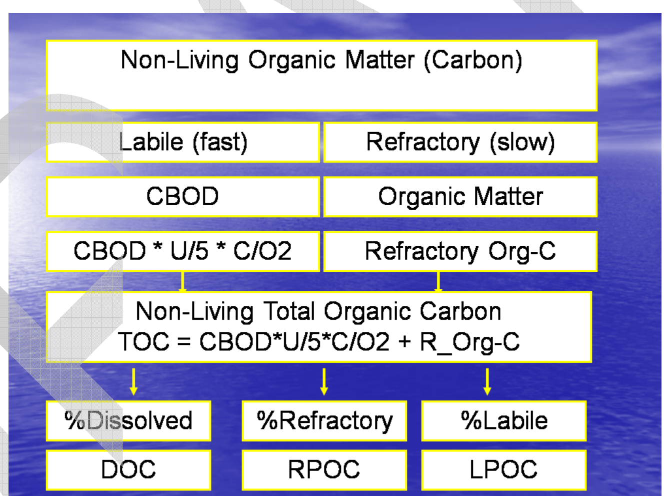


Figure 6.15 Linkage of Total Organic Carbon from HSPF to EFDC

SECTION 7.0

DATA ACQUISITION

To perform watershed and lake modeling, the Project Team will use necessary secondary data collected through AQUA TERRA's in-house databases and data received from other sources. A tremendous 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 preliminary review and will continue to be reviewed as a part of the ongoing data quality assessment. 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 WAM, the Project 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. Project 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. AQUA TERRA 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 WAM.

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, AQUA TERRA is dependent upon the detail and accuracy of the QA/QC information that accompanies the individual data sets collected to potentially support this study. AQUA TERRA 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 AQUA TERRA Team, in consultation with the EPA WAM, 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 AQUA TERRA 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 Project 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 Project Team (both AQUA TERRA and Dynamic Solutions) 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 AQUA TERRA and Dynamic Solutions 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 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.

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

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