Simulation Plan for Illinois River Watershed Nutrient Modeling Development

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Submitted to

US EPA Region 6
Dallas, TX 75202

Under

EPA Contract EP-C-12-052 Order No. 0002
Dated 15 September 2013

October 31, 2013

EXECUTIVE SUMMARY

The Illinois River is a multi-jurisdictional tributary of the Arkansas River, approximately 160 miles long, in the states of Arkansas and Oklahoma. The objective of this study is to develop a scientifically robust and defensible watershed and lake model to determine reductions in nutrient loads needed to meet water quality standards in both states, Arkansas and Oklahoma. This watershed and lake model will serve as a tool for sound technical decisions on appropriate point and nonpoint source controls to meet those standards. Ultimately, the intent is development of a modeling tool that can lead to the determination of scientifically sound TMDLs.

Prior efforts related to this study under different contracts have included the Project Quality Assurance Project Plan (QAPP), the Draft Data Report, and the Draft Model Selection Technical Memorandum. 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, acquisition efforts, and subsequent responses from numerous State and federal agencies and other stakeholders. These documents essentially provide the foundation for the Simulation Plan presented in this report.

This Simulation Plan describes details of the model application effort, including model setup procedures and assumptions, calibration and validation time periods, constituents to be simulated, model scales and resolution, model performance targets, and an initial discussion of potential scenarios to be investigated as part of the TMDL development procedure. Thus, the previous documents are viewed as companion and supporting information to this Simulation Plan, and numerous references are made to information in those documents to avoid duplication herein.

This Simulation Plan is just that, a plan, and as such it is subject to change and refinement as the modeling process evolves, as additional data is discovered, and as modeling issues arise and need to be resolved during the model application process. This Plan is also a communication tool to maintain a transparent process for all stakeholders to understand how the models are constructed, how the data is used, how the models are being applied to the Illinois River Watershed (IRW) and Lake Tenkiller and how the watershed and lake modeling will be used as part of the TMDL development process.

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INTRODUCTION

1.1 BACKGROUND AND STUDY OBJECTIVES

The Illinois River is a multi-jurisdictional tributary of the Arkansas River, approximately 160 miles long, in the states of Arkansas and Oklahoma. The objective of this study is to develop a scientifically robust and defensible watershed and lake model to determine reductions in nutrient loads needed to meet water quality standards in both states, Arkansas and Oklahoma. This watershed and lake model will serve as a tool for sound technical decisions on appropriate point and nonpoint source controls to meet those standards. Ultimately, the intent is development of a modeling tool that can lead to the determination of scientifically sound TMDLs.

The U.S. Environmental Protection Agency's (EPA's) Region 6 has incrementally funded the development of the Illinois River Watershed Nutrient Model through a number of contracts including the current one under EPA Contract EP-C-12-052 with Michael Baker Jr., Inc. Previous contracts include EPA Purchase Order #EP-11-000023, and Work Assignments #3-36, #4-36, and 5-36 -- Water Quality Modeling and TMDL Development for the Illinois River Watershed -- under EPA's BASINS contract (# EP-C-06-029) with AQUA TERRA Consultants, Mountain View, California.

The Illinois River begins in the Ozark Mountains in the northwest corner of Arkansas, and flows for 50 miles west into northeastern Oklahoma (See Figure 1.1). 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 the reservoir Tenkiller Ferry Lake, also known as 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, several tributaries to the Illinois River in Arkansas (e.g. Osage Creek, Muddy Fork, and Spring Creek) are designated as Phosphorus-impaired and included in the State's Clean Water Act 303(d) list. (See Figure 1.2)

On 19 January 2010 a Call for Data was published in the Federal Register requesting that data relevant to this project be submitted before 3 March 2010. On 4 February 2010, EPA organized meetings in Fort Smith AR with the core state and federal agencies participating in the study, and with local stakeholder groups. These meetings provided an overview of the project and its objectives, and further elaborated on the data needs included in the FR Call for Data. Following the Fort Smith meeting and the FR Notice, a wide range of groups and agencies at all levels – federal, state, local, university – have been supportive of the of the effort by providing reports, documents, references, and data for use in the study.

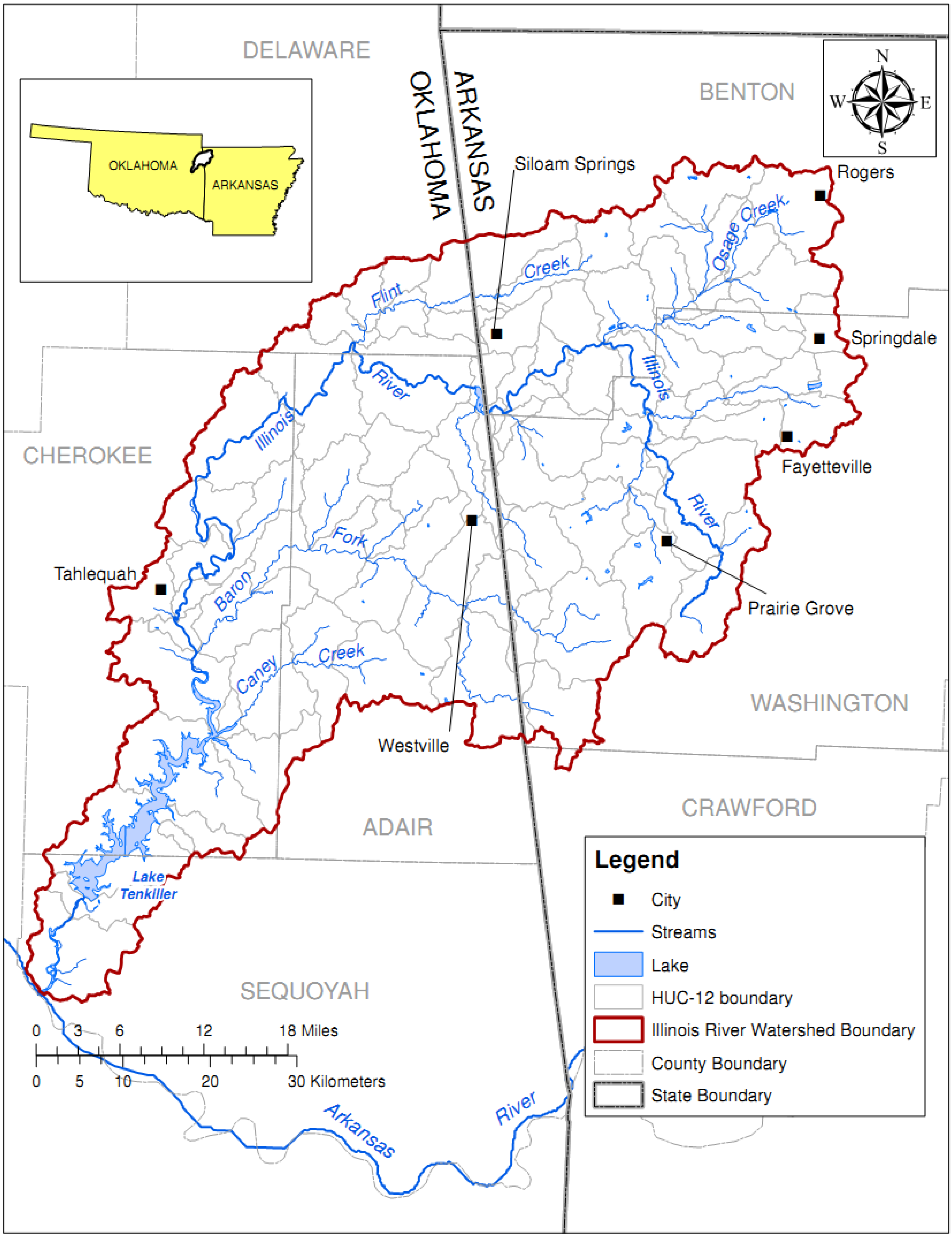


Figure 1.1 Illinois River Watershed Location map

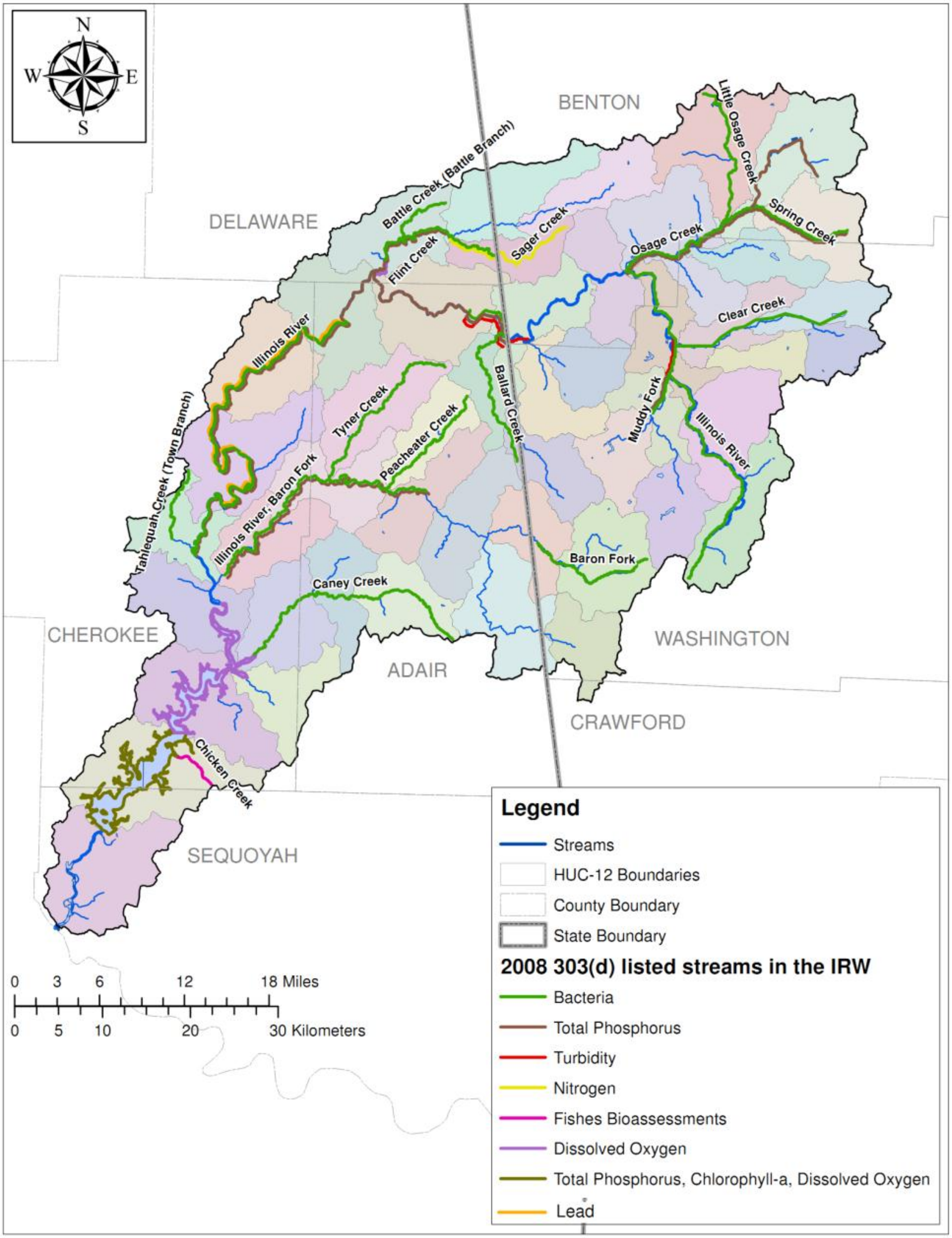


Figure 1.2 Section 303(d) Listed Impaired Segments within the Illinois River Watershed

In addition, individuals in each lead State agency – OK Department of Environmental Quality and AR Department of Environmental Quality – were identified and designated as the primary Points of Contact (POC) within each State.

The data gathering and accumulation efforts continued throughout 2010 and into 2011, with a significant increase in the volume of data and reports arriving after each of numerous project coordination and stakeholder meetings in September 2010 (Siloam Springs, AR), January 2011 (Tahlequah, OK), and May 2011 (Rogers, AR). In addition, review comments on the Data Report were received from a number of stakeholders, providing additional contacts and direction for data gaps identified in the report. The Final Data Report was provided in September 2011 (AQUA TERRA, 2011).

As part of the study effort, a model selection task was performed and produced a Draft Model Selection Technical Memorandum dated November 22, 2010 (Donigian and Imhoff, 2010). This model comparison and selection process resulted in the recommendation that the US EPA HSPF (Hydrological Simulation Program – FORTRAN (Bicknell et al., 2005)) watershed model and the US EPA EFDC (Environmental Fluid Dynamics Code (Hamrick 1992, 1996; Tetra Tech, 2007) lake model be used in a linked application to provide the necessary modeling framework for performing this study. Following receipt of review comments, the Final Memo was submitted in September 2011 (Donigian and Imhoff, 2011).

This Simulation Plan describes details of the model application effort for both models, including model setup procedures and assumptions, calibration and validation time periods, constituents to be simulated, model scales and resolution, model performance targets, and an initial discussion of potential scenarios to be investigated as part of the TMDL development procedure. Thus, the previous documents are viewed as companion and supporting information to this Simulation Plan, and numerous references are made to information in those documents to avoid duplication herein.

This Simulation Plan is just that, a plan, and as such it is subject to change and refinement as the modeling process evolves, as additional data is discovered, and as modeling issues arise and need to be resolved during the model application process. This Plan is also a communication tool to maintain a transparent process for all stakeholders to understand how the model is constructed, how the data is used, how the model is being applied to the Illinois River Watershed (IRW) and how the modeling will be used as part of the TMDL development process.

1.2 PRIOR MODELING STUDIES AND MANAGEMENT PLANS

The initial step in any modeling and/or data assessment effort is to review prior modeling studies that may identify and compile relevant data on the IRW and Lake Tenkiller, since all modeling efforts essentially use the same general types and categories of watershed and waterbody data. This section summarizes the major prior modeling efforts on the IRW and Lake Tenkiller, along with recent watershed management plans published for both sides of the state line.

Over the recent past, the IRW has been the focus of at least two previous modeling efforts by Donigian et al., (2009) and Storm et al., (2006 and 2009) which focused on the entire IRW. Under WA 2-11 of EPA Contract EP-C-06-029, AQUA TERRA and Eco Modeling completed an integrated-linked watershed and ecosystem modeling effort of the Illinois River and Tenkiller Reservoir, using the US EPA HSPF watershed model and AQUATOX ecosystem model (Donigian et al., 2009). This effort was directed to nutrient criteria development and was based on a relatively limited period of available data. The watershed simulation covered a 20-year period from 1984 through 2003, but available water quality data (at that time) limited the TN calibration to the period 1990-1996 and the TP calibration from 1999-2003, with downstream stations primarily in OK. In this HSPF/AQUATOX effort, the AQUATOX calibrations were limited to 1992-1993 using Clean Lakes Program data from Oklahoma State University (1996).

The watershed modeling effort by Storm et al. (2006) used the USDA SWAT model to represent the IRW, including specific consideration of the poultry litter applied to pasture areas, and subsequent runoff to the river system. That effort used relatively simple instream algorithms to approximate the complex instream fate and transport interactions of dissolved and particulate phosphorus. SWAT model runs were performed for the period of 1980 through 2006, including both calibration and validation; water quality calibration for TP (and dissolved P) was performed for 1990 through 2006. The OK DEQ provided to EPA and AQUA TERRA the most recent modeling report submitted by Dr. Storm (Storm et al., 2009), along with the model input and data files, including GIS files used in this SWAT model setup, for possible use in this effort.

There have been at least two studies of Lake Tenkiller using the US EPA HSPF watershed model for loadings and the US EPA EFDC model for hydrodynamics and water quality simulation of the lake. These include an initial study performed in support of TMDL development by EPA Region 6 and OK DEQ (US EPA and OK DEQ, 2001), with Tetra Tech contracted to perform the modeling, and a subsequent revision and refinement of that effort performed by Dynamic Solutions LLC (DSLLC, 2006) with AQUA TERRA Consultants (2005) subcontracted to upgrade the HSPF model of the IRW. Water quality calibrations were performed with available Clean Lakes Program data for 1992 and 1993, the same period as the subsequent AQUATOX application noted above. Additional water quality investigations of Lake Tenkiller, developed using watershed and lake data collected by CDM/USGS for the State of Oklahoma (Olsen, 2008), included a laterally-averaged CE-QUAL-W2 hydrodynamic and water quality (Wells and Berger, 2008) and an analysis of the effects of watershed nutrient loading on eutrophication in the lake (Cooke and Welch, 2008; Cooke et al., 2011; Welch et al., 2011)

More recently Saraswat et al., (2010) and White (2009) have published modeling efforts using the SWAT model applied to the AR portion of the IRW. The Saraswat effort focused on the 12-Digit HUC (Hydrologic Unit Code) spatial level within the IRW, and addressed issues of impaired water quality for the Illinois River and selected tributaries within AR. White's study appears to be a refinement of the previous study by Storm et al (2009), with greater detail on the AR side. Both efforts were primarily directed to monthly comparisons of observed and simulated loads and concentrations, but include a comprehensive assessment of phosphorus sources and potential impacts of conservation efforts and management practices.

Both of these modeling studies also were part of development efforts for watershed management planning for the IRW on both sides of the state line. Near the end of 2010, a draft watershed management plan (WMP) was published by the Illinois River Watershed Partnership (IRWP) Watershed Management Plan (IRWP, 2010). This WMP presents a watershed management strategy with the goal to "improve water quality in the Illinois River and its tributaries so that all waters meet their designated uses both now and in the future." Although this document focuses on the AR portion of the IRW, a comparable effort was ongoing for the OK portion by the Oklahoma Conservation Commission (OCC), who recently finalized their draft plan (OCC, 2010). Both of these plans have been very helpful in our efforts to identify previous studies, available data, water quality issues of concern, and potential remediation and restoration alternatives within their respective portions of the IRW.

1.3 MODELING APPROACH

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

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

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

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

EFDC was selected because it allows a more mechanistic modeling of thermal stratification and is capable of a high level of spatial resolution in Lake Tenkiller, both of which are essential to support water quality compliance issues in OK, particularly time- and space-varying anoxic conditions. EFDC also provides moderately complex *biochemical* process representation that enables modeling and evaluation of chlorophyll *a* concentrations expressed as Carlson's Trophic State Index (TSI). Oklahoma statutes use TSI values to determine whether or not water bodies are threatened by nutrients. The EFDC water quality model is internally coupled to a sediment diagenesis model (Di Toro, 2001) so that the effect of external nutrient loading on organic matter production and settling to the bed, decomposition within the bed, sediment oxygen demand and benthic release of nutrients to the lake can be simulated within a consistent mass balance model framework. The sediment diagenesis model is the only lake model methodology available to provide a simulated cause-effect link between watershed loading, nutrient enrichment, eutrophication, sediment oxygen demand and internal release of nutrients from the lake bed back to the water column.

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

1.3.1 *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.

1.3.2 *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, 1996). Subsequent support for EFDC development at VIMS was provided by the U.S. Environmental Protection Agency and the National Oceanic and Atmospheric Administration's Sea Grant Program. Tetra Tech, Inc. became the first commercial user of EFDC in the early 1990's and upon Dr. Hamrick's joining Tetra Tech in 1996, the primary location for the continued development of EFDC (Tetra Tech, 2007). Primary external support of both EFDC development and maintenance and applications at Tetra Tech has been provided by the U.S. Environmental Protection Agency including the Office of Science and Technology, the Office of Research and Development, and Regions 1 and 4. The ongoing evolution of the EFDC modeling system has to a great extent been application driven by a diverse group of EFDC users in the academic, governmental, and private sectors

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

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

a. EFDC provides an effective spatial framework and process representation scheme that will allow the mechanistic modeling of thermal stratification phenomena in Lake Tenkiller. This capability is deemed essential to one of the two most important evaluation endpoints, i.e., the identification of time-varying anoxic conditions.
b. By offering a more mechanistically based simulation of stratification, EFDC in turn offers a capability to model the *physica*l component (i.e., vertical movement of the biotic and chemical materials within reservoir) of the eutrophication process.
c. The spatial resolution and the physical detail achieved by the EFDC flow simulation provides significant benefit to a water quality simulation performed at the same level of spatial resolution as the EFDC hydrodynamics simulation.
d. The high spatial resolution that is inherent in EFDC applications (and results) offers advantages in applications that are intended to support compliance with water quality standards. The planned application for this project has that objective.
e. EFDC provides appropriate *biochemical* process representation to model and evaluate chlorophyll a concentrations expressed as Carlson's Trophic State Index. Further, EFDC enables accurate spatial mapping of observed data using its detailed grid system.
f. The EFDC sediment diagenesis model is the only lake model methodology available to provide a simulated cause-effect link between watershed loading, nutrient enrichment, eutrophication, sediment oxygen demand and internal release of nutrients from the lake bed back to the water column.
g. Previous applications of EFDC to Lake Tenkiller provide significant opportunities for leveraging.

1.3.3 *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 1.3 shows the various components and capabilities of the PERLND module of HSPF. Each of the boxes in Figure 1.3 identifies a capability used by HSPF to model the corresponding process, or processes, that occur on each category of land; thus, the PWATER subroutine models the water budget, SEDMNT models soil erosion and delivery to the stream, PSTEMP models soil temperatures, etc. For runoff loadings of water quality constituents, HSPF provides alternative methods, among which the user can select, to calculate loadings either with simple, empirical build-up and washoff algorithms used in the PQUAL subroutine, or the detailed mass balance formulations used within the group of subroutines within the dashed-line box marked as AGCHEM. The PQUAL (and IQUAL for impervious surfaces) are commonly used for urban land uses, as the buildup/washoff formulations have traditionally been applied for urban runoff quality models, and for applications that are primarily focused on impacts of urbanization and a general assessment of land use changes. For watersheds that are dominated by agriculture, and agricultural practices and impacts are key elements 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.

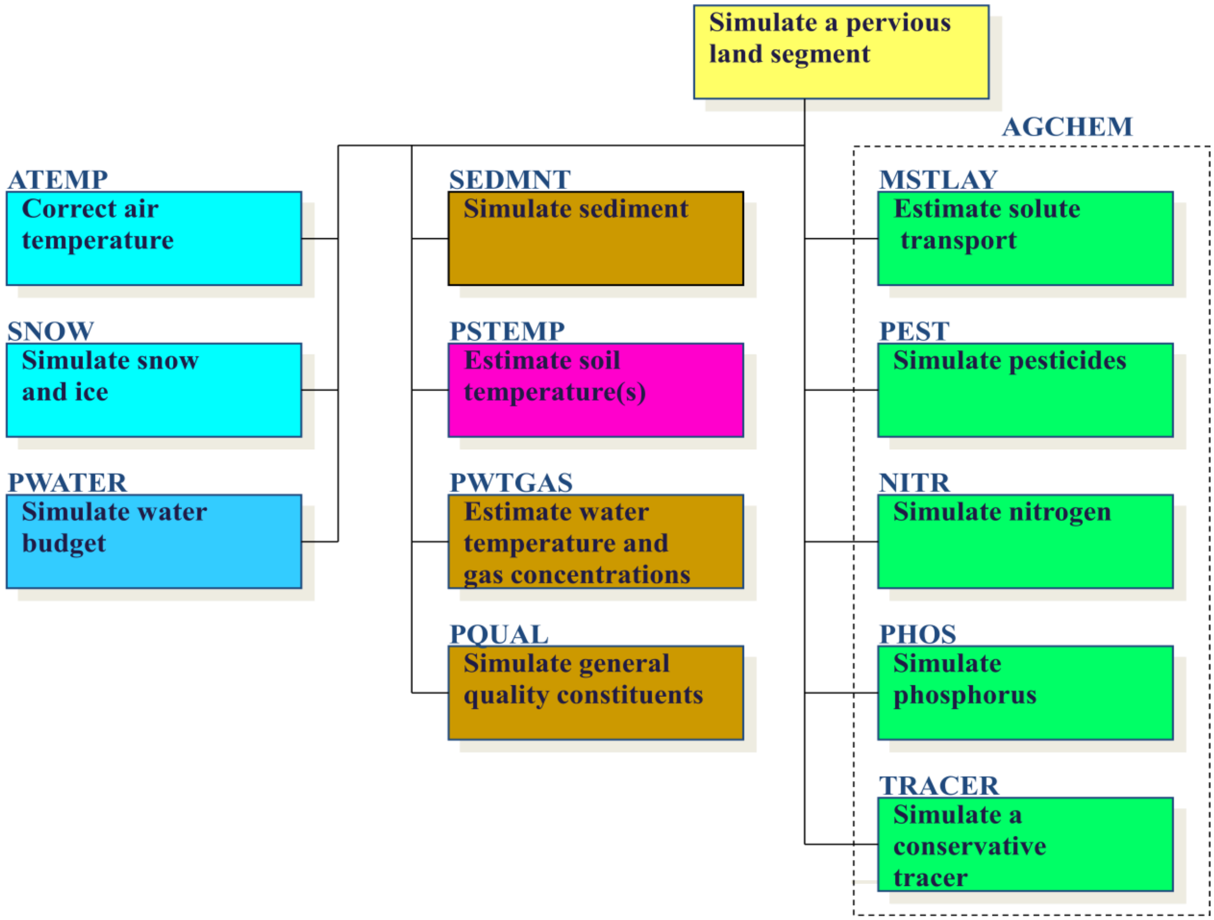


Figure 1.3 Pervious Land Simulation (PERLND) Module in HSPF

Figure 1.4 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 1.5 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.

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. The HSPF-EFDC linkage is further discussed in Section 5.4.

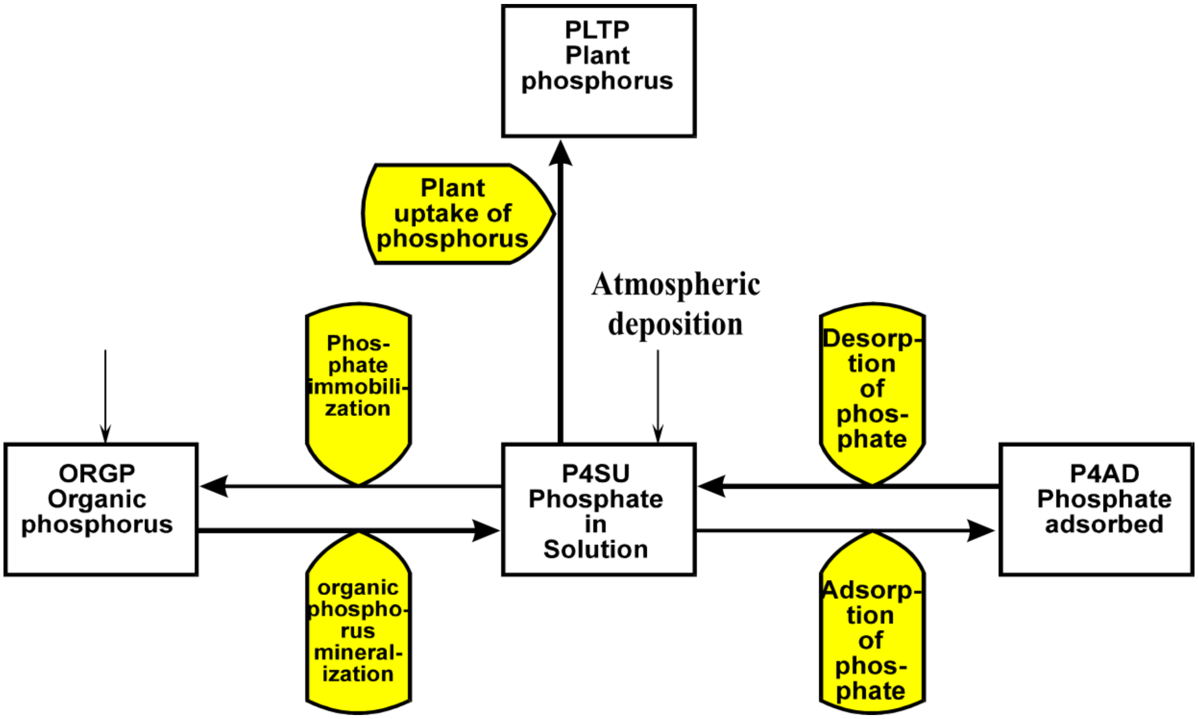


Figure 1.4 Soil Phosphorus Cycle in HSPF AGCHEM

As previously stated, modeling of hydrodynamics and water quality processes in Lake Tenkiller will be performed using the Environmental Fluid Dynamics Code (EFDC) (Hamrick, 1992; 1996; Tetra Tech, 2007). EFDC is a state-of-the-art hydrodynamic and water quality model that can be used to simulate surface water systems in one, two, and three dimensions. EFDC uses stretched, or a sigma bottom following vertical coordinate system, and Cartesian or curvilinear, orthogonal horizontal coordinates to represent the physical characteristics of a waterbody. EFDC solves three-dimensional, vertically hydrostatic, free surface, turbulent averaged barotropic and baroclinic equations of motion for a variable-density fluid. Dynamically-coupled transport equations for turbulent kinetic energy, turbulent length scale, salinity and water temperature are also solved. The EFDC model allows for drying and wetting in shallow areas using a mass conservation scheme and includes capabilities to model flushing time, age of water and Lagrangian particle tracking. The hydrodynamic model of EFDC is equivalent to other 3D finite difference models such as the Estuarine Coastal and Ocean Model (ECOM) (Blumberg and Mellor, 1987), and the Curvilinear Grid Hydrodynamics Model in 3-Dimensions (CH3D) model (Sheng, 1987, 1990). EFDC, unlike most surface water models, is a single source code model that internally links sub-models for the smooth interface of hydrodynamics with sediment transport, water quality and sediment diagenesis sub-models. Any technical issues related to the linkage of EFDC hydrodynamic results for input to water quality models are eliminated with the full EFDC model. Sediment transport of cohesive and non-cohesive solids internally links hydrodynamics with deposition and resuspension and wind-driven resuspension processes. The water quality model includes organic carbon, nutrients, dissolved oxygen and eutrophication processes that can represent up to three classes of phytoplankton and benthic macroalgae. The water quality model includes internal coupling with a sediment diagenesis model to provide sediment fluxes of nutrients and oxygen to the water column. Wet and dry atmospheric deposition of nutrients is represented in the lake model with data from the National Atmospheric Deposition Program (NAPD) and the Clean Air Status and Trends Network (CASTNet) monitoring networks used in the HSPF model.

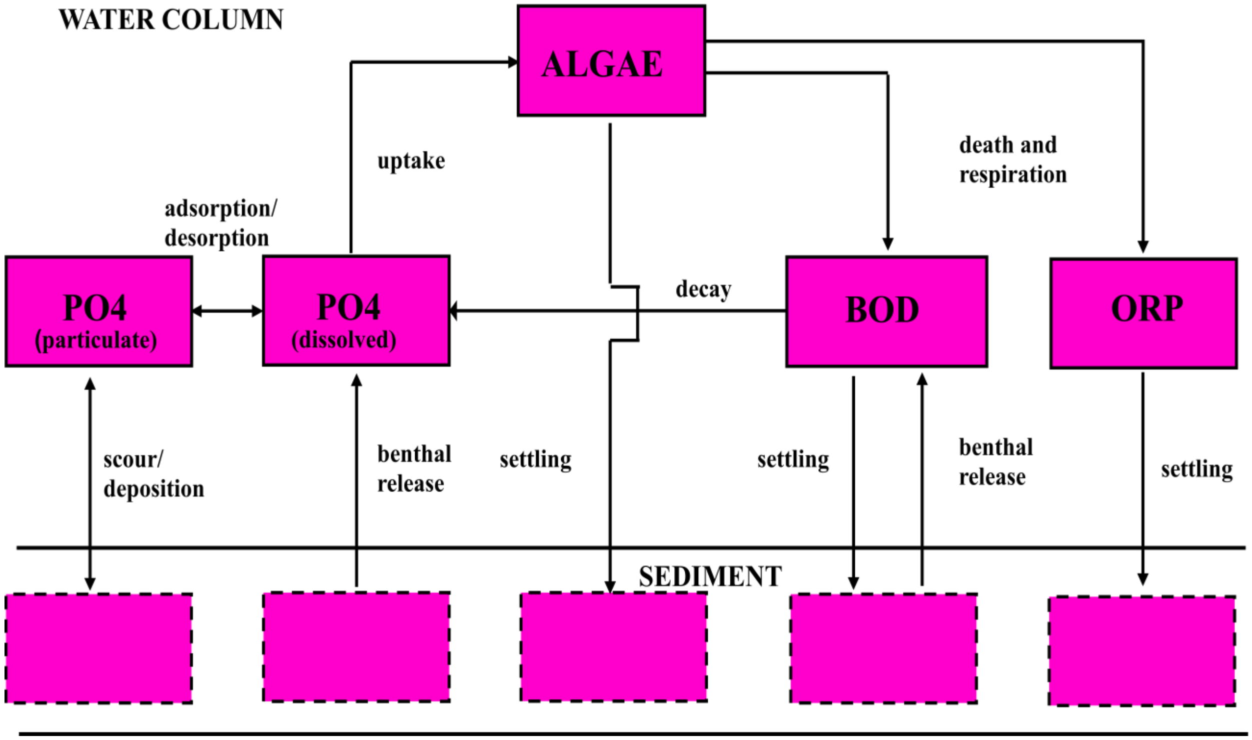


Figure 1.5 Instream Phosphorus Processes in HSPF RCHRES

1.4 OVERVIEW OF DATA IDENTIFICATION, ACQUISITION, AND INVESTIGATION EFFORTS

A wide variety of different types of data is required for watershed and waterbody modeling efforts such as those planned for this TMDL effort. These categories include precipitation and meteorologic data, land characteristics (e.g. topography, land use, soils, climate variability), hydrography and waterbody characteristics, monitoring data, and other supporting information (e.g. prior studies, source identification).

As noted above, on 19 January 2010 a Call for Data was published in the Federal Register requesting that data relevant to this project be submitted before 3 March 2010. Following a project coordination and stakeholders meeting in Fort Smith, AR, on 4 February 2010, a number of agencies were forthcoming with an extensive array of data and reports. The information was received primarily through email submittals, but also some hard copy and other electronic forms of transmission. This information was further supplemented by directed online searches and by leads (or actual data) provided by the designated POCs for both States, Oklahoma and Arkansas.

In August 2010, a preliminary data review and analysis report was prepared and submitted to stakeholders as a summary and compilation of the data and information received through the various data gathering efforts described above. The Data Review report also served as an opportunity for the Study Team members and stakeholders to review the data accumulated and assess whether there existed other additional data and information, or not discussed therein, that should be included in the study effort. Thus, it provided a check on whether those efforts had been effective and complete in identifying all available data and information to support the IRW water quality model development effort.

The data gathering and accumulation efforts continued throughout 2010 and into 2011, with a significant increase in the volume of data and reports arriving after each of numerous project coordination and stakeholder meetings in September 2010 (Siloam Springs, AR), January 2011 (Tahlequah, OK), and May 2011 (Rogers, AR). In addition, review comments on the Data Report were received from a number of stakeholders, providing additional contacts and direction for data gaps identified in the report. The Data Report was revised to reflect and respond to the review comments received, and to incorporate the tremendous amount of additional information received since the draft report was issued. The Final Data Report was completed by the end of September 2011 (AQUA TERRA Consultants, 2011).

1.5 THIS REPORT

As noted above, this report presents the Simulation Plan for the IRW, including details of the model application effort for both models – HSPF and EFDC, model setup procedures and assumptions, calibration and validation time periods, constituents to be simulated, model scales and resolution, model performance targets, and an initial discussion of potential scenarios to be investigated as part of the TMDL development procedure.

Following this overview, Section 2 describes the time series data available to support watershed model setup and operation, and Section 3 describes the model segmentation characterization of the IRW. Section 4 follows with a description of the watershed model calibration and validation procedures and model performance targets, while Section 5 describes those planned efforts for the EFDC application to Lake Tenkiller. Model linkage issues between HSPF and EFDC are also discussed in Section 5. Since this Simulation Plan is just that, a plan, and as such it is subject to change and refinement as the modeling process evolves, Section 6 discusses some remaining special issues and considerations that need to be resolved as the process continues. These include modeling karst conditions within the IRW, phosphorus source issues, poultry litter representation, and alternative modeling scenarios.

SECTION 2.0

TIME SERIES DATA AVAILABILITY FOR THE IRW MODEL

Simulation of hydrology and water quality within the IRW requires the following types of time series data:

1. Precipitation
2. Potential evapotranspiration
3. Other meteorologic data (e.g. air temperature, wind, solar radiation, dewpoint, cloud cover)
4. Streamflow
5. Water quality observations
6. Other data (e.g. points sources, diversions, withdrawals, atmospheric deposition)

This section discusses the availability and selection of these time series data for use in the watershed modeling. In addition, other data types, such as point sources, diversions, atmospheric deposition, etc. are also discussed as they help to define the inflow, outflow, and quality of water in the watershed, and their use in the modeling effort.

2.1 PRECIPITATION

For hydrology calibration of the IRW, all watershed models require precipitation timeseries that are complete records (*i.e.*, no missing data) at a daily or shorter timestep, depending on the selected model, and with adequate spatial coverage and density across the model domain. Precipitation is the critical forcing function for all watershed models as it drives the hydrologic cycle and provides the foundation for transport mechanisms, both flow and sediment, that move pollutants from the land to the waterbody where their impacts are imposed.

For this study, long-term precipitation data have been obtained from the following primary sources:

a. Prior modeling efforts with BASINS/HSPF and SWAT
b. Online databases (e.g., NOAA, USGS) accessed through the BASINS download data capability
c. OK Mesonet data network (provided by ODEQ)
d. Daily NEXRAD data (provided for AR by Drs Matlock and Saraswat at the University of Arkansas (Personal communication, 1 January 2011)
e. BASINS data extended through 12/31/09 (from an ongoing BASINS data project)

The last two precipitation data items (listed above) were obtained since the publication of the Draft Data Report in August 2010. Figure 2.1 shows the precipitation stations proposed for use in the IRW modeling effort. These stations are a subset of all the available stations, following a screening of the data to ensure recent and complete records from about 1980 through 2009. This time period provides a 30-year database to support longterm model runs for evaluation of watershed scenarios over a wide range of meteorologic conditions.

In addition to the actual precipitation gage stations, Figure 2.1 shows the ‘pseudo’ stations for the NEXRAD data (discussed below) for the AR portion of the watershed, and a Thiessen polygon analysis for the OK side of the watershed based on the locations of the NWS and OK Mesonet station locations. Thus a hybrid approach is proposed, i.e. Thiessen analysis of gage stations on the OK side, and NEXRAD data on the AR side, to make use of the best available precipitation data on both sides of the watershed. Both of these approaches are further discussed below.

The Data Report identified an area of relatively sparse coverage on the AR side of the watershed, about the center of the area where the Illinois River bends toward the west (see Figure 2.1). The study was fortunate to obtain daily precipitation data from Drs Matlock and Saraswat at the University of Arkansas for 28 'pseudo' gage sites (shown as the yellow circles in Figure 2.1), located at the approximate centroid of the HUC12 subwatersheds. This daily data set was developed as a combination of three NWS stations (Bentonville, Fayetteville, and Gravette) for the period 1981-93, and NWS NEXRAD (Next Generation Weather Radar) data for the period 1994-2008.

The station data for the early period (1981-93) were adjusted to the subwatershed centroids using an inverse distance weighting method developed by Zhang and Srinivasan (2009). The extension of these data through 2008 was derived from the NEXRAD Stage III data for 82 4x4 km grid cells within the IRW. In the words of Dr. Saraswat … "The data required several levels of post processing including unzipping, untarring, and transformation from the NEXRAD hydrological rainfall analysis project (HRAP) grid to a geographical coordinate system….. All NEXRAD grid points falling within a subwatershed were aggregated; an average value calculated; and assigned to pseudo weather stations at the centroid of the … subwatersheds." (Saraswat, 2010, pg 18). These data help to fill in the sparse coverage on the AR portion of the IRW; however, due to the manner in which NWS observed data was processed and then combined with NEXRAD data to cover the 1981-2008 period for the 'psuedo' stations, further analysis and evaluation of these data sets is needed as part of the model setup and calibration efforts. It is critical that the precipitation data demonstrate consistency across the entire IRW in order to produce a scientifically sound hydrologic model.

On the OK side of the IRW, four Mesonet stations are combined with up to seven NWS stations, (denoted as BASINS in Figure 2.1, since they are available by download) to provide a reasonable coverage of the watershed within OK. An initial Thiessen analysis is shown in Figure 2.1 (green lines) for the OK side. A Thiessen analysis is a standard hydrologic technique to define the watershed area that will receive rainfall recorded at a specific gage; it involves constructing polygons around each gage using perpendicular bisecting lines drawn at the midpoint of connecting lines between each gage. In other words, the first step is to draw lines connecting the gages, then at the midpoint draw a perpendicular line, then erase the connecting lines, and the result is a polygon around each gage. In Figure 2.1, there are nine gages for which the Thiessen analysis produced nine polygons, although two or three are at the fringes of the watershed boundary and will either be combined with an adjacent gage, or deleted.

Table 2.1 tabulates all the available precipitation stations, and identifies the Mesonet sites and the specific stations used by Donigian et al (2009) in a prior HSPF/AQUATOX study. In addition to providing detailed 5-minute data, the Mesonet stations by their locations appear to fill in some areas with otherwise sparse gage coverage in the southern and western portions of the IRW. The Mesonet stations also provide extensive meteorologic data, discussed below.

Based on the previous HSPF and SWAT modeling efforts, and the precipitation stations identified in Table 2.1 and Figure 2.1, the coverage of daily stations appears sufficient for coverage of the IRW, especially with the addition of the Mesonet stations on the OK side, and the NEXRAD data for the AR side.

To simulate individual storm events, HSPF requires hourly data, and the conventional practice is to use nearby hourly stations to disaggregate daily precipitation values to hourly increments.

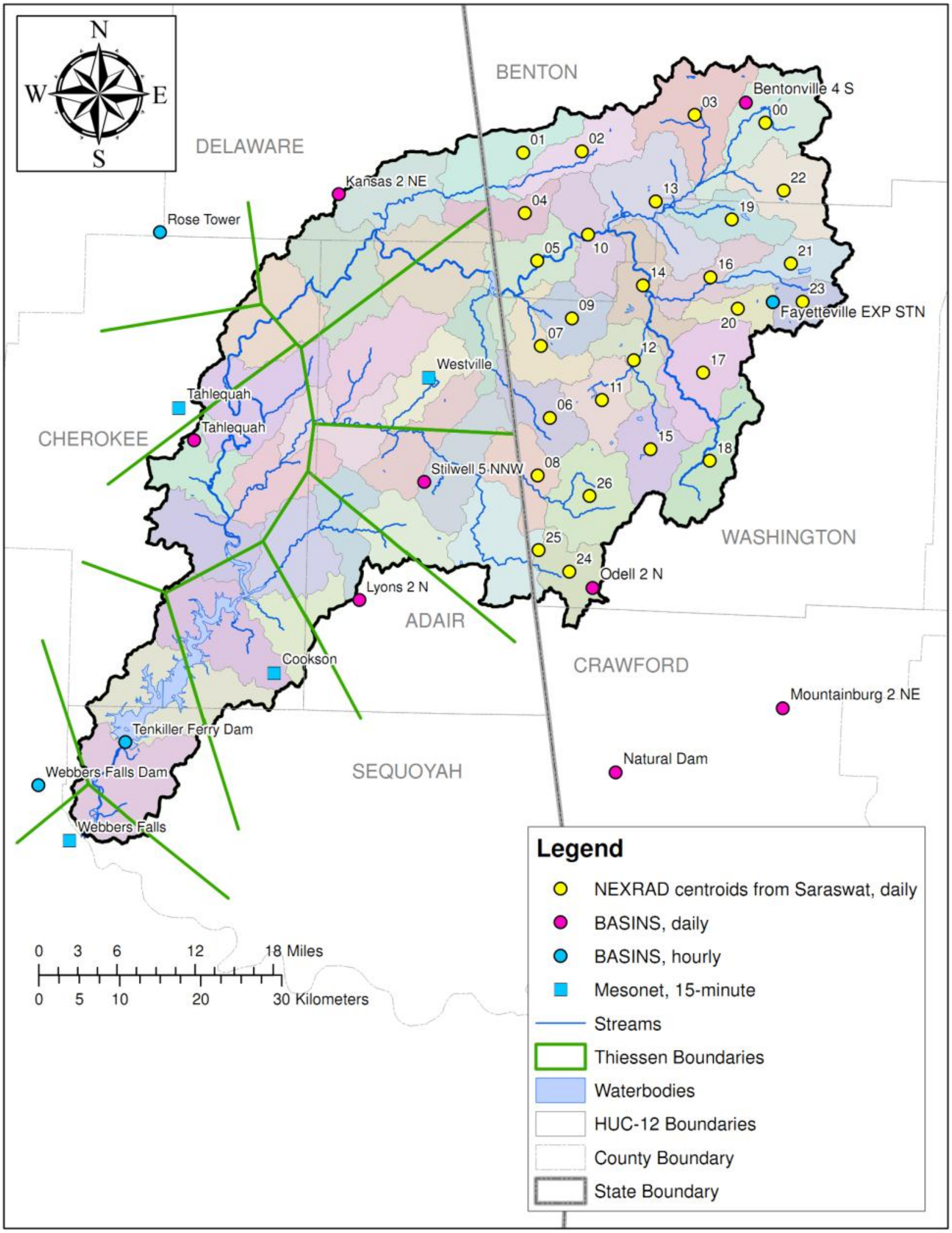


Figure 2.1 Precipitation Stations Selected for Use in the IRW Model

Table 2.1 Precipitation Stations in/near the Illinois River Watershed

Site Name	Site Number	Source	Start	End	Av Annual Precip (in)
Bentonville 4S	AR030586	BASINS daily	12/31/1947	2/28/2007	46.79
Cookson	31	Mesonet 5-min	1/1/1994	5/26/2010	
Fayetteville Exp Sta*	AR032444	BASINS hourly	4/1/1966	3/31/2006	46.17
Fayetteville Exp Sta*	AR032444	BASINS daily	12/14/1926	8/31/2003	46.17
Mountainburg 2NE	AR035018	BASINS daily	8/31/1985	12/31/2009	50.61
Natural Dam	AR035160	BASINS daily	12/31/1962	12/31/2009	49.39
Odell 2 N*	AR035354	BASINS daily	12/31/1947	12/31/2009	51.56
Kansas 2 NE*	OK344672	BASINS daily	3/31/1959	12/31/2009	48.23
Lyons 2 N*	OK345437	BASINS daily	12/31/1947	9/30/2003	47.75
Rose Tower*	OK347739	BASINS hourly	1/1/1974	12/31/2003	46.79
Stilwell 5 NNW*	OK348506	BASINS daily	9/30/1948	4/30/2003	49.11
Tahlequah*	OK348677	BASINS daily	12/31/1947	12/31/2006	47.64
Tahlequah	92	Mesonet 5-min	1/1/1994	5/26/2010	
Tenkiller Ferry Dam*	OK348769	BASINS hourly	4/1/1949	1/31/1999	46.33
Webbers Falls	103, 132	Mesonet 5-min	1/1/1994	5/26/2010	
Westville	104	Mesonet 5-min	1/1/1994	5/26/2010	

*This station was previously used in the HSPF/AQUATOX study by Donigian et al (2009).

The BASINS procedures for performing this disaggregation involve identifying up to 30 nearby stations, selecting the hourly station based on both geographic distance (proximity) and similarity of daily vales, and then using the hourly distribution at that station to transform the daily station value into 24 hourly values. A tolerance threshold is used to only select stations whose daily total is within a certain percentage of the daily value for the station being disaggregated. Typical tolerance values are in the range of 30% to 90%, depending on the availability of nearby alternate gages.

For the IRW, there are nine hourly stations, which include four Mesonet and five BASINS stations derived from NWS data. The combined Mesonet and BASINS hourly sites provide a good distribution for the OK side of the watershed, whereas hourly distributions for the AR side will be derived from Fayetteville and the Westville Mesonet site in OK.

Another indicator of rainfall patterns on the watershed is an annual isohyetal map, as shown in Figure 2.2, which displays lines of equal annual rainfall (i.e., isohyets) across the watershed, based on the 1971-2000 period. The data for this map were obtained from the Oregon State University web site for their PRISM model (Parameter-elevation Regressions on Independent Slopes Model) (www.ocs.orst.edu/prism/). Gridded data, generated by this model based on point rainfall data, a DEM for topographic data, and other GIS data, was processed to produce the isohyets shown in the map. The information from Figure 2.2 can be helpful to assess the consistency of other rainfall estimates, and allow a determination of whether point rainfall data should be adjusted to better represent the area it is applied to. The pattern shows an overall range of 47 to 52 inches per year, but the large majority of the water shed experiences an annual range of only 48 to 50 inches.

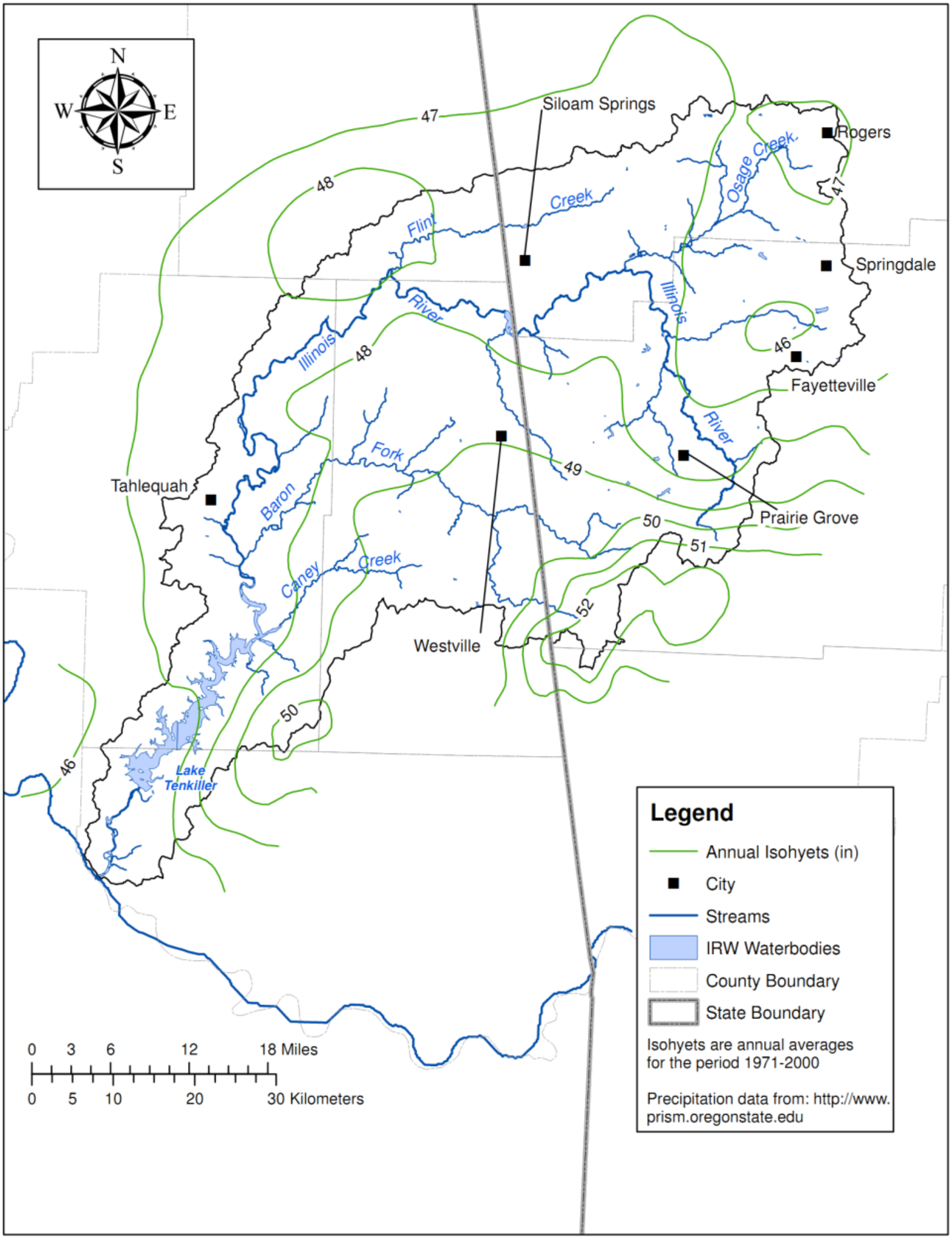


Figure 2.2 Annual Isohyetal Map of the IRW

2.1.1 *Snow Data*

Snow depth and 'snow on ground' data is used to calibrate the snow accumulation and melt processes when they are activated on a specific watershed. These same data are also used in conjunction with mean and maximum winter air temperatures to assess whether or not to activate the snow simulation capability within the watershed model. Snow data for selected sites within the IRW from the Southern Regional Climate Center in Baton Rouge, LA (http://www.srcc.lsu.edu/) was reviewed. For the Fayetteville region, mean temperatures during the winter generally range from the mid-thirties to the mid-forties (degrees F);mean annual total snowfall is in the range of 6 to 12 inches, at most, and rarely exceeds a few inches in any event. Such minor amounts usually melt within a few days at most, and will normally have little impact on storm runoff and the hydrologic regime of the IRW.

Based on the lack of persistent snow cover, as demonstrated in the data we received and based on reviewer comments on our data report, we do not plan to activate the snow simulation on the IRW, at least for our initial hydrology calibration runs. If model results indicate problems with matching storm events during winter periods, we may consider if activating the snow modules will improve the simulations. The recent 2010-2011 winter, especially the storm of 9 February 2011, demonstrated that significant snow can occur in the region, but it is not a common occurrence.

2.2 EVAPOTRANSPIRATION AND OTHER METEOROLOGICAL DATA

Watershed models require evaporation data as a companion to precipitation to drive the water balance calculations inherent in the hydrologic algorithms contained in these types of models. In addition, other meteorologic time series are also often required in temperate climates where snow accumulation and melt are a significant component of the hydrologic cycle and water balance. These same time series, such as air temperature, solar radiation, dewpoint temperature, wind, and cloud cover, are often required if soil and/or water temperatures are simulated. Water temperature is subsequently used to adjust rate coefficients in most water quality processes, and other time series are used in selected calculations, like solar radiation affecting algal growth.

Both HSPF and SWAT have similar weather data requirements (with some slight differences), so the availability of weather data is expected to be adequate for model application, considering both models have been previously applied to the IRW.

HSPF generally uses measured pan evaporation to derive an estimate of lake evaporation, which is considered equal to the potential evapotranspiration (PET) required by model algorithms, i.e., PET = (pan evap) X (pan coefficient). The actual simulated evapotranspiration is computed by the program based on the model algorithms that calculate dynamic soil moisture conditions, ET parameters, and the input PET data. Where pan evaporation is not available, potential evapotranspiration (PET) can be computed from minimum and maximum daily air temperatures using the Hamon formula (Hamon, 1961). This method was used to compute the PET data included in the BASINS database of available meteorologic time series. The Hamon method generates daily potential evapotranspiration (inches) using air temperature (F or C), a monthly variable coefficient, the number of daylight hours (computed from latitude), and absolute humidity (computed from air temperature).

Recently, BASINS has been enhanced to also allow computation of PET according to the Penman-Monteith method, which involves a more detailed computation requiring air temperature, solar radiation, relative humidity, and wind speed, along with other coefficients. The method incorporated into BASINS was based on procedures included in the SWAT model. As part of the model setup effort, PET estimates from both the Hamon and Penman-Monteith methods will be compared and researched to determine the most appropriate method for the IRW.

The primary source of evapotranspiration and the other meteorologic data was the BASINS database of thousands of stations across the US; the download capability within BASINS allows users to identify their selected watersheds and then access all the data available, including meteorologic data. Figure 2.3 shows the available meteorologic stations in and near the IRW available through BASINS; it also shows the nearest OK Mesonet stations. The OK Mesonet is an automated network of about 120 remote meteorologic stations across OK instrumented to monitor and measure soil and meteorologic conditions. As shown in Figure 2.3, there are five Mesonet stations within or near the IRW. Table 2.2 lists the meteorologic stations found through BASINS along with the Mesonet sites.

The nearest pan evaporation station to the IRW is the Blue Mountain Dam NWS site approximately 30 miles southeast of the watershed. This site was used as the only evaporation data station for the HSPF/AQUATOX study; since PET generally demonstrates little spatial variability in this climate region, compared to rainfall variability, the distance was not considered excessive. Table 2.2 shows 14 sites with BASINS computed evapotranspiration data providing sufficient coverage for the IRW. Also, the stations available for the remaining weather data, combined with the Mesonet sites, appears to provide a similar level of coverage.

As part of the model setup effort, the various estimates of PET – Blue Mountain Dam pan data, Hamon method, Penman-Monteith method – will be compared and researched to determine the best method to use for this study. In addition, Thiessen analyses will be performed to identify the watershed areas for which each meteorological timeseries will be applied, analogous to what was discussed above for the precipitation stations. Since PET and air temperature are the more critical of the meteorologic forcing data sets, and more data sites are available, we expect to have a denser network for PET and air temperature than for wind, solar radiation, dewpoint temperature, or cloud cover. The periods of available historic data for these meteorologic data, starting mostly about 1995, is consistent with our expected calibration and validation periods (discussed in Section 4). However, except for air temperature and PET, we will need to address the issue of developing the supporting meteorologic data for longterm model runs, from about 1980 through 2009, for the other meteorologic data types. The only longterm station shown for these other data types is Webber Falls Dam which started in 1970. We may need to either look for more distant sites, or generate the needed data with accepted procedures and/or correlations.

2.3 STREAMFLOW

Flow data is needed for both calibration and validation of the watershed model to ensure it is reproducing the hydrologic behavior of the IRW, and providing proper boundary inflows into Lake Tenkiller, along with its transport of sediment and water quality constituents. The BASINS download capability provided the means to access all the USGS flow (and water quality) data for sites in the watershed.

Figure 2.4 shows the locations of the USGS gaging sites within the watershed, Table 2.3 and lists their names, USGS ID numbers, periods of record, tributary areas, and elevations for selected sites. In addition, recently AWRC (B. Haggard, personal communication, 2011) provided supplemental data for Ballard Creek and Moore’s Creek that could also be used for model application.

The USGS sites designated with red circles (●) are those used for model calibration and/or validation in the previous HSPF and SWAT model applications discussed above. Section 4 addresses the issue of selection of calibration/validation sites in both states, and the corresponding time periods. There appears to be adequate periods of record for three to five calibration sites within each state, if project resources support this level of calibration effort.

Data and information on Lake Tenkiller is discussed separately in Section 5.

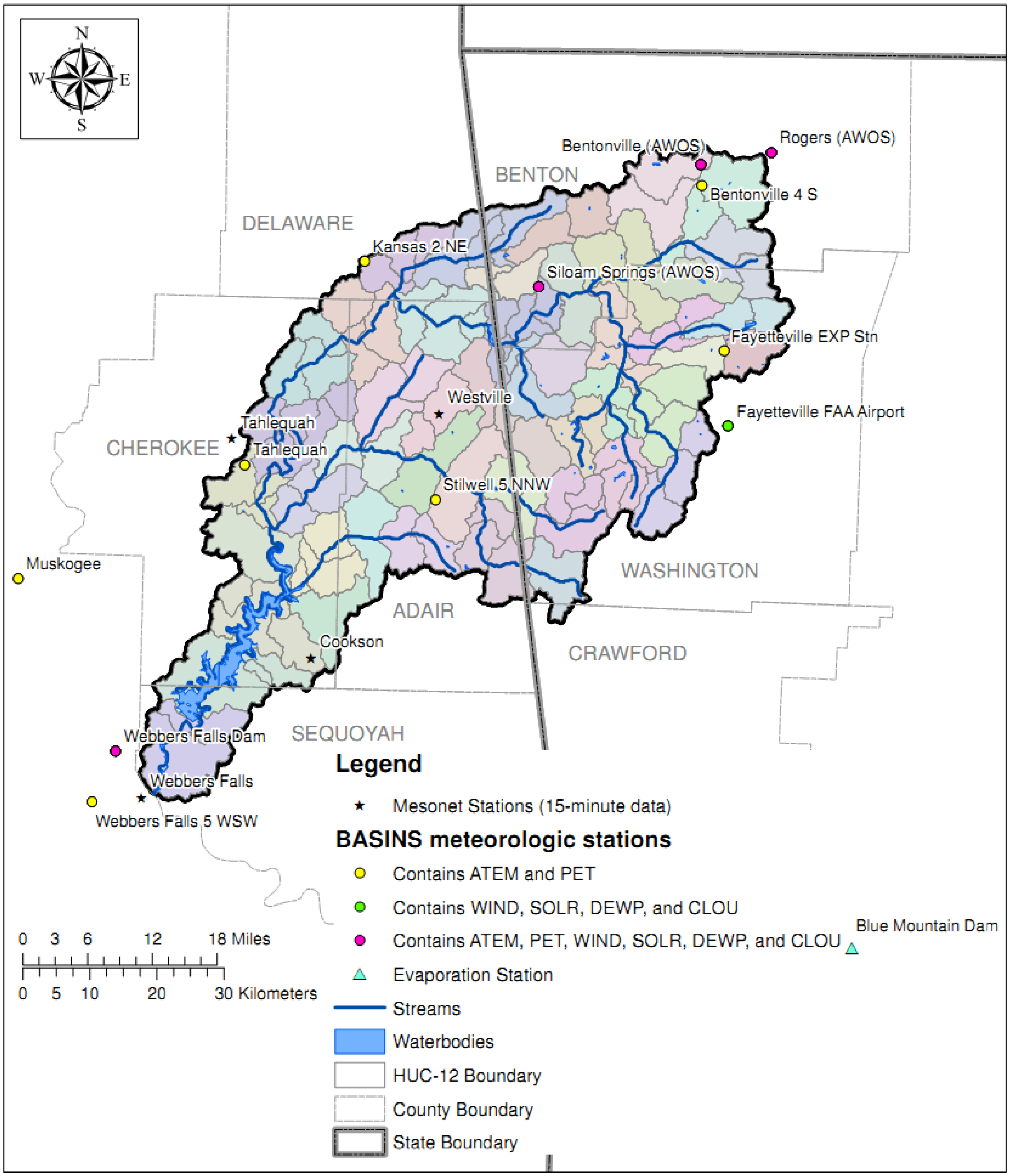


Figure 2.3 Other Meteorological Stations in/near the Illinois River Watershed

Table 2.2 Meteorological Stations in/near the Illinois River Watershed

Site Name	Site Number	Source	Data Type	Start	End
Bentonville (AWOS)	AR723444	BASINS	ATEM, PET, WIND, SOLR, DEWP, CLOUD	1/1/1995	12/31/2009
Bentonville 4S	AR030586	BASINS	ATEM, PET	1/1/1948	2/28/2007
Blue Mountain Dam*[1]		previous study	ATEM, PET	1/1/1984	9/30/2004
Cookson	31	Mesonet	ATEM, BP, SOLR, WIND	1/1/1994	present
Fayetteville Exp Sta	AR032444	BASINS	ATEM, PET	8/26/1921	8/31/2003
Fayetteville FAA Airport	AR032443	BASINS	WIND, SOLR, DEWP, CLOUD	12/31/1994	12/31/2009
Kansas 2 NE	OK344672	BASINS	ATEM, PET	4/1/1959	1/1/2010
Muskogee	OK346130	BASINS	ATEM, PET	1/1/1948	12/31/2009
Rogers	AR723449	BASINS	ATEM, PET, WIND, SOLR, DEWP, CLOUD	1/1/1995	12/31/2009
Siloam Springs (AWOS)	AR723443	BASINS	ATEM, PET, WIND, SOLR, DEWP, CLOUD	1/1/1995	12/31/2009
Stilwell 5 NNW	OK348506	BASINS	ATEM, PET	1/1/1960	4/30/2003
Tahlequah	OK348677	BASINS	ATEM, PET	1/1/1948	12/31/2006
Tahlequah	92	Mesonet	ATEM, BP, SOLR, WIND	1/1/1994	present
Webbers Falls	103, 132	Mesonet	ATEM, BP, SOLR, WIND	1/1/1994	present
Webbers Falls Dam	OK349450	BASINS	ATEM, PET, WIND, SOLR, DEWP, CLOUD	1/1/1970	12/31/2009
Westville	104	Mesonet	ATEM, BP, SOLR, WIND	1/1/1994	present

Location	Gage Station	Flow Data		Tributary Area (mi^2)	Elevation (ft)
Illinois River near Tahlequah, OK	07196500	10/1/1935	present	959.0	664
Baron Fork at Eldon, OK	07197000	10/1/1948	present	307.0	701
Baron Fork at Dutch Mills, AR	07196900	4/1/1958	present	40.6	986
Illinois River near Watts, OK	07195500	10/1/1955	present	635.0	894
Illinois River near Viney Grove, AR	07194760	9/5/1985	10/16/1986	80.7	1051
Illinois River at Savoy, AR	07194800	6/21/1979	present	167.0	1019
Niokaska Creek at Township St at Fayetteville, AR	07194809	9/19/1996	present	1.2	1482
Osage Creek near Elm Springs, AR	07195000	10/1/1950	present	130.0	1052
Illinois River at Hwy. 16 near Siloam Springs AR	07195400	6/21/1979	2/7/2011	509.0	1170
Illinois River South of Siloam Springs, AR	07195430	7/14/1995	present	575.0	909
Flint Creek at Springtown, AR	07195800	7/1/1961	present	14.2	1173
Flint Creek near West Siloam Springs, OK	07195855	10/1/1979	present	59.8	954
Sager Creek near West Siloam Springs, OK	07195865	9/12/1996	present	18.9	960
Flint Creek near Kansas, OK	07196000	10/1/1955	present	110.0	855
Peacheater Creek at Christie, OK	07196973	9/1/1992	9/16/2004	25.0	802
Caney Creek near Barber, OK	07197360	10/1/1997	present	89.6	638
Illinois River near Gore, OK	07198000	3/25/1924	present	1626.0	468

Table 2.3 USGS Stream Gages Containing Flow Data

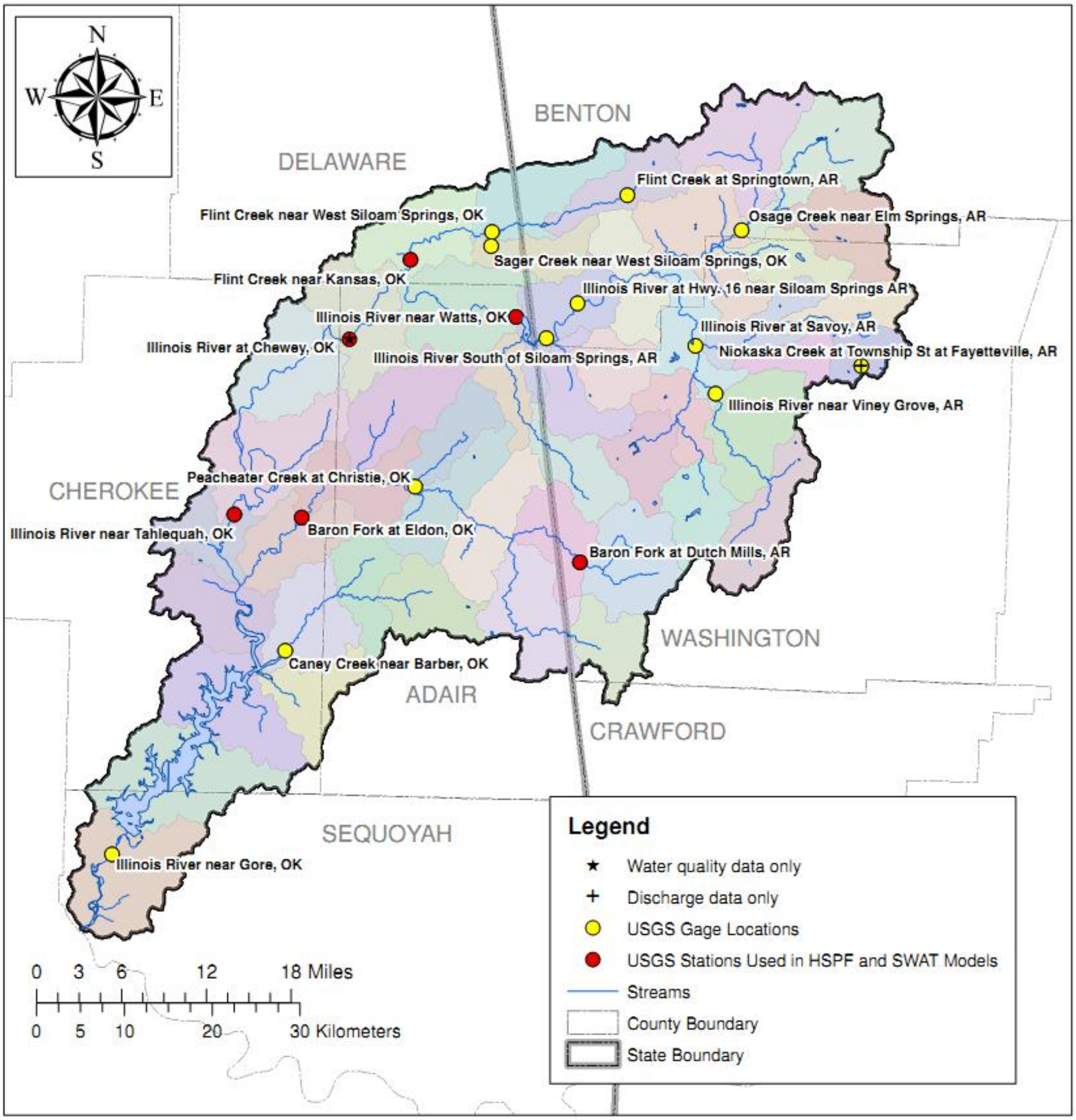


Figure 2.4 USGS Stream Gage Locations in the IRW

2.4 WATER QUALITY DATA

Water quality data is used primarily for model calibration and validation, but also to help quantify source contributions and boundary conditions, such as for point sources, selected agricultural sources, and atmospheric deposition. A number of agencies contributed a wide variety water quality related data to be used in this effort. The Draft Data Report (AQUA TERRA Consultants, 2010) listed the specific sites and constituents available, along with the period of record for each site and constituent, to support the model application.

The specific constituents to be modeled in this study include all constituents needed for modeling nutrients, with a specific focus on phosphorus species. The following list shows the conventional constituents that are modeled whenever nutrients are the purpose of a modeling effort:

1. Flow/discharge
2. TSS
3. water temperature
4. DO
5. BOD ultimate, or total BOD
6. NO3/NO2, combined
7. NH3/NH4
8. Total N
9. PO4
10. Total P
11. Phytoplankton as Chl a
12. Benthic algae (as biomass)

These are the constituents that will be modeled for the IRW; they include flow and TSS as the basic transport mechanisms for moving the nutrients, along with the environmental conditions (e.g. temperature) and other state variables (e.g. DO/BOD), that are involved in the aquatic fate, transport, and cycling of nutrients in aquatic systems.

For most modeling efforts of moderate to large watersheds, the USGS is the primary source of both flow and water quality data. In the IRW, the USGS works collaboratively with both the OK DEQ and AWRC for flow and water quality data collection efforts. Data was obtained from both the USGS NWIS system through direct downloading, along with files provided by the state agencies. Table 2.4 lists the USGS flow gages that also include water quality data, along with their period of record. The Data Report provides a compilation of the number of data points and their period of record for each relevant water quality constituent, at each water quality observation gage.

As a supplement to the USGS water quality data, the AR Water Resources Center (AWRC) provided a series of annual reports, along with spreadsheets of loading calculations, for four sites within the AR portion of the IRW (B. Haggard, personal communication, 25 May 2010). Daily loads are available for the IR at Highway 59 (USGS gage #07195430), Ballard Creek, Moore’s Creek, and Osage Creek, and for various time periods from 1999 to 2009 (see Nelson et al., 2006 as an example annual report).

Another source of water quality data is the US EPA STORET system; the system is divided into data collected and input prior to 1999 (known as Legacy STORET) and those that were collected post 1999 (known as Modern STORET). In Figure 2.5, STORET data sites are shown within the IRW, differentiating the pre – and post-1999 stations. The Data Report documented more than 4,000 water quality samples related to nutrients and TSS available from Modern STORET for the Post-1999 period; these data will be used to supplement the USGS data for both model calibration and validation. In addition, as listed in the Data Report, Legacy STORET includes thousands of additional data values for water quality (e.g., temperature, DO, BOD) and nutrient-related variables that can be useful for model-data comparisons during the pre-1999 validation period (see Section 4). Comparing Figure 2.5 and Figure 2.4, it is clear that many of the STORET sites coincide with USGS gage sites, and others provide an opportunity for comparisons at intermediate points on a number of streams.

Table 2.4 USGS Stream Gages with Water Quality Data in the IRW

Location	Gage Station #	Period of Record		Tributary Area (mi^2)	Elevation (ft)
Illinois River near Tahlequah, OK	07196500	8/23/1955	12/15/2009	959	664
Baron Fork at Eldon, OK	07197000	5/7/1958	12/14/2009	307	701
Baron Fork at Dutch Mills, AR	07196900	3/17/1959	8/25/2009	40.6	986
Illinois River near Watts, OK	07195500	9/12/1955	10/26/2009	635	893
Illinois River near Viney Grove, AR	07194760	9/6/1978	7/19/2007	80.7	1051
Illinois River at Savoy, AR	07194800	9/11/1968	8/25/2009	167	1019
Osage Creek near Elm Springs, AR	07195000	9/10/1951	8/25/2009	130	1052
Illinois River at Hwy. 16 near Siloam Springs AR	07195400	9/8/1978	9/20/1994	509	1170
Illinois River South of Siloam Springs, AR	07195430	10/3/1972	8/25/2009	575	909
Flint Creek at Springtown, AR	07195800	10/15/1975	7/1/1996	14.2	1173
Flint Creek near West Siloam Springs, OK	07195855	7/11/1979	8/28/1996	59.8	954
Sager Creek near West Siloam Springs, OK	07195865	5/24/1991	10/21/2009	18.9	960
Flint Creek near Kansas, OK	07196000	9/7/1955	10/26/2009	110	855
Peacheater Creek at Christie, OK	07196973	8/6/1991	5/16/1995	25.0	802
Caney Creek near Barber, OK	07197360	8/25/1997	10/27/2009	89.6	638
Illinois River at Chewey, OK	07196090	7/16/1996	10/27/2009		
Illinois River near Gore, OK	07198000	4/12/1940	8/16/1995	1626	468

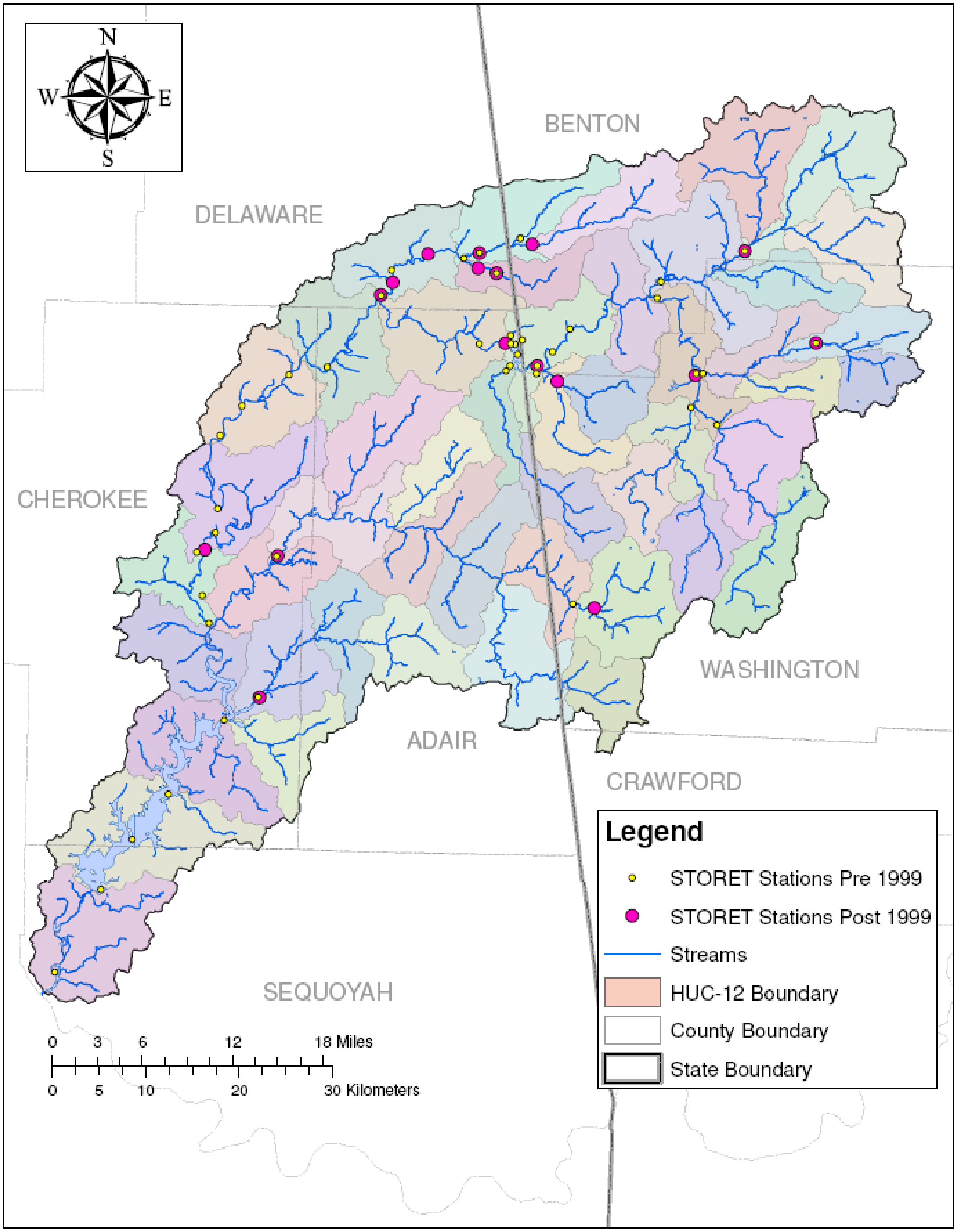


Figure 2.5 STORET Sampling Station Locations

As part of the prior litigation(circa 2010-11) between the OK Office of the Attorney General (OAG) and AR Poultry Producers, extensive sampling and analyses were performed between 2005 and 2010. As part of this case, the engineering firm Camp, Dresser, & McKee (CDM) worked with the USGS to collect a variety of samples from different media, and analyze them for various water quality constituents, including sediment (TSS), and various forms of both nitrogen and phosphorus (Olsen, 2008). In response to the January 19, 2010 a Call for Data, the OAG provided the resulting database to EPA and AQUA TERRA for use in this effort, through the ODEQ (A. Fang, personal communication, 19 May 2010).

Table 2.5 summarizes the types of data, number of locations within the IRW, the time period, and the number of samples related to sediment, nitrogen, and phosphorus available in the CDM database. The Data Report provides a more complete description along with a location map of the sample points. Since portions of this database were challenged during the litigation, we plan to use only data from this database that provides unique and significant value to the modeling effort either during the model setup phase or as part of the model calibration effort. When such data is identified, it will be reviewed along with its accompanying Quality Assurance Project Plan (QAPP) documenting the data collection QA/QC procedures implemented in the data collection effort, to ensure that the data meets EPA's QA/QC standards. In addition, we will review the QA/QC concerns identified during the litigation to assess their potential impact on our use of the data. The results of these analyses will be reported and documented in the model calibration report.

Table 2.5 Summary of IR CDM Database Provided by OK Attorney General's Office

Locations	Number of Locations	Sediment	Phosphorus	Nitrogen	Approximate Time Period
Edge Of Field	68		45	77	2005-2007
Tenkiller and other Lakes	22	4	492	473	2005-2008
Tenkiller Lake Sediment	5	12	89	100	2005-2006
Poultry Litter Sample	4		4	4	2006
Reach	221	1	1069	445	2005-2008
Springs	35		40	48	2005-2007
USGS Gage	7		237	183	2005-2010
Water Treatment Plant	2				2006
Litter Application Locations	54	51	171	116	2006

2.5 POINT SOURCES

Data on point sources discharges have been compiled from a number of different sources of information, including data provided by EPA, State representatives, and the dischargers. Prior modeling efforts focused on the major dischargers, and ignored the contributions from the numerous minor and smaller ones. A similar approach is being followed in this effort as the detailed time series data needed is not available for the minor dischargers.

Point source loads have been developed for 13 primary facilities (Table 2.6) that discharge to the Illinois River and its tributaries. The primary basis for developing the point source loads were (1) internal monitoring data provided by individual facilities (Springdale, Fayetteville, Lincoln, Rogers, Siloam Springs, Tahlequah, Stilwell) and (2) Discharge Monitoring Report (DMR) data provided by Oklahoma DEQ (Andrew Fang) and Arkansas DEQ. Bicknell and Donigian (2012) document the data, procedures, and assumptions that were used to develop the loads. The data availability and frequency are summarized in Table 2.7, and the average daily values (in units of lbs/day) of all quantities for the full 1990-2009 period are shown in Table 2.8; spreadsheets of the daily and monthly values were provided to EPA and stakeholders November 2012. Total TN, TP, and $CBOD_u$ loads for 2009 are shown in Table 2.9. Although these tables show summaries of average daily and annual loads, the model actually receives the daily loads as a timeseries for the entire period of 1990-2009; these values are included with the daily load spreadsheet provided to EPA and stakeholders.

Table 2.6. Point Sources in Illinois River Watershed

NPDES #	Facility	Discharge Location (Tributary)	Typical Flow (MGD)
AR0022098	Prairie Grove, City of	Muddy Fork	0.3
AR0020010	Fayetteville - Paul Noland WWTP	Mud Ck	4.5
AR0050288	Fayetteville - Westside WWTP	Goose Ck	5.8
AR0033910	USDA FS - Lake Wedington Rec. Area	Trib to Illinois R	0.0013
AR0035246	Lincoln, City of	Bush Ck/Baron Fork	0.45
AR0022063	Springdale WWTP, City of	Spring Ck/Osage Ck	12
AR0043397	Rogers, City of	Osage Ck	6.5
AR0020184	Gentry, City of	SWEPCO Res/L Flint Ck	0.45
AR0020273	Siloam Springs, City of	Sager Ck/Flint Ck	3
AR0037842	SWEPCO Flint Ck Power Plant	SWEPCO Res/Flint Ck	5/400 *
OK0026964	Tahlequah Public Works Authority	Tahlequah Ck	2.7
OK0028126	Westville Utility Authority	Shell Branch/Baron Fork	0.2
OK0030341	Stilwell Area Development Authority	Caney Ck	0.85

* - Once-through cooling water outflow (400 MGD) and wastewater outflow (5 MGD)

The quantities that were generated are listed below. They include flow, heat, and the water quality-related constituents that are being modeled by HSPF.

Quantity	Units
Flow	MG (input as ac-ft)
Heat	BTU
TSS	lbs (input as tons)
DO	lbs O
NO3/NO2	lbs N
NH3/NH4	lbs N
Organic N	lbs N
PO4	lbs P
Organic P	lbs P
$CBOD_u$	lbs O

Organic C lbs C

The primary data available for many of the facilities was derived from DMR sources, and consists of monthly averages of flow and the following constituents: $CBOD_5$, TSS, DO, NH3, and TP. Eight of the facilities provided daily/weekly data for selected time periods, and those data were used when available. While it is likely that most flow rates are based on frequent (daily) measurements, the other constituent monthly averages were apparently obtained from one to two measurements per month. For five of the facilities, this type of monthly data are the only data available (facilities with "n/a" in Table 2.7); four of the facilities (Fayetteville-Noland, Fayetteville-Westside, Rogers, and Springdale) have essentially a complete period (1990/1/1 - 2009/12/31) of daily/weekly data; and the remaining four facilities (Lincoln, Siloam Springs, Tahlequah, and Stilwell) utilize monthly data for the earlier years, and are supplemented by more frequent measurements (typically weekly) for the later years. In general, where monthly and weekly (or daily) data overlapped in time, the more frequent measurements were used to develop the final loads. Table 2.7 provides a summary of the data frequency at the facilities.

Table 2.7. Data Availability and Measurement Frequency of Point Sources

NPDES #	Facility	Monthly DMR Data	Weekly/Daily Data
AR0022098	Prairie Grove	1990/1 - 2009/12	n/a
AR0020010	Fayetteville - Noland	1990/1 - 2008/6	1990/1 - 2008/6
AR0050288	Fayetteville - Westside	n/a	2008/6 - 2009/12
AR0033910	USDA FS - Lake Wedington	1990/1 - 2009/12	n/a
AR0035246	Lincoln	1990/1 - 2009/12	2001/1 - 2009/12
AR0022063	Springdale	1990/1 - 2009/12	1991/10 - 2009/12
AR0043397	Rogers	1990/1 - 2009/12	1990/1 - 2009/12
AR0020184	Gentry	1990/1 - 2009/12	n/a
AR0020273	Siloam Springs	1990/1 - 2009/12	2002 - 2009/12
AR0037842	SWEPCO	1990/1 - 2009/12	n/a
OK0026964	Tahlequah	1990/1 - 2009/12	2001/1 - 2009/12
OK0028126	Westville	1990/1 - 2009/12	n/a
OK0030341	Stilwell	1990/1 - 2009/12	2006/1 - 2009/12

Missing Data

The general methodology for filling missing values was interpolation or averaging. Very little of the monthly data were missing. However, the daily/weekly data were filled in to generate daily time series by interpolation and averaging. Also, at the facilities where the monthly data did not extend over the entire period of point source data development (1990/1/1 - 2009/12/31), the existing data were extended back in time using selected averages of the existing data for that facility. For example, at the Lincoln facility, many of the constituents were not available prior to 2001, and were therefore estimated from the available data from 2001 through 2009. The procedures applied for filling in missing data at each facility are documented in Bicknell and Donigian (2012).

Table 2.8 Average Daily Point Source Loads for 1990-2009

Facility	Flow mgd	Heat btu/day	DO lb/day	TSS lb/day	$CBOD_5$ lb/day	$CBOD_U$ lb/day	Ref Org C lb/day	TP lb/day	PO4 lb/day	Org P lb/day	TN lb/day	NH3 lb/day	NO3 lb/day	OrgN lb/day
Prairie Grove	0.27	7.5E+7	19	19	9.0	25.5	2.4	10	7.7	2.6	17.4	1.9	11	4.4
Fayetteville Noland (1990-2008/6)	3.9	1.1E+9	311	82	65	184	17	14	10	3.5	242	12	164	65
Fayetteville Westside (2008/6-2009)	5.8	1.7E+9	441	43	93	265	71	21	16	5.3	349	7.6	244	98
USDA-Lake Wedington	.0013	3.7E+5	0.095	0.063	0.050	0.14	0.014	.0046	.0035	.0012	.0864	0.011	0.054	0.022
Lincoln	0.46	1.1E+8	34	15	24	68	6.4	6.0	4.5	1.5	24.3	3.2	13	7.7
Springdale	11	3.2E+9	872	352	199	566	53	304	270	54	558	41	369	149
Rogers	5.5	1.5E+9	450	218	123	348	33	67	17	50	262	10	202	54
Gentry	0.47	1.3E+8	35	44	41	118	11	15	11	3.7	32	4	20	7.9
Siloam Springs	2.7	8.1E+8	187	203	73	207	19	76	57	19	290	13	231	46
SWEPCO	359	5.7E+11	2.7E+4	575	33*	94*	8.8*	15*	11*	3.7*	32*	4*	20*	7.9*
Tahlequah	2.7	7.7E+8	176	53	85	241	23	21	16	5.3	176	20	111	45
Westville	0.18	4.9E+7	13	38	18	50	4.7	3.1	2.3	0.8	13.2	2.8	7.5	3.0
Stilwell	0.71	2.0E+8	44	50	58	164	15	6.0	4.5	1.5	52.5	11.3	29	12

* SWEPCO nutrient loads based on Gentry data

Table 2.9. Annual Loads (lbs/year) of TP, TN, and $CBOD_u$ for 2009

NPDES #	Facility	TP	TN	$CBOD_u$
AR0022098	Prairie Grove	3,400	7,100	5,310
AR0020010	Fayetteville - Noland (2007)	3,980	125,000	126,000
AR0050288	Fayetteville - Westside	7,910	139,000	106,000
AR0033910	USDA FS - Lake Wedington	4.54	92.5	192
AR0035246	Lincoln	1,540	11,500	6,020
AR0022063	Springdale	16,900	248,000	169,000
AR0043397	Rogers	5,380	192,000	75,400
AR0020184	Gentry	4,920	13,600	19,000
AR0020273	Siloam Springs	12,600	63,000	42,000
AR0037842	SWEPCO	*4,920	*13,600	*19,000
OK0026964	Tahlequah	3,910	75,000	55,400
OK0028126	Westville	489	6,910	7,910
OK0030341	Stilwell	1,920	26,100	57,500

* SWEPCO loads based on Gentry data

2.6 ATMOSPHERIC DEPOSITION

Atmospheric deposition of nutrients is commonly included in watershed modeling efforts that focus on nutrient issues, like the current study. Atmospheric deposition data were obtained online through the National Atmospheric Deposition Program (NAPD) (http://nadp.sws.uiuc.edu/) and the Clean Air Status and Trends Network (CASTNet) (http://java.epa.gov/castnet/). Sites in the NADP precipitation chemistry network began operations in 1978 with the goal of providing data on the amounts, trends, and geographic distributions of acids, nutrients, and base cations in precipitation. The network grew rapidly in the early 1980s funded by the National Acid Precipitation Assessment Program (NAPAP), established in 1981 to improve understanding of the causes and effects of acidic precipitation. Reflecting the federal NAPAP role in the NADP, the network name was changed to NADP National Trends Network (NTN). The NTN network currently has 250 sites.

CASTNet began collecting measurements in 1991 with the incorporation of 50 sites from the National Dry Deposition Network, which had been in operation since 1987. CASTNET provides long-term monitoring of air quality in rural areas to determine trends in regional atmospheric nitrogen, sulfur, and ozone concentrations and deposition fluxes of sulfur and nitrogen pollutants in order to evaluate the effectiveness of national and regional air pollution control programs. CASTNET operates more than 80 regional sites throughout the contiguous United States, Alaska, and Canada. Sites are located in areas where urban influences are minimal. The primary sponsors of CASTNET are the Environmental Protection Agency and the National Park Service.

The data available from NADP/NTN are wet deposition of NH4 and NO3 in the form of precipitation-weighted concentrations (mg-N/L) on a monthly basis from 1980-2009. There are two active stations near the watershed: one is in Fayetteville, AR, and the other is in McClain County, OK. Two inactive stations in Oklahoma at Lake Eucha and Stilwell have data only for a limited period (2000-2003). There are no phosphorus data available.

The CASTNet data available for the watershed are weekly, quarterly, seasonal, and annual dry deposition fluxes of NH4, HNO3, and NO3- for 10/88-12/09. There are some missing periods, one of which is approximately one year long. The units are kg/ha as the species; therefore, the data will be converted to N for use in the model. The stations near the watershed are Cherokee Nation in Adair County, OK and Caddo Valley in Clark County, AR. The Caddo Valley station is near an NADP station, but not the Fayetteville station.

There are very little data available to estimate phosphorus deposition. Most of the literature concludes that atmospheric deposition is a small contributor to the total P budget. The mass-balance study of phosphorus in the Illinois R watershed (Smith et al., 2008) does not mention atmospheric deposition as a potential source. Similarly, a NOAA report on "Flux and Sources of Nutrients in the Mississippi–Atchafalaya River Basin" does not mention atmospheric deposition as a source of P, while it includes extensive discussion of N atmospheric deposition. A study of phosphorus in Minnesota watersheds (MPCA, 2004) documents ranges of atmospheric P of 0.059-0.273 kg/ha/yr for wet deposition and 0.028-0.241 kg/ha/yr for dry deposition. The high end of this range is 0.5 kg/ha/yr, which is approximately 4% of the current human-caused annual additions of P to Illinois River soils according to the Smith (2008) study. The low end of the range (0.09 kg/ha/yr) is approximately 1% of the total human-caused P additions. Based on this evidence, our current plan is to assume atmospheric deposition of phosphorus is negligible compared to other sources.

SECTION 3.0

SEGMENTATION AND CHARACTERIZATION OF THE IRW

Whenever any watershed model is set up and applied to a watershed, the entire study area must undergo a process sometimes referred to as 'segmentation'. The purpose of watershed segmentation is to divide the study area into individual land and channel segments, or pieces, that are assumed to demonstrate relatively homogenous hydrologic/hydraulic and water quality behavior. This segmentation provides the basis for assigning similar or identical input and/or parameter values or functions to where they can be applied logically to all portions of a land area or channel length contained within a model segment. Since most watershed models differentiate between land and channel portions of a watershed, and each is modeled separately, each undergoes a segmentation process to produce separate land and channel segments that are linked together to represent the entire watershed area.

Watershed segmentation is based on individual spatial characteristics of the watershed, including topography, drainage patterns, land uses and distribution, meteorologic variability, and soils conditions. The process is essentially an iterative procedure of overlaying these data layers and identifying portions of the watershed with similar groupings of these characteristics. The results of the land segmentation process are a series of model segments, sometimes call hydrologic response units (HRUs) that demonstrate similar hydrologic and water quality behavior. Over the past few decades, geographic information systems (GIS), and associated software tools, have become critical tools for watershed segmentation. Combined with advances in computing power, they have allowed the development of automated capabilities to efficiently perform the data-overlay process.

GIS data, or coverages, are used to spatially quantify the characteristics of the watershed landscape to develop the model input that informs the model as to how the watershed characteristics change across the study area. GIS data used in the segmentation process that affect the hydrologic and water quality response of a watershed are: topography and elevation, hydrography/drainage patterns, land use and land cover, soils information, and other various types of spatial data.

The primary sources for GIS data obtained for the IRW were those accessed through the use of the BASINS data download capability, from the SWAT 2009 modeling files provided by OK DEQ, and additional coverages provided by stakeholders in response to the Federal Register data request. Through the BASINS interface a wide range of GIS data layers were downloaded and displayed. BASINS accesses GIS data from a variety of sources such as The National Land Cover Data (NLCD), National Hydrography Dataset (NHD), and the U.S.G.S. seamless data server (http://seamless.usgs.gov/). Other sources include the earlier HSPF modeling efforts, Geospatial One-Stop (http://gos2.geodata.gov/wps/portal/gos), and contacts with the OK DEQ and AR DEQ. Geospatial One-Stop is an e-government initiative sponsored by the Federal Office of Management and Budget (OMB) to make it easier, faster, and less expensive for all levels of government and the public to access geospatial information

The Data Report provided a catalog of the various GIS data coverages that were downloaded and are currently available for this study of the IRW. Below we discuss the major categories of GIS data used in model segmentation, display and discuss the major categories, and describe the model segmentation of the IRW.

3.1 TOPOGRAPHY AND ELEVATION

GIS layers of topography are important in setting up HSPF because they provide elevation and slope values for the project area, and are needed for characterizing the landscape and the land areas of the watershed. These elevation values are used to delineate subbasins, determine average elevations for each model subbasin, and/or to compute average slopes for model subbasins and land uses within a subbasin. A very detailed topographic layer (e.g. LIDAR data) can also be useful for determining stream cross-sections used to define the hydraulic characteristics of the streams.

The National Elevation Dataset (NED) available through BASINS 4.0 is a 30-meter Digital Elevation Model (DEM) grid, with vertical units in centimeters. A 10-meter resolution DEM was also available and was obtained from the USGS seamless site, This layer has been converted to feet and is shown in Figure 3.1. It will be used in the lower slope areas for better spatial resolution, as needed.

3.2 HYDROGRAPHY/DRAINAGE PATTERNS

Hydrography includes GIS layers of stream segments, at various levels of detail, as well as subbasins or drainage boundaries, and waterbodies. Several layers of hydrographic data are available for use in the Illinois River Watershed modeling effort. A set of coverages that is commonly used in watershed modeling is the NHDPlus dataset. NHDPlus is an integrated suite of geospatial data sets that incorporates many of the best features of the National Hydrography Dataset (NHD), the National Elevation Dataset (NED), the National Land Cover Dataset (NLDC), and the Watershed Boundary Dataset (WBD).

The NHDPlus dataset includes elevation, flow accumulation, and flow direction grids. These grids can be used to automate the subbasin delineation process for reaches with high topographic variation, e.g., mountainous regions of the watershed. The grids have undergone significant processing to ensure that drainage patterns are consistent with the 1:100,000 scale NHD and WBD using the "New England Method" (Dewald, 2006). These grids are the most hydrologically accurate 30 meter DEMs available to the water resources community. Figure 3.2 shows the available stream hydrography coverage with the 1st order streams shown in light blue, and the 2nd through 6th order streams in dark blue. The 12-Digit hydrologic Unit Code (HUC) boundaries are also shown in Figure 3.2, which is the starting point for the spatial resolution for the watershed model.

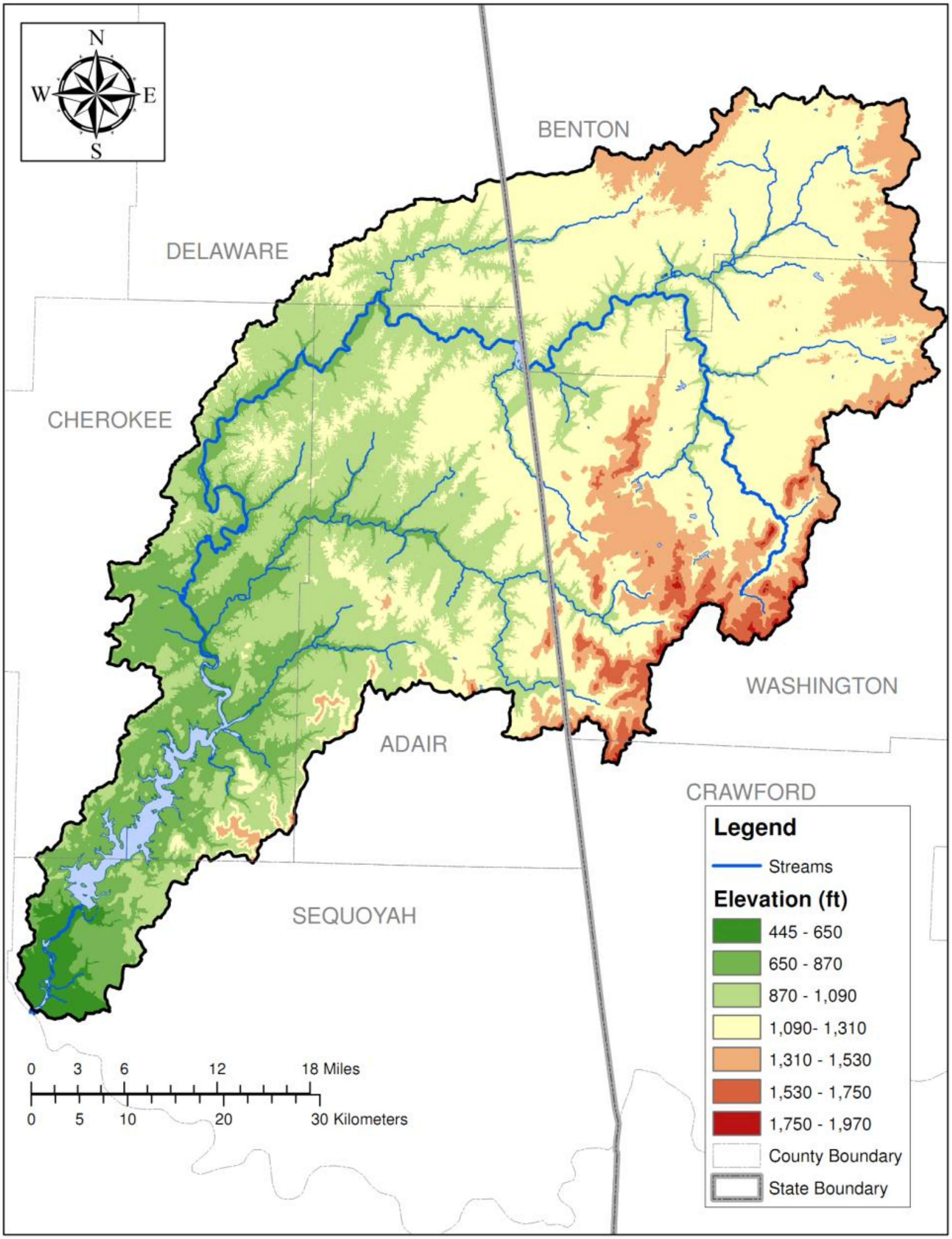


Figure 3.1 Derived from a 10-Meter DEM from the USGS Seamless Server

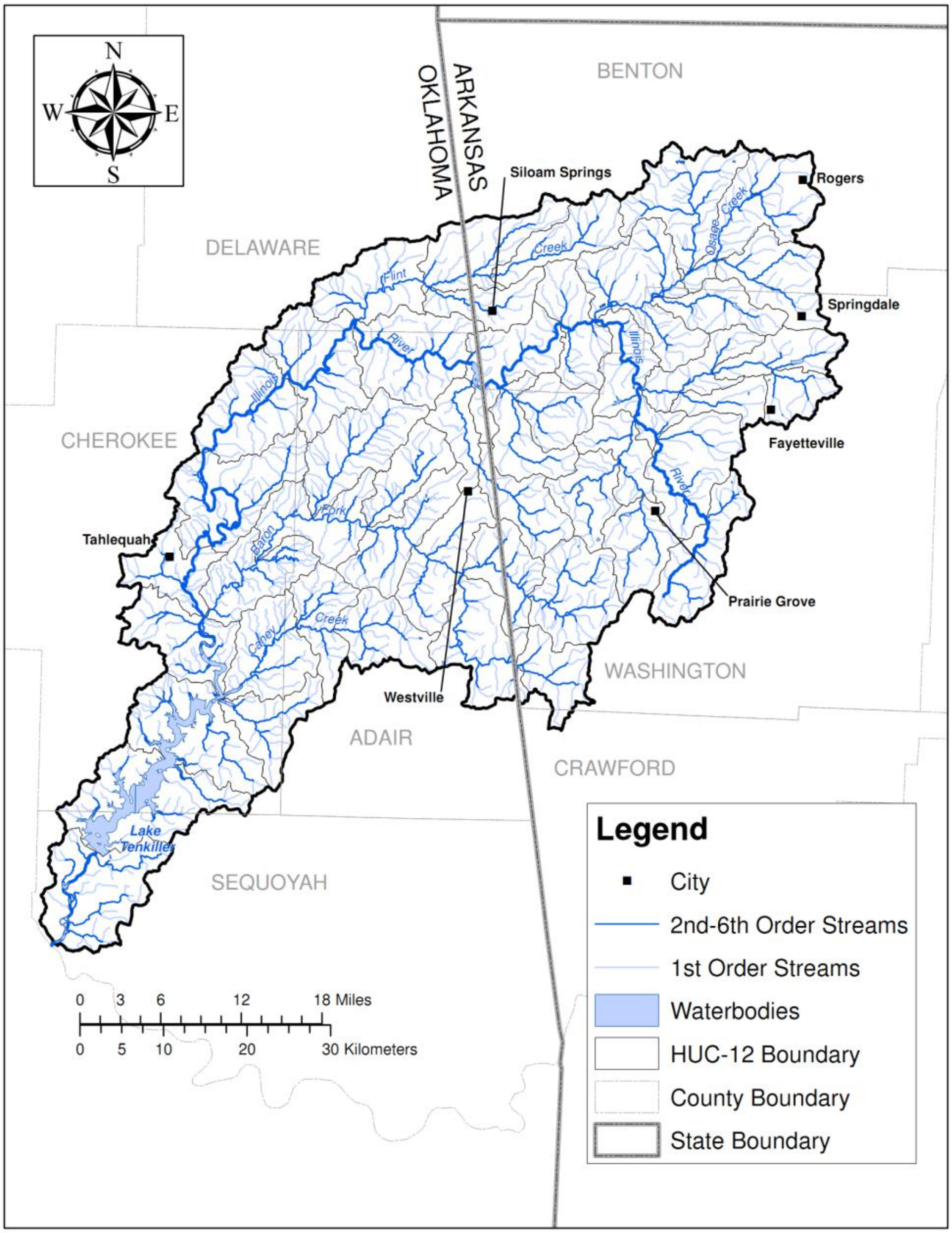


Figure 3.2 Stream Hydrography Coverage for the IRW from NHDPlus

3.3 LAND USE

Land use, or land cover, data is a critical factor in modeling complex multi-land use watersheds as it provides the detailed characterization of the potentially primary source of pollutants entering the streams and rivers as nonpoint source contributions. In addition the land use distribution has a major determining impact on the hydrologic response of the watershed.

As discussed in the Data Report, a number of sources of land use data were investigated but, at that time, no single, consistent coverage, spanning both States, existed for the entire IRW other than the 2001 NLCD. Fortunately, in early 2011, the 2006 NLCD data was released and provided the consistent recent coverage needed covering both States, and applicable to a relatively recent time period with significant available water quality data. Table 3.1 lists the land use categories and distributions for the 1992, 2001, and 2006 NLCD, while Table 3.2 shows the correspondence between the NLCD categories and the model categories. Figure 3.3 shows and compares the spatial distribution of the NLCD categories for the 2001 and 2006 data layers.

Both Table 3.1 and Table 3.2 are color-coded to identify likely groupings of land uses with similar characteristics, with dark green showing forest categories, light brown for grasslands and shrub/scrub, pink for urban developed categories, etc. Comparing the category distributions for the three different time periods indicates the following:

1. There are some obvious inconsistencies between 1992 and the more recent 2001 and 2006 distributions, most likely due to differences in classifications within categories. For example, there is a big increase in grassland/herbaceous from 1991 to 2001, and a comparable decrease in cultivate cropland. Although cropland likely did decrease, the amount of the decrease indicates a classification issue.
2. Forest distributions between 1992 and 2001 also show a big jump in deciduous and decreases in both evergreens and mixed categories. However, the differences between 2001 and 2006 are relatively small and in the expected directions.
3. Developed land shows a decrease in the high and medium intensity categories, and then a big jump in the developed open space category, most likely due to a classification change. The changes in developed categories between 2001 and 2006 are more consistency and in the expected direction.
4. Overall, the land use distributions for 2001 and 2006 shown in appear to be consistent, with modest changes and in the expected direction.

Based on this review of the NLCD data, the coverages for 2001 and 2006 appear to be the most consistent and reliable, representative land use data layers for use in modeling the IRW. The Data Report also noted the availability of the USDA-NASS Cropland Data Layer (CDL) as a potential source of recent land use data, and digital orthophotos available from the State of OK . In addition, since the Data Report was submitted, land use coverages for the AR portion of the IRW were obtained from the University of Arkansas Center for Advanced Spatial Technologies (CAST) for a number of years from 2003 to 2009. All of these additional land use data layers are available for refinements or adjustments to the NLCD coverage, as needed, for use in the watershed modeling.

Table 3.1 lists the 15 NLCD land use categories and their percentages for both 2001 and 2006, along with the aggregation of these categories into the eight categories that will be simulated by the watershed model; the Open Water category is listed in but its area is included in the model as the surface area of streams and lakes. The practice of aggregating GIS land use categories for modeling is common in watershed modeling, depending on study objectives and

Table 3.1 Distribution of NLCD Land Use for 1992, 2001, and 2006

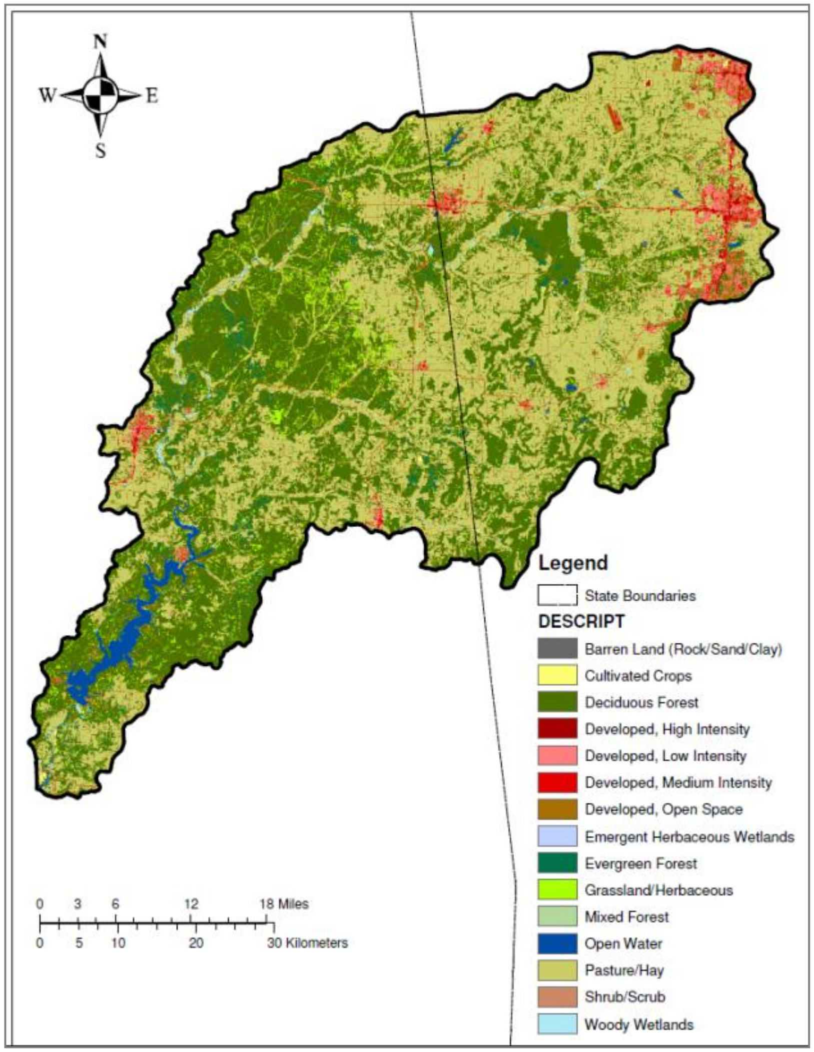
	1992		2001-v2		2006	
Description	Area (Sq. Mi.)	% Land Use	Area (Sq. Mi.)	% Land Use	Area (Sq. Mi.)	% Land Use
Deciduous Forest	555.98	33.63	684.66	41.40	679.64	41.11
Evergreen Forest	33.96	2.05	19.79	1.20	19.62	1.19
Mixed Forest	114.88	6.95	8.14	0.49	8.09	0.49
Pasture/Hay	769.13	46.52	693.31	41.92	679.15	41.08
Grassland/Herbaceous	0.21	0.01	56.38	3.41	60.05	3.63
Shrub/Scrub	13.56	0.82	7.69	0.46	8.27	0.50
Barren land (rock/sand/clay)	3.30	0.20	1.86	0.11	3.20	0.19
Developed, Open Space	7.50	0.45	92.85	5.61	97.99	5.93
Developed, Low Intensity	28.66	1.73	35.66	2.16	39.93	2.41
Developed, Medium Intensity	13.69	0.83	12.23	0.74	15.22	0.92
Developed, High Intensity	12.34	0.75	4.76	0.29	5.73	0.35
Woody Wetlands	5.04	0.31	9.75	0.59	9.73	0.59
Emergent Herbaceous Wetlands	1.63	0.10	0.12	0.01	0.12	0.01
Cultivated Crops	61.14	3.70	2.55	0.15	2.45	0.15
Open Water	32.34	1.96	24.13	1.46	24.15	1.46
Total	1653.35	100.00	1653.87	100.00	1653.35	100.00

Table 3.2 Aggregation of NLCD Land Use to Model Categories

NLCD Class (2001, 2006)	2001 Percent	2006 Percent	Aggregated Model Categories	2001 Percent	2006 Percent
Deciduous Forest Evergreen Forest Mixed Forest	41.40% 1.20% 0.49%	41.11% 1.19% 0.49%	Forest	43.09%	42.78%
Pasture/Hay	41.92%	41.08%	Pasture/Hay	41.92%	41.08%
Grassland/Herbaceous Shrub/Scrub Barren Land (Rock/Sand/Clay)	3.41% 0.47% 0.11%	3.63% 0.50% 0.19%	Grass/Shrub/Barren	3.99%	4.33%
Developed, Open Space	5.61%	5.93%	Developed, Open Space	5.61%	5.93%
Developed, Low Intensity	2.16%	2.42%	Developed, Low Intensity	2.16%	2.42%
Developed, Medium Intensity Developed, High Intensity	0.74% 0.29%	0.92% 0.35%	Developed, Medium/High Intensity (includes Commercial/Industrial)	1.03%	1.27%
Woody Wetlands Emergent Herbacious Wetlands	0.59% 0.01%	0.59% 0.01%	Wetlands	0.60%	0.60%
Cultivated Crops	0.15%	0.15%	Cultivated Crops	0.15%	0.15%
Open Water	1.46%	1.46%	Open Water**	1.46%	1.46%
Totals	100%	100%	Totals	100%	100%

** - Open Water modeled as a water surface (stream/lake), not a land component

2001 NLCD



2006 NLCD

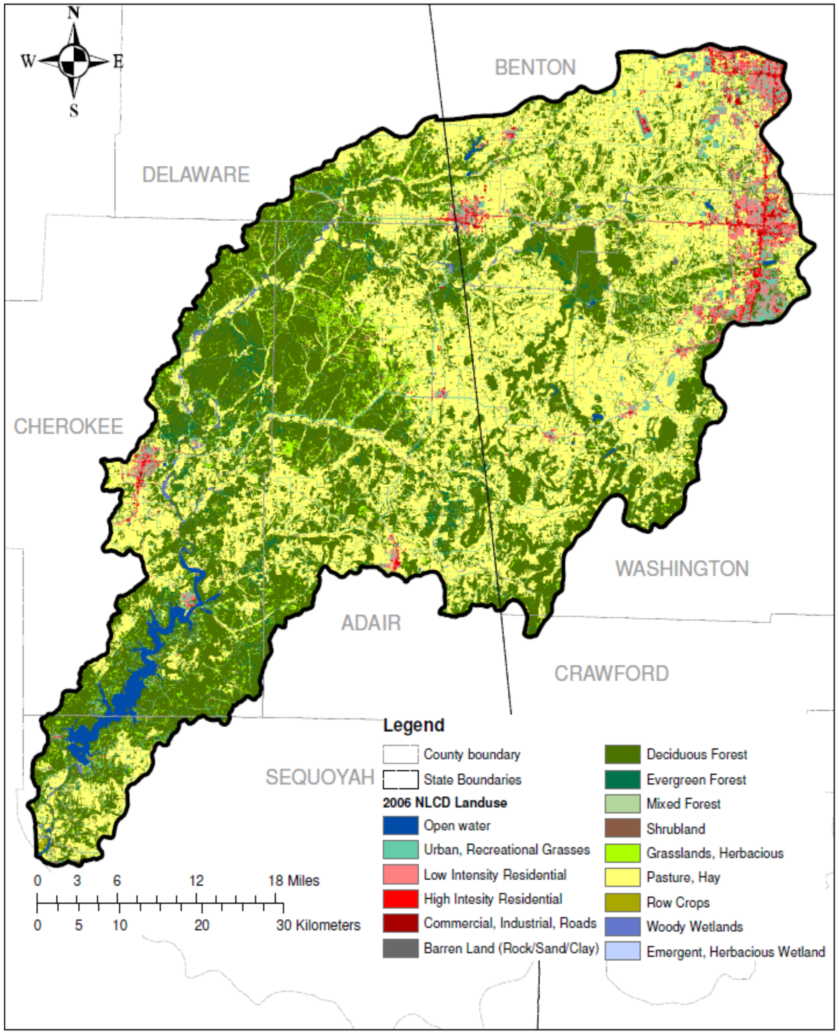


Figure 3.3 National Land Cover Data (NLCD) for 2001 and 2006

details of the GIS layers. Small percentages of a land use category, such as evergreen and mixed forests in Table 3.2, are lumped with the dominant category, with similar land use/land cover characteristics for modeling, such as deciduous forests in Table 3.2. It is often difficult to distinguish and quantify model parameter values for such similar categories with only slightly different characteristics. In a similar manner, grasslands, shrub/scrub and barren are combined into one category, and the wetland categories are combined into another. Since projecting the impacts of future urbanization is a common use of watershed models, the developed categories are mostly left in tact. One exception is combining the medium and high intensity classes since these are often small fractions of the total area, and the difference between them is arbitrary in many cases.

3.3.1 *Effective Impervious Area*

Effective Impervious Area, or EIA, is important to accurately represent in watershed models because of its impact on the hydrologic processes occurring in urban environments. The term “effective” implies that the impervious region is directly connected to a local hydraulic conveyance system (e.g., gutter, curb drain, storm sewer, open channel, or river) and the resulting overland flow will not run onto pervious areas and, therefore, will not have the opportunity to infiltrate along its respective overland flow path before reaching a stream or waterbody.

The EIA for the IRW will be represented using the NLCD 2001 v2 and NLCD 2006,as described above, but with specific focus on the Percent Imperviousness grid layers from those coverages. However, the NLCD Percent Imperviousness grids represent **total impervious area (TIA)**, and it is important to address the distinction, and difference between TIA and **EIA**. EIA is always less than or equal to TIA.

For the IRW, the process for estimating the EIA for each land use involves first calculating the TIA of each developed urban land use category by overlaying the land use data over the impervious area grid, thus computing the impervious area (i.e., TIA) within each developed land use category. A summary of the results for the IRW, and for both the NLCD 2001 v2 and NLCD 2006 are shown in 3.3. Note that the TIA totals shown in the last row of the table represent the total TIA for the entire watershed; the total TIA percent values in the last row are derived from the total TIA area and the watershed area, not from the TIA percent values listed in the table.

Table 3.3 Total Impervious Areas (TIA) and Percent Imperviousness of Each Urban Land Use for NLCD 2001 v2, and NLCD 2006, and Calculation of EIA

	NLCD 2001		NLCD 2006		Average			
Land use Category	Impervious Area (ac)	TIA, %	Impervious Area (ac)	TIA, %	Total	TIA, %	EIA/TIA Ratio, %	Estimated EIA, %
Developed, Open Space	4,051	6.8	4,268	6.8	4,160	6.8	30	2
Developed, Low Intensity	6,953	30.5	7,785	30.5	7,369	30.5	45	14
Developed, Medium Intensity	4409	56.4	5309	54.5	4,859	55.5	55	30
Developed, High Intensity	2454	80.5	2844	77.9	2,649	79.2	80	63
Total	17,867	19.2	20,206	19.9	19,037	19.6		

In order to convert these TIA values to the EIA values needed for use in the HSPF model, we used data and studies presented by Laenen (1980, 1983), as reported by Sutherland (1995). Sutherland (1995) also describes a number of methods and formulas for calculating EIA from TIA, using equations such as the following:

$EIA = 0.1(TIA)^{1.5}$ **3.1**

The equations provided by Sutherland however, are not distinguished, or defined separately, for individual urban land use categories. Therefore, using the Sutherland EIA-TIA curves, we estimated the EIA/TIA ratio for each of the developed urban land use categories for the IRW, based on their TIA values in Table 3.3, and then used these ratios to calculate the Estimated EIA for each developed land use category.

The last two columns of Table 3.4 show the EIA/TIA ratios and the resulting 'Estimated EIA Percent' value (last column) for each developed category. The final step was to calculate a weighted value for our combined 'High/Medium Intensity' category, using an assumed distribution of 70% Medium Intensity and 30% High Intensity uses; this produced a weighted EIA value of 40% for the combined category. Table 3.4 shows the final EIA values assigned for the urban developed land use categories defined in the models for the IRW.

Table 3.4 Effective Impervious Area Percentage in Developed Land Use Classes in The IRW

Urban Land Use Category	EIA, %
Developed, Open Space	2
Developed, Low Intensity	14
Developed, Medium and High Intensity	40

These same EIA values will be used for 2006 NLCD land uses as well. During the BASINS UCI generation process, these EIA percentages are multiplied by the area of each corresponding developed NLCD category to compute the areas of the developed IMPLND and PERLND model categories. The model setup plug-in for HSPF in BASINS 4.0 allows entry of this data through the user interface.

Although these EIA values are reasonable and consistent with past HSPF applications performed by AQUA TERRA, it may be necessary to consider slight adjustments to the values, in the range of 10-20%, if supported by the model results during calibration. These values, and this approach, provide the added benefit of being able to estimate EIA values for future land use changes and scenarios related to urban growth and development.

3.4 SOILS DATA

Soils data is used to characterize the infiltration and soil moisture capacity characteristics of the watershed soils, along with the erodibility parameters for soil erosion. SSURGO (Soil Survey Spatial and Tabular Data) soils data for the IRW were downloaded from the USDA/NRCS Data Gateway site (http://soildatamart.nrcs.usda.gov/). SSURGO depicts information about the kinds and distribution of soils on the landscape. This dataset is a digital soil survey and generally is the most detailed level of soil geographic data developed by the National Cooperative Soil Survey. This dataset consists of georeferenced digital map data, computerized tabular attribute data, and associated metadata.

The properties of this dataset of interest in this watershed modeling study are: soil description, slope gradient, water table depth, flooding frequency, available water storage, hydrologic group, and hydric group. Spatial data on the SCS Hydrologic Soil Groups (HSG) were obtained and used to generate a map of the spatial distribution of these properties, shown in Figure 3.4. The

HSG B, C, and D distributions by subwatershed will be used as a basis for model parameterization related to infiltration and soil moisture capacity values in the model.

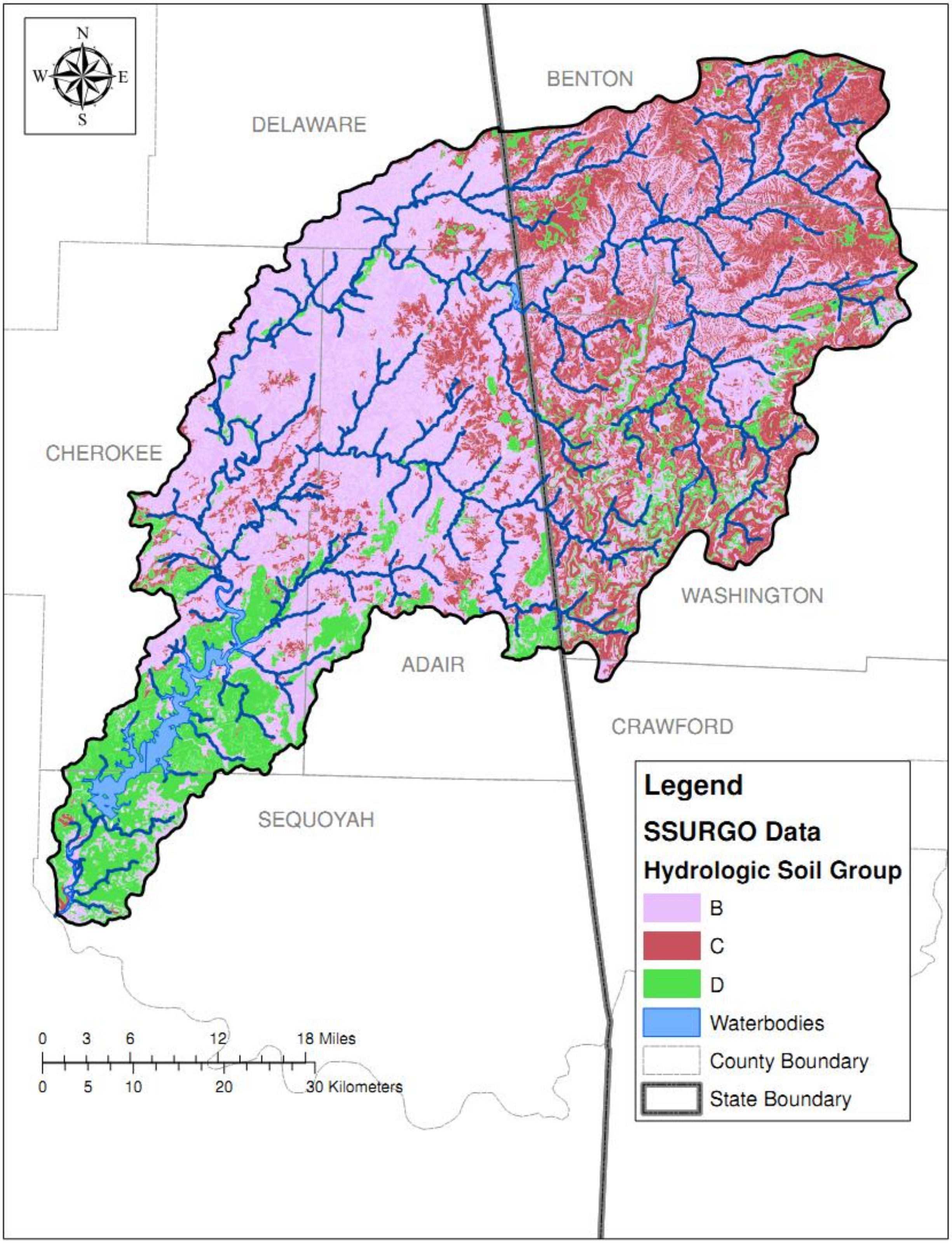


Figure 3.4 Distribution of NRCS Hydrologic Soil Groups for the IRW.

3.4.1 Channel Characteristics

The river channel network in the Illinois River Watershed is the major pathway by which flow, sediment and contaminants are transported from the watershed to the Lake Tenkiller. As such, it is important to accurately represent or characterize the channel system in the HSPF model of the watershed. The river reach segmentation considered river travel time, riverbed slope continuity, cross section and morphologic changes, and entry points of major tributaries. When partitioning the channel segments, additional considerations included the Arkansas-Oklahoma state line, the USGS stream gage locations, Total Maximum Daily Load (TMDL) stream segments, and PCS (Permit Compliance System) facilities.

Although not a strict GIS type data layer, channel characteristics are needed to help define routing and stage-discharge behavior, bed composition for sediment, carbon, and nutrients, and bed/water column interactions related to temperature, benthic oxygen demand, nutrient fluxes, and benthic algal mass. Since they need to be defined spatially throughout the stream system, they will require information from as many sites as possible, and then assumptions will be needed to extend the parameterization to the rest of the stream segments..

Many of the USGS gage sites have cross section data available. These data consist of actual measured cross sections, and at some sites where no cross sections have been provided, idealized cross sections can be developed from available data. The USGS has multiple measurements of streamflow, stream width, and cross sectional area that have been made over a period of years, available online (provide web site). These data have been obtained and are being utilized for the corresponding stream reaches. However, that still leaves many portions of the stream system without localized physical measurements. Alternatively, this information can be developed from existing flood insurance studies with models used for calculating flood inundation levels (e.g. HEC-RAS). Lacking detailed physical data, geomorphic relationships between drainage area and channel width and depth values are sometimes used, but they are approximate and can lead to misleading stage-discharge relationships. Thus, actual cross section data at various points in the stream system are preferred.

Stream bed characteristics are also needed for setup of the instream sediment transport modeling, and for representing the bed/water column interactions for nutrients. Bed storages for sediment, including particle size distributions, and for nutrients provide the basis for both starting conditions and the potential magnitude of bed contributions to the water column.

Citations and data provided by M. Derichsweiler (personal communication, email dated 18 February 2010) included information on pebble counts for Battle Branch and Baron Fork (dated 1998), and the a paper by Harmel, Haan, & Dutnell,(1999) identifies median bed particle diameters (D_{50}) for 36 sites along the Illinois River mainstem, as part of study on bank erosion and riparian vegetation impacts. As part of the court case, Grip (2008, 2009) performed aerial photography and analyses to study and define meander conditions and patterns for the Illinois River mainstem, and to estimate bank erosion contributions to the sediment load entering Lake Tenkiller. His data include hundreds of cross section measurements, with channel bottom, bank, and floodplain elevations that may be helpful for channel characterization. The Oklahoma Conservation Commission published two 319(h) reports (OCC, 1999, 2007) on water quality monitoring and analysis that included measurements of stream channel parameters (bank slopes, channel widths, bottom substrates, etc.) and streambank erosion potential. These studies focused largely on Peacheater and Tyner Creeks.

Haggard and Soerens (2006) discuss bed phosphorus releases from a small breached impoundment, the former Lake Frances, near the OK/AR state line. They present some bed information and phosphorus release estimates that will help to include these processes in the modeling. Sediment bed data for phosphorus is also reported for selected Ozark catchments (Haggard et al., 2007). Sediment flux data for phosphorus under aerobic and anaerobic conditions is available from investigations in Lake Eucha (Haggard et al., 2005). Sen et al. (2007) have reported sediment phosphorus release rates from Beaver Reservoir in northwest Arkansas.

3.4.2 Hydraulic Characterization of River and Reservoir Segments

As part of the stream segmentation, the stream segments were analyzed to define their hydraulic behavior and characteristics, along with the tributary areas of the land use categories that drain to them. Within the channel module (RCHRES) of HSPF, the stream hydraulic behavior of each waterbody (stream/river or reservoir) is represented by a hydraulic function table, called an FTABLE, which defines the flow rate, surface area, and volume as a function of the water depth. In order to develop an FTABLE, the waterbody geometric and hydraulic properties (e.g., slope, cross-section, Manning's n) must be defined using data or estimated values. Once the geometry and hydraulic properties have been defined, it is possible to develop the FTABLE as a function of the depth of water (i.e., stage) at the outlet. The method used to develop FTABLEs for streams and rivers in the IRW involves using a single cross-section at the outlet (endpoint) of the reach, applying Manning's equation to calculate flow rate for a given depth, and then assuming the channel to be prismatic (i.e., constant cross-section and bottom slope) along its length, to calculate the corresponding surface area and volume; in some cases, multiple cross sections are utilized, if available to improved the representation of volume and surface area in long reaches.

The initial set of FTABLEs for the streams and rivers within the Illinois River Watershed were developed using this method, but with adjustments where USGS rating curves are available. The cross sections for the reaches are a mixture of: 1) measured cross sections from the USGS, 2) inferred cross sections developed from multiple measurements of flow/width/cross sectional area, and 3) simple prismatic cross sections developed from regional geomorphic relationships. At locations where a rating curve has been developed by the USGS, we merged the cross section with the rating curve to obtain a more accurate discharge representation. The following examples illustrate the FTABLE development at locations where (1) a cross section is available, and (2) where the geomorphic relationships are used.

The cross section shown in Figure 3.5 was measured at a riffle on Osage Creek, and is considered representative of the reach in subbasin 302. A trapezoid was fitted to this cross-section, and dimensions were estimated as follows: top width = 62’, bottom width = 26’, and bankfull height = 3.8’. The floodplain adjacent to the stream was characterized using Google Earth^{TM}. A line perpendicular to the stream was drawn at three locations for each stream reach to estimate the average floodplain slope: close to the upstream end, at the center, and the downstream end. Google Earth provides an elevation profile of the line and using these elevation profiles, floodplain slopes on both sides of the channel were computed, along with the distance from the stream. Roughness values (Manning’s n) for the stream (range of 0.031 - 0.045) and the flood plain (range of 0.05 - 0.10) were estimated based on site photographs, Google Earth imagery and expert guidance. The FTABLEs were constructed using Manning’s Equation, an assumed trapezoidal channel, and a trapezoidal floodplain.

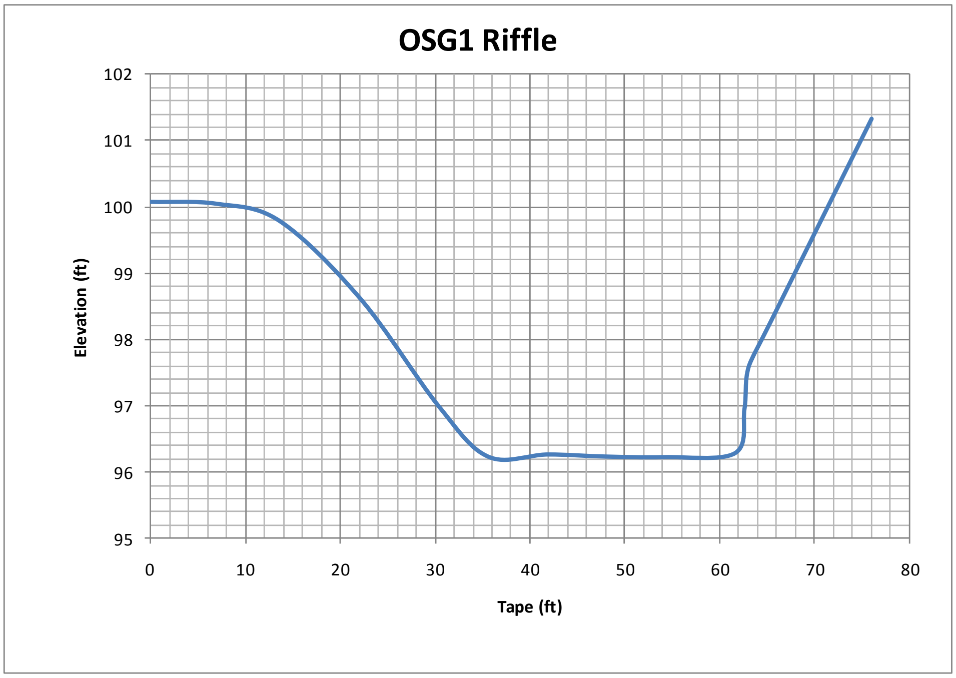


Figure 3.5 The cross-section of a riffle at site OSG1.

At the locations where cross-section data were not available, bankfull width, bankfull depth, and channel depth were estimated as a function of drainage area using regional geomorphic equations (Equations 1 - 3). These equations were developed based on data available for 20 locations in the Illinois River Watershed (USGS field data, and Marty Matlock's research). These equations are different than the regional curve equations proposed by Dutnell (2000); although they are similar in form, Dutnell represented the channel cross-section as rectangular. $BW = 3.89DA^{0.48}$ 1

$BnkW = 30.69DA^{0.31}$ 2

$BD = 2.31DA^{0.22}$ 3

where

BW = channel bottom width in feet

BnkW = bankfull width in feet

BD = bankfull depth in feet

DA = drainage area in square miles

The remaining hydraulic characteristics of the stream (length, slope, floodplain slopes, Manning's roughness coefficients) were estimated as explained earlier for reach 302. Example FTABLEs for reach 302 (developed with cross-section data), and 312 (developed with regional curve equation, drainage area 20.7 mi^2) are shown in Table 3.5.

There are several small reservoirs and lakes such as Lake Wedington, SWEPCO Lake, and Lake Frances that are the defining reaches in their subbasins. FTABLEs for these lakes were derived from available stage-surface area data and stage-volume data, plus outlet data that defined their releases.

Table 3.5 Example FTABLEs for Reaches 302 and 312

FTABLE	302				
ROWS	COLS		***		
17	4				
	Depth	Surface Area	Volume	Discharge	***
	(ft)	(ac)	(ac-ft)	(cfs)	***
	0.0	0.0	0.0	0.0	
	0.3	12.0	9.3	11.0	
	0.6	25.1	19.6	35.8	
	1.0	37.3	30.9	72.0	
	1.3	40.5	43.2	119.2	
	1.6	43.7	56.6	177.2	
	1.9	46.9	70.9	246.3	
	2.5	53.3	102.7	418.6	
	3.2	59.7	138.5	638.5	
	3.8	66.1	178.3	908.9	
	5.1	128.8	301.8	1770.9	
	6.3	191.4	504.5	3020.9	
	7.6	254.0	786.6	4758.9	
	8.9	316.7	1148.1	7068.9	
	10.1	379.3	1588.8	10027.8	
	11.4	441.9	2108.9	13706.8	
	12.7	504.6	2708.4	18173.7	
END FTABLE	302				
FTABLE	312				
ROWS	COLS		***		
17	4				
	Depth	Surface Area	Volume	Discharge	***
	(ft)	(ac)	(ac-ft)	(cfs)	***
	0.0	0.0	0.0	0.0	
	0.4	9.9	5.6	8.7	
	0.8	14.8	12.7	29.6	
	1.1	24.8	21.2	62.2	
	1.5	28.7	31.2	107.4	
	1.9	32.6	42.7	166.2	
	2.3	36.6	55.6	239.6	
	3.0	44.4	86.0	434.4	
	3.8	52.3	122.3	700.2	
	4.5	60.2	164.4	1044.6	
	6.0	102.9	286.6	2243.5	
	7.5	145.6	472.9	4083.9	
	9.0	188.3	723.1	6743.4	
	10.5	231.0	1037.4	10372.7	
	12.0	273.7	1415.6	15108.6	
	13.5	316.4	1857.9	21078.7	
	15.0	359.1	2364.2	28403.5	
END FTABLE	312				

3.5 OTHER DATA TYPES AND SOURCES

For the Illinois River Watershed, comprehensive watershed modeling also requires a wide range of disparate data, especially related to potential pollutant sources and their locations throughout the watershed. For this effort, the focus is on nutrients, primarily phosphorus, and sources for phosphorus include, among others, point sources from wastewater treatment plants, industrial discharges, urban stormwater, wildlife populations, and commercial agriculture, including possible contributions from the hundreds of poultry houses located throughout the watershed

Comprehensive modeling needs to consider ALL potential sources of phosphorus in order to accurately represent the relative contributions and impacts of any single source. A number of expert reports developed in association with the ongoing court case address the issues of phosphorus contributions (and mass balances) from various sources; these documents present the perspectives of both sides of the court case, from both the plaintiffs (e.g. Smith (2008), Johnson (2008), Engel (2008) and the defendants (e.g. Connolly (2009), Clay (2008), Jarman (2008). Our review of this information continues, with the objective of developing methods to consider all significant sources of phosphorus within the IRW, accurately include their contributions within the model structure for this study, and thereby develop a realistic representation of how these sources impact water quality within the IRW in both AR and OK. Section 6.2 discusses some of the issues related to the phosphorus source representation, which will be an ongoing effort as part of the model development effort.

3.6 FINAL SEGMENTATION

As noted at the beginning of this section, whenever any watershed model is set up and applied to a watershed, the entire study area must undergo a process sometimes referred to as 'segmentation'. The purpose of watershed segmentation is to divide the study area into individual land and channel segments, or pieces, that are assumed to demonstrate relatively homogenous hydrologic/hydraulic and water quality behavior.

Based on the GIS data layers discussed in this section, the proposed Final Segmentation for the IRW is shown in Figure 3.6. Table 3.6. lists the stream reach characteristics with the reach number and name, along with the length, slope, downstream reach, and local drainage area.

The segmentation process started with the 12-digit HUC boundaries, as the basic spatial unit for the study, which were then overlaid with the NHD+ hydrography down to 2nd-3rd order streams. The 12-digit HUC boundaries were then adjusted to match reach endpoints at the various USGS gage sites, the AR/OK state line, the endpoints of the impaired segments on each State's 303d list, and the identified major point source dischargers. Some further subdivisions were made where stream segments were judged to be too long, and to allow finer spatial representation of the main stem and selected tributaries. We then solicited suggestions for further subdivisions from State agency representatives and local experts, before arriving at the Final Segmentation proposed in Figure 3.6. This Final Segmentation incorporates the results of those comments.

The reach numbers were assigned to correspond to the subbasin numbers. The numbering scheme is related to the original 12-digit HUC watersheds, and is arranged with lower upstream numbers and higher downstream numbers. Illinois River mainstem reaches have numbers that end with 0, and the hundreds digit corresponds to the original 12-digit HUC. The most upstream reach is 110, Lake Tenkiller is 970, and the most downstream reach is 990. Tributaries also have the same hundreds digit as the original HUC12 watersheds, and are numbered so that they flow downstream to higher reach/segment numbers. All mainstream and tributary stream reaches have the same number as the land segment that they drain.

This segmentation process resulted in **134 model subbasins (or segments) and 127 stream reaches.** The segmentation around Lake Tenkiller has been finalized through linkage discussions with Dynamic Solutions as part of the model linkage to the refined EFDC model of Lake Tenkiller.

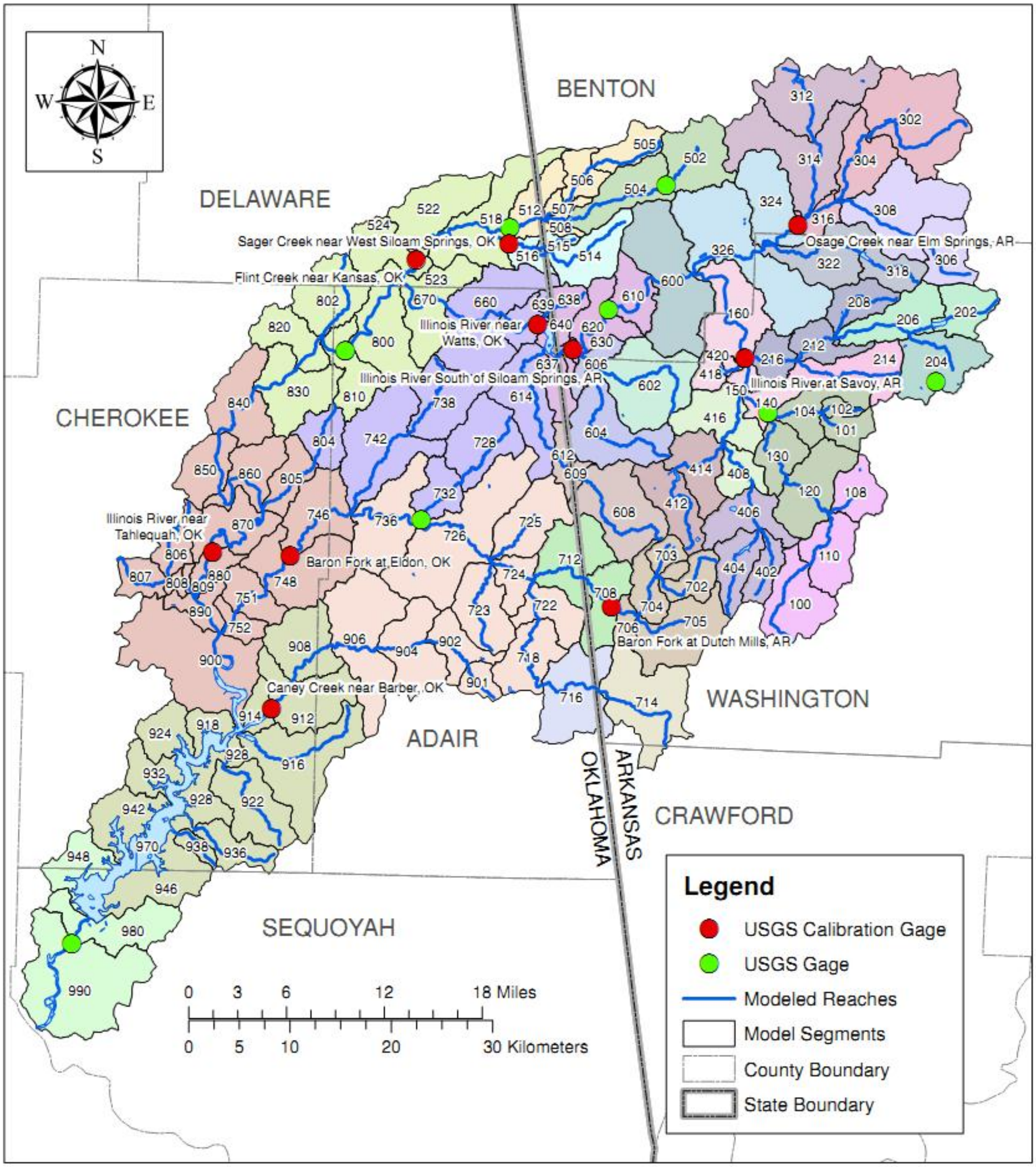


Figure 3.6 Final Segmentation of the IRW

Table 3.6 IRW Stream Reach Characteristics

Subbasin/ Reach Number	Stream Name/Location	Length (miles)	% Slope	Downstream Reach/Segment	Drainage Area (sq. mi.)
100	Illinois River	6.69	1.45	110	16.0
101	Farmington Creek	1.35	1.63	104	5.5
102	Goose Creek	2.85	0.24	104	2.2
104	Goose Creek	3.69	0.20	140	17.7
108	Hickory Creek	2.63	0.84	120	8.6
110	Illinois River	4.43	0.77	120	28.4
120	Illinois River	4.62	0.74	130	54.0
130	Illinois River near Viney Grove, AR (USGS gage 07194760)	5.02	0.31	140	63.2
140	Illinois River	2.69	0.28	150	86.4
150	Illinois River at Savoy, AR	2.76	0.27	160	167.5
160	Illinois River	8.91	1.29	600	262.8
202	Clear Creek	4.65	1.07	206	9.2
204	Mud Creek	4.56	0.36	206	16.8
206	Clear Creek	6.89	0.80	212	39.4
208	Little Wildcat Creek	6.18	0.15	212	8.7
212	Clear Creek	3.31	0.15	216	55.5
214	Hamestring Creek	7.32	0.25	216	14.8
216	Clear Creek	3.48	0.56	160	76.9
302	Osage Creek	8.80	0.67	304	29.9
304	Osage Creek	5.71	0.44	316	42.2
306	Spring Creek	4.94	0.48	308	11.3
308	Spring Creek	6.04	0.22	316	36.6
312	Little Osage Creek	6.39	0.46	314	20.7
314	Little Osage Creek	5.82	1.83	316	46.8
316	Osage Creek near Elm Springs, AR (USGS gage 07195000)	3.07	0.24	324	129.9
318	Brush Creek	4.68	0.68	322	7.7
322	Brush Creek	7.76	0.42	326	23.7
324	Osage Creek	3.54	0.29	326	146.4
326	Osage Creek	6.09	0.52	600	206.3
402	Muddy Fork	4.69	0.45	406	6.4
404	Blair Creek	6.54	0.24	406	9.7
406	Muddy Fork	3.24	0.91	408	27.8
408	Muddy Fork	3.98	0.31	416	34.7
412	Moores Creek	7.01	0.02	414	12.4
414	Moores Creek	4.59	0.46	416	24.5
416	Muddy Fork	3.96	0.39	150	73.3
418	Lake Wedington	0.78	0.21	420	3.9
420	Lake Wedington Outlet Stream	1.46	0.24	150	4.9
502	Flint Creek at Springtown, AR (USGS gage 07195800)	3.68	1.07	504	14.9
504	Flint Creek	7.46	0.14	508	29.3
505	Little Flint Creek	5.12	0.10	506	7.6
506	SWEPCO Lake	3.14	0.35	507	14.1
507	Little Flint Creek	1.85	0.15	512	16.4
508	Flint Creek	1.47	0.09	512	31.3
512	Flint Creek near West Siloam Springs, OK (USGS gage 07195855)	2.59	0.11	518	56.6
514	Sager Creek	6.80	0.57	516	13.0
515	Sager Creek Tributary	2.73	0.29	516	1.9
516	Sager Creek near West Siloam Springs, OK (USGS gage	3.42	0.24	518	19.1

Subbasin/ Reach Number	Stream Name/Location	Length (miles)	% Slope	Downstream Reach/Segment	Drainage Area (sq. mi.)
	07195865)				
518	Flint Creek	7.84	2.76	522	98.3
522	Flint Creek	1.94	0.27	523	114.9
523	Flint Creek near Kansas, OK	0.76	0.24	524	115.7
524	Flint Creek	1.58	0.26	800	126.6
600	Illinois River	3.12	0.58	610	499.7
602	Weddington Creek	9.10	0.35	606	23.3
604	Cincinnati Creek	10.91	0.48	606	20.5
606	Cincinnati Creek	1.29	0.14	630	48.3
608	Ballard Creek	8.62	0.09	609	21.7
609	Ballard Creek	1.55	0.06	612	23.3
610	Illinois River at Hwy. 16 near Siloam Springs, AR (USGS gage 07195400)	4.98	0.42	620	508.9
612	Ballard Creek	1.70	0.24	614	27.6
614	Ballard Creek	8.93	0.38	637	45.5
620	Illinois River	4.47	0.50	630	519.0
630	Illinois River South of Siloam Springs, AR (USGS gage 07195430)	0.54	0.77	635	567.7
635	Illinois River	1.07	0.49	637	569.1
637	Illinois River	2.89	0.21	640	623.2
638	East Beaver Creek	2.40	0.23	639	4.9
639	East Beaver Creek	1.43	0.36	640	6.1
640	Illinois River near Watts, OK (USGS gage 07195500), Lake Francis Reach	0.48	0.24	650	629.5
650	Illinois River	3.34	0.12	660	635.0
660	Illinois River	4.90	0.18	670	662.6
670	Illinois River	5.17	0.27	800	679.5
702	Jordan Creek	5.98	0.40	704	7.0
703	Bush Creek	2.31	0.33	704	3.8
704	Jordan Creek	3.18	0.17	706	19.3
705	Fly Creek	5.11	0.37	706	18.1
706	Baron Fork at Dutch Mills, AR (USGS gage 07196900)	2.17	0.51	708	41.1
708	Baron Fork	2.94	1.20	712	52.4
712	Baron Fork	4.19	0.13	724	69.4
714	Evansville Creek	7.36	0.13	716	24.3
716	Evansville Creek	4.47	0.12	718	45.1
718	Evansville Creek	6.05	1.01	722	58.4
722	Evansville Creek	2.98	0.63	724	67.8
723	Peavine Creek	7.23	0.16	726	14.4
724	Baron Fork	3.15	0.35	726	143.9
725	Shelll Branch	4.49	0.68	726	15.1
726	Baron Fork	6.60	0.44	736	209.9
728	Peacheater Creek	6.13	0.35	732	16.6
732	Peacheater Creek at Christie, OK (USGS gage 07196973)	4.09	0.61	736	25.1
736	Baron Fork	5.96	1.45	746	254.2
738	Tyner Creek	6.53	0.65	742	15.4
742	Tyner Creek	7.34	0.27	746	41.8
746	Baron Fork at Eldon, OK (USGS gage 07197000)	6.34	1.18	748	311.6
748	Baron Fork	3.21	0.57	751	332.8
751	Baron Fork	3.74	0.24	752	341.3
752	Baron Fork	1.84	0.77	900	345.8

Subbasin/ Reach Number	Stream Name/Location	Length (miles)	% Slope	Downstream Reach/Segment	Drainage Area (sq. mi.)
800	Illinois River at Chewey, OK (USGS gage 07196090)	7.01	0.41	810	824.7
802	Black Fox Springs	6.29	0.09	820	16.0
804	Dumpling Hollow	4.19	0.08	805	8.5
805	Dumpling Hollow	5.18	0.08	870	16.7
806	Tahlequah Creek	6.22	0.05	808	6.7
807	Ross Branch	4.56	0.04	808	6.1
808	Tahlequah Creek	1.11	0.46	809	14.2
809	Tahlequah Creek	0.75	1.55	890	15.1
810	Illinois River	2.85	0.20	820	836.6
820	Illinois River	2.79	0.86	830	863.3
830	Illinois River	3.43	2.22	840	880.7
840	Illinois River	4.89	1.15	850	896.4
850	Illinois River	3.69	3.87	860	907.2
860	Illinois River	6.25	4.58	870	918.7
870	Illinois River near Tahlequah, OK (USGS gage 07196500)	8.83	1.44	880	949.5
880	Illinois River	4.39	2.67	890	954.7
890	Illinois River	3.06	2.44	900	975.9
900	Illinois River	9.46	1.14	970	1359.3
901	Caney Creek	2.75	0.86	902	4.2
902	Caney Creek	3.64	1.81	904	13.1
904	Caney Creek	3.42	1.22	906	29.5
906	Caney Creek	3.87	0.13	908	56.7
908	Caney Creek	4.03	0.16	912	72.4
912	Caney Creek near Barber, OK (USGS gage 07197360)	2.68	2.25	914	90.2
914	Caney Creek	2.25	0.70	970	94.6
916	Dry Creek	10.14	0.69	970	27.6
918	Local Drainage to Lake Tenkiller	1.46	0.22	970	4.8
922	Elk Creek	8.33	0.44	970	20.3
924	Local Drainage to Lake Tenkiller	2.09	0.49	970	8.5
928	Local Drainage to Lake Tenkiller	1.07	1.15	970	6.1
932	Local Drainage to Lake Tenkiller	1.31	1.07	970	7.4
936	Terrapin Creek	6.42	0.86	970	10.0
938	Chicken Creek	3.59	0.16	970	2.8
942	Local Drainage to Lake Tenkiller	1.96	0.44	970	11.7
946	Local Drainage to Lake Tenkiller	2.10	1.63	970	16.5
948	Local Drainage to Lake Tenkiller	1.65	0.83	970	9.7
970	Lake Tenkiller	36.61	0.95	980	1598.5
980	Illinois River	2.21	1.69	990	1614.6
990	Illinois River	6.96		-999	1653.4

SECTION 4.0

CALIBRATION AND VALIDATION OF THE IRW MODEL

4.1 CALIBRATION AND VALIDATION TIME PERIODS

Selection of time periods for model calibration and validation depends on a number of factors, including the availability of data for model operations, land use data for model setup, climate variability, and observed data for model-data comparisons. The principal time series data needed for hydrologic and water quality calibration – rainfall, evaporation, air temperature, wind speed, dew point temperature, cloud cover, solar radiation, observed flow, and water quality observations – indicates that long-term simulations are possible at a number of the USGS and AWRC gages within the IRW, spanning the time period covering the early 1990s through 2009.

Precipitation and meteorologic data are a fundamental necessity for model execution, and those data must span the entire simulation period, covering both calibration and validation periods. Partial periods of record, while not ideal, can still be used for consistency checks as part of the calibration and validation process. Land use data are available as snapshots in time, and partially control the selection process as it is preferable to have the land use data at the approximate mid-point of each period, calibration and validation, so that it provides a reasonable representation of conditions throughout each period.

Climate variability is considered once the potential time periods are identified, so that both calibration and validation are performed over a range of climate conditions, including a reasonable balance of wet and dry periods. Finally, the observed data for both flow and water quality exert the primary influence on the selection as the data must be available for performing the model-data comparisons for both components of the model application process.

As discussed in Section 2, the available precipitation and meteorologic data provide an adequate coverage of the watershed for the time period extending from about 1994 through 2009. Prior to 1994, the limitation is primarily related to the availability of hourly precipitation and meteorologic data other than air temperature and evaporation; the OK Mesonet network did not start until 1994 and the AWOS sites started in 1995.

The NLCD land use coverages are for 1992, 2001, and 2006. However, the 1992 data shows considerable inconsistencies as compared to the coverages for the other two dates.

The climate variability is most often assessed by analyzing annual rainfall records. Figure 4.1 shows the annual rainfall data from 1980 to 2009 for Fayetteville, Kansas 2 NE, and Odell 2N. The years 2002-2007 were dryer than normal at Fayetteville, but the same period at Odell included only 3 dry years compared to 3 wet years, and at the Kansas gage only 1 wet year occurred during that 6-year period. In general, the 1990s decade appears to be about normal, or slightly wetter than normal, whereas the decade of the 2000s is generally a little dryer than normal.

Based on these considerations, our preliminary selection of the calibration and validation periods is as follows:

- Calibration: WY 2001-2009
- Validation: WY 1992-2000.

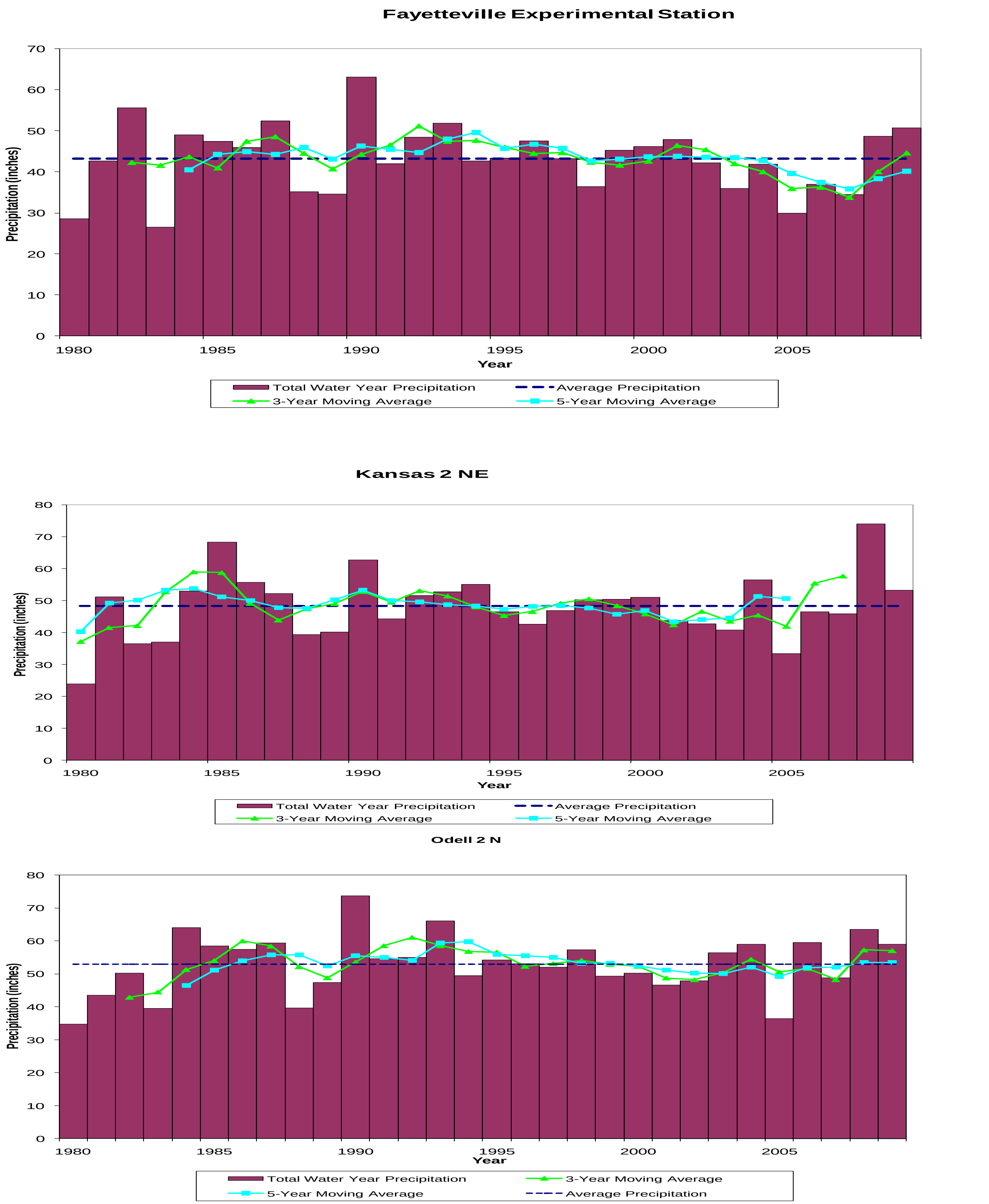


Figure 4.1 Annual Rainfall Data for Fayetteville, Kansas , and Odell for 1980-2009

Our rationale for this selection is as follows:

a. The most complete data for water quality calibration occurs during the period from about 2003 to 2009; thus, we selected the most recent time period for calibration. It is a general truism that model calibration should be performed for the period with the 'best' and most complete data coverage. In addition, calibration on the most recent time period, establishes a solid foundation for projecting impacts and changes for future conditions and potential scenarios.
b. We extended the calibration period back to 2001 to include a more even balance of wet and dry years.
c. The NLCD 2006 coverage will be used for the calibration period, and the NLCD 2001 coverage will be used for validation. We chose the 2001 coverage over the 1992 coverage due to the inconsistencies in classifications noted in Section 3.3. Although the 2001 NLCD land use coverage is just outside the validation period, it still is expected to provide a good representation of conditions for the 1992-2000 time period.
d. We extended the validation period back to 1992 in spite of the limitations on hourly precipitation data noted above. We still have three hourly stations prior to 1994. This earlier time period is for validation, and we may decide to use the first few years as 'spin-up' – a common technique for attaining proper starting moisture conditions – and then not use the model results for those years in the model-data analysis for validation.

Table 4.1 shows the gage sites with flow and water quality data in the IRW. The highlighted sites are those 10 sites selected for model calibration and validation, with the green sites indicating the AR gages, the yellow sites indicating OK gages, and the pink sites indicating the border sites above and below the AR/OK state line. The highlighted gages are those generally with the longest and most recent period of data.

Table 4.1 IRW Gage Stations for Watershed Model Calibration and Validation

Location	Gage Station	Water Quality		Tributary Area (mi²)	Elevation (ft)
Illinois River near Tahlequah, OK	7196500	8/23/1955	12/15/2009	959	664
Baron Fork at Eldon, OK	7197000	5/7/1958	12/14/2009	307	701
Baron Fork at Dutch Mills, AR	7196900	3/17/1959	8/25/2009	41	986
Illinois River near Watts, OK	7195500	9/12/1955	10/26/2009	635	894
Illinois River near Viney Grove, AR	7194760	9/6/1978	7/19/2007	81	1051
Illinois River at Savoy, AR	7194800	9/11/1968	8/25/2009	167	1019
Osage Creek near Elm Springs, AR	7195000	9/10/1951	8/25/2009	130	1052
Illinois River at Hwy. 16 near Siloam Springs AR	7195400	9/8/1978	9/20/1994	509	1170
Illinois River South of Siloam Springs, AR	7195430	10/3/1972	8/25/2009	575	909
Flint Creek at Springtown, AR	7195800	10/15/1975	7/1/1996	14	1173
Flint Creek near West Siloam Springs, OK	7195855	7/11/1979	8/28/1996	60	954
Sager Creek near West Siloam Springs, OK	7195865	5/24/1991	10/21/2009	19	960
Flint Creek near Kansas, OK	7196000	9/7/1955	10/26/2009	110	855
Peacheater Creek at Christie, OK	7196973	8/6/1991	5/16/1995	25	802
Caney Creek near Barber, OK	7197360	8/25/1997	10/27/2009	90	368
Illinois River at Chewey, OK	7196090	7/16/1996	10/27/2009	825	820
Illinois River near Gore, OK	7198000	4/12/1940	8/16/1995	1626	468

Pink – Border Stations; Green – AR Station; Yellow – OK Stations.

4.2 HYDROLOGY CALIBRATION/VALIDATION PROCEDURES AND COMPARISONS

Calibration of the IRW model will be an iterative process of making parameter changes, running the model and producing comparisons of simulated and observed values, and interpreting the results. This process occurs first for the hydrology portions of the model, followed by the water quality portions. The procedures have been well established over the past 30 years as described in the HSPF Application Guide (Donigian et al., 1984) and summarized by Donigian (2002). The hydrology calibration process is greatly facilitated with the use of the HSPEXP, an expert system for hydrologic calibration, specifically designed for use with HSPF, developed under contract for the USGS (Lumb, McCammon, and Kittle, 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 comparison plots. HSPEXP still has some limitations, such as 'how much' to change a parameter and relative differences among land uses, which requires professional modeling experience and judgment. The post-processing capabilities of GenScn (e.g., listings, plots, statistics, etc.) (Kittle et al., 1998) are also used extensively during the calibration/validation effort. Software linkages to HSPEXP and selected GenScn capabilities are available through BASINS 4.0. Most recently, BASINS 4.0 scripting capabilities are used extensively to provide the HSPEXP analyses and additional summary statistics, in addition to plots and tables needed for calibration.

Calibration of HSPF to represent the hydrology of the IRW is an iterative trial-and-error process. Simulated results are compared with recorded data for the entire calibration period, including both wet and dry conditions, to see how well the simulation represents the hydrologic response observed under a range of climatic conditions. By iteratively adjusting specific calibration parameter values, within accepted and physically-based ranges, the simulation results are changed until an acceptable comparison of simulation and recorded data is achieved.

The standard HSPF hydrologic calibration is divided into four phases:

- **Establish an annual water balance.** This consists of comparing the total annual simulated and observed flow (in inches), and is governed primarily by the input rainfall and evaporation and the parameters LZSN (lower zone nominal storage), LZETP (lower zone ET parameter), and INFILT (infiltration index).

- **Adjust low flow/high flow distribution.** This is generally done by adjusting the groundwater or baseflow, because it is the easiest to identify in low flow periods. Comparisons of mean daily flow are utilized, and the primary parameters involved are INFILT, AGWRC (groundwater recession), and BASETP (baseflow ET index).

- **Adjust stormflow/hydrograph shape.** The stormflow, which is compared in the form of short time step (1 hour) hydrographs, is largely composed of surface runoff and interflow. Adjustments are made with the UZSN (upper zone storage), INTFW (interflow parameter), IRC (interflow recession), and the overland flow parameters (LSUR, NSUR, and SLSUR). INFILT also can be used for minor adjustments.

- **Make seasonal adjustments.** Differences in the simulated and observed total flow over summer and winter are compared to see if runoff needs to be shifted from one season to another. These adjustments are generally accomplished by using seasonal (monthly variable) values for the parameters CEPSC (vegetal interception), LZETP, UZSN. Adjustments to KVARY (variable groundwater recession) and BASETP are also used.

The procedures and parameter adjustments involved in these phases are more completely described in Donigian et al. (1984), and the HSPF hydrologic calibration expert system (HSPEXP) (Lumb, McCammon, and Kittle, 1994).

The same model-data comparisons will be performed for both the calibration and validation periods. The specific comparisons of simulated and observed values include:

- Annual and monthly runoff volumes (inches)
- Daily time series of flow (cfs)
- Storm event periods, e.g. hourly values (cfs)
- Flow frequency (flow duration) curves (cfs)

In addition to the above comparisons, the water balance components (input and simulated) are reviewed. This effort involves displaying model results for individual land uses, and for the entire watershed, for the following water balance components:

- Precipitation
- Total Runoff (sum of following components)
    - Overland flow
    - Interflow
    - Baseflow

Potential Evapotranspiration

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 the overall water balance reflect local conditions.

Table 4.2 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.

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.

Table 4.2 General Calibration/Validation Targets or Tolerances for HSPF Applications (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)

Figure 4.2 provides value ranges for both correlation coefficients (R) and coefficient of determination (R2) 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.

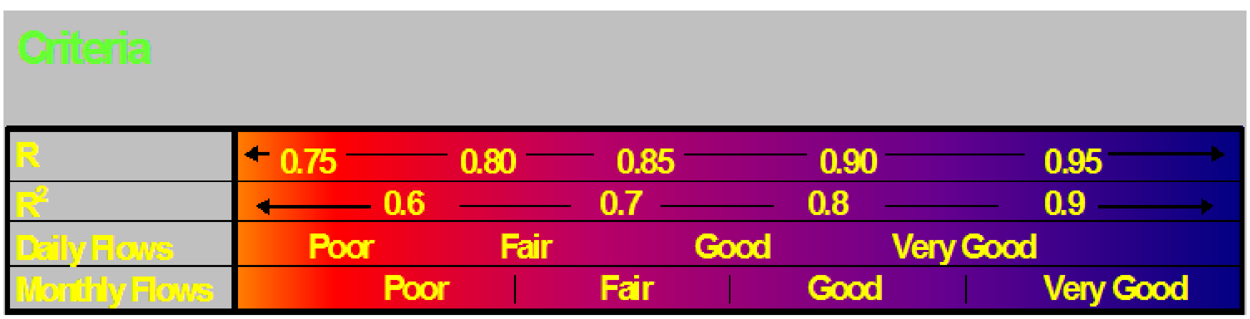


Figure 4.2 R and R^2 Value Ranges for Model Performance

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?".

Consequently, for the IRW modeling effort, we propose that the targets and tolerance ranges for **'Daily'** flows should correspond, at a minimum, to a **'Fair to Good'** agreement, and those for **'Monthly'** flows should correspond to **'Good to Very Good'** agreement for calibration. For the validation comparisons, we expect some decrease in model performance due to less dense gage coverage during for that time period. Thus we expect the validation results to correspond to the **'Fair to Good'** ranges for both daily and monthly flows.

For any watershed modeling effort, the level of expected agreement is tempered by the complexities of the hydrologic system, the quality of the available precipitation and flow data, and the available information to help characterize the watershed and quantify the human impacts on water-related activities. These tolerances would be applied to comparisons of simulated and observed mean flows, annual runoff volumes, mean monthly and seasonal runoff volumes, and daily flow duration curves. Larger deviations would be expected for individual storm events and flood peaks 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.

4.3 WATER QUALITY CALIBRATION PROCEDURES AND COMPARISONS

Water quality calibration is an iterative process; the model predictions are the integrated result of all the assumptions used in developing the model input and representing the modeled sources and processes. Differences in model predictions and observations require the model user to re-evaluate these assumptions, in terms of both the estimated model input and parameters, and consider the accuracy and uncertainty in the observations. At the current time, water quality calibration is more an art than a science, especially for comprehensive simulations of nonpoint, point, and atmospheric sources, and their impacts on instream water quality.

The following steps will be performed at each of the calibration stations, following the hydrologic calibration and validation, and after the completion of input development for point source, atmospheric, and other contributions:

A. Estimate all model parameters, including land use specific accumulation and depletion/removal rates, washoff rates, and subsurface concentrations
B. Tabulate, analyze, and compare simulated annual nonpoint loading rates with the expected range of nonpoint loadings from each land use (and each constituent) and adjust loading parameters when necessary
C. Calibrate instream water temperature to observed data
D. Compare simulated and observed instream concentrations at each of the calibration stations, and compare simulated and estimated loads where available.
E. Analyze the results of comparisons in steps B, C, and D to determine appropriate instream and/or nonpoint parameter adjustments needed until model performance targets are achieved

The essence of watershed water quality calibration is to obtain acceptable agreement of observed and simulated concentrations (i.e. within defined criteria or targets), while maintaining the instream water quality parameters within physically realistic bounds, and the nonpoint loading rates within the expected ranges from the literature. The nonpoint loading rates, sometimes referred to as 'export coefficients' are highly variable, with value ranges sometimes up to an order of magnitude, depending on local and site conditions of soils, slopes, topography, climate, etc.

4.4 SENSITIVITY AND UNCERTAINTY ANALYSES

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.

When calibration and parameter sensitivity analysis are completed, the uncertainty in the calibrated model caused by uncertainty in the estimates of the model input and parameters will be assessed. Formal uncertainty analyses for watershed model applications have not historically been done, largely due to the complexity and computational demands of most watersheds that are modeled. To address the need for uncertainty analyses while recognizing such restrictions when complex codes are involved, a previously used approach is to identify key parameters using a sensitivity analysis and then to focus on the model uncertainty associated with those parameters identified as most "sensitive."

A Draft Technical Memo on the proposed sensitivity and uncertainty analysis procedures has been developed and is currently being revised in response to EPA comments (Mishra and Donigian, 2013). The Tech Memo describes the proposed sensitivity and uncertainty analysis procedures in more detail, with specific reference to the sites and parameterization of the IRW model. The sensitivity analyses will focus on the most sensitive model parameters, as determined through the calibration process and past experience, and additional model runs will be performed, one at a time (OTA) with parameters increased and decreased from the calibrated value. The model results will be analyzed to assess the relative percent change in model output compared to the percent change in the parameter value, positive and negative. The parameters will then be ranked, and the most sensitive parameters will be subjected to a Monte Carlo type uncertainty analysis, to establish confidence intervals about (above and below) the calibration condition, so that the overall model uncertainty can be established. When the procedures have been finalized and approved by EPA, they will be added to this Simulation Plan.

SECTION 5.0

LAKE TENKILLER EFDC APPLICATION AND WATERSHED LINKAGE

5.1 OVERVIEW OF EFDC AND LAKE TENKILLER MODELING

The Illinois River watershed (Hydrologic Unit Code (HUC) 11110103) encompasses a drainage area of 1,052,032 acres in northwest Arkansas and northeast Oklahoma. The Illinois River, Baron Fork, Tahlequah Creek, Flint Creek and Caney Creek are the major streams in the watershed that flow into a 13,000 acre reservoir with 130 miles of shoreline known as Tenkiller Ferry Lake or Lake Tenkiller. Downstream of the dam, the lower reach of the Illinois River flows 10 miles to the confluence with the Arkansas River. Nutrient loading from wastewater facilities, watershed runoff and large-scale agricultural poultry production are suspected of contributing to impairments of many segments of the Illinois River, other streams in the watershed and eutrophication of Lake Tenkiller. In order to develop scientifically defensible tools that can be used for state/local planning purposes to meet water quality management goals in Arkansas and Oklahoma a linked surface water modeling framework is being constructed to account for flow and pollutant loading within the Illinois River watershed and the effects of watershed flow and loading on water quality conditions in Lake Tenkiller. The surface water model framework will incorporate two well-accepted, public domain, open-source models. The Hydrological Simulation Program-FORTRAN (HSPF) was selected as the watershed model and the Environmental Fluid Dynamics Code (EFDC) was selected as the hydrodynamic, sediment transport, water quality and sediment diagenesis model.

EFDC is an advanced surface water model for 3D hydrodynamics, sediment transport, toxic chemicals, water quality and eutrophication processes in rivers, lakes, estuaries, reservoirs, and coastal systems. The EFDC model, originally developed at the Virginia Institute of Marine Science (Hamrick, 1992; 1996), is now supported by the USEPA Office of Water as one of several surface water models endorsed for water quality management planning including TMDL investigations (Tetra Tech, 2007). EFDC 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 (DSLLC, 2006). 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). The state variables of the hydrodynamic model include water level, salinity, and water temperature with the capability to use a dye tracer to model flushing time, age of water and Lagrangian particle tracking. The hydrodynamic model incorporates the baroclinic mode so that vertical density gradients can be correctly simulated under well-mixed and stratified conditions. Physical and biogeochemical processes of the EFDC model include surface processes (wind shear; reaeration; surface heat exchange; atmospheric deposition of nutrients) and bottom processes (wind induced bed stress; sediment deposition, resuspension; bottom heat exchange; and sediment diagenesis processes that govern SOD and benthic nutrient fluxes).

In order to remedy some of the complexities associated with EFDC, Dynamic Solutions has enhanced the original EFDC source code by adding (a) dynamic time stepping algorithms to decrease model execution time and (b) input file driven dynamic allocation of arrays to increase the efficiency of model setup. Dynamic Solutions has also developed EFDC_Explorer as a software interface to support pre- and post-processing tasks for the EFDC model (Craig, 2012). 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. Horizontal maps and vertical sections can be displayed as very effective AVI animations for Stakeholder meetings to enhance the communication of complex space/time processes and patterns that occur in the lake. EFDC_Explorer is used by federal agencies (USEPA, USGS, USACE), state agencies, including Oklahoma DEQ, academic groups, national laboratories and consulting firms.

5.2 DATA AVAILABLE FOR MODEL DEVELOPMENT

The EFDC model that Dynamic Solutions developed previously for Oklahoma DEQ (DSLLC, 2006) and the laterally averaged CE-QUAL-W2 model developed by Wells and Berger (2008) will be used to support the development of an updated model for Lake Tenkiller for the project. The previously developed lake model consisted of 195 horizontal cells per layer and 10 vertical layers to represent the effect of seasonal stratification on hypolimnetic oxygen depletion. Figure 5.1 shows a plan view map of the previous 195 cell computational grid where the lake shoreline is defined by the normal conservation pool elevation of 632.0 ft (192.63 m). The previous EFDC model of the lake was calibrated with data collected by the Clean Lakes Program during the 1992-1993 time period. In this current project, the grid resolution of the lake model has been made finer to address technical issues related to grid resolution identified in the previous study (DSLLC, 2006). Grid resolution has been increased in the Forebay area of the lake where bathymetry is characterized by steep bottom slopes. This refinement of the previous grid should reduce numerical diffusion errors caused by the bottom following vertical layers. Figure 5.2 shows a plan view map of the updated 277 horizontal cells per layer grid that has been developed for the current model for Lake Tenkiller. Vertical resolution of the lake model will be represented with at least 10 vertical layers (actual number of layers will be determined during model calibration) to account for seasonal stratification of the water column. The total number of horizontal and vertical cells represented in the model will thus be at least 2,770 cells. In the increased resolution grid, the shoreline of the lake is defined by the normal pool elevation of 632.0 ft (192.63 m). A comparison of the previous and current grid resolution is shown in Figure 5.3 with bathymetry for the Forebay area of the lake near the dam. In this map, the previous grid is shown with red lines and the new current grid is shown with gray lines.

Setup of the model grid was tested with different horizontal grid cell resolution schemes used to determine the effect of grid resolution on differences in model execution runtime and ability of a 10 layer model to simulate water temperature profiles under summer stratified conditions. Model runtime is controlled by the number of cells and the minimum time step needed for a stable solution. A comparison of vertical profiles of water temperature simulated at station locations in the Forebay area showed very little difference in 10 layer model results generated with 277 horizontal cells shown in Figure 5.2 and a finer resolution grid with almost 800 horizontal grid cells. Model runtime for the finer resolution grid, however, was not feasible for this project because runtime was significantly longer than with the 277 horizontal cell grid. As shown in Figure 5.3, the current grid scheme based on 277 horizontal cells improves the spatial resolution in the Forebay area used in the previous EFDC model (DSLLC, 2006), provides a simulation of water temperature profiles that are comparable to the 10 layer model results generated with the finer resolution grid scheme and results in an acceptable model runtime that is consistent with the project schedule.

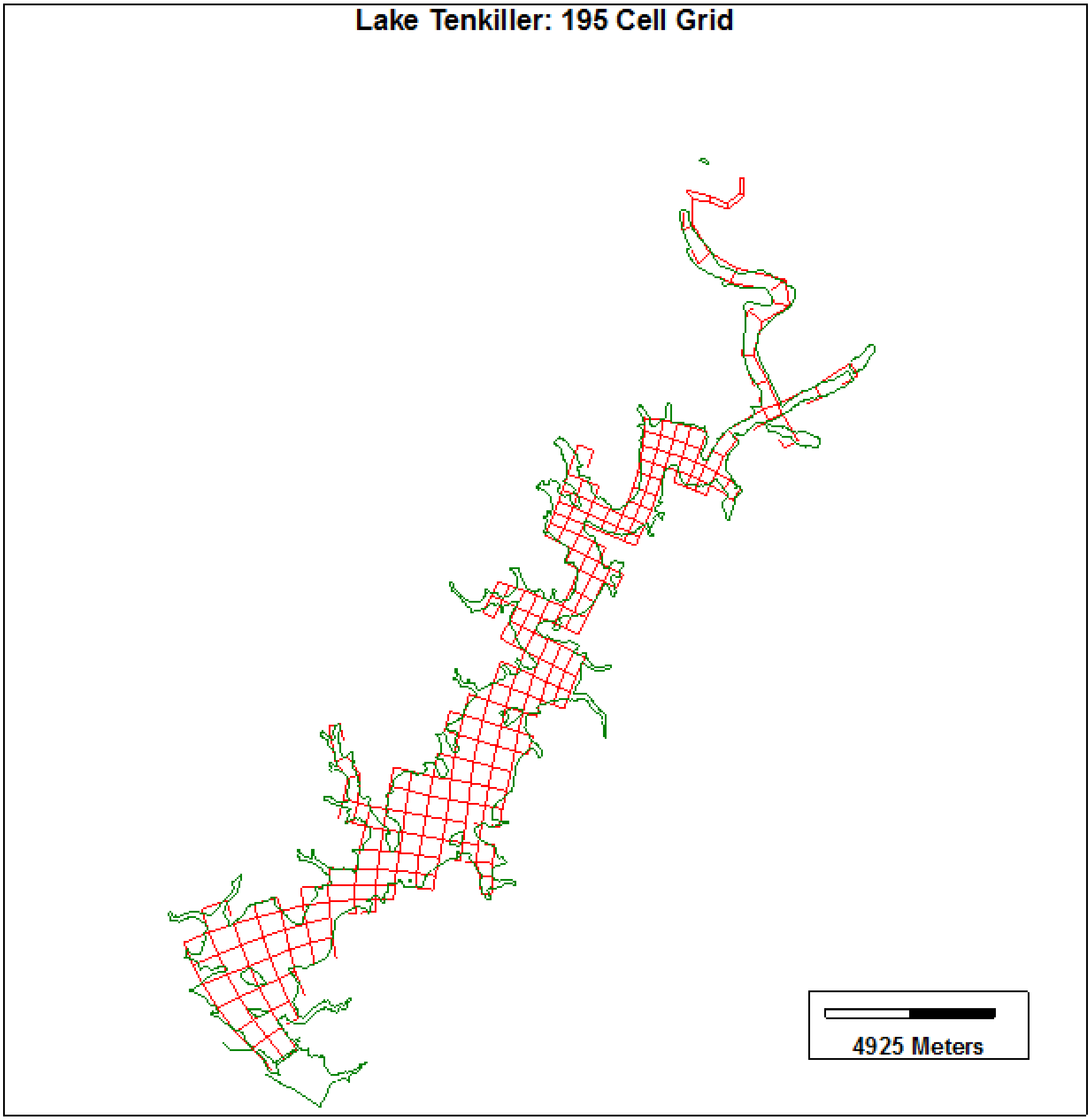


Figure 5.1 Computational Grid with 195 Horizontal Cells for Previous EFDC Model of Lake Tenkiller (DSLLC, 2006)

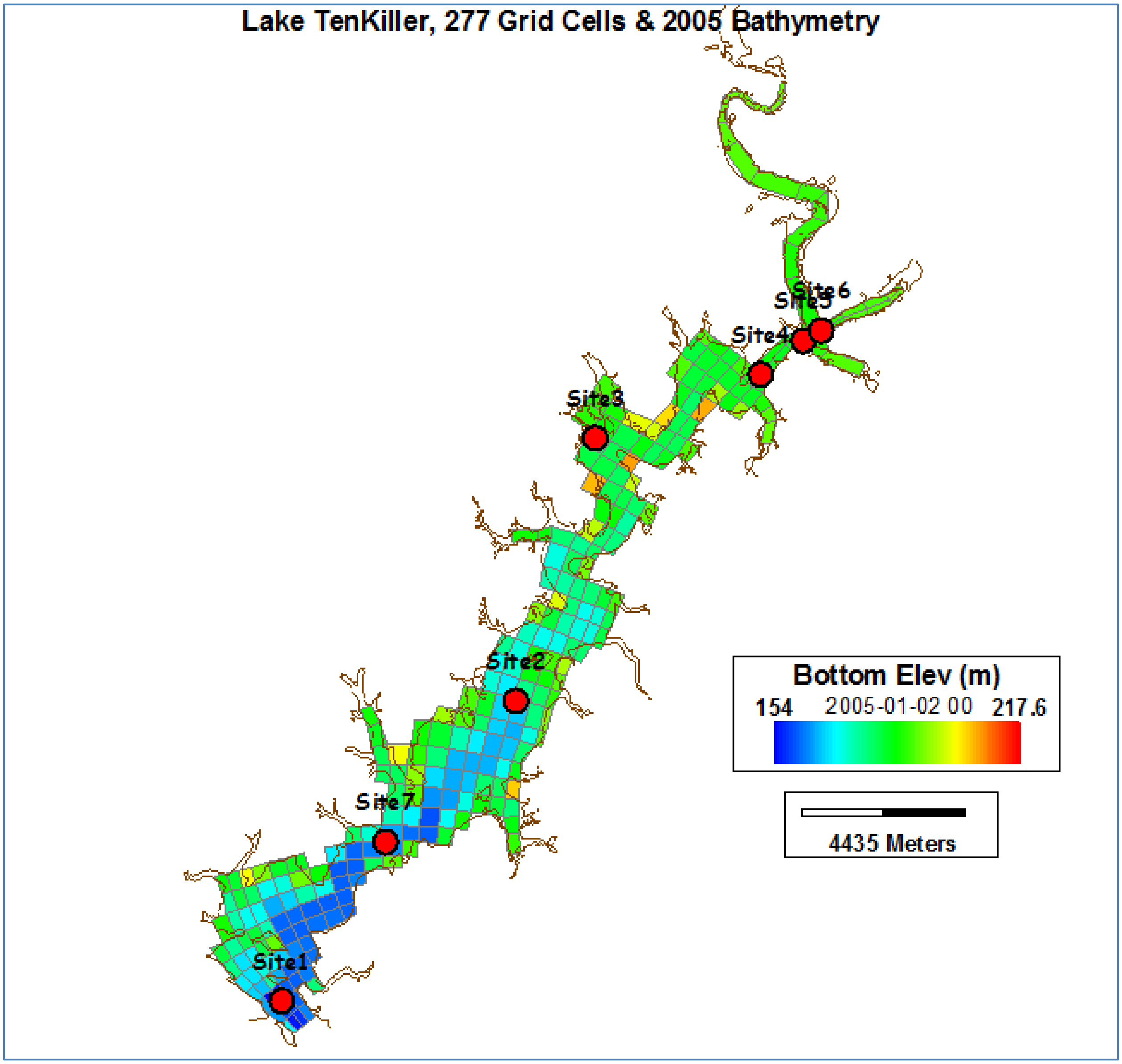


Figure 5.2 New Computational Grid with 277 Horizontal Cells for Current EFDC Model of Lake Tenkiller. Station locations are the OWRB BUMP monitoring program sites.

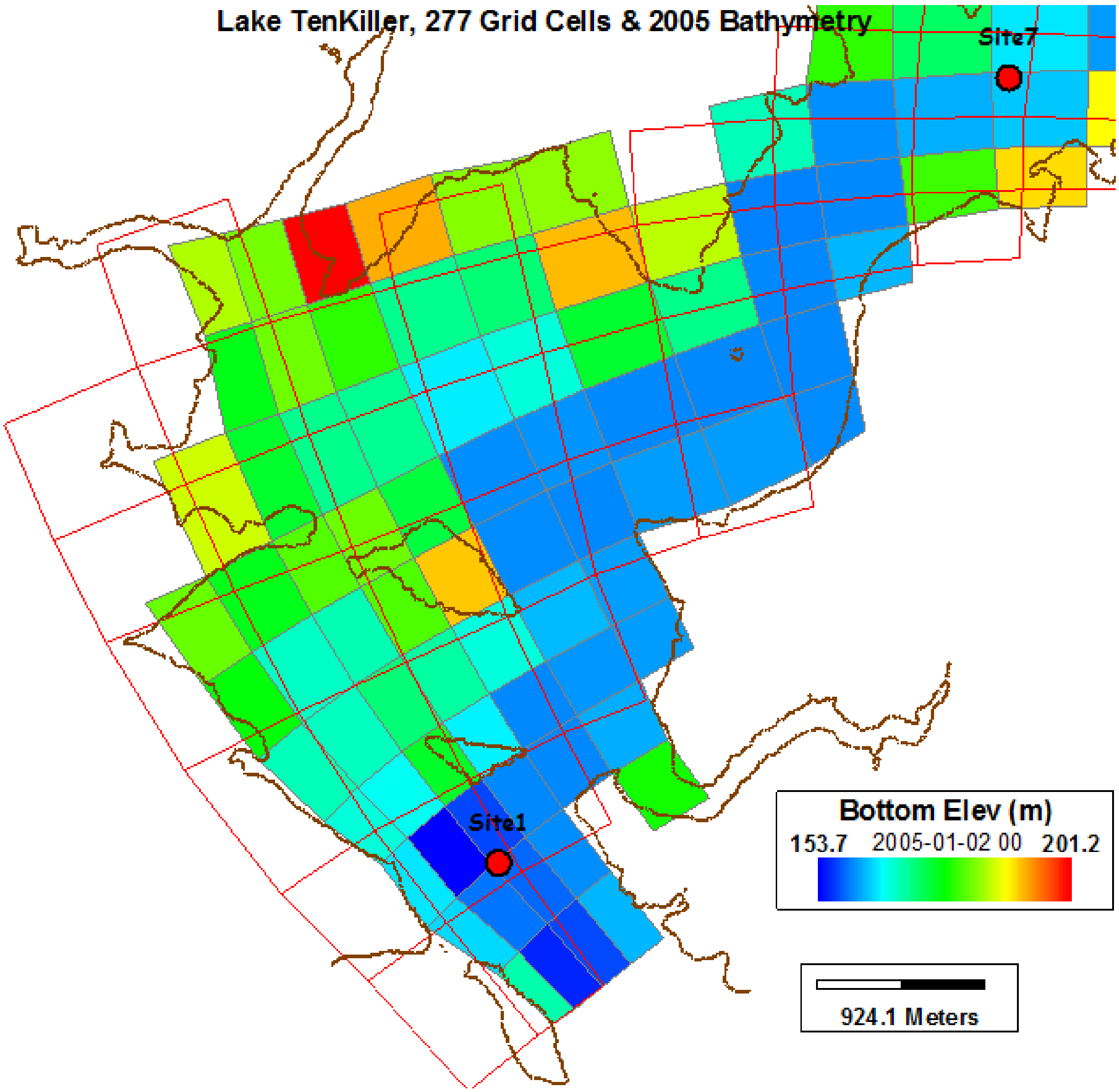


Figure 5.3 Comparison of Grid Resolution for 195 Horizontal Cell and 277 Horizontal Cell Models and Bathymetry in the Forebay Area of Lake Tenkiller.

In the previous model for the lake, bottom elevation data was digitized from historical USGS quadrangle maps that represented the topography of the area before construction of the dam in the early 1950s (DSLLC, 2006). Detailed contemporary bathymetric data is now available from a 2005 survey that was conducted to support the collection of sediment cores (Fisher, 2008; Fisher et al., 2009) and the development of a laterally-averaged hydrodynamic and water quality model of Lake Tenkiller (Wells et al., 2008). The new refined lake model grid (Figure 5.2) has been updated with the bathymetry data collected in 2005. The model has been setup and will be calibrated with more recent data sets that have been identified in an assessment of available data for the Illinois River basin and Lake Tenkiller (AQUA TERRA, 2010). Data sets have been identified from the USACE Tulsa District, Oklahoma OWRB, USGS, and EPA Modern STORET. In addition to these data sets, lake water quality data was collected for the State of Oklahoma from 2005-2007 by CDM and the USGS as a component of an extensive monitoring program of the watershed and the lake (Olsen, 2008). The CDM/USGS database has been reviewed and evaluated and it has been determined that the CDM/USGS data sets will be used with the OWRB data sets for calibration and validation of the lake model. As a component of the Beneficial Use Monitoring Program (BUMP) surveys in Oklahoma lakes, OWRB has maintained a long-term data collection effort in Tenkiller Lake at 7 station sites (Figure 5.2) with water quality data available from 1994 through 2012 (Figure 5.1) .Based on our review and evaluation of hydrologic conditions, lake data and sediment bed data, the period from 2005-2006 has been identified for lake model calibration and validation and the availability of the above described data sets are considered to be adequate for lake model calibration and validation. The EFDC model will be calibrated to the 2005 period and validated to the 2006 period using data collected from 2005-2006. The choice of the calibration and validation years will be reviewed in consultation with EPA Region 6 to ensure that the calibration and validation periods selected represent a sufficient range of hydrologic conditions. Flow boundary conditions used for input to the current lake model have been updated to account for the new data linkage from the current HSPF model results. Station data sets from the OWRB and CDM/USGS data sources for water quality data have been compiled as time series and vertical profiles for comparison of model results.

Table 5.1 Summary of OWRB station data for Lake Tenkiller

Query/Selection Results - Mozilla Firefox

File Edit View History Bookmarks Yahoo! Tools Help

http://maps.owrb.state.ok.us/ms/servlet/com.esri.esrimap.Esrimap?ServiceName=PUB_Custom&CustomService=Query&ClientVersion=4.0&Form=

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

Data sets collected for this project from the OWRB stations, the CDM/USGS database and other data sources have been reformatted, as needed for input to the EFDC lake model and for model calibration and validation. Data sources, types of data, overall usability and technical accuracy of the data acquired from the USACE Tulsa District, USGS, OWRB, CDM/USGS and other agencies will be documented in project modeling results report. An inventory will be developed to document the spatial and temporal availability of data for development of the lake model.

5.3 EFDC MODEL COMPONENTS, STATE VARIABLES AND MODEL SETUP

EFDC, unlike most surface water models, is a single source code model designed to internally link sub-models for the smooth interface of hydrodynamics with sediment transport, toxic chemicals, water quality and sediment diagenesis. Any technical issues related to the linkage of EFDC hydrodynamic results as input to water quality models (e.g., WASP7), are eliminated with the full EFDC model. State variables of the hydrodynamic model will include water level, water temperature and salinity (specific conductance). The sediment transport, water quality/eutrophication and sediment diagenesis models will be activated for calibration of the Lake Tenkiller model. The sediment transport model will be represented with a single state variable for inorganic cohesive sediments since any sediment that remains suspended in the lake for any length of time is typically fine-grained organic matter and cohesive silts and clays. Bottom velocities will be internally linked from the hydrodynamic model to provide bottom stresses for deposition and resuspension processes. State variables of the water quality eutrophication model will include organic carbon, nutrients, algae, and dissolved oxygen. Total organic matter (C,N,P) provided by the HSPF watershed model will be split into dissolved, labile particulate and refractory particulate fractions. Inorganic nutrients, provided directly by the HSPF watershed model, will include ammonia-N, nitrate+nitrite-N and orthophosphate-P. 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. The sediment diagenesis model includes state variables for sediment bed organic content (C,N,P) and porewater concentrations of ammonia-N, nitrate+nitrite-N, orthophosphate and methane (for freshwater) and sulfide (for saltwater). The ability to explicitly represent the coupled interaction between organic matter production and deposition, SOD and nutrient releases across the sediment-water interface is a significant advance in the state-of-the-art for water quality models. The sediment flux model will be invaluable in helping to understand the cause-effect interactions associated with existing pollutant loading, sediment bed properties and ambient water quality conditions. The capability of the sediment flux model will be demonstrated with the “what-if?” predictive modeling of management scenario options by identifying response time scales and changes in lake water quality conditions that might be expected from changes in watershed-based pollutant loading.

Data that has been compiled and processed for setup of the current EFDC lake model includes lake shoreline and the 2005 bathymetry survey of the lake and tributaries that was used to refine the model grid. Data needed for the hydrodynamic model includes atmospheric and wind forcing, watershed flow, release flow over the dam, water supply withdrawals, water temperature and in-lake station measurements of water surface elevation and water temperature. Data needed for the sediment transport model includes watershed loading of total suspended sediments (TSS), sediment bed characterizations of solids content, grain size and porosity, and in-lake station measurements of TSS. Data needed for the water quality model includes watershed loading and in-lake station measurements of nutrients (N, P), organic matter (CBOD or TOC), dissolved oxygen and algae biomass (as chlorophyll-a). Data needed for the sediment diagenesis model includes sediment bed distributions of organic matter (as C, N, P) content and porewater concentrations of ammonia, nitrate/nitrite and orthophosphate. Wet and dry atmospheric deposition of nutrients will be represented based on data available from the EPA National Atmospheric Deposition Program (NADP) and Clean Air Status and Trends Network (CASTNET) monitoring stations in proximity to Lake Tenkiller.

With the refined grid completed and new bathymetry data incorporated in the current model, setup of the lake model will be completed with the assignment of initial conditions, external forcing functions and flow boundary conditions. Initial conditions will be assigned for water column and sediment bed state variables to represent conditions at the beginning of the calibration and validation periods. Station data from OWRB and CDM/USGS will be used to estimate spatial distributions of water temperature, TSS and water quality constituents for the water column. Data needed to characterize sediment bed initial conditions includes sediment bed concentrations of organic carbon and nutrients (N,P). Initial conditions for solids content and organic matter content (C,N,P) of the sediment bed will be estimated from a sediment core survey conducted in Lake Tenkiller in 2005 by Fisher et al. (2009). Figure 5.4 shows the locations of the sediment core stations collected by Fisher et al. The 2005 sediment bed data from Lake Tenkiller may be supplemented, as needed, with sediment bed data collected in other lakes and reservoirs in NW Arkansas and NE Oklahoma (Haggard and Soerens, 2006; Haggard and Smith, 2007; Haggard et al., 2005; Sen et al., 2007; Corral et al., 2011).

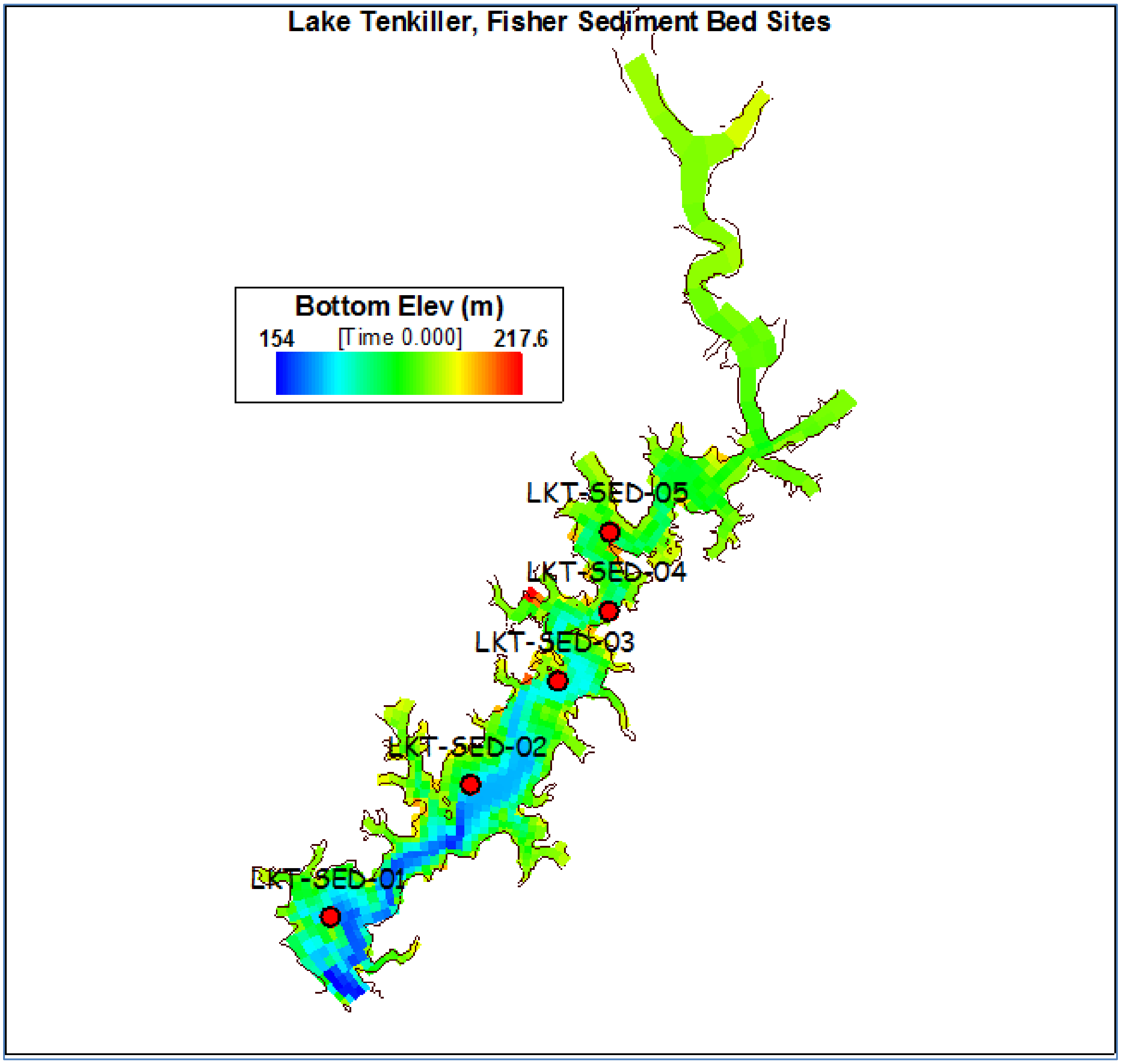


Figure 5.4 Lake Sediment Bed Locations (LKTSED-01,LKT SED-02,LKT SED-03,LKT SED-04, LKT SED-05) during 2005 Survey of Lake Tenkiller (Fisher et al., 2009).

External time series data sets will be assigned to describe atmospheric forcing (dry and wet bulb temperature; relative humidity, barometric pressure, cloud cover and incident solar radiation), and wind forcing (speed and direction) for the calibration and validation period. Atmospheric and wind forcing data will be obtained from the Oklahoma MESONET monitoring network and meteorological stations used for construction of the HSPF watershed model (as described in Section 2).

The HSPF watershed model for this project will provide external flow boundary conditions for streamflow, water temperature and water quality loading of TSS, CBOD, algae, dissolved oxygen, and nutrients (N, P) for input to the EFDC lake model. In addition to flow data provided by the watershed model, time series data sets are needed to assign release outflows at the dam and water supply withdrawals from the lake. Data processing required for linkage of the HSPF results for input to the EFDC model is described below.

5.4 LINKAGE OF ILLINOIS RIVER WATERSHED MODEL (HSPF) WITH LAKE TENKILLER MODEL (EFDC)

Dynamic Solutions has been involved in a number of surface water modeling projects where HSPF and EFDC have been selected as the watershed and hydrodynamic/water quality models to build a linked surface water model framework. To facilitate the data processing needed for the HSPF-EFDC linkage, we have developed custom software to provide a systematic approach for the linkage of flow boundary conditions from HSPF and boundary conditions obtained from other data sources (e.g., lake withdrawals) to provide a set of boundary condition files formatted for input to the EFDC model.

Linkage of the results generated by the calibrated 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 HSPF can be structured to provide time series data needed for input to the EFDC model. 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, organic matter is represented as labile organic matter (as CBOD-Ultimate) and refractory organic matter (as C,N,P). Linkage of 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. Linkage of algae biomass from HSPF to algae biomass as organic carbon in EFDC will be performed using carbon/dry weight (0.45 mg C/mg DW) and carbon/chlorophyll (65 mg C/ug Chl) ratios for watershed derived algal biomass. Linkage of labile organic matter (as CBOD) and refractory organic matter (as C,N,P) from HSPF to total organic matter in EFDC is accomplished by assigning stoichiometric ratios for O2/C (2.67 mg C/mg O2), C/N (5.7 mg C/mg N) and C/P (41.1 mg C/mg P) to convert CBOD-Ultimate to C,N,P equivalent forms of labile organic matter. The labile organic C,N,P is added to refractory organic C,N,P to compute the labile plus refractory components of TOC, TON and TOP. Fractional splits are assigned to transform TOC, TON and TOP to obtain dissolved particulate labile and particulate refractory components for input to EFDC.

5.5 CALIBRATION AND VALIDATION OF LAKE TENKILLER EFDC MODEL

Prior to completion of calibration of the HSPF watershed model, Dynamic Solutions acquired and compiled the 2005 bathymetry data to refine the computational grid (see Figure 5.2). Data has been acquired from the USACE Tulsa District and compiled for water levels, storage volume and release flow at the dam. Water quality data has been acquired and compiled for the OWRB and CDM/USGS lake stations and sediment bed data has been acquired from Fisher et al. (2009). Sediment core data collected by Fisher et al. (2009) in 2005 will allow specification of sediment bed initial conditions for the sediment transport and sediment diagenesis models. Station data available from the OWRB BUMP and CDM/USGS data sets during 2005-2006, will allow specification of initial water quality conditions for the water column. OWRB BUMP and CDM/USGS station data sets will also provide time series and vertical profile observations for calibration and validation of the lake model. When the HSPF calibration results for flow, water temperature, suspended sediment and water quality loading become available for linkage to the EFDC model, the lake model will be calibrated and validated to data collected during 2005-2006. In order to provide reliable flow and loading data from the watershed for input to the lake model, significant efforts have been expended to ensure that the HSPF watershed model is well calibrated and meets the stringent model performance criteria established in the modeling QAPP. Calibration of the lake model will not be initiated without satisfactory calibration of the watershed model.

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

Calibration of the lake model will be accomplished by comparison of model results to observed data extracted from grid cells matching the OWRB and CDM/USGS station locations in Lake Tenkiller shown in Figure 5.2 (OWRB) and Figure 5.5 (CDM/USGS). Model-data comparisons will be presented and analyzed for water level, water temperature, TSS, dissolved oxygen, total-N and total-P, and algae biomass (as chlorophyll-a). Model variables will be displayed as (a) time series plots to show surface layer and near bottom layer results; (b) vertical profiles for selected time snapshots matching sampling dates; and (c) spatial maps of surface layer and bottom layer results for selected time snapshots and/or animation of simulation results as AVI files. The EFDC_Explorer pre- and post-processor software will be an essential tool for calibration and validation of the lake model since this software supports the capability to extract EFDC model results for comparison to observed data sets for time series, longitudinal transects and/or vertical profile plots, compute model performance statistics, and edit values of adjustable parameters (Craig, 2012).

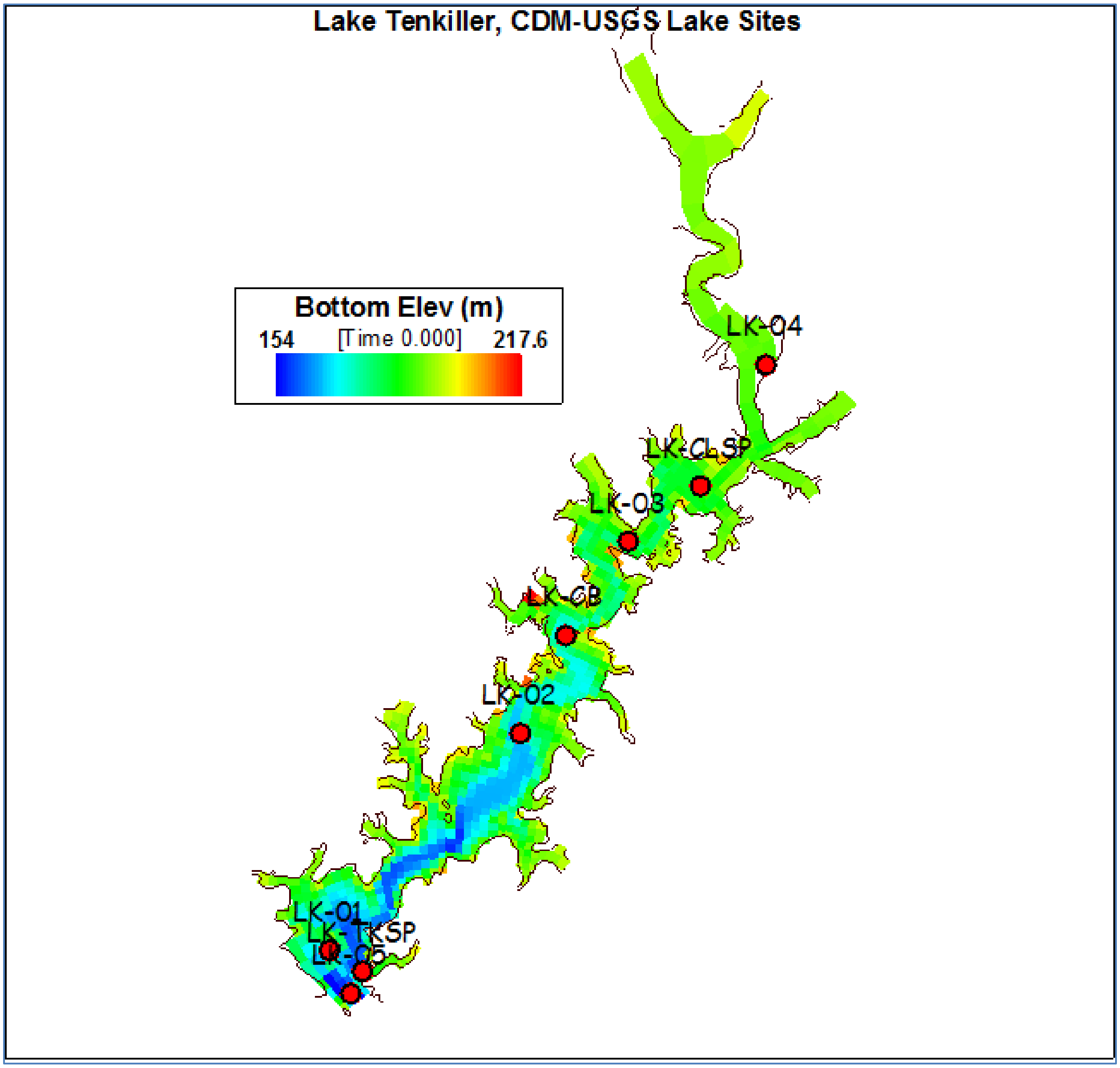


Figure 5.5 CDM/USGS Station Locations in Lake Tenkiller

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

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

In addition to the analysis of model-data results as described above, lake model results will also be post-processed to evaluate water quality targets for dissolved oxygen, the anoxic volume of the lake, chlorophyll-a, and Carlson’s Trophic State Index for chlorophyll-a (TSI). EFDC_Explorer (Craig, 2012) was upgraded for our previous Lake Tenkiller modeling project (DSLLC, 2006) to support the display of the TSI and anoxic volume of Lake Tenkiller. An example of the anoxic volume display extracted from the EFDC model results for the 1992-1993 calibration is shown in Figure 5.6.

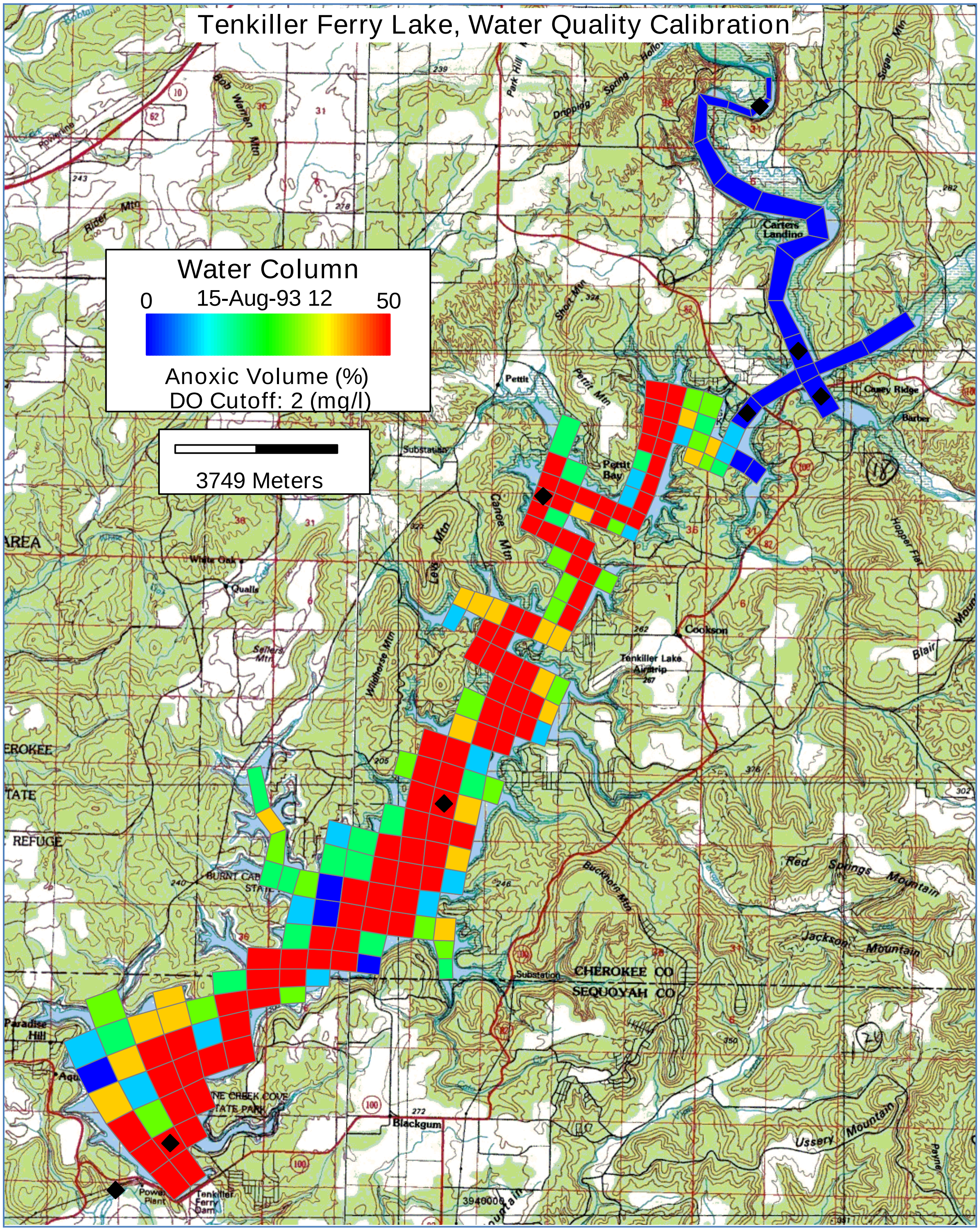


Figure 5.6 Anoxic Volume of Lake Tenkiller on 15-August-1993 at 12:00 (DSLLC, 2006)

5.6 SKILL ASSESSMENT AND MODEL PERFORMANCE EVALUATION

Skill assessment will be evaluated to determine the endpoint for model calibration using a "weight of evidence" approach that has been adopted for many surface water modeling studies.

Our "weight of evidence" approach includes the following steps: (a) visual inspection of plots of model results compared to observed data sets (e.g., station time series or vertical profiles); and (b) analysis of model performance statistics (e.g., RMS Error and Relative RMS Error) that will be presented in a separate revised Modeling Quality Assurance Project Plan (QAPP) for the Lake Tenkiller project. The "weight of evidence" approach recognizes that the lake model, as an approximation of the lake, will not be able to provide perfect agreement with all the available observed data and, as such, perfect agreement is not specified as a performance criterion for the lake model. Model performance statistics will be used, not as absolute criteria for acceptance or rejection of the re-calibrated model results, but rather, as guidelines to supplement visual inspections of model-data plots to determine the most appropriate endpoint for calibration of the Lake Tenkiller model. The "weight of evidence" approach thus acknowledges the approximate nature of a numerical model and the inherent uncertainty in external forcing data, bathymetry of the lake, EFDC model coefficients and observed data. Following calibration of the lake model, model performance statistics will also be computed and evaluated for the model validation period.

5.7 SUPPORTING ANALYSES- SENSITIVITY ANALYSIS

Sensitivity analysis is a procedure to determine how lake model output changes with respect to changes in lake model input parameters. This analysis will provide information on the model response to changes in different model input parameters and coefficients. During the model calibration process a series of iterative adjustments are typically made to selected model coefficients to determine how changes in model input will affect model results. Based on this iterative approach to model calibration, one set of model coefficients are identified to achieve overall acceptable model results. It is important to note that the parameter values assigned during model calibration must be within an accepted low to high range of the parameter where such data is available from the literature. The model calibration process thus provides important insight to the modeling team that informs the modeling team about the sensitivity of key model parameters and coefficients. Calibration and validation results of the EFDC model of Lake Tenkiller will be reviewed and evaluated to identify those model input parameters and kinetic coefficients to be considered for the sensitivity analyses.

Key kinetic coefficients (e.g., algae growth rate) and model input parameters (e.g., settling velocity) expected to have the greatest effect on the water quality response of the calibrated EFDC lake model will be selected for review and approval in consultation with EPA Region 6. The sensitivity analyses (SA) of the EFDC lake model will be performed using accepted modeling practice by setting up a series of model runs based on a systematic low and high adjustment of selected key model coefficients and parameters. The model calibration results are compared to the model results obtained for the low and high adjustment of model inputs to identify model sensitivity to the input variable. One model input variable that is of particular importance in the Illinois River Watershed and Lake Tenkiller is watershed loading of TP to the lake. Low and high ranges of HSPF watershed TP loading conditions will be provided as input for one of the variables selected for sensitivity analysis of the lake model.

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

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

5.8 SUPPORTING ANALYSES- UNCERTAINTY ANALYSIS

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

The overall joint uncertainty of the EFDC lake model will be evaluated for the combined set of four (4) model input parameters (watershed TP load + 3 other model input parameters) using results of the calibration run, the sensitivity runs based on the low and high values, and the additional model runs based on the middle low and middle high values. Pooled model results will be used to compute summary statistics and 90% confidence intervals around the model calibration results. Summary statistics (number of records, mean, and standard deviation) and the 90% confidence interval for key variables of the lake model will be aggregated over time (e.g., stratified summer conditions) for the two (2) station locations selected for the Sensitivity Analysis.

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

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

5.9 EVALUATION OF MANAGEMENT SCENARIOS FOR WATERSHED LOAD REDUCTIONS ON LAKE TENKILLER

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

The load reduction scenarios will be primarily focused on changes to the IRW watershed model, through changes to the HSPF model inputs (see discussion in Section 6.4, below), while the EFDC model of Lake Tenkiller will be used to assess lake impacts of the HSPF watershed load reduction scenarios. Based on a uniform percent reduction of TP, TN, and/or TSS (i.e., across the board), up to ten (10) scoping scenarios for load reduction will be developed with the watershed HSPF model. The modeling team will review the watershed load reduction scenarios and coordinate with EPA Region 6 to identify the load reduction scenarios selected for input to the Lake Tenkiller EFDC model for an assessment of the lake impacts. If further refinements to the selected scoping scenarios for load reduction are needed, the modeling team will coordinate with EPA Region 6 for the selection of no more than five (5) additional refinements of HSPF load reduction scenarios. This process will be completed progressively as a means of assessing and identifying the appropriate number of load reduction scenarios for evaluation with the lake model. Prior to conducting EFDC modeling to assess the impacts of the additional selected scenarios on Lake Tenkiller, the modeling team will coordinate with EPA Region 6 on the selection of up to ten (10) additional EFDC load reduction scenarios. The total number of EFDC load reduction scenarios to be simulated shall be no more than ten (10) model runs including those chosen from the initial scoping scenarios and the HSPF refinement scenarios.

It is likely that, even with reductions in nutrient loading to the lake, the reservoir of organic matter in the bed may continue to serve as a significant source of nutrients to the water column for several years particularly when benthic phosphate releases are triggered by hypolimnetic oxygen depletion. The sediment diagenesis model will provide important information about the likely time scale that may be required to gradually reduce the benthic flux of nutrients and decrease ambient levels of phosphorus in the water column. After reviewing scenario results with USEPA Region 6, ADEQ and ODEQ, the EFDC model will be used to “spin-up” the sediment diagenesis model to attain new quasi-equilibrium conditions for the sediment-water interface that results from the selected management loading scenario. The lake model will be able to identify the response time scale and changes in sediment-water fluxes and lake water quality that can be expected from implementation of the management loading scenario. The fact that several years may pass before the effects of nutrient reduction efforts will be observed in Lake Tenkiller is obviously important information that USEPA Region 6, ODEQ and ADEQ will want to communicate to stakeholders. The sediment diagenesis model incorporated in EFDC is the only lake model methodology that exists to provide a quantitative cause-effect link between watershed loading, nutrient enrichment, eutrophication, sediment oxygen demand and release of nutrients from the lake bed back to the water column.

SECTION 6.0

SPECIAL ISSUES AND CONSIDERATIONS

This section discusses a number of issues and considerations that are still being addressed within the IRW TMDL modeling effort at the time of publication of this Simulation Plan. These topics are primarily challenging technical issues that are not often, and therefore difficult, to accurately represent in any comprehensive watershed modeling study. In the following sections we discuss karst conditions within the IRW and our approach to their representation, phosphorus sources and their comprehensive representation within the modeling effort, and specific consideration of poultry litter generation, handling, application, and exportation as part of the phosphorus source for this TMDL modeling development effort. The final section directly addresses the approach for TMDL development through execution of alternative model scenarios, and subsequent analysis of the scenario results for selected key locations, such as the AR/OK state line and Lake Tenkiller, in addition to other impaired waterbody segments.

6.1 KARST CONDITIONS, IMPACTS, AND REPRESENTATION

Karst conditions are evident and known to occur in many parts of the IRW. Well-developed karst conditions appear to occur in approximately 40-65 percent of the IRW. The highest concentration of karst conditions appears in the Upper IRW of the AR portion of the watershed and portions of the Osage, Spring, and Flint creek tributaries. Any hydrologic model of the IRW must consider karst areas in order to accurately represent the hydrology of the watershed.

6.1.1 *Physiographic and Hydrologic Features*

Karst conditions, which develop as a result of the dissolution of soluble bedrock such as limestone or dolostone, is characterized by distinctive physiographic and hydrologic features (Field, 2002) as illustrated in Figure 6.1. The resulting topography often includes depressions, sinkholes, sinking (or losing) streams, caves, and karst springs. These areas have hydrologic characteristics that generally include:

- internal drainage of surface runoff through sinkholes;
- underground diversion or partial subsurface piracy of surface streams;
- temporary storage of ground water within a shallow, perched epikarst zone;
- rapid, turbulent flow through subsurface pipe-like or channel-like solutional openings called conduits; and
- discharge of subsurface water from conduits by way of one or more large perennial springs (Rosenberry and LaBaugh, 2008).

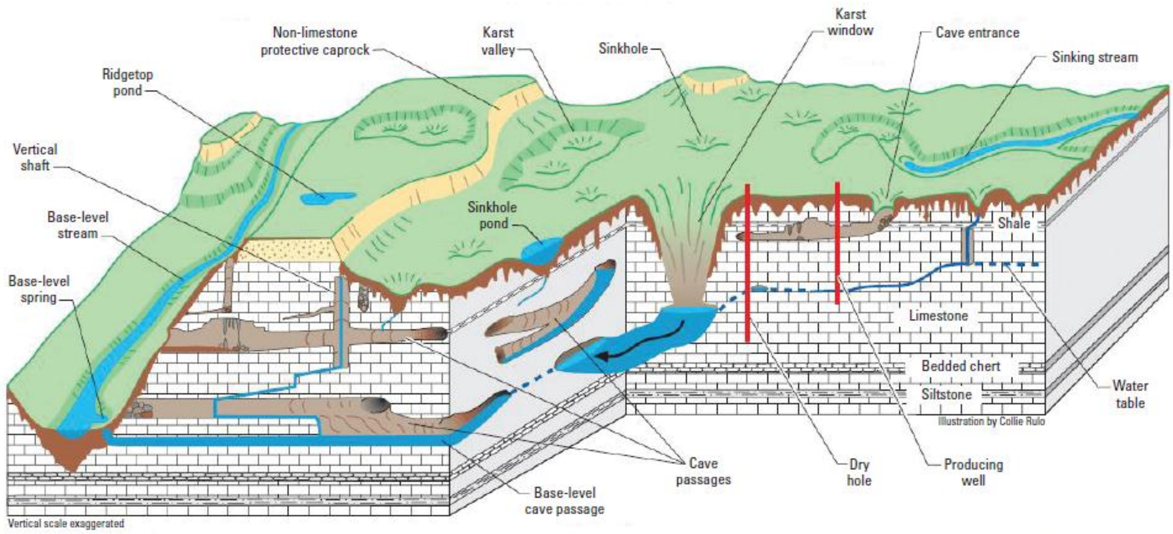


Figure 6.1 Physiographic and Hydrologic Features Typical of Well-Developed Karst Terrain (Taken from USGS Document, Techniques and Methods 4-D2, Chapter 3, Rosenberry and LaBaugh, 2008)

Surface water and groundwater are highly interconnected and often constitute a single, integrated and dynamic flow system in karsts areas. Due to this interconnection, subsurface drainage boundaries do not always coincide with surface topographic drainage divides. In addition, the caves and subsurface tunnels common to this hydrogeology behave as conduits channeling water from distant parts of the watershed to other regions without any apparent surface pathway. These combined impacts often lead to difficulties in establishing accurate water balances and even accurate drainage boundaries when karst conditions dominate the watershed and its hydrologic response (Rosenberry and LaBaugh, 2008).

The hydrologic impacts of karst terrain within a watershed are numerous and varied, in both space and time. Karst watersheds often exhibit multi-peaked hydrographs resulting from the varied pathways that the water travels to reach an outlet or gaging site Fast, or quick flow may result from water entering sinkholes and turbulent travel through subsurface caves and conduits. Slow responses can reflect storage impacts through surface depressions and ponds, and subsequent infiltration through perched 'epikarst' areas in the shallow subsurface. The extent to which the fast flows occur will lead to lower evapotranspiration opportunity and less storage within the watershed (Long, 2009).

6.1.2 *Modeling Karst Conditions*

Modeling watersheds dominated with karst terrain can be problematic due to lack of direct observation of water pathways, and the resulting need to interpret movement based on analysis of flow and/or water quality data and records. Much of the investigation of modeling karst conditions has been done within a research environment using instrumentation to track and measure water pathways and movement through karstic features such as underground caves and tunnels, sinkholes and ultimate discharge from springs. For hydrologic impacts, model parameter adjustments can be implemented for areas with karst conditions through increases in infiltration and interfow related parameters, along with adjustments to subsurface (i.e., interflow and baseflow) recession parameters to help match observed behavior. Evapotranspiration might also be impacted when rapid movement to the subsurface is evident, minimizing opportunity for soil storage; thus adjustments to the ET parameters may also be needed (Storm et al, 2006).

Identifying where within the IRW karst conditions are prevalent, and possibly dominant, is the first step in attempting to represent their impacts within the watershed model.

Karst-type maps for Benton and Washington County, AR, are available at http://www.nwarpc.org/pdf/GIS-Imagery/KASM_WASHINGTON_CO.pdf, which show the spatial distribution and concentrations of karst features. These maps were overlaid onto the model segments of the IRW as shown in Figure 6.2. The red areas (lines) indicate regions where the presence of karst formations are 'extremely high', versus the green areas where karst is extremely low. These maps depict the results of a correlation model since they were developed by correlating information on depth to groundwater, recharge, soils, topography, vadose zone characteristics, and faults/fracture zones to provide some indication of where in the AR portion of the IRW watershed karst impacts exert considerable influence. Comparable spatial information or data for the OK portion of the IRW is not available other than a state-wide karst map for Oklahoma (Figure 6.3) which merely confirms the existence of karst formations in the vicinity of the IRW, but little detail is available.

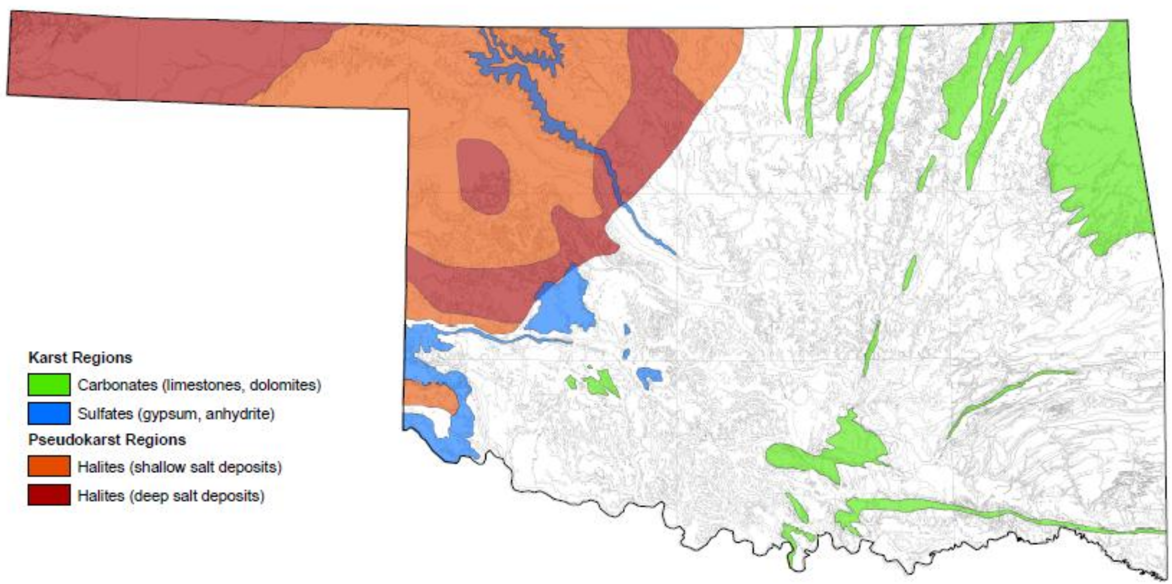


Figure 6.2 Karst and Pseudokarst Regions of Oklahoma

Our approach to representing karst impacts on the hydrology of the IRW has been to identify the subwatersheds with the highest concentrations of the red and orange shading in Figure 6.3, indicating 'extremely high' and 'high' karst features, and then imposing adjustments to the infiltration, interflow, and recession parameters as part of the hydrologic calibration process. Clearly, the success of this approach depends on whether the observed flow record at the downstream calibration gage demonstrates sufficient evidence of karst impacts so that it can be considered as part of the calibration procedures.

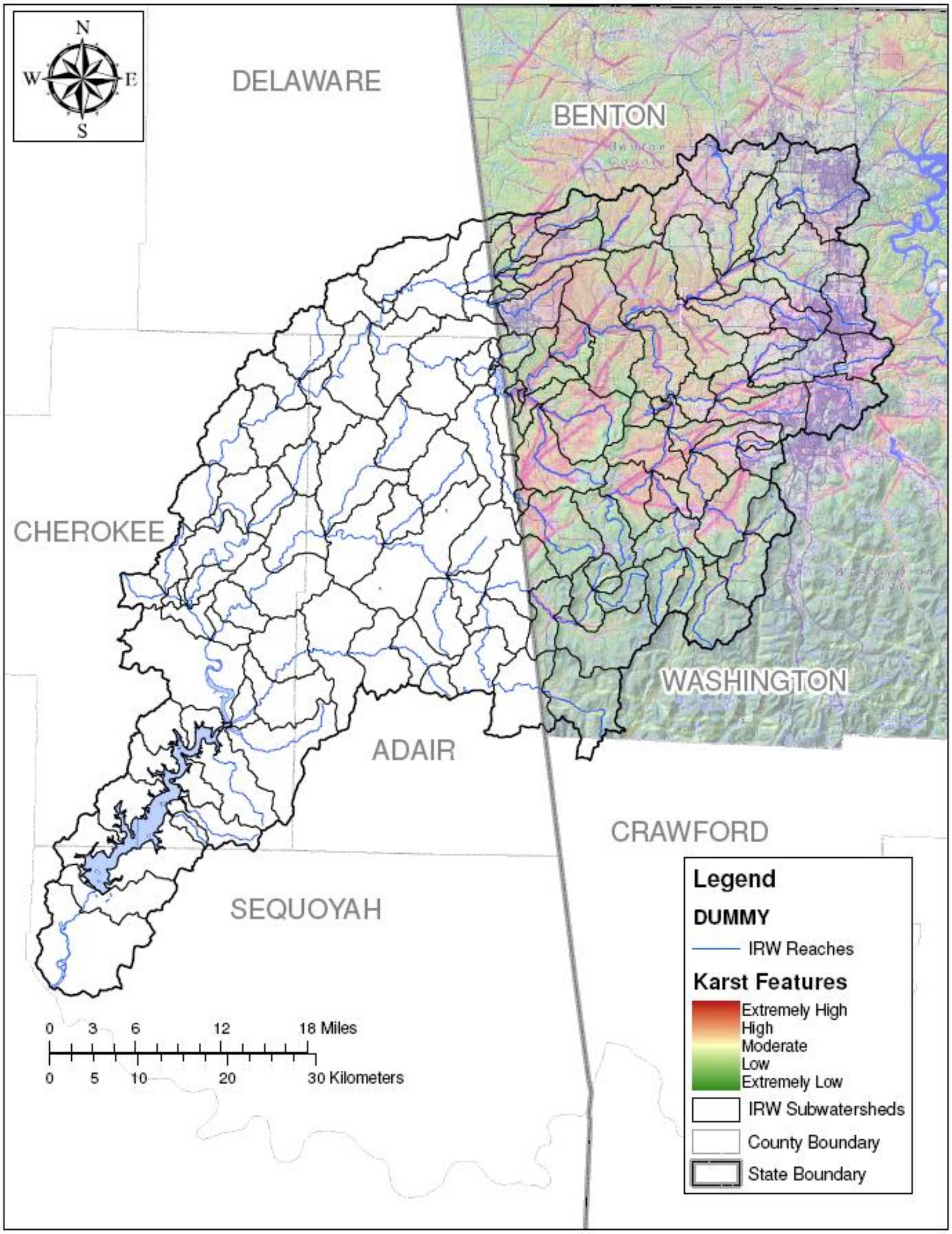


Figure 6.3 Karst Features in AR with Outline of IRW Model Segments

6.2 PHOSPHORUS SOURCE REPRESENTATION

There are a wide variety of sources of P within the IRW due to the many and varied activities that abound within its boundaries. For this TMDL effort, our focus is on those sources of P that are, or can be, transported to the rivers, streams and lakes, and ultimately contribute to the P concentrations and water quality conditions within the IR. Below we discuss our approach to quantifying the various sources of P included in the model, along with a brief description of the method, or reference to other sections of this Simulation Plan. Approaches for selected sources are still under development and will be subject to the available data to support their inclusion.

- **Wastewater Treatment Plants:** These are represented as point sources and the available data to support their inclusion is discussed in Section 2.5.
- **Poultry Litter:** Section 6.3 discusses in detail our approach to modeling poultry litter applications and runoff contributions based on use of the HSPF-AGCHEM module, along with some of the issues still being resolved. **Other Animal Wastes:** Other animals that may provide significant contributions of P include cattle, swine/hogs, and wildlife. Data on animal populations are included in the data provided by ODAFF and ANRC, and prior mod**eling efforts by Stor**m (2009) and Saraswat (2010) describe procedures for these sources that might be adapted for this effort. Swine/hogs are likely to be enclosed in Animal Feeding Operations (AFOs) or Confined Animal Feeding Operations (CAFOs), and data for these have been provided by ODAFF for OK; we are pursuing similar data for AR. Wildlife populations and their P contributions will be included with loads from forested areas as their primary habitats. If wildlife population data is available, we can use it to adjust loading parameters spatially within the watershed.
- **Commercial Fertilizers:** This is a P source that is still being investigated. The prior modeling efforts by Storm and Saraswat may provide information on application rates appropriate for this watershed. One of the challenges for this source is to distinguish pasture areas that receive commercial fertilizer as opposed to poultry litter, so that each can be modeled separately. This is still being investigated.
- **Urban Stormwater:** The model includes multiple categories of urban lands (see Section 3.3) so stormwater from these categories will be explicitly modeled and their contributions tabulated along with all land uses. We have identified the MS4 areas within the IRW for each state, and those are available for overlay onto the model segments.
- Bank Erosion: Bank erosion is known to exist in various parts of the IRW and has been studied in selected stream reaches, as noted earlier in this document. This data is being used to identify where bank erosion is likely to exist and its general magnitude. Furthermore, these studies and data are being used to guide the sediment transport calibration, and will impact the phosphorus simulation as the sediment from bank erosion is known to be a source of phosphorus to the stream channel at sites where it exists.
- **Septic Systems:** We have located very little data to identify locations and numbers of septic systems within the IRW. In light of this, our standard approach is to assume these systems exist primarily in the low-density residential areas urban sewered districts, and adjust the subsurface loadings to partially compensate for septic systems.
- **Industrial Sources:** Smith et al., (2008) lists Industrial sources as a significant addition of P to the IRW, but that list of industries appears to be mostly those that discharge to treatment plants. We will investigate further.

- **Unpaved Roads:** Unpaved roads, especially in forested areas, have been recognized as a potential source of both sediment and attached P throughout the US, and in the IRW by the IRWP (2010) as part of their watershed management plan. We are presently searching for appropriate unpaved road coverages, in both states, that can help to locate their occurrence and serve to overlay this information onto our model segments. Without that data, we will attempt to identify where such roads exist in general and increase sediment loads from those forest, in an attempt to allow for its contributions of sediment and P.
- **Nurseries, Golf Courses, Recreational Users:** This is a mixed bag of potential sources that we will investigate to identify what data is available for their inclusion in the model, if warranted.

6.3 POULTRY LITTER REPRESENTATION

As part of the overall approach to modeling phosphorus (P) loads and concentrations within the IRW, consideration of poultry litter practices and their potential contributions to water quality conditions must be an important part of the modeling effort. With more than 30 million birds in the watershed, generating more than 300,000 tons of litter each year, it is critical to attempt to represent the potential impacts of this source of P as part of the overall balance of P for this watershed. With historical litter application practices based on nitrogen needs, resulting in over-application of P and increases in soil P levels and subsequent runoff (Maguire et al., 1999), both states have instituted restrictions on land application of poultry litter with applications rates guided by soil P indices within each state (Delaune et al, 2006; Sharpley et al., 2003).

These restrictions, along with required Nutrient Management Plans (NMP) at the farm level, have promoted exportation of litter to neighboring, non nutrient surplus watersheds for use as fertilizer on pasturelands for feed production. In the neighboring Eucha-Spavinaw watershed, Sharpley (2011) reports that up to 75% of the litter is exported from that watershed following a settlement focused on P contributions from both litter and wastewater dischargers. Herron (2011) notes that litter exported from the IRW just by BMPs, Inc., a nonprofit exporter, has risen from 60,000 tons in 2006 to more than 100,000 tons in 2010, representing about 30% of the generated amounts. Due to this recent growth in litter exports, any modeling effort for P in the IRW must consider not only the generated and applied litter, but also the exported amounts as part of the overall P balance for the watershed. Furthermore, if the modeling confirms that poultry litter applied to pasture within the IRW is a significant contributor to the identified water quality impairments, additional exportation might be an alternative means of attaining the standard.

In brief, our approach to representing poultry litter nutrient contributions within the watershed model involves use of the HSPF-AGCHEM module, as discussed in Section 1.3, in combination with data from ANRC and ODAFF on litter amounts and practices, as follows:

1. Use the detailed soil nutrient model, HSPF-AGCHEM, to represent phosphorus (and nitrogen) cycles on pasture lands, and subsequent P (and N) runoff as a function of soil processes and litter application rate.
2. Develop litter application rates (including timing and methods) from data supplied by ANRC and ODAFF. Table 6.1 shows data by 12-digit hydrologic unit code (HUC-12), provided by ANRC and ODAFF for their respective sides of the IRW. These data are preliminary, and somewhat incomplete, and are currently being further investigated. For

example, ANRC provided total generated litter amounts in addition to application and exported values, but the generated amounts were not available from ODAFF. Also, the ODAFF database included values for the entire period from 2001-2009, whereas ANRC graciously agreed to review all the NMPs and summarize the data but it was only done for 2011. We have requested a few additional years of data to help better characterize this contribution with time over the calibration period, and especially during the recent past when exports have begun and increased. For these reasons, the data in Table 6.1 is considered preliminary, but it is exemplary of what we expect to acquire.

3. Figure 6.4 shows a map of the litter application rates from the last column of Table 6.1. The rates generally range from about 1.0 to 2.0 tons/acre, with some up to 3.0 tons/acre on the OK side. Although these rates are preliminary, they are generally consistent with rates noted by Sharpley (2011, 2009).

4. Use standard nutrient composition values for poultry litter (e.g., Sharpley et al., 2009) to convert litter applications to elemental nutrient applications required by AGCHEM.

5. Consult previous modeling efforts (by Storm and Saraswat), along with local experts, and the literature to help parameterize the AGCHEM model and its representation of litter handling, application practices (e.g., typical times and methods for application). We also plan to consider restrictions on application rates in each state, such as slope and STP restrictions, subject to the data available to support this task.

6. Develop ‘target’ runoff rates (lb/ac/yr) for both nitrogen and P, from local studies and use to calibrate and check model simulations. We are reviewing the literature to identify loading rates differences between littered and non-littered pastures, such as shown by Sharpley (2009) to support our model representation.

Clearly, the details of our approach to representing poultry litter within the watershed model are still evolving as we continue to analyze the data we have received, and work with the State representatives to explore what additional data might be available to support our approach.

Table 6.1 Poultry Litter Data from ANRC (2011) and ODAFF (2009) – PRELIMINARY

Hydrologic Unit Code (12 digit)	State	HUC-12 Name	Number of Birds	Litter Generated (tons)	Litter Applied (tons)	Number of Houses	Area Applied (acres)	Application Rate (tons/acre)
111101030101	AR	Headwaters Illinois River	208,200	2,990	449	24	467	0.961
111101030102	AR	Goose Creek-Illinois River	221,000	1,408	527	17	618	0.853
111101030103	AR	Lake Weddington-Illinois River	100,800	245	20	6	60	0.333
111101030201	AR	Lake Fayetteville-Clear Creek	79,000	1,069	240	12	890	0.270
111101030202	AR	Mud Creek-Clear Creek	0	0	0	0	0	0.000
111101030203	AR	Hamestring Creek	75,400	397	16	4	8	2.000
111101030204	AR	Little Wildcat-Clear Creek	551,400	3,212	157	29	1,090	0.144
111101030301	AR	Headwaters Osage Creek-Illinois River	59,000	671	0	6	25	0.000
111101030302	AR	Spring Creek-Osage Creek	1,065,600	10,415	163	63	-	0.000
111101030303	AR	Little Osage Creek	1,122,000	7,038	521	62	540	0.965
111101030304	AR	Brush Creek-Osage Creek	1,068,200	7,406	1,668	65	1,714	0.973
111101030305	AR	Osage Creek-Illinois River	797,270	7,693	1,067	70	3,393	0.314
111101030401	AR	Upper Muddy Fork-Illinois River	782,886	14,239	1,666	37	1,910	0.872
111101030402	AR	Moores Creek-Muddy Fork	1,337,383	11,698	487	79	614	0.793
111101030403	AR	Lower Muddy Fork-Illinois River	798,890	9,700	684	55	811	0.844
111101030501	AR	Headwaters Flint Creek	1,692,400	11,668	653	95	1,596	0.409
111101030502AR	AR	Sager Creek	615,250	3,688	392	27	2,790	0.141
111101030502OK	OK	Sager Creek	64,000	-	0	6	0	0.000
111101030503AR	AR	Middle Flint Creek	1,247,200	9,199	227	71	167	1.358
111101030503OK	OK	Middle Flint Creek	404,430	-	1,692	25	911	1.857
111101030504	OK	Lower Flint Creek	1,237,700	-	904	57	588	1.538
111101030601	AR	Chambers Hollow-Illinois River	2,187,675	52,135	543	86	4,368	0.124
111101030602	AR	Weddington Creek	808,900	5,281	1,370	41	1,725	0.794
111101030603	AR	Cincinnati Creek	1,536,100	14,537	524	121	612	0.856
111101030604AR	AR	Upper Ballard Creek	1,347,732	12,784	523	90	1,112	0.470
111101030604OK	OK	Upper Ballard Creek	0	-	80	0	90	0.889
111101030605	OK	Lower Ballad Creek	880,000	-	785	38	689	1.139
111101030606AR	AR	Lake Frances-Illinois River	413,000	998	48	15	408	0.118
111101030606OK	OK	Lake Frances-Illinois River	0	-	0	0	0	0.000
111101030607AR	AR	Dripping Springs Branch-Illinois River	0	0	0	0	0	0.000
111101030607OK	OK	Dripping Springs Branch-Illinois River	1,206,600	-	1,419	60	870	1.632
111101030701	AR	Headwaters Baron Fork	1,597,800	12,106	3,084	86	3,184	0.969
111101030702AR	AR	Lower Fly Creek	850,525	10,481	812	41	480	1.692
111101030702OK	OK	Lower Fly Creek	0	-	215	0	140	1.536
111101030703	AR	Upper Evansville Creek	351,000	2,422	395	14	215	1.840
111101030704AR	AR	Lower Evansville Creek	0	0	0	0	0	0.000
111101030704OK	OK	Lower Evansville Creek	151,000	-	402	6	139	2.892
111101030705	OK	Shell Branch Creek-Baron Fork	304,000	-	1,061	27	840	1.263
111101030706	OK	Peacheater Creek	282,000	-	211	17	240	0.879
111101030707	OK	Green Creek-Baron Fork	1,763,400	-	1,019	94	626	1.628
111101030708	OK	Tyner Creek	3,210,500	-	645	140	482	1.338
111101030709	OK	Dennison Hollow-Baron Fork	0	-	170	0	85	2.000
111101030710	OK	Willow Branch-Baron Fork	0	-	563	0	282	1.996
111101030801	OK	Black Fox Springs-Illinois River	94,000	-	65	5	90	0.722
111101030802	OK	Scraper Hollow-Baron Fork	273,200	-	820	18	637	1.287
111101030803	OK	Dumpling Hollow-Illinois River	0	-	0	0	0	0.000
111101030804	OK	City of Tahlequah-Illinois River	0	-	0	0	0	0.000
111101030901	OK	Upper Caney Creek	70,000	-	681	7	569	1.197
111101030902	OK	Middle Caney Creek	523,000	-	845	26	396	2.134
111101030903	OK	Lower Caney Creek	80,000	-	0	4	0	0.000
111101030904	OK	Hill Branch-Tenkiller Ferry Lake	0	-	0	0	0	0.000
111101030905	OK	Dry Creek	72,000	-	220	12	175	1.257
111101030906	OK	Elk Creek-Tenkiller Ferry Lake	24,000	-	0	4	0	0.000
111101030907	OK	Tenkiller Ferry Lake Dam	0	-	150	0	75	2.000
111101030908	OK	Outlet Illinois River	59,400	-	958	4	469	2.043
		Arkansas Total	20,914,611	213,480	16,235	1,216	28,795	
		Oklahoma Total	10,699,230	-	12,905	550	8,392	
		IRW Total	31,613,841	213,480	29,140	1,766	37,188	

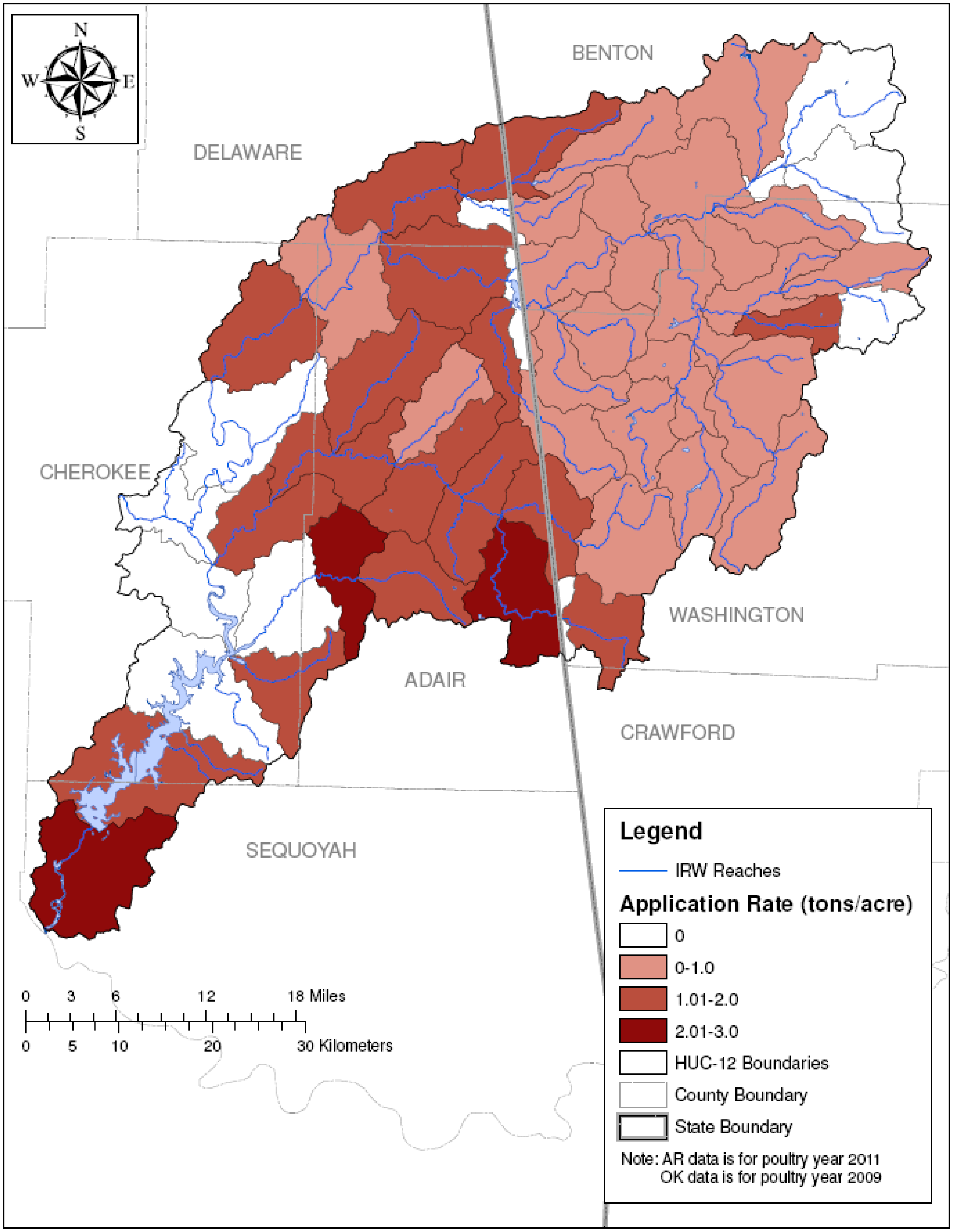


Figure 6.4 Litter Application Rates by HUC-12 in the IRW – PRELIMINARY

6.4 DEVELOPMENT OF MODEL SCENARIOS

Following the calibration and validation of the IRW model, a series of model runs, or 'scenarios', representing alternative conditions on the watershed will be developed which will be used as a basis for developing the TMDL. The scenarios will be designed to address contaminant loads upstream of each of the impaired sites identified in Figure 1.2 as being on each state's 303d list. For complex watersheds, like the IRW, with a large drainage area, and with multiple land uses, multiple contaminant sources contributing to each impairment, and multiple stakeholders, scenario development will be an iterative process. The IRW watershed/lake modeling system will be used as a tool to assess impacts of each proposed scenario until a scenario is found that meets water quality standards and is acceptable to EPA and the stakeholders.

The modeling process for TMDL development involves a series of steps, envisioned as follows:

a. Define Baseline conditions, usually representing or approximating 'current' conditions
b. Revise the model inputs/conditions to represent the Baseline condition
c. Perform the Baseline simulation, and confirm that the model represents the impaired conditions at the impaired reach, or reaches, within the model
d. Quantify load contributions from all sources to each impairment site
e. Design scenarios to reduce loads and re-run the model
f. Repeat Step e (above) until the relevant water quality standard is achieved

The Baseline represents the conditions to which the model results for the alternative scenarios will be compared. Thus, they are usually some variation of 'current' conditions since the intent is to assess what changes are needed to the model setup so that the future scenario will result in reduced loads and a better opportunity of achieving the water quality standard. In defining the Baseline conditions, model changes might include point source discharges, land use conditions, BMPs scheduled to be applied to nonpoint sources, etc., or any other changes that are known, or expected to occur in the watershed. For this reason, stakeholder involvement in establishing the Baseline conditions is also needed.

For the IRW, Baseline conditions might include a land use coverage that approximates current (e.g. 2011) conditions, point source discharges with planned treatment improvements, litter exports comparable to current levels, nutrient application rates similar to current levels, etc. The Baseline also provides an opportunity to include planned improvements outlined in the watershed management plans developed by both states; however, there should be some assurance that the planned improvements will actually be implemented. If that is not the case, then the management plans, or portions thereof, should be considered for inclusion as one or more scenarios for load reductions.

Identification of specific details of the scenarios to assess, and the mix of load reductions will be a cooperative effort among EPA, ODEQ, ADEQ, the Tribes, and the contractors, AQUA TERRA and Dynamic Solutions when Lake Tenkiller simulations are involved. Initial 'scoping' scenarios may be identified and analyzed by EPA, AQUA TERRA, and Dynamic Solutions, as examples to demonstrate use of the linked HSPF watershed and EFDC lake models for TMDL development. These scoping scenarios will be documented and provided to the stakeholders as a basis for establishing further refinements to the scenarios, and possibly additional scenarios. This is likely to be an iterative process, with the ‘final’ scenarios selected by the above groups, with EPA approval.

As noted in Section 5.9, the load reduction scenarios will be primarily focused on changes to the IRW HSPF watershed model, through changes to the HSPF model inputs, while the EFDC model of Lake Tenkiller will be used to assess lake impacts of the HSPF watershed load reductions. Up to ten (10) scoping scenarios for load reduction will be developed with the watershed HSPF model. The modeling team will review the watershed load reduction scenarios and coordinate with EPA Region 6 to identify the load reduction scenarios selected for input to the Lake Tenkiller EFDC model for an assessment of the lake impacts. If further refinements to the selected scoping scenarios for load reduction are needed, the modeling team will coordinate with EPA Region 6 for the selection of no more than five (5) additional refinements of HSPF load reduction scenarios. This process will be completed progressively as a means of assessing and identifying the appropriate number of load reduction scenarios needed for evaluation.
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Once one or more scenarios have been determined to meet the OK standard at the state line, the impacts of selected scenarios on Lake Tenkiller will be assessed with respect to meeting lake water quality standards for DO, Chlorophyll-a, and Carlson’s Trophic State Index, as discussed in Section 5.9. If the Lake Tenkiller standards are not met, then further reductions will be investigated until simulated lake water quality conditions are in compliance with standards. The assumptions and results of these scoping scenarios will be documented and provided to stakeholders for review and comment, followed with either a conference call or project meeting to allow direct input and interaction with stakeholders, before the TMDL, or TMDLs, are developed and finalized.

SECTION 7.0

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APPENDIX A: AQUA TERRA Responses to EPA-Identified Stakeholder Comments on the IRW Simulation Plan

EPA identified selected Stakeholder comments for which AQUA TERRA Consultants either responded with changes to the text in this Simulation Plan, or provided an explanatory response. Below each of the EPA-identified comments are listed followed by our response.

1. Comment: We very much appreciate it that the project team added break points for the watershed segmentation upon Oklahoma's request. However, the final watershed segmentation still has some problems: 1) state line break points for the Illinois River and the Flint Creek are either at a wrong place or non-existent; 2) there is no break point for the Westville treatment plant; 3) there are no break points for the treatment facilities of the cities of Lincoln and Gentry (Is it due to the location of the discharge points of these facilities close enough to existing watershed divides?)

   Response: This is a comment from late 2011 and all the issues with the break points at the State Line have been resolved, to our knowledge. The primary source of the differences was due to an inaccurate GIS coverage for the State Line that was resident in the BASINS system, and that has been corrected. Also, the discharge facilities do not require a separate breakpoint, as long as the discharge is directed to the proper stream location of the facility, and this information was obtained from the discharge permits.

2. Comment: Page 77, item #2: the amount of poultry litter generated in the Illinois River watershed in Oklahoma could be estimated either based on:
   - the estimated average amount of litter generated of 125 -150 tons per house, per year;
   - or the estimated amount of litter generated of 18 lbs per bird space, per year.

   The former method of estimation gives a lower amount than the latter.

   It is noted that the number of poultry houses operated in 2009 in the Upper Illinois River watershed, where scenic river status is designated, was 357, and the corresponding number of birds was 7,070,530. The numbers given in the Simulation Plan of 550 houses and 10,699,230 birds are for the whole Illinois River watershed, which includes both the Upper and Lower Illinois River watersheds.

   Response: We are still investigating the most appropriate method of estimating the litter applications based on the data we have received from ODAFF and ANRC; this work is ongoing at the current timeHowever, we stand by the 'preliminary' data on litter included in Table 6.1 of the IRW Simulation Plan; these data were received directly from ODAFF and ANRC. The number of poultry houses in the entire IRW is generally stated to be in the range of 1500 to 2000; the 550 number in our table applies to just the OK portion of the IRW, and it is only about 1/3 of the total number of houses in the entire watershed.

3. Comment: Line 6, first full paragraph, Page 19: The total number of Mesonet stations is 120 with at least one station per county in Oklahoma (77 counties in total).
   Response: The Sim Plan text has been revised to reflect this number.

4. Comment: Line 5, Section 3.4.1, Page 41, please provide the website.

   Response: Line 5 on page 41 reads as … "The river reach segmentation considered river travel time, riverbed slope continuity, cross section, and morphologic changes, and entry points of major tributaries." This information was derived from numerous GIS data layers and other information, and not from a single web site.

5. Comment: Line 3, first paragraph, Page 43: please provide Dutnell (2000) citation in the reference section.
   Response: The Dutnell (2000) citation has been added to the references. It is a MS thesis from the University of OK.

6. Comment: Line 2, paragraph after the formula, Page 43: "… is shown B", what is "B"?
   Response: The words '… is shown B.' is a typo and have been replace with '… is discussed below.'

7. Comment: Paragraph above Table 4.1, Page 53: …. "the green sites indicating OK gages"….; it should be yellow instead of green.
   Response: This has been corrected in the Sim Plan.

8. Comment: Section 2.4 states "The specific constituents to be modeled in this study include all constituents needed for modeling nutrients with a specific focus on phosphorus species." Section 1.1 states that the goal of the study is to determine reductions needed to meet state water quality standards. In order to attain this goal, the list of parameters to be modeled will have to be expanded to address all of those constituents that exceed state water quality standards and lists phosphorus as the cause - turbidity, bacteria, aquatic life, all constituents affecting aesthetics.

   Response: The list of constituents to be modeled is listed on page 24, and the clear focus of this effort is the scenic rivers TP standard of 0.037 mg/l at the State Line, along with Lake Tenkiller Water Quality Standards for DO, Chl a, and Carlson's Trophic State Index will be considered for the TMDL development. Turbidity is related to TSS and sediment, which are modeled, along with biotic components. Based on OWRB BUMP data collected during 2005-2006 turbidity was in compliance with the 25 NTU water quality standard and the designated uses related to turbidity were fully supported.The other metrics, such as aquatic life and aesthetics, noted in this question, are not commonly modeled but derived from the modeled constituents. Bacteria, by design, is not included in the current scope of the modeling work.

9. Comment: Section 6.2 under the Water Temperature Calibration section. How is canopy cover or the lack of canopy cover used by EPA and Aqua Terra to determine the impacts on temperature?

   Response: The HSPF parameter that considers canopy cover for the instream water temperature simulation is CFSAEX, which 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 have been set using a combination of colored orthophotos, pictures from site visits, Google Earth observations, calibration process, and professional judgment.

10. Comment: Section 6.2 Instream Sediment Calibration. How will the model take into consideration short-term, high intensity storm events that do not cause a significant increase in instream flow, but can add significant amounts of sediment?

    Response: If the 'short-term, high intensity storm events' have been recorded at the precipitation gages used in the modeling, and if the intensity (and antecedent soil moisture conditions) are high enough to generate significant runoff, then sediment erosion will occur and the stream will receive a significant amount of sediment. However, if those events are so localized that the precipitation gage network does not record the event, no sediment will be modeled. This is a common issue with watershed modeling, and a major justification for modeling over many years, to avoid as many of these occurrences as possible, and obtain an acceptable overall calibration.

11. Comment: Previous Arkansas stakeholder review comments have raised concerns regarding the temporal context for calibration and validation. For example, the City of Springdale Arkansas completed upgrades to its wastewater treatment plant (WWTP) in 2004 that reduced TP in the outfall to Spring Creek from >5 mg/L to <1 mg/L. Only after 2005 did in-stream total phosphorus (TP) concentrations begin to reflect the total impact of Springdale's reductions because of stream channel sediment release of P. If the model selected for the TMDL is calibrated with pre-2004 data, it will not .represent current conditions. In fact, calibrating the model under pre-2005 conditions could result in boundary condition failures for validation. Page 51. Section .1: Aqua Terra has selected a model calibration time period of 2001 to 2009 and a validation time period of 1992 to 2000. While these calibration/validation steps are appreciated, we have questions regarding how Aqua Terra plans to address changes to WWTP discharges during the calibration period.

    Response: During the simulation period, both calibration and validation, the actual (or estimated) wastewater discharges are input to the model based on the available data obtained from the DMRs, EPA, and the individual dischargers. So when treatment upgrades are implemented and the TP discharges are reduced (such as noted for TP, above), those reductions will be reflected in the actual data going into the model, for each facility. The Point Source Memo (Bicknell and Donigian, 2012) describes the data and procedures used to develop the complete point source (i.e., wastewater discharges) inputs to the model, along with the daily and monthly spreadsheets provided to EPA and Stakeholders.

12. Comment: Page 77. Section 6.3. This section describes Aqua Terra's overall approach to representing poultry litter application in the watershed. Currently the plan is to develop litter application rates from data supplied by the Arkansas Natural Resources Commission (ANRC) and the Oklahoma Department of Agriculture, Food and Forestry (ODAFF). Comment: Table 6.1 presents the data that have been acquired to date; however, the table is identified as being preliminary in nature and "somewhat incomplete." The methodology used to develop application rates will need to be further explained once a full data set is acquired. Aqua Terra reports that litter exports (via trucks) from the Illinois River Watershed have grown substantially in recent years, particularly during the proposed model calibration period. How will the model represent changing application rates in the watershed as a result of the increase in litter export?

Response: The development of litter application rates is still ongoing at the current time (i.e., September 2013). Data provided by both ODAFF and ANRC is being analyzed as a basis for determining actual litter application rates, which have already been adjusted to account for litter export.

13. Comment: Page 26. Section 2.5. This section discusses the availability of water quality data for point sources within the watershed. Comment: Currently, the report indicates no water quality data are available for one of the largest contributing point sources in the watershed. The SWEPCO electric generating facility. How does Aqua Terra plan on addressing this large data gap?

    Response: As noted above, the Point Source Memo (Bicknell and Donigian, 2012) describes the data and procedures used to develop the complete point source (i.e., wastewater discharges) inputs to the model, along with the daily and monthly spreadsheets provided to EPA and Stakeholders. The data and procedures used for SWEPCO are described in that document.

14. Comment: Section 3.4.1 discusses channel characteristics and hydraulics that pertain to sediment transport, and ultimately phosphorus transport. The description of the channel hydraulics indicates that a single cross section (at the outlet to the reach, wil1 be used to establish the channel dimensions for the entire reach. If a reach is defined by a single HRU, then the entire HRU will have the same channel dimensions. This approach is inadequate in that it does not resemble reality, as streams in this ecoregion are dominantly riffle-pool complexes and are generally represented by a series of riffles, pools and runs. The creation of average channel morphology for each reach could eliminate the deeper pool sections that will serve as long term sinks for sediment. In addition, the elimination of the shallow riffle sections that generally contain the most benthic algal, wil1 skew the productivity predictions. At a minimum each reach should contain a "pool" component and a "riffle-run" component to account for these very different hydraulic channel features.

    Response: Such a capability is not available in the HSPF model, and resources are not available to support a model development effort that would incorporate such a capability and its application in the current IRW modeling effort. Also, with the long reach lengths used to allow simulations of the entire 1500 sq mi IRW, representing the average or effective behavior of each reach is the primary goal. The capability to represent separate pools, riffles, and runs is simply not available for modeling at this scale.

15. Comment: According to Section 3.4.1 the channel in each reach will be represented as a trapezoid with the bottom width equal to the bankfull width, determined (or estimated) from some existing data source. Use of the bankfull width as the bottom width will generally tend to increase cross sectional area, thereby increasing shear stress, which will then increase bottom scour during rain events transporting more sediment downstream. Bottom widths should be adjusted based on bank slope to correct this problem.

    Response: That discussion is outdated and our current FTABLE estimation procedures include use of trapezoidal cross sections when real cross-section data is not available, with different bottom and top width values. However, most of our FTABLES are derived from actual cross-section data, and the regional geomorphic relationships are used in a much smaller fraction of the stream reaches.

16. Comment: Section 3.5 states that "Comprehensive modeling needs to consider ALL potential sources of phosphorus in order to accurately represent the relative contributions and impacts of any single source." A major source of sediment and phosphorus that has not been considered is stream bank erosion. Several studies have been completed in the Illinois River watershed that indicate that stream bank erosion could be the single largest contributor of sediment and one of the top three contributors of phosphorus. However, no effort appears to be included in the TMDL to quantify this component. If a source as large as stream bank erosion is omitted from the TMDL, it will not be possible to " ... accurately represent the relative contributions and impacts of any single source." There are at least three (and possibly many others) possible avenues to include bank erosion in the TMDL modeling. The first would be to add a new sub-routine to the model specifically to address bank erosion. This option would take considerable time to program, test and validate prior to its usage in the TMDL. The second would be to add sediment and nutrient loads from bank erosion into the stream channel incrementally, as is being done for atmospheric deposition or a ground water source. The third, would be to treat stream channels as a separate land use, much like is suggested for unpaved roads. Each of these possible options would require that some sediment load data from bank erosion be available as well as sub-surface soil nutrient content (that not directly associated with manure). There are several studies cited in Section 3.4.1 of the Simulation Plan that were used to develop channel characteristics for the HSPF model, that were all originally focused on stream bank erosion in the Illinois River watershed.
    Erosion rates should be available from those sources or from other scientific literature sources.

    Response: Bank erosion is not explicitly represented in the channel simulation with HSPF, but it is included as part of channel scour since the shear stress calculation, which determines scour and erosion, is based on the wetted perimeter of the channel including both bed and banks. We are currently using the available literature and data (as noted above and in Section 3.4.1) to identify those stream sections of the IRW channels where bank erosion is known, or expected, to occur. As sediment is eroded or scoured, nutrients are subsequently entrained and added to the water column, incrementing the nutrient load (both P and N), to represent/approximate this contribution.

17. Comment: Section 4.3 describes the water quality calibration procedures. One of the main calibration components is comparison of non-point source loading rates from each land use to the expected values. The expected values are noted as "highly variable". If a significant source of sediment and nutrients (i.e. bank erosion) is left out of the modeling, it is likely that erroneously high loading rates (export coefficients) will be utilized in the model to account for the load of TSS and nutrients that are actually coming from another source. These erroneously high rates will not be detected by the modeler as a problem, since the literature value range is broad and may easily encompass the utilized rates.

    Response: As noted above, bank erosion and its nutrient contributions are addressed in Comment #16. Balancing the representation of nonpoint loading rates and instream processes, and their impact on the model results, is part of the science, and art, of water quality model calibration. We are attempting to include ALL major sources of nutrients, subject to the available data and knowledge, so that a fair and reasonable representation of the various sources is included in the final calibrated model.

18. Comment: Section 5.5 of the Simulation Plan cites a turbidity standard in Lake Tenkiller of 25 ntu that is one of the targets of the TMDL. Neither the HSPF model nor the EFDC model performs prediction for turbidity. It is possible to use TSS or Secchi depth as a surrogate for turbidity, however, the accuracy of the relationships is questionable. A new method of assessing attainment of the 25 ntu turbidity standard for the TMDL may be required. No mention of the targets for the other Oklahoma water quality standards are discussed in the Simulation Plan. It is difficult to assess the ability of the EFDC model to predict the proper water quality constituents at the proper locations in the lake if details of the standards are not discussed along with the way comparisons will be made. This issue should be addressed in the Simulation Plan.

    Response: TSS vs. turbidity regression relationships can be developed and applied for TMDL determinations; however, the relationship must be developed using site-specific paired data. TSS vs. turbidity relationships have been applied for other modeling studies to transform EFDC model results for TSS to turbidity as a derived model output variable for comparison to water quality criteria for turbidity where turbidity has been determined to be a cause of impairment for a waterbody. Based on OWRB BUMP data collected during 2005-2006 turbidity was in compliance with the 25 NTU water quality standard and the designated uses related to turbidity were fully supported.
    As noted above, the focus of this effort is clearly TP for the watershed, and DO, Chl a, and Carlson's Trophic State Index for Lake Tenkiller.

19. Comment: Sections 6.2 and 6.3 discuss phosphorus sources and the way poultry litter will be represented in the model. There is no discussion of bank erosion as a source. There is mention of other animal wastes" as a source, which includes cattle, but no discussion anywhere in the Simulation Plan of how the cattle manure (which is the second largest source of animal based nutrients in the watershed) will be applied to appropriate land uses. It can be assumed that the cattle manure will be spread evenly in the each HRU, according to cattle density in those areas. However, how will the nutrients from cattle then be separated from poultry nutrients? The detail provided in the Simulation Plan for poultry liter leads one to assume that it is a major focus of the TMDL, which would seem to bias the results of the study. This issue needs to be clarified and discussed in the Simulation Plan.

    Response: This comment is a mixed bag of topics. Bank Erosion is addressed in Comment #16 above. Animal waste contributions, and their representation, is currently being analyzed. Separating the poultry litter and other animal waste applications and contributions is a difficult challenge that we are still currently investigating. We are making every attempt to avoid any bias and treat all the major sources of nutrients in an equitable and reasonable fashion.