Wisconsin River Total Maximum Daily Load
Technical Scope of Work

Wisconsin Department of Natural Resources
October 2013

This document was developed by the Wisconsin Department of Natural Resources in conjunction with the United States Army Corps of Engineers. **This draft document represents the current proposed technical approach to be used in development of the TMDL, and is subject to change.** Questions regarding this document or the Wisconsin River TMDL project should be directed to dnrwisconsinrivertmdl@wisconsin.gov.

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LIST OF ACRONYMS

ALG 1	Algal Group 1
CBOD	Carbonaceous Biochemical Oxygen Demand
DO	Dissolved Oxygen
DOC	Dissolved Organic Carbon
DRP	Dissolved Reactive Phosphorus
GIS	Geographic Information System
GUI	Graphical User Interface
HUC12	Hydrologic Unit Code - 12
ISS1	Inorganic Suspended Solids
LOADEST	Load Estimator
LDOC	Labile Dissolved Organic Carbon
LDOM	Labile Dissolved Organic Matter
LDON	Labile Dissolved Organic Nitrogen
LDOP	Labile Dissolved Organic Phosphate
LPOC	Labile Particulate Organic Carbon
LPOM	Labile Particulate Organic Matter
LPON	Labile Particulate Organic Nitrogen
LPOP	Labile Particulate Organic Phosphate
MDRNA	Medium Density Residential No-Alleys
mi^2	Square miles
MS4	Municipal Separate Storm Sewer Systems
NH4	Ammonia
NO3	Nitrate
NO3-NO2	Nitrate Nitrite
PEST	Parameter Estimation
PO4	Phosphate
POC	Particulate Organic Carbon
PON	Particulate Organic Nitrogen
POP	Particulate Organic Phosphate
QAPP	Quality Assurance Plan
RDOC	Refractory Dissolved Organic Carbon
RDOM	Refractory Dissolved Organic Matter
RDON	Refractory Dissolved Organic Nitrogen
RDOP	Refractory Dissolved Organic phosphate
RPOC	Refractory Particulate Organic Carbon
RPOM	Refractory Particulate Organic Matter
RPON	Refractory Particulate Organic Nitrogen
RPOP	Refractory Particulate Organic Phosphate
SLU	Standard Land Use
SWAT	Soil and Water Assessment Tool
TDS	Total Dissolved Solids
TKN	Total Kjeldahl Nitrogen

LIST OF ACRONYMS (continued)

TMDL	Total Maximum Daily Load
TIN	Triangulated Irregular Network
TOC	Total Organic Carbon
TP	Total Phosphorus
TSS	Total Suspended Solids
W2	CE-QUAL-W2
WDNR	Wisconsin Department of Natural Resources
WinSLAMM	Windows Source Loading and Management Model
WRB	Wisconsin River Basin
USACE	United States Army Corps of Engineers
USDA - ARS	United States Department of Agriculture – Agricultural Research Service
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey

1.0 Wisconsin River TMDL Overview

The Wisconsin River Basin (WRB) Total Maximum Daily Load (TMDL) study area drains 9,156 mi^2 of Wisconsin's central corridor from the basin's headwaters in Vilas County to Lake Wisconsin in Columbia County. The Wisconsin River has experienced a long history of impaired water quality conditions, including low dissolved oxygen in the river and severe algal blooms in its impoundments. Several water bodies are currently listed on the state and federal Sec. 303(d) impaired waters list due to degraded habitat, algal problems, or eutrophication. The cause of the algae blooms is excessive phosphorus loading from point and nonpoint sources in the watershed. Because the Wisconsin River system is an important recreational, industrial, and natural resource to the State of Wisconsin there is a need to identify nutrient loading sources and environmental conditions causing impaired water quality and to develop decision-making capabilities for improving these conditions.

Utilizing a four-year water quality monitoring effort throughout the WRB, the modeling effort will be initiated to focus on two environments; the simulation of upland loading and transport of sediment and nutrient loads, and simulation of in-reservoir or in-lake process for waters including (but not limited to) Spirit Flowage, Big Eau Pleine Reservoir, Lake DuBay, Dexter Lake, Tri-Lakes, Petenwell and Castle Rock flowages, and Lake Wisconsin. To simulate the water quality and address TMDLs throughout the basin a methodology has been proposed that combines several applications to define components of the basin (landscape, river, and reservoir) (Figure 1). The types of water quality models proposed for this TMDL include:

- Watershed response
- Urban / Stormwater response
- Empirical reservoir response
- Mechanistic reservoir response

This document outlines the modeling technical scopes. Wisconsin Department of Natural Resources (WDNR) has developed the scopes of work for watershed, urban, and empirical reservoir modeling. The United States Army Corps of Engineers (USACE) has developed the scope of work for the two-dimensional reservoir modeling. The scopes of work are not representative of a quality assurance project plan (QAPP), but provide the foundation from which the technical applications of the TMDL are accomplished. The document provides a reviewable deliverable for the Wisconsin River TMDL technical stakeholders prior to model development.

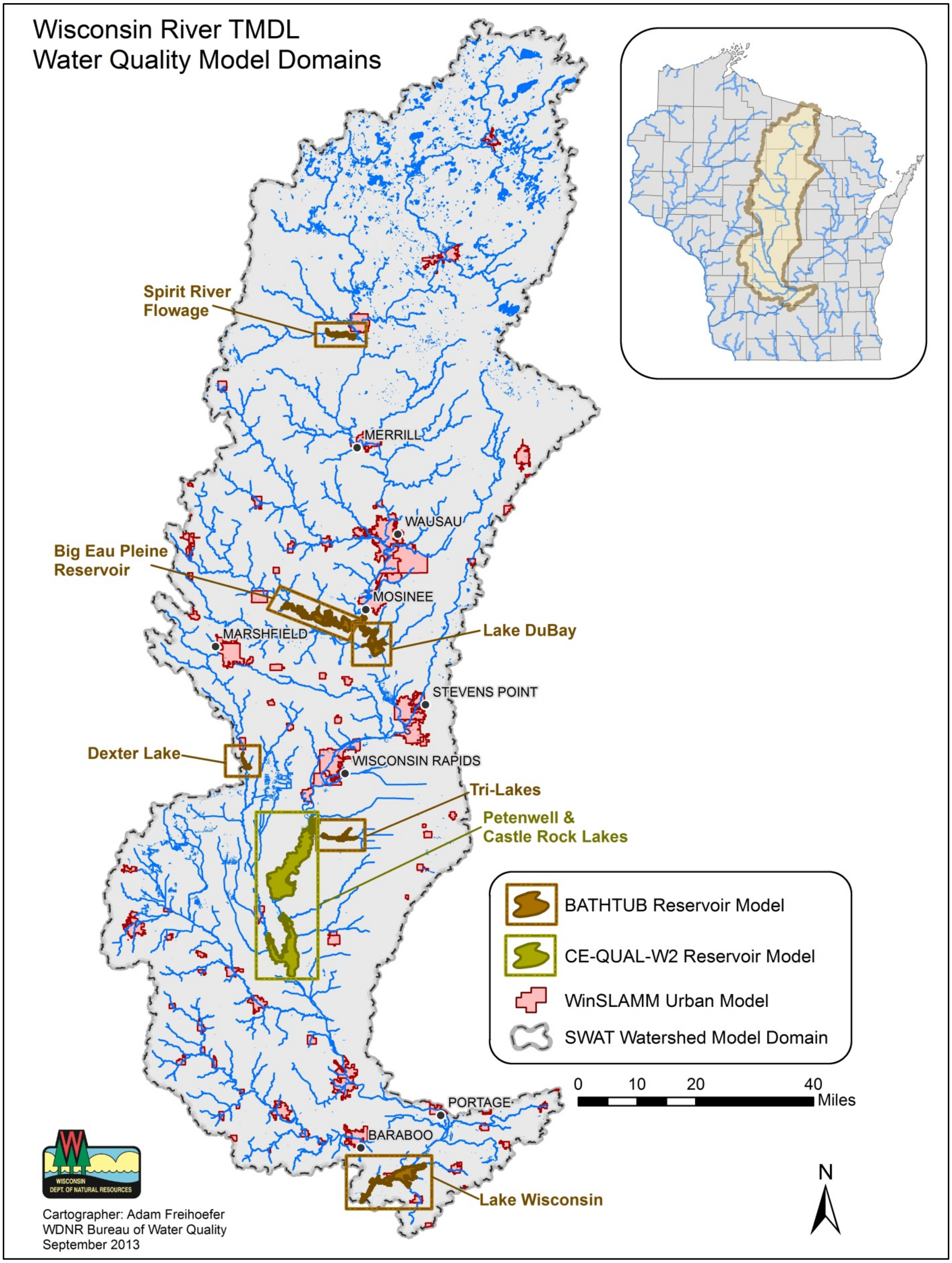

Figure 1 – Wisconsin River TMDL Water Quality Model Domains

2.0 Watershed Response Modeling

The purpose of this section is to describe the development of a watershed model used to simulate discharge, sediment and nutrient export from point and nonpoint sources throughout the WRB in support of the development of TMDLs. The WRB watershed model will define the current (2002 – 2013) and baseline (assumes the landscape meets regulatory requirements) monthly sediment and phosphorus loads within subwatersheds of the WRB. The monthly outputs from the baseline model will be included in the model integration database to support the TMDL allocation process.

2.1 Watershed Response Model Project Management

The watershed response and transport model that is proposed to support the WRB TMDL is the Soil and Water Assessment Tool (SWAT). The SWAT model is a physically based model developed by the U.S. Department of Agriculture - Agriculture Research Service (USDA-ARS) that simulates stream flow, sediment loss, and nutrient exports (Neitsch et al. 2002). The simulation of urban areas within the WRB TMDL area, including the regulated Municipal Separate Storm Sewer Systems (MS4), will be completed using the Source Loading and Management Model for Windows (WinSLAMM v10.0) and the results will be integrated into the SWAT model.

The WDNR Bureau of Water Quality modeling staff located in Madison, Wisconsin will be responsible for all necessary components of the SWAT modeling and documentation (Table 1). The goal is to complete the model including documentation by 2015. A detailed list of tasks is provided in Table 2.

Table 1 – SWAT Modeling Project Staff

Staff	Position	WRB TMDL Role
Adam Freihoefer	WDNR TMDL Modeler	Modeling Lead
Theresa Nelson	WDNR TMDL Modeler	Dataset Development , Modeling Support
Aaron Ruesch	WDNR Water Resources Specialist	Dataset Development , Modeling Support
Tom Beneke	WDNR Water Resources Specialist	Dataset Development

Table 2 – Estimated SWAT Modeling Project Timeline

Time Period		Project Task
2013	January - December	1. Model Input Data Collection a. Define model subwatersheds b. Develop spatial data inputs c. Meet with county land and water conservationists to gain spatial and temporal definition of agricultural land management d. Evaluate quality of various measured data (climate) 2. Model Input Data Analysis a. Develop calibration target datasets (annual water budgets, hydraulic and loading data)
2014	January - February	3. Model development a. Convert input datasets into SWAT required format b. Incorporate all inputs into sub-models, ensure model stability
	March - April	4. Pre-calibration simulations a. Run pre-calibration simulations to ensure model is functional and initial water balance looks acceptable
	May - December	5. Calibration of model outputs to measured variables *(flow, water quality, crop yields, water budget)*
2015	January	6. Validation of model outputs to measured variables
	February	7. Summarize model outputs for model integration database a. Develop baseline model scenario b. Join baseline scenario model files and outputs with model integration database
	March - July	8. Draft modeling report

2.2 Watershed Background

The watershed response modeling will simulate hydrologic flow and water quality conditions throughout the entire WRB TMDL study area (9,156 mi^2). A separate model (WinSLAMM v10.0) will be used to simulate the urban land cover throughout the watershed. Separate reservoirs models will be used to simulate the conditions of reservoirs within the system. From the basin's headwaters at Lac Vieux Desert in Vilas County to the outlet of Lake Wisconsin at Prairie du Sac Dam in Columbia County the Wisconsin River travels 335 river miles and flows through landscapes comprised of various land uses.

Due to its size, the WRB is broken into four segments for modeling purposes: headwaters, upper, central, and lower (Figure 2). The headwaters section consists of 2,178 mi^2 from the headwaters of the WRB TDML (Lac Vieux Desert) to Tomahawk, WI and is dominated by wetlands and forests, soils with a high infiltration capacity, and relatively few point sources and urban areas. The upper region (Tomahawk, WI to the outlet of Lake Dubay) consists of 2,717 $mi^2$with a relatively high percentage of agriculture, urban, and soils with lower infiltration capacity. The central segment drains 2,121 mi^2 from the outlet of Lake Dubay to the outlet of the Castle Rock Flowage and consists of a mix of agricultural and wetland landcover with high infiltration capacity with the exception of the northwest portion of the segment which has low infiltration. The lower section between Castle Rock Flowage and the Prairie Du Sac dam consists of 2,140 mi^2 of primarily agricultural land with medium infiltration capacity.

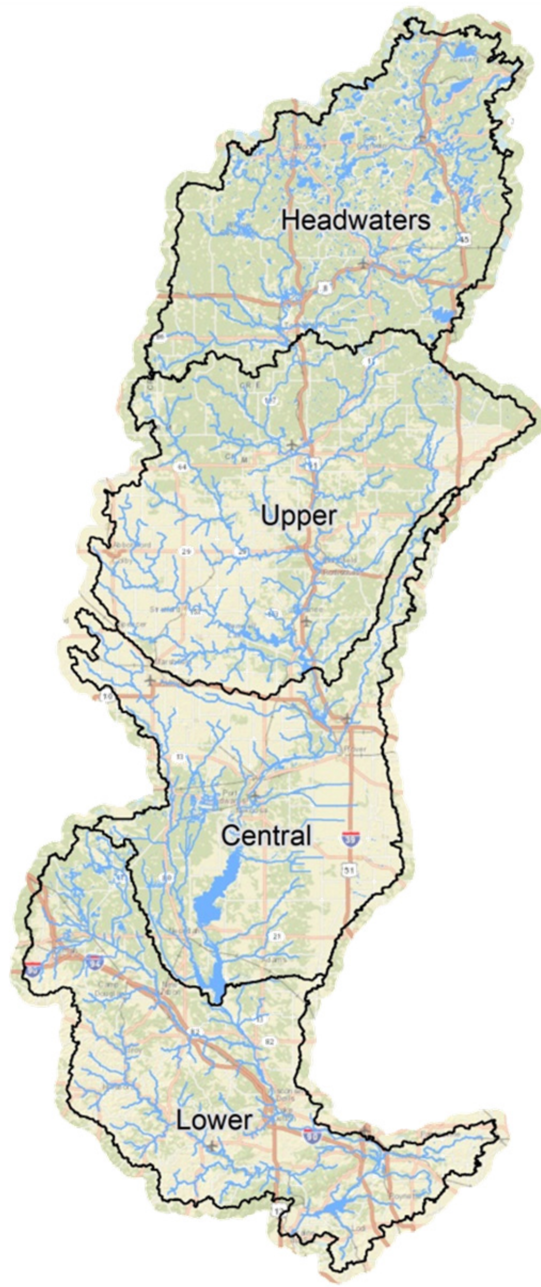

Figure 2 – WRB Segments

2.3 Measured Data Assessment and Analysis

There are several types of measured data that will be used for model input, calibration, or validation. The types of measured data that will serve as model input include climatology, stream flow, water quality (stream, lake, and subsurface), and baseflow separation of stream flow. Each model input is described in detail within Section 2.4.3 of this scope of work.

In 2009, a network of monitoring stations measuring discharge and water quality was deployed in support of the SWAT model calibration. There are 14 monitoring stations on the main stem of the Wisconsin River and 20 monitoring stations on Wisconsin River's tributaries (Figure 3). Discharge consists of the mean daily discharge at either a United States Geological Survey (USGS) gage site or an outlet of a privately owned dam. Water quality was evaluated at or near the discharge measurement site using bi-weekly concentration samples of total suspended sediment (TSS) and total phosphorus (TP). The combination of daily discharge and bi-weekly TSS and TP samples will be used to estimate monthly TSS and TP loads for model calibration (Robertson, 2003). The calculation of pollutant loads will be completed by the USGS with the use of a regression model such as LOAD ESTimator (LOADEST).

In addition to the 34 monitoring stations that were established to support the TMDL modeling effort, there are other sites where discharge and/or water chemistry was previously collected in support of other studies. An attempt will be made to use those data as well in support of the model input, calibration, or validation.

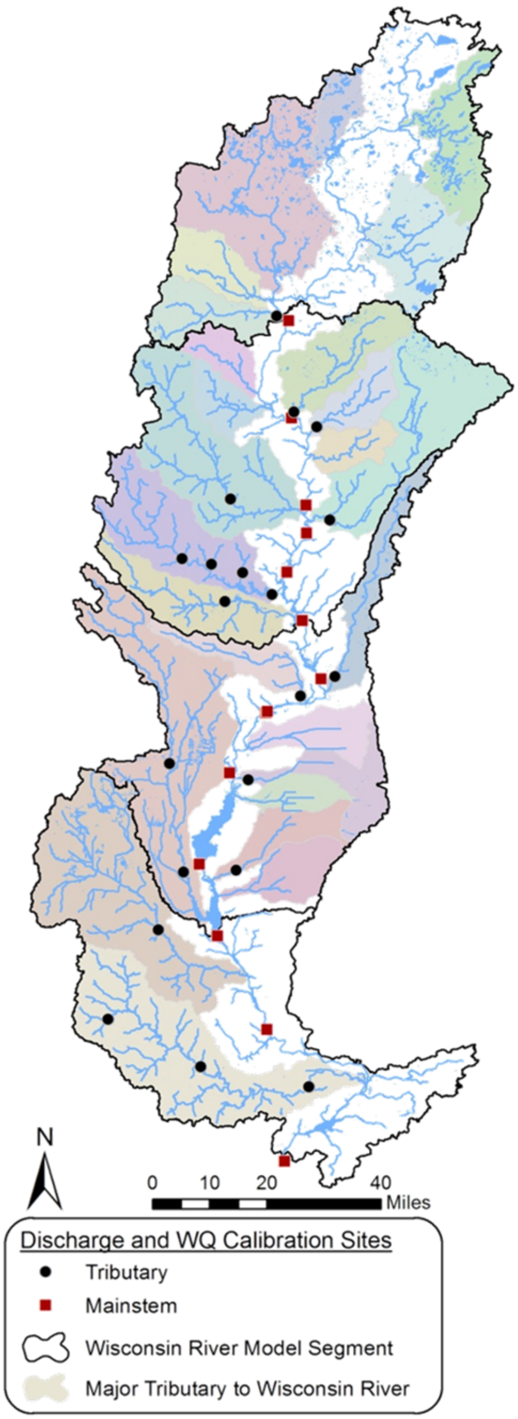

Figure 3 – WRB River and Stream Calibration Locations

2.4 SWAT Model Design

The most up-to-date version of the SWAT model (*SWAT 2012, Version 591 as of October 2013*) will be used to simulate the hydrologic and water quality response within the WRB. The model will be constructed using SWAT's ESRI ArcGIS-based graphical user interface (GUI) called ArcSWAT. The SWAT model is a physically-based, deterministic, continuous, geographic information system (GIS) based model developed by the U.S. Department of Agriculture - Agriculture Research Service (USDA-ARS) for the prediction and simulation of discharge, sediment, and nutrient yields from mixed landuse watersheds. The SWAT model incorporates the effects of climate, surface runoff, evapotranspiration, crop growth, groundwater flow, nutrient loading, land use, land management, and in-stream water routing to predict hydrologic response (Douglas-Mankin, et al. 2010; Neitsch et al., 2011).

Within the SWAT model a watershed is divided spatially into subwatersheds using digital elevation data according to the density specified by the user. Subwatersheds are further subdivided into lumped, non-spatial hydrologic response units (HRUs) consisting of all areas within the subwatershed having similar landscape characteristics (soils, management, slope). The SWAT model includes subbasin, reservoir, and channel routing components. The subbasin component simulates runoff and erosion processes, soil water movement, evapotranspiration, crop growth and yield, soil nutrient and carbon cycling, and pesticide and bacteria degradation and transport. SWAT simulates a wide array of agricultural structures and practices, including tillage, fertilizer and manure application, subsurface drainage, irrigation, ponds and wetlands, and edge-of-field buffers. The reservoir component detains water, sediments, and pollutants and degrades nutrients, pesticides, and bacteria during detention. The channel component routes flows, settles and entrains sediment, and degrades nutrients, pesticides, and bacteria during transport. SWAT typically produces daily results for every subwatershed outlet, each of which can be summed to provide monthly and annual load estimates (Douglas-Mankin, et al. 2010).

A complete description of the model inputs, outputs, and processes can be found at http://swat.tamu.edu/documentation/

2.4.1 Selecting SWAT as the Watershed Response Model

The SWAT model has successfully been used to evaluate agriculturally dominant watersheds for sediment and nutrient TMDLs (Cadmus, 2012; Cadmus 2011; USEPA 2004). SWAT was selected because it maintains open-source model code, contains an easily updateable graphic user interface, has a history of successful implementation throughout Wisconsin, and a strong knowledge base throughout the Midwest United States.

2.4.2 SWAT Model Setup

Model setup begins by using ArcSWAT to bring in the pre-processed GIS data (soils, land use, DEM, point sources) and tabular data to create model input files. After ArcSWAT creates the necessary model files (in both required ASCII format as well as within a Microsoft Access database), the user can run the SWAT model within the GUI or via the command prompt window. Specific ArcSWAT set-up processes are described below in more detail.

Model Segmentation

Due to the size of the study area, the model domain will be sub-divided into four separate sub-models (headwaters, upper, central, and lower) to provide model simulations that are computationally feasible. The model outputs from the headwaters sub-model will be used as an input for the next downstream sub-model (upper).

Boundary Conditions

As a result of the model being broken into four separate pieces, each sub-model will require the upstream sub-model's outputs for the entire simulation period.

Subwatershed Definition

Part of the model set-up process is to partition the WRB into multiple subwatersheds for which TMDL allocations will be made. The subwatershed is the lowest level of delineated geographic identity within the SWAT model and serves to route hydrology through adjacent subwatersheds. The initial subwatershed framework will rely on the predefined hydrologic unit code 12 (HUC12) subwatersheds that are part of the national Watershed Boundary Dataset. There are 266 HUC12 delineations in the WRB and the average HUC12 size is 34 mi^2. The HUC12 delineations may be aggregated or split into smaller subwatersheds based on the following:

- Changes in stream reach phosphorus criteria (0.075 mg/L or 0.100 mg/L);
- Impaired stream reaches;
- Location of point source outfalls;
- Variation in land cover or land management;
- Locations upstream and downstream of reservoirs or impoundments;
- Significant changes in flow.

Time Step

The model will simulate conditions and provide output on a daily time-step; however, the final results of the model will be delivered as a monthly average mean (discharge) or sum (sediment and phosphorus).

Simulation Period

The total simulation period will be based off of 6-year crop rotation cycle. It is proposed that the model warm-up period extend the length of one crop rotation cycle (1996 – 2001). The simulation period would extend the length of two crop rotation cycles (2002 – 2013) to allow for climatological variability.

HRU Definition

During the model set-up SWAT creates unique combinations of slope, soil, and land cover and management within each subwatershed. The unique combinations called HRUs are not synonymous with a field, but rather areas in a subwatershed with similar soils, management, and slope. Potentially every unique combination could be preserved within each subwatershed; however, that would lead to an extremely large number of HRUs in the model and is typically not recommended by the SWAT model developers (Arnold et al. 2012). This approach could potentially cause the model run times to be unacceptably long. To lessen the number of HRUs, two lumping mechanisms can be applied within ArcSWAT. One option is to use the dominant value or values per subwatershed. If a threshold of 20% was set for the soils, the model would lump the soils that were less than 20% of the subwatershed area with the soils that were greater than 20%. The second lumping option is to create classes as proposed for slope. Each input's suggested threshold is listed below (Table 3).

Table 3 – SWAT HRU Thresholds

HRU Input	HRU Threshold
Landcover / Land Management	Maintain integrity
Soils	> 20%
Slope	Use percent slope classes (0 - 3, 4 - 7, 8 - 12, 13 - 100)

2.4.3 SWAT Model Inputs

The SWAT model requires primary model inputs (elevation, soils, landcover, land management, hydrography, and climate) and secondary inputs that help define the specific model parameters (baseflow contribution, groundwater phosphorus concentration, internally drained areas, ponds, wetlands, and reservoir characteristics). Table 4 identifies the likely inputs for the WRB SWAT model.

Table 4 – SWAT Model Inputs

Model Input	Data	Data Source
Topography	10-meter Digital Elevation Model (NRCS)	USDA
Land Cover	2011 Cropland Data Layer merged with Wisconsin Wetland Inventory	USDA WDNR
Land Management	2008 – 2012 Cropland Data Layer rotation analysis merged with county specific information management information	USDA County Land and Water Conservation Offices
Urban (MS4)	WinSLAMM v10.0 model outputs	WDNR
Hydrography	1:24,000-scale hydrography	WDNR
Soils	NRCS SSURGO	USDA
Climate	National Climate Data Center stations	NOAA
Internally Drained Areas	Identified with 10-meter Digital Elevation Model sink analysis	NRCS
Pond / Wetland Complexes	1:24,000-scale hydrography (Ponds) Wisconsin Wetland Inventory (Wetlands)	WDNR
Reservoirs	Volume, area, max depth, water chemistry	WDNR
Point Sources	Geolocation, discharge, and water quality	WDNR
Soil Phosphorus	Average soil phosphorus concentration per county	University of Wisconsin
Groundwater Quantity	Baseflow separation of streamflow data using baseflow separation techniques	USGS
Groundwater Quality	Lower 10% percentile in-stream phosphorus concentrations per subwatershed	WDNR

2.4.4 SWAT Initial Model Evaluation

Prior to a sensitivity analysis or model calibration, the model will be evaluated with a tool called SWAT Check (White et al. 2012) to ensure that model outputs (runoff, potential evapotranspiration, evaporation, etc.) aren't outside typical ranges.

2.4.5 SWAT Sensitivity Analysis

Prior to model calibration, a sensitivity analysis will be conducted for the SWAT model. The sensitivity analysis estimates the rate of change in the output of the model with respect to changes in model inputs. This process is important because the model has hundreds of parameters and isolating the most sensitive parameters helps identify which parameters warrant the most precise estimation and to better understand overall system response to variation in each parameter. There are two possible tools that will be used in support of the sensitivity analysis: SWAT-CUP (Abbaspour, 2013) or Parameter Estimation (PEST) (Doherty, 2005). SWAT-CUP is a calibration, validation, and sensitivity analysis tool that was developed specifically for the SWAT model. PEST is a freeware tool that uses a model's input and output files to find optimal parameterization. PEST is a non-linear parameter estimation package used to fit mechanistic models with a large number of parameters such as SWAT.

2.4.6 SWAT Calibration

Model calibration generally involves varying model input parameters within acceptable ranges to obtain a realistic match between model-simulated data and field-observed or estimated data. Calibration targets include average annual water budget, annual crop yield, daily discharge volume, monthly total suspended sediment load and monthly total phosphorus load. Discharge, sediment, and phosphorus will be calibrated subsequently because of interdependencies between constituents due to shared transport processes (Arnold et al. 2012). The monitoring dataset that exists for the simulation period (2002 – 2013) will be split to support both model calibration and validation. The period between 2008 and 2013 represents the most comprehensive monitoring data and will be used specifically for model calibration.

Autocalibration techniques may be used to adjust model parameters within their parameter bounds. The same software (SWAT-CUP or PEST) that will be used for the model sensitivity analysis will also be used for autocalibration. The autocalibration process will be constrained to ensure that model parameters remain within acceptable measured or literature cited ranges and are relatively consistent among the four model segments in order to achieve minimization of the aforementioned objective functions. The accuracy of the calibrated model is measured using statistical metrics of fit. The two metrics used as objective functions include the coefficient of determination (R2) and Nash–Sutcliffe simulation efficiency (NSE). The R2 describes the proportion of the variance in measured data explained by the model with a range of 0 to 1. The NSE is a normalized statistic that determines the relative magnitude of the residual variance compared to the measured data variance. The NSE ranges from $-\infty$ to 1, with 1 being the optimal value (Moriasi et al. 2007).

Ancillary statistics will be used to verify model calibration, including percent bias (PBIAS) and the ratio of the root mean square error to the standard deviation of the observations (RSR). PBIAS measures the average tendency of the simulated data to be larger or smaller than their observed counterparts. An optimal value for PBIAS is 0 with positive values indicating model underestimation and negative values indicating overestimation (Moriasi et al. 2007). Another statistic is the RSR which is calculated as the ratio of the root mean square error and standard deviation of measured data. A lower RSR equates to a better the model simulation performance (Moriasi et al. 2007).

2.4.7 SWAT Validation

Model validation is the process of comparing the calibrated model results to observed data not used in the calibration process. The validation period should be different than the calibration period to ensure that the model calibration represents variable conditions. Validation will occur during the first half of the simulation period (2002 through 2007) at locations where daily discharge and/or monthly sediment and nutrient loads are available. The accuracy of the model simulation to the validation dataset will be assessed with the same metrics used in calibration.

2.4.8 SWAT Baseline Scenario

The calibrated and validated sub-models representing the entire WRB TMDL study area will provide the best representation of current conditions. To support the TMDL allocation process, conditions need to assume that nonpoint sources are meeting regulatory requirements as described in components of Wisconsin's administrative code. As a result, a model scenario called baseline will be created in which each pollutant source is assumed to be implementing regulatory requirements.

2.4.9 SWAT Outputs

The SWAT model outputs will include daily values of discharge, total suspended sediment, and total phosphorus. The daily discharge will be aggregated to a monthly mean discharge and the daily total suspended sediment and total phosphorus loads will be summed into monthly loads.

3.0 Urban Modeling

The objective of urban area modeling is to determine the magnitude of existing and baseline TSS and TP loads discharged from permitted MS4s, and other urban areas within the Wisconsin River TMDL study area. Urban TSS and TP loads will be incorporated into the watershed response model (SWAT) as "point source" discharges.

3.1 Urban Modeling Project Management

The proposed application for simulating TSS and TP loads from urban areas is the Source Loading and Management Model for Windows (WinSLAMM) version 10.0.

The primary tasks associated with this objective are outlined in Table 5. The Wisconsin River TMDL urban modeling will be led by WDNR TMDL project staff in WDNR's central office, located in Madison, WI. Table 6 lists staff assigned to the project and describes the role of each person.

Table 5 – Estimated WinSLAMM Project Timeline

Time Period		Project Task
2013	July - December	1. Data Collection and Compilation a. Permitted MS4 Data[1] b. Published Data c. Wisconsin River Reach Definition
2013	September - December	2. Delineate and categorize geographic areas to be modeled in WinSLAMM a. Delineate urban model boundaries b. Categorize urban model areas, as "permitted" or "unpermitted"
2014	January - May	3. Permitted MS4 Modeling a. Export SLAMM data for SWAT model input
2014	January - May	4. Unpermitted area modeling

[1] For area where this data is not available in a GIS compatible format, or is not provided upon request, HUC 12 watershed boundaries and the statewide MCD layer will be used.

Table 6 – WinSLAMM Modeling Project Team

	Name	Project Role	Tasks
Wisconsin River TMDL Development Team	Ann Hirekatur	Wisconsin River TMDL Project Manager and WinSLAMM modeling lead	Conduct WinSLAMM modeling in accordance with statewide guidance developed by WDNR stormwater TMDL guidance development team. Oversee spatial data collection from permitted MS4s.
	Adam Freihoefer	Wisconsin River TMDL Technical/Modeling lead	Oversee and supervise the collection, compilation and processing of spatial data from all MS4s. Provide Ann with information on type/format of SLAMM data output needed for SWAT model input.
	Aaron Ruesch	GIS Analyst	Assist as needed with processing of spatial data.
	Tom Beneke	Data collection and GIS	Take the lead role in the compilation and processing of all spatial data
Stormwater/Guidance Staff	Brad Johnson	Wisconsin River TMDL Stormwater Sector Lead	Assist with outreach/communications and data collection from permitted MS4s located in WDNR's Western District.
	Kevin Kirsch	Statewide TMDL Policy Coordinator and WDNR TMDL Stormwater Guidance Team Co-Leader	Co-lead TMDL Stormwater Modeling guidance development.
	Eric Rortvedt	WDNR TMDL Stormwater Guidance Team Co-Leader	Co-lead TMDL Stormwater Modeling guidance development.
	Jim Bertolacini	Statewide MS4 Permit Coordinator	Identify permitted MS4s within TMDL study area
	Laura Bub	South Central Region MS4 compliance.	Assist with data collection from permitted MS4 located in WDNR's Southern District.

3.2 Urban Background

3.2.1 Urban Model Area

The portion of the study area to be modeled by WinSLAMM will henceforth be referred to as the 'urban model area' and is comprised of the two of areas listed below:

1) Cities and villages, excluding any large, non-urbanized undeveloped areas within city/village limits,
2) Urbanized areas within townships that have a permitted MS4.

'Urbanized area' is defined herein as an area classified as "urbanized" by the 2010 Decennial Census. For the purpose of this document, "urbanized area" and "urban model area" are not the same.

3.2.2 Load Types

The scope document references the calculation of several different TSS load types for the urban model area. These types are defined as follows:

Permitted MS4 Urban Model Areas

- *No Controls TSS Load* – TSS load discharged from urban model area to waters of the state, with no stormwater controls

  [Unit area TSS load rate X Area]

- *Existing Conditions TSS Load* - TSS load discharged from urban model area to waters of the state, with existing stormwater controls

  [Unit area TSS load rate X Area X (1 – current TSS load reduction rate)]

- *Baseline Conditions TSS Load* - TSS load discharged from urban model area to waters of the state with stormwater controls that achieve the 20% TSS reduction required by NR 151

  [Unit area TSS load rate X Area X 0.8]

Unpermitted Urban Model Areas

For unpermitted areas the "no controls", "existing conditions" and "baseline conditions" loads are all equal to the "no controls" load.

Existing conditions loads will be incorporated into the existing conditions SWAT model that will be calibrated using basin-wide TMDL monitoring data. ***Baseline condition loads*** will be incorporated into the SWAT baseline conditions model, that used is to calculate the proportion of the overall load originating from each source.

3.2.3 Unit Load Per Area Approach

The average annual per acre TSS load predicted by WinSLAMM for permitted MS4s in Wisconsin has been found to be similar to the average annual TSS load generated by the WinSLAMM standard land use (SLU) file 'medium density residential no-alleys' (MDRNA), with the drainage system defined as curb and gutter (Cadmus 2011). For TMDL development, monthly TSS and TP loads for the urban model area will be predicted using a 'unit load per area' approach. Under this approach, the monthly per acre TSS and TP load for sand, silt and clay soil textures will be predicted in WinSLAMM using the 2002-2013 rainfall record nearest to each urbanized area, with the standard land use (SLU) file 'medium density residential no-alleys' (MDRNA) and the drainage system defined as curb and gutter (WinSLAMM Model A). For each rainfall-soil texture combination, the monthly load per acre will be calculated. The total monthly no controls load for each MS4 will be the sum of the loading rates for each soil texture, times the number of acres of each soil type within the municipality.

The same approach described in the previous paragraph will be used for unpermitted urban model areas, except that the drainage system for the SLU MDRNA will be defined as 'swale' instead of curb and gutter (WinSLAMM Model B).

The decision framework delineating which model approach applies to each urban model area is illustrated in Figure 4. The modeling approach for each area type is summarized in Table 7.

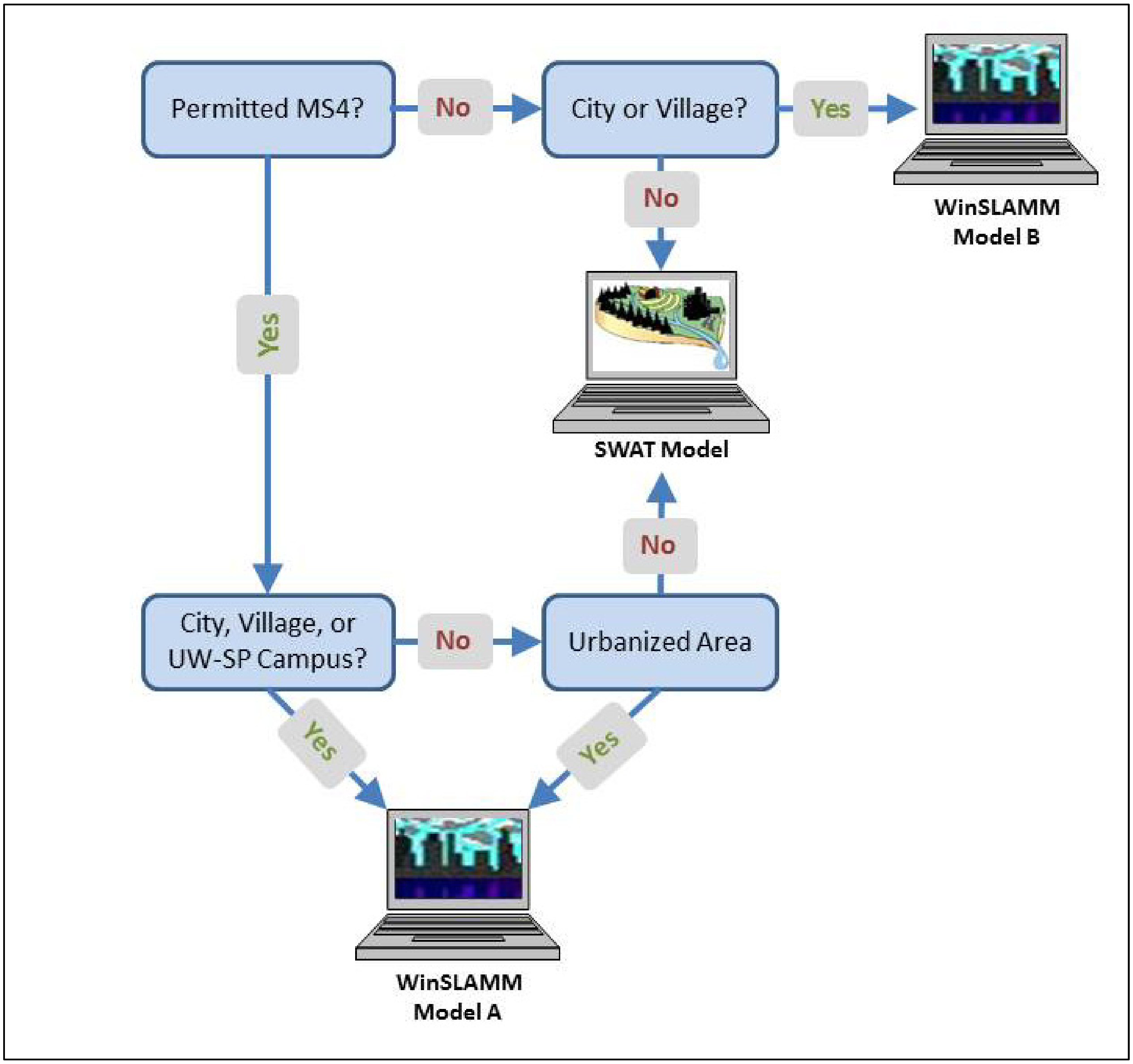

Figure 4 – Decision Framework for Delineating Model Areas

Table 7 – Urban Model Area Model Approach for Permitted and Unpermitted Areas

	Standard Land Use	**Drainage**	**Existing Conditions**	**Baseline Conditions**
WinSLAMM Model A (Permitted MS4s)	Medium Density Residential No-Alleys	Storm sewer w/ curb and gutter	Reduce TP load loads by existing TSS reduction rate	Reduce TSS loads by 20%, and TP load by equivalent amount
WinSLAMM Model B (Unpermitted Areas)		Swale drainage	No reduction	No reduction

3.3 Measured Data Assessment and Analysis

The measured data that will be incorporated into SLAMM modeling includes the following:

NOAA precipitation data - The rainfall data files used for SWAT modeling will be converted into WinSLAMM compatible rain file format using the rain file creator module. This module compiles rain data into separate events.

Soil mapping - Detailed soil mapping will be converted into a simplified soil texture map consistent with SLAMM model input requirements, by categorizing each soil type as sand, silt or clay using the gSSURGO database. According to the WinSLAMM manual and WDNR guidance, SLAMM soil textures correspond to hydrologic soil groups as follows: A=Sand, B=Silt, C and D = clay. A/D and B/D soils will be classified as sand and silt, respectively, since these are likely drained if they are in urban areas and soil texture in SLAMM is used to calculate runoff volumes rather than particle size.

3.4 WinSLAMM Model Design

The model that will be used to simulate TSS and TP loads from urban areas is WinSLAMM (Version 10.0). WinSLAMM is a WDNR approved model recommended for use in determining TSS and TP loading and attenuation rates.

3.4.1 Selecting WinSLAMM as the Urban Loading Model

WinSLAMM was selected because of its unique ability to model pollutant loads generated by small storm events. WinSLAMM was specifically developed by its authors to better understand the relationships between sources of urban runoff pollutants and runoff quality, and to address the frequent discrepancy in many existing urban runoff models between actual field measurements of pollutant loads to the solutions obtained from model algorithms.

WinSLAMM has been used in many areas of North America and has been shown to accurately predict stormwater flows and pollutant characteristics for a broad range of rains, development characteristics, and control practices. It applies stochastic analysis procedures to more accurately represent actual uncertainty in model input parameters in order to better predict the actual range of outfall conditions (especially pollutant concentrations).

A detailed list of references documenting the applicability of WinSLAMM for urban pollutant load modeling can be found here http://winslamm.com/references.html#_Toc96698437

3.4.2 WinSLAMM Setup

The model will be developed to simulate conditions from 2002 – 2013, to be consistent with the timeframe of the watershed (SWAT) modeling.

3.4.3 *WinSLAMM Inputs*

Land use Type and Source Area Definition

SLAMM divides land up into 6 broad land use classes (residential, institutional, commercial, industrial, open, and freeways). Within each class of land use, the land area is further classified into 14 "source areas" (such as turf, roofs, parking, playgrounds, and freeways). Source areas are further classified according to their runoff behavior (for example, whether roofs are flat or pitched, and whether they drain directly to the drainage system or drain onto silt, sand or clay soils).

Since data with this level of specificity is not typically available at a municipal or watershed scale, the WinSLAMM model comes with *Standard Land Use Files* (SLU files) which describe the distribution of source areas within a particular land use type. These files have been prepared by the authors of the WinSLAMM model based on studies of Wisconsin communities. As previously described, the standard land use file medium density residential no alleys (MDRNA) will be used to simulate urban loading rates. The breakdown of source areas within this SLU file is summarized in Table 8.

Table 8 – WinSLAMM Standard Land Use File MDRNA Source Area Summary

	Percent Area (%)		
Source Area	**Directly Connected Impervious**	**Impervious Draining to Pervious**[2]	**Pervious Area**
Pitched roof	4.5	10.5	
Driveways	5.6	1.9	
Sidewalks	1.1	1.1	
Parking	0.2		
Streets, smooth	3.7		
Streets, intermediate	7.6		
Streets, rough	1.5		
Landscaped Areas			57.7
Undeveloped/Other Pervious/Isolated			4.6
Total	24.2	13.5	62.3

[2] Impervious Draining to Pervious means disconnected impervious surface. DNR has guidance defining what qualifies as disconnected within its April 27, 2011 Post-Construction Guidance Memo.

Pollutant Loading and Hydrologic Characteristics

Input data required by WinSLAMM for each model application includes a number of data files that describe general pollutant loading and hydrologic characteristics. Some of these files are prescribed for use in the WinSLAMM model by the USGS Wisconsin Water Science Center including *Pollutant Probability Distribution File, Runoff Coefficient File, Particulate Solids Concentration File, Particulate Residue Reduction File, and a Street Delivery Parameter File.* Each of these file types are described in more detail below.

- The ***Pollutant Probability Distribution File*** describes the pollutant loading from different source areas (land use types). This data is based upon actual pollutant loading collected from the study area or region.

- The ***Runoff Coefficient File*** describes parameters specific to different source areas (land use types) that determine the runoff volumes resulting from rainfall events of different depth during the year.

- The ***Particulate Solids Concentration File*** contains parameters allowing the WinSLAMM model to determine the weight of particulate solids loadings resulting from runoff events of different volumes. The particulate solids concentration file includes data measured by the USGS from source areas including the following: residential, commercial, and industrial rooftops; residential lawns; residential driveways; residential, commercial and industrial streets; commercial and industrial parking lots; freeways; and undeveloped areas.

- The ***Particulate Residue Reduction File*** describes the fraction of total particulates that remains within the drainage system after rainfall events and thus does not reach the system outfall.

- The ***Street Delivery Parameter File*** contains data describing the fraction of total particulates that do not reach the outfall during a rain event, for different rain depths and street textures.

The pollutant loading and hydrologic input files developed and prescribed for Wisconsin WinSLAMM modeling are listed on the USGS Wisconsin Water Science Center website and within Table 9. These files will be used in WinSLAMM modeling for evaluation of pollutant loadings from municipal and urban areas within the WRB TMDL study area.

Table 9 – USGS Recommended Parameter Files for Wisconsin WinSLAMM V.10.0 Modeling

File Type	File Name
Pollutant Probability Distribution File	WI_GEO02.ppd
Runoff Coefficient File	WI_SL06 Dec06.rsv
Particulate Solids Concentration File	Wi_avg01.psc
Particulate Residue Delivery File	Wi_dlv01.prr
Street Delivery File	WI_Res and Other Urban Dec06.std
Particle size distribution	NURP.cpz

Modeled Area Data

Other input data requirements include soil texture and rainfall data. See section 3.3 for details about these data.

3.4.4 WinSLAMM Sensitivity Analysis, Calibration and Validation

No sensitivity analysis, calibration or validation will be conducted as part of WinSLAMM modeling for WRB TMDL Development. As previously discussed, the WinSLAMM model itself has been rigorously calibrated using pollutant input files specifically developed to represent conditions typical in Wisconsin. Furthermore, WinSLAMM contains stochastic procedures to more accurately represent actual uncertainty in model input parameters and thereby better predict the actual range of outfall conditions.

3.4.5 WinSLAMM Outputs

WinSLAMM model outputs include pollutant loads (TP and particulate solids) and runoff volumes for each rainfall event, reported daily and by source area. The output will be summarized per month and incorporated into the SWAT model as a point source.

4.0 Empirical Reservoir Modeling

The computer model BATHTUB (Walker, 1999) will be used as a management tool to forecast the trophic response of several reservoirs in the WRB including the Big Eau Pleine Reservoir, Lake Dubay and Lake Wisconsin. In addition, other reservoirs in the project area have been modeled previously with BATHTUB. These previous modeling efforts will be reviewed and updated as necessary to conform to the protocols outlined in this document.

4.1 Empirical Reservoir Modeling Project Management

The proposed application for evaluating eutrophication response variables on a number of Wisconsin River basin reservoirs is BATHTUB Version 6.1 or the most current BATHTUB version available at the time of modeling.

The Wisconsin River TMDL BATHTUB modeling will be led by either WDNR TMDL staff in WDNR's Western District, or USACOE staff/contractors pending available resources. In either event WDNR will take the lead role in providing input data for Task 1 (Table 10).

Table 10 – Estimated BATHTUB Reservoir Modeling Project Timeline

<table>
<tr><th colspan="2">Time Period</th><th>Project Task</th></tr>
<tr><td rowspan="3">2014</td><td>July - March</td><td>1. Model Input Data Collection
a. Watershed Data Reduction
i. Summarize hydraulic and loading data from USGS
ii. Preliminary estimates of loading data from ungagged areas
b. Reservoir Data Reduction
i. Develop reservoir morphometric data from existing map sources
ii. Develop reservoir water quality data using Profile or similar</td></tr>
<tr><td>April - September</td><td>2. Model Development
a. Develop water balances
b. Determine model averaging period based on nutrient turnover ratios
c. Check and possibly calibrate diffusive model
d. Select, test, and possibly calibrate nutrient sedimentation sub-model
e. Select, test, and possibly calibrate eutrophication response sub-models</td></tr>
<tr><td>October - December</td><td>3. Reporting</td></tr>
</table>

4.2 Reservoir Background

Empirical reservoir response modeling will be applied to multiple reservoirs in the basin, each with unique characteristics. The original purposes of these reservoirs range from flow regulation (Big Eau Pleine and Spirit River Reservoir) hydropower generation (Lakes DuBay and Wisconsin), and recreation (Dexter and Tri-lakes). The locations of these reservoirs in the basin are depicted in Figure 1. Physical characteristics of these reservoirs are summarized in Table 11 below.

Table 11 - Physical characteristics and dam ownership of select Wisconsin River reservoirs

Reservoir	Area (acre)	Max Depth (ft.)	Watershed Area (mi^2)	Dam Owner/Operator
Spirit River Reservoir	158	26	158	Wisconsin Valley Improvement Company
Big Eau Pleine Reservoir	6,830	46	363	Wisconsin Valley Improvement Company
Lake DuBay	7,800	30	4,900	Consolidated Water Power
Lake Dexter	287	17	205	Wood County
Tri-Lakes				
Camelot	350	38	TBD	Adams County
Sherwood	246	27	TBD	Adams County
Arrowhead	445	24	99	Adams County
Lake Wisconsin	9,500	39	9,156	Alliant Energy

4.3 Measured Data Assessment and Analysis

The general approach for BATHTUB model preparation is to develop a nutrient and hydrologic budget along with an assessment of in lake water chemistry. The Big Eau Pleine Reservoir, Lake DuBay, Lake Dexter and Lake Wisconsin were routinely monitored as part of the TMDL development project. Monthly tributary loads will be developed for major tributaries to the reservoirs. At each reservoir site, surficial samples were analyzed for total phosphorus, ortho-phosphorus and chlorophyll-a, bottom samples were analyzed for total phosphorus, and DO/Temp/pH/Cond profiles were collected. In addition to the limnological analysis, sediment cores were collected and incubated to determine phosphorus release rates on certain reservoirs. A short synopsis of monitoring methodology for each reservoir is outlined in Table 12 below.

Table 12 – Monitoring methodology for each reservoir modeled with BATHTUB

Reservoir	Reservoir Monitoring Period (May – September)	# In-Lake Sites	Measured Sediment P Release
Big Eau Pleine Reservoir	2010 – 2013	4	Yes
Lake DuBay	2010 – 2013	3	Scheduled
Lake Dexter	2010 – 2012	1	No
Lake Wisconsin	2010 – 2013	3	Scheduled
Reservoir	**Tributary Monitoring Period**	**Tributary Monitoring Sites**	
Big Eau Pleine Reservoir	October 2009 – Nov. 2013	Big Eau Pleine River, Fenwood Creek, Freeman Creek	
Lake DuBay	May 2009 – Nov. 2013	Wisconsin River, Big and Little Eau Pleine Rivers	
Lake Dexter	October 2009 – Nov. 2013	Yellow River	
Lake Wisconsin	October 2009 – Nov. 2013	Wisconsin and Baraboo Rivers	

In addition to the reservoirs listed above, both the Spirit River Reservoir and Tri-Lakes have had previously been modeled with Bathtub (Turyk 2006; James 2002). These past modeling efforts will be reviewed, updated, and merged into the larger reservoir modeling effort.

4.4 BATHTUB Model Design

The proposed application for evaluating eutrophication response variables on a number of Wisconsin River basin reservoirs is BATHTUB Version 6.1 or the most current BATHTUB version available at the time of modeling.

4.4.1 Selecting BATHTUB for Empirical Model

BATHTUB applies a series of empirical eutrophication models to morphologically complex lakes and reservoirs. The program performs steady-state water and nutrient balance calculations in a spatially segmented hydraulic network which accounts for advective and diffusive transport, and nutrient sedimentation. Eutrophication-related water quality conditions (total phosphorus, total nitrogen, chlorophyll-a, transparency, and hypolimnetic oxygen depletion) are predicted using empirical relationships derived from assessments of reservoir data.

Applications of BATHTUB are limited to steady-state evaluations of relations between nutrient loading, transparency and hydrology, and eutrophication responses. It has been used as the basis for the development of several nutrient TMDLs in the upper Midwest. Three examples include a BATHTUB model developed and calibrated for nutrients and algae for Lakes Tainter and Menomin in western Wisconsin (WDNR, 2012), Bald Eagle Lake in the Twin Cities Metropolitan Area of Minnesota (Wenck Associates Inc., 2012), and Black Hawk Lake in northwest Iowa (Iowa DNR, 2011)

4.4.2 BATHTUB Set-up

BATHTUB models will be developed for the individual reservoirs based on their own unique characteristics and available data. Formulation of mass balances is an important first step in model development. Monthly loading estimates for gauged tributaries will be provided by USGS and summarized for model input. Given the relatively short hydraulic residence times of the reservoirs, it is likely that the modeling period will be the summer growing season (May-September). However, if the use of the growing season approach violates the steady-state assumption of the model, the modeling period will need to be expanded. Sensitivity to choice of averaging period can be tested by creating separate input files for different averaging periods. Ungaged inflows and stream concentrations will be estimated from SWAT outputs once available, preliminary estimates will be made via unit area approximations of flow and loading.

Morphometric information will be estimated from contour maps developed by WDNR, WVIC or private sources (e.g. Fishing Hot Spots Maps). PROFILE (Walker, 1999) may be used to summarize observed water quality conditions by segment and calculate oxygen depletion rates in stratified reservoirs.

Generally, it is appropriate to aggregate adjacent reservoir areas with similar water quality into a single segment. If significant spatial variations in water quality are not apparent, segments may be combined for modeling purposes. Box plots and summarizing water quality data by station will be used for this purpose along with t-tests (or a nonparametric equivalent). However, defining multiple segments may be required to support management decisions. Simulating spatial variations within the reservoir may provide evidence of model applicability and reliability that is not available in single-segment applications.

4.4.3 BATHTUB Model Inputs

Table 13 defines the inputs for BATHTUB.

Table 13 – BATHTUB Model Inputs

Model Component	Data / Routine Applied	Data Sources
Lake Morphometry	Calculation of area and volume of reservoir segments	WDNR, WVIC and/or private mapping companies (e.g. Fishing Hot Spots)
Lake Chemistry	Bi-weekly sampling at most reservoirs, chemistry data pre-processed in Profile (or similar) to determine summary statistics	WDNR, UW-Stevens Point, USACOE- ERDC
Load Inputs	Loadest, Fluxmaster, or similar	USGS, USACOE-ERDC, UW-Stevens Point
Sediment Release	Oxic and anoxic phosphorus release rates from all reservoirs except Lake Dexter	USACOE-ERDC, UW-Stout
Climatological	May-September precipitation	NOAA

4.4.4 BATHTUB Sensitivity Analysis

BATHTUB contains several functions that allow for error estimation and sensitivity analysis. Using a first-order error analysis procedure, the model core is executed repeatedly in order to estimate output sensitivity to each input variable and sub-model and to develop variance estimates and confidence limits for each output variable. BATHTUB includes a built-in routine for automatically testing the sensitivity of predicted concentrations to sedimentation rates and dispersion coefficients.

In addition, sensitivity to critical assumptions made in the modeling process will be evaluated by using alternative assumptions in model setup (e.g. segmentation scheme, averaging period, sub-model selection, etc.) and comparing results to the final selected model(s).

4.4.5 BATHTUB Calibration

The first step in the mass balance formulation is the water balance. It may be appropriate to adjust certain inflow, outflow, and/or increase-in-storage terms until balances are established. Flow-balance errors are often attributed to ungaged surface or groundwater inflows. Based on the gaging network and use of calibrated SWAT outputs for estimation of ungaged areas flow-balance errors are likely to be minimal.

In BATHTUB, calibration involves adjusting the global calibration factor and/or segment calibration factors to match observed data. Where possible, adjustments will be made only to the global calibration factor (keeping segment calibration factors at their default setting of 1.0); this is a more conservative calibration approach than adjusting values for each segment individually. In all cases, any changes to calibration factors will apply to the entire period of record.

Conservative tracer data (conductivity) will be used to calibrate transport terms in reservoirs involving more than one segment. An overall tracer mass balance would be established prior to calibrating transport terms. If numeric dispersion exceeds the estimated dispersion in a given segment, segmentation schemes may be revised to increase the number of segments. However, if the sensitivity of predicted nutrient profiles to alternative segmentation schemes is shown to be minimal, segment numbers would not be increased.

Differences between observed and predicted nutrient profiles may reflect random errors in the data, as well as true differences between the model predictions and reservoir responses. As noted above, the approach to calibration will be conservative (global where possible, by segment only where necessary).

BATHTUB provides statistical comparisons of observed and predicted concentrations. These are computed using three alternative measures of error: observed error only, T(1); error typical of model development data set, T(2); and observed and predicted error, T(3). Once an appropriate sedimentation model is selected, T(1) can be used as a basis for deciding whether calibration is appropriate. If the absolute value of T(1) exceeds 2, then there is less than a 5-percent chance that the observed and predicted means are equal, given the error in the observed mean. Therefore in these situations, calibration of the model is warranted.

BATHTUB provides several sedimentation models for phosphorus. The various models will all be evaluated for fit prior to any calibration. BATHTUB provides two calibration methods for phosphorus: In the first case, the calibration factors are applied to estimated sedimentation rates in computing nutrient balances. In the second case, the factors are applied to estimated concentrations. The choice of method will be largely dependent on the significance of the inflow and outflow portions of the mass balance.

In some cases, nutrient retention coefficients for phosphorus may be negative. Apparent negative retention coefficients may reflect use of an improper averaging period or underestimation of significant external loads. Independent evidence and estimates of sediment nutrient sources will be obtained for most of the modeled reservoirs. Introduction of internal loading factors into the models will be approached with caution. One limitation of this approach is that it renders the estimates of model errors provided by BATHTUB invalid, as internal loading is implicitly included in the model development datasets. Evaluation of management strategies directed toward significant internal loading may require a different modeling approach (e.g. a simplified dynamic mass balance model).

Once the phosphorus balance has been developed, chlorophyll and Secchi responses will be evaluated. As with phosphorus, BATHTUB provides several models to select. Previous experiences in Wisconsin and Minnesota indicate that the Jones and Bachman chlorophyll model will be a likely candidate; however use of other regressions in the model will not be discounted. The approach for chlorophyll and Secchi calibration will follow that outlined for phosphorus.

4.4.6 BATHTUB Validation

Given the limited number of years for which sampling data is available, the entire monitoring dataset will be used for calibration.

4.4.7 BATHTUB Outputs

For each modeled reservoir segment output data would include hydraulic and mass balances and all diagnostic variables listed in Table 4.5 of the Simplified Procedures for Eutrophication Assessment and Prediction: User Manual (Walker, 1999).

5.0 Two-Dimensional Reservoir Modeling

The objective of the CE-QUAL-W2 (W2) modeling is to develop lake response models for Lake Petenwell and Castle Rock flowages on the Wisconsin River. The W2 model will be a calibrated hydrodynamic and water quality model that successfully captures the phosphorus, dissolved oxygen and chlorophyll dynamics for the monitoring period of record (2009-2013). The calibrated model will link with SWAT watershed models to provide the WDNR the ability to run TMDL scenarios for the WRB.

5.1 Two-Dimensional Reservoir Management

W2 will cover the Lake Petenwell and Lake Castle Rock Flowages of the Wisconsin River. All of tasks related to the W2 modeling will be done by the Corps of Engineers, St. Paul District – Jim Noren (Table 14).

Table 14 – W2 Project Timeline

Time Period		Project Task
Completed		1. Data Analysis and Model Preparation
2013	September - December	2. Calibration and Validation for temperature and flow/stage
2015	April - June	3. Calibration and Validation for water quality constituents
	June - August	4. Training
	September - December	5. Scenario application 6. Reporting

5.2 Petenwell and Castle Rock Reservoir Background

Petenwell and Castle Rock Flowages are located at the downstream section of the central portion of the Wisconsin River Mainstem. Petenwell Flowage is 23,173 acres with a maximum depth of 44 feet. Castle Rock Flowages is 12,981 acres with a maximum depth of 36 feet. Both Flowages are listed on the USEPA Sec. 303(d) impaired waters list. A comprehensive management plan developed in 1996 for the flowages provides a summary of the impaired beneficial uses and recommends measures to mitigate the problems. Based on information in the Management Plan, impaired beneficial uses to Petenwell and Castle Rock flowages include:

- Impaired recreation
- Impaired aesthetics
- Undesirable blue-green algae blooms, some toxic algae
- Phosphorus loading from both point and nonpoint sources, causing eutrophication
- Dioxin, Mercury and PCB contaminated fish and sediments
- Degradation of desirable phytoplankton, zooplankton, bottom-dwelling organisms (benthos), and fish and wildlife communities because of poor water quality and lack of established rooted aquatic plants.
- Low dissolved oxygen, and fish (carp) kills on the Petenwell Flowage

5.3 Measured Data Assessment and Analysis

Several types and sources of data will be used to construct and calibrate the W2 model for Petenwell and Castle Rock Flowages. Input data for the model includes:

- Bathymetry
- Initial conditions
- Boundary conditions
- In-pool water quality
- Hydraulic parameters
- Kinetic parameters

Bathymetry

Bathymetry data for Petenwell and Castle Rock Flowages are needed to define the model's computational grid. The bathymetry data set used was a topographic GIS shapefile provided by Fishing Hot Spots, Inc. The shapefile contained digitized contour lines of water depths at 5 foot increments. Using the grid generation capabilities of the Watershed Modeling System software developed by Aquaveo, the shapefile was transformed into a 10-meter grid and then into a triangulated irregular network (TIN). From the TIN, the flowages were broken into separate water bodies with multiple branches containing user-defined longitudinal segments and vertical layers. The resulting segment lengths, layer heights, average widths, segment orientations and watershed and branch configurations were imported into the model's bathymetry and control files. A depiction of the shapefile for Lake Petenwell is shown in Figure 5, along with an example of a possible computation grid in Figure 6 (top-view) and Figure 7 (side-view).

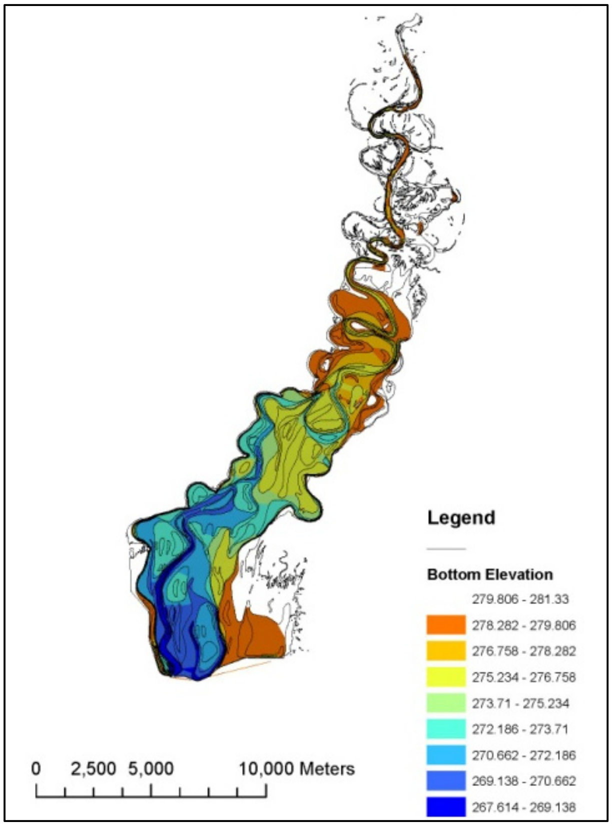

Figure 5 – Lake Petenwell Bathymetry

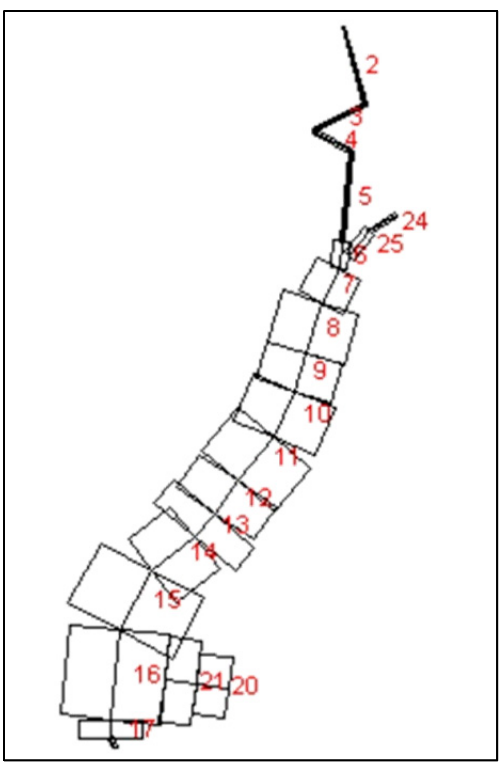

Figure 6 – Lake Petenwell computational grid top-view

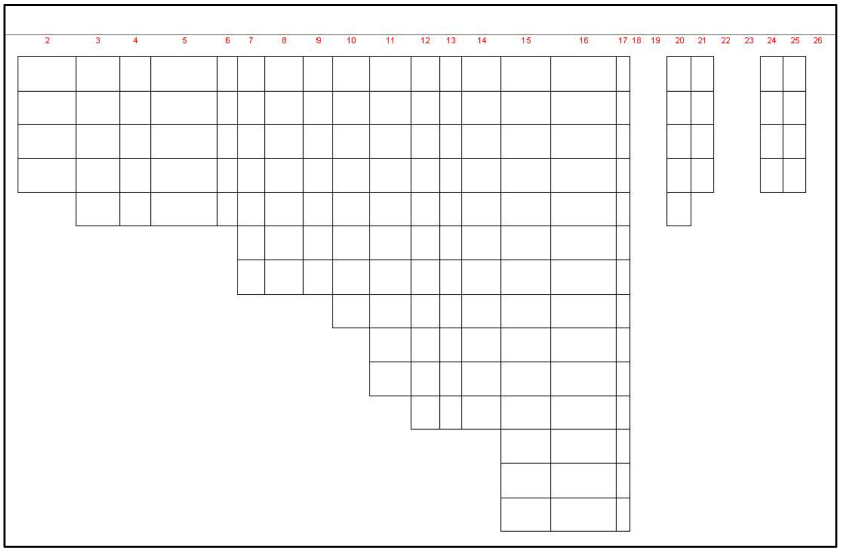

Figure 7 – Lake Petenwell computational grid side-view

The reliability of any W2 model is heavily dependent on the accuracy of the bathymetry data. If the bathymetry data doesn't capture the natural condition closely, the predictive ability of the calibrated model for observed stages, temperature and water quality will be in doubt. Usually, if matching temperature and pool level data during model calibration is problematic, the accuracy and/or the resolution of the bathymetry data should be questioned.

Initial Conditions

In the model's control file and vertical/longitudinal profile files, in-pool initial condition parameters will be defined using Wisconsin DNR's in-pool sampling data for water quality and temperature and the Wisconsin River Power Company's lake stage data. The availability of the in-pool sampling data and lake stage data should provide a realistic initialization of the model for any particular simulation's starting period.

Boundary Conditions

The boundary conditions for the W2 model consist of water quality, flow, meteorological and control structure information for the periods of simulation (2009-2013). The water quality data used will primarily be obtained from the Wisconsin DNR. The flow data used will be either from the Wisconsin DNR, USGS or the hydroelectric dams, depending on the location. The meteorological data were taken from Volk Field near Lake Petenwell. And the physical configurations of the control structures on Petenwell and Castle Rock flowages were made available by the Wisconsin River Power Company.

All of the needed boundary condition data were collected in a manner and at a spatial and a temporal resolution that should be sufficient for accurately simulating the existing condition. If calibration of the model seems overly difficult, the accuracy and/or the resolution of the boundary condition data may be at fault.

In-pool water quality

Water quality grab samples, in situ profile measurements and thermistor string temperature readings were collected by the Wisconsin DNR at several locations for each flowage between 2009 and 2013. The in-pool data should provide the model with enough calibration and verification data to fulfill the objective of developing a predictive model for use in TMDL scenarios.

Hydraulic and Kinetic parameters

Hydraulic and kinetic parameters in the model will be selected from the scientific literature and in the model's manual (Cole, T M., and S. A. Wells. 2002). Calibration of the model may require further adjustments within the range of expected variances. Calibration parameters will be provided once the model is completely setup and running since we are still in the process of investigating the input data and state variables and processes.

5.4 CE-QUAL-W2 Design

CE-QUAL-W2 version 3.8 will be used for this application. The carbon, nitrogen and phosphorus cycles implemented within W2 version 3.8 are illustrated in Figures 8 to 10. The objective of the model is to simulate the fate and transport of phosphorus in Petenwell and Castle Rock Flowages for the evaluation of TMDL scenarios. Along with the phosphorus cycle, the carbon and nitrogen cycles will be simulated in order to model dissolved oxygen and algal growth.

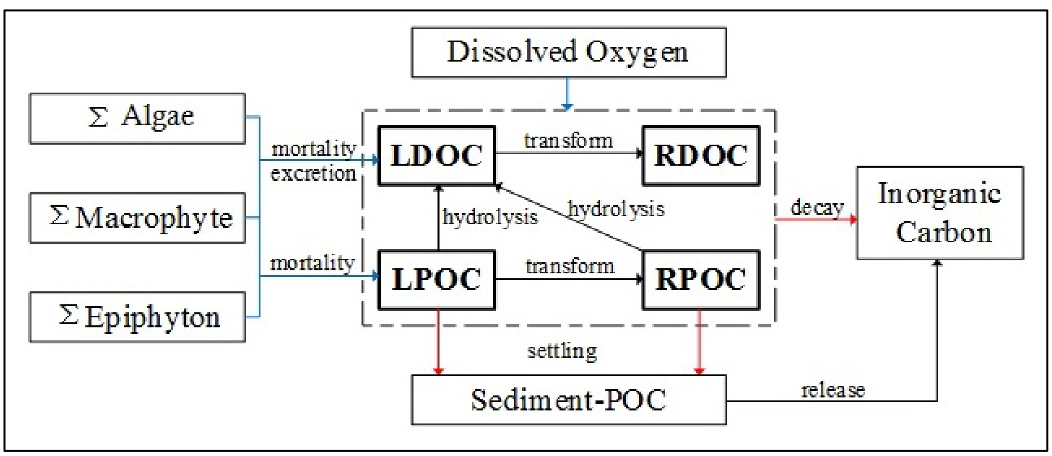

Figure 8 – Carbon cycle of W2 model

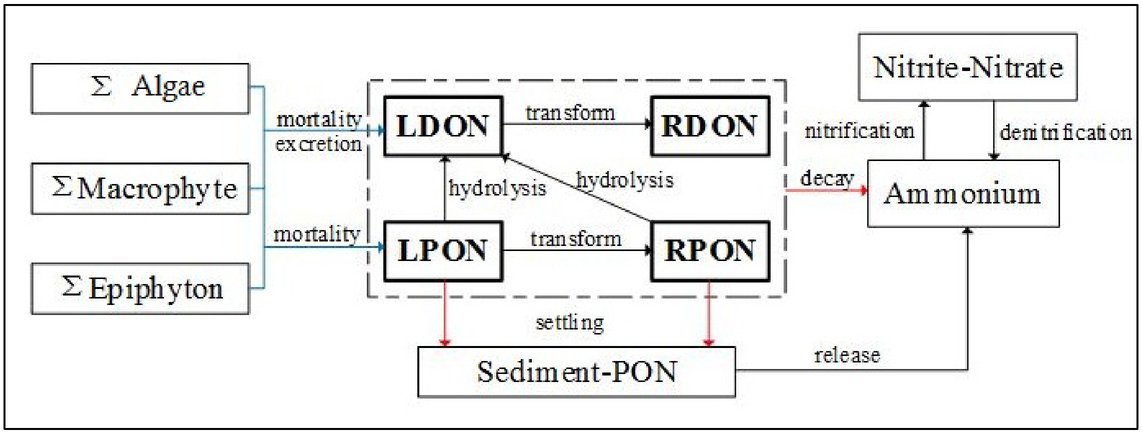

Figure 9 – Nitrogen cycle of W2 model

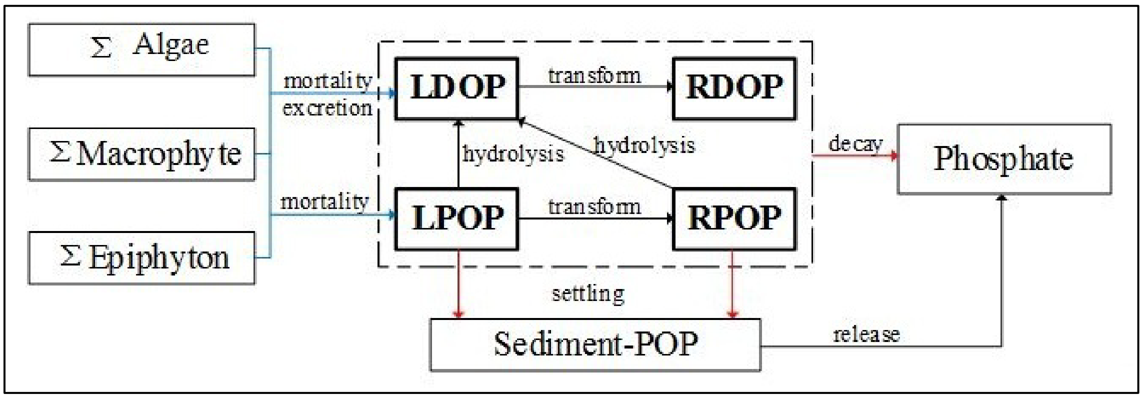

Figure 10 – Phosphorus cycle of W2 model

5.4.1 Selecting CE-QUAL-W2 for 2-D Reservoir Model

The U.S. Army Corps of Engineers CE-QUAL-W2 model was selected as the receiving water model for simulating nutrients in the Wisconsin River from Lake Petenwell to Castle Rock Dam. W2 is a two-dimensional, longitudinal/vertical, hydrodynamic and water quality model. Because the model assumes lateral homogeneity, it is best suited for relatively long and narrow waterbodies exhibiting longitudinal and vertical water quality gradients. The model has been applied to rivers, lakes, reservoirs, and estuaries and has been tested on a number of analytical solutions and over 400 real-world applications. Reasons for choosing W2 for this application include:

- W2 is able to simulate the parameters of concern in Lake Petenwell and Castle Rock Flowages (e.g. phosphorus, nitrogen, dissolved oxygen and chlorophyll a).

- W2 is a two-dimensional, longitudinal/vertical, hydrodynamic and water quality model that can output data from upstream to downstream in the flowages and at depth.

- Code has been successfully developed by the Army Corps of Engineers to link loading outputs from SWAT into W2. Changes to the code include:

- Removed organic matter (refractory particulate organic matter (RPOM), labile particulate organic matter (LPOM), refractory dissolved organic matter (RDOM), labile dissolved organic matter (LDOM)) since organic matter are not SWAT water quality measurements.

- Add organic carbon (refractory particulate organic carbon (RPOC), labile particulate organic carbon (LPOC), refractory dissolved organic carbon (RDOC), labile dissolved organic carbon (LDOC)), organic nitrogen (refractory particulate organic nitrogen (RPON), labile particulate organic nitrogen (LPON), refractory dissolved organic nitrogen (RDON), labile dissolved organic nitrogen (LDON)), and organic phosphorus (refractory particulate organic phosphate (RPOP), labile particulate organic phosphate (LPOP), refractory dissolved organic phosphate (RDOP), labile dissolved organic phosphate (LDOP)) as state variables.

- Add hydrolysis of particulate organic carbon (POC), particulate organic nitrogen (PON), particulate organic phosphate (POP).

- W2 is capable of simulating cause-and-effect relationship between loading and reservoir response.

- Simpler receiving water models would be limited in their ability to address the characteristics of the system (long, occasionally stratified, and with multiple control structures and branches).

Model Capabilities

The model provides:

- longitudinal-vertical hydrodynamics and water quality in stratified and non-stratified systems, with multiple algae, epiphyton/periphyton, zooplankton, macrophyte, carbonaceous biochemical oxygen demand (CBOD), and generic water quality groups

- internal dynamic pipe/culvert model, hydraulic structures (weirs, spillways) algorithms including for submerged and 2-way flow over submerged hydraulic structures, dynamic shading algorithm based on topographic and vegetative cover.

Model Limitations

W2 is well-mixed in lateral direction but relies on a hydrostatic assumption for vertical momentum equation. As a laterally averaged model, a possible limitation for this study may be W2's inability to show localized water quality changes, such as, algal blooms that only form close to shore.

Model Assumptions

- One algae group will be in the initial model setup, but modeling two or three algal groups are more reasonable to catch dynamic changes of chlorophyll-a with time. Zooplankton may be excluded from the initial model setup, but could be included during calibration if deemed significant for algal dynamics and recycling.

- Modeling the following constituents will be adequate for representing the overall primary production and nutrient interactions in the system:
  - total dissolved solids (TDS)
  - inorganic suspended solids (ISS1)
  - phosphate (PO4)
  - ammonia (NH4)
  - nitrate (NO3)
  - labile dissolved organic carbon (LDOC)
  - refractory dissolved organic carbon (RDOC)
  - labile particulate organic carbon (LPOC)
  - refractory particulate organic carbon (RPOC)
  - labile particulate organic nitrogen (LPON)
  - refractory particulate organic nitrogen (RPON)
  - labile particulate organic phosphate (LPOP)
  - refractory particulate organic phosphate (RPOP)
  - algal biomass (ALG1)
  - dissolved oxygen (DO)

Similar Previous Studies

There are several studies that have used the W2 model in support of reservoir modeling. Examples include a CE-QUAL-W2 model to simulate hydrology and nutrients, dissolved oxygen, and temperature in the Tongue River Reservoir (US EPA 2007), a CE-QAUL-W2 model developed and calibrated for temperature, nutrients and algae for the Black River which was used as a receiving model for linked SWAT model of the Black River Watershed (Ohio EPA, 2008). Finally, dissolved oxygen was added to an existing Lake Powell hydrodynamic and water quality CE-QUAL-W2 model. The previously developed model has been used at Lake Powell to simulate hydrodynamics, temperature, and total dissolved solids with a reasonable degree of accuracy (Williams, 2007).

5.4.2 CE-QUAL-W2 Model Setup

Boundary Conditions

Lake Petenwell and Castle Rock will be modeled in CE-QUAL-W2 as two water bodies with 5 branches. The flow and water quality boundary conditions for the periods of simulation are contained in the model's input files for each branch.

- Upstream
  The upstream inputs occur only at a branch's upstream segment, which may vary during a simulation. Besides flow and water temperature, the upstream boundary condition includes concentrations of: total dissolved solids (TDS), inorganic suspended solids (ISS1), phosphate (PO4), ammonia (NH4), nitrate (NO3), labile dissolved organic carbon (LDOC), refractory organic carbon (RDOC), labile particulate organic carbon (LPOC), refractory particulate organic carbon (RPOC), labile particulate organic nitrogen (LPON), refractory particulate organic nitrogen (RPON), labile particulate organic phosphate (LPOP), refractory particulate organic phosphate (RPOP), algal biomass (ALG1) and dissolved oxygen (DO). These parameter time-series are either from direct measurements or derived from other related field data. The labile and refractory partitions will be estimated from Hendrickson, et al., 2007.

- Tributary
  Inflows, temperatures and parameter concentrations of tributaries or point sources, if any, can enter any segment of the computational grid. These inputs can either be distributed evenly throughout a segment or placed according to their density.

- Distributed tributary
  Similar to tributary, but inflows can be evenly distributed along the entire branch. This option may be used for the SWAT loading inputs.

- Precipitation/evaporation
  Precipitation and/or evaporation can be specified for each branch.

- Internal inflows/outflows
  Control structures, such as, gates, pumps, weirs and spillways are routed internally inside the computational grid.

- Downstream and lateral outflows
  Downstream and lateral outflows can be specified if needed.

- Meteorological data
  The W2 model requires a meteorological input file that includes: wind speed, wind direction, solar radiation or cloud cover percent, air temperature and relative humidity.

Model Segmentation

The Lake Petenwell and Castle Rock W2 computational grid is currently setup as 2 waterbodies containing 5 branches. There is a total of 51 segments with an average length around 2000 meters and 16 layers with and average depth increments of 1-2 meters.

Time Step

The maximum time step is currently set at an hour, but the model can slow down to a minute time step to get through problems with numerical instability.

Data Integration

The W2 control file and associated input files need to be setup correctly according to the formatting requirements of the model version being used. Besides the control file that contains the variables used to run the model, much of the input data are in a time series format that covers the length of time for the simulation run. At each time step, the model interpolates the needed input data from the applicable time series. The SWAT output loading data will need to be converted into W2 files through the use of a newly developed Corps of Engineers script or manually.

5.4.3 CE-QUAL-W2 Inputs

The flow and water quality data for the simulation period were collected and quality checked by the Wisconsin DNR. Flow data from USGS/WDNR gages were provided on the Wisconsin River and tributaries as seen in Table 15. Hourly flow data at the Petenwell and Castle Rock dams were provided by the Wisconsin River Power Company. Weekly and monthly grab sample data for chlorophyll a, dissolved organic carbon (DOC), dissolved reactive phosphorus (DRP), NH4, nitrate-nitrite (NO3-NO2), TDS, total kjeldahl nitrogen (TKN), total organic carbon (TOC), TP, TSS, conductivity, DO, pH and temperature were collected on the Lake Petenwell and Castle Rock Flowages, main-stem Wisconsin River and selected tributaries by the Wisconsin DNR (Tables 15 and 16). In addition to the grab sample data, continuous temperature data was collected on the Wisconsin River at the Nekoosa, Petenwell, and Castle Rock dams and on Tenmile Creek, Big Roche a Cri Creek, and the Yellow River. The meteorological data were taken from Volk Field near Lake Petenwell and the physical configurations of the control structures on Petenwell and Castle Rock flowages were made available by the Wisconsin River Power Company. The in-pool data and downstream data will be used for calibration and verification of the model. The upstream boundary condition data and meteorological data will be used to run the model. Figure 11 shows the relevant data collection stations that will be used for the W2 input and calibration data.

Table 15 – CE-QUAL-W2 flow and WQ monitoring sites for Lake Petenwell and Castle Rock

Site Name	River	Flow Frequency	USGS Station ID	Drainage Area (mi^2)	Semi-monthly parameters [1]	Purpose
Nekoosa-W	Wisconsin	Hourly	05400975	5,640	TP, OP, Chl-a, TOC, DOC, TDS, TKN, NH3, NOx, Algal ID	Upstream boundary
Petenwell	Wisconsin	Hourly	05401400	5,970	TP, OP, Chl-a, TOC, DOC, TDS, TKN, NH3, NOx , Algal ID	Calibration
Castle Rock	Wisconsin	Hourly	05403200	7,060	TP, OP, Chl-a, TOC, DOC, TDS, TKN, NH3, NOx	Calibration
Wisconsin Rapids	Wisconsin	15 min	05400760	5,420	TP, OP, Chl-a, TOC, TDS, TKN, NH3, NOx, TSS	Upstream boundary
Nekoosa-T	Tenmile	15 min	05401050	73	TP, OP, TOC, DOC, TDS, TKN, NH_3, NO_x, TSS	Tributary input
Arkdale	Big Roche a Cri	15 min	05401558	151	TP, OP, Chl-a, TOC, DOC, TDS, TS, TKN, NH3, NOx, TSS	Tributary input
Necedah	Yellow	15 min	05403000	491	TP, OP, Chl-a, TOC, DOC, TDS, TKN, NH3, NOx, TSS	Tributary input

Notes: (1) TP = total phosphorus; OP = orthophosphate, Chl-a = chlorophyll a, TOC = total organic carbon, DOC = dissolved organic carbon, TDS = total dissolved solids, TKN = total Kjeldahl nitrogen, NH3 = ammonia, NOx = nitrate + nitrite nitrogen and Algal ID = Algal ID to genus and biovolume estimate.

Table 16 – CE-QUAL-W2 flow and WQ monitoring sites for Lake Petenwell and Castle Rock

Reservoir	# Sites and Depths	Semi-monthly parameters	Purpose
Petenwell	(5 sites/3 depths)	TP, OP, Chl-a, TOC, TDS, TKN, NH_3, NO_x, Algal ID	CE-QUAL-W2 Calibration
Castle Rock	(4 sites/3 depths)	TP, OP, Chl-a, TOC, TDS, TKN, NH_3, NO_x, Algal ID	CE-QUAL-W2 Calibration

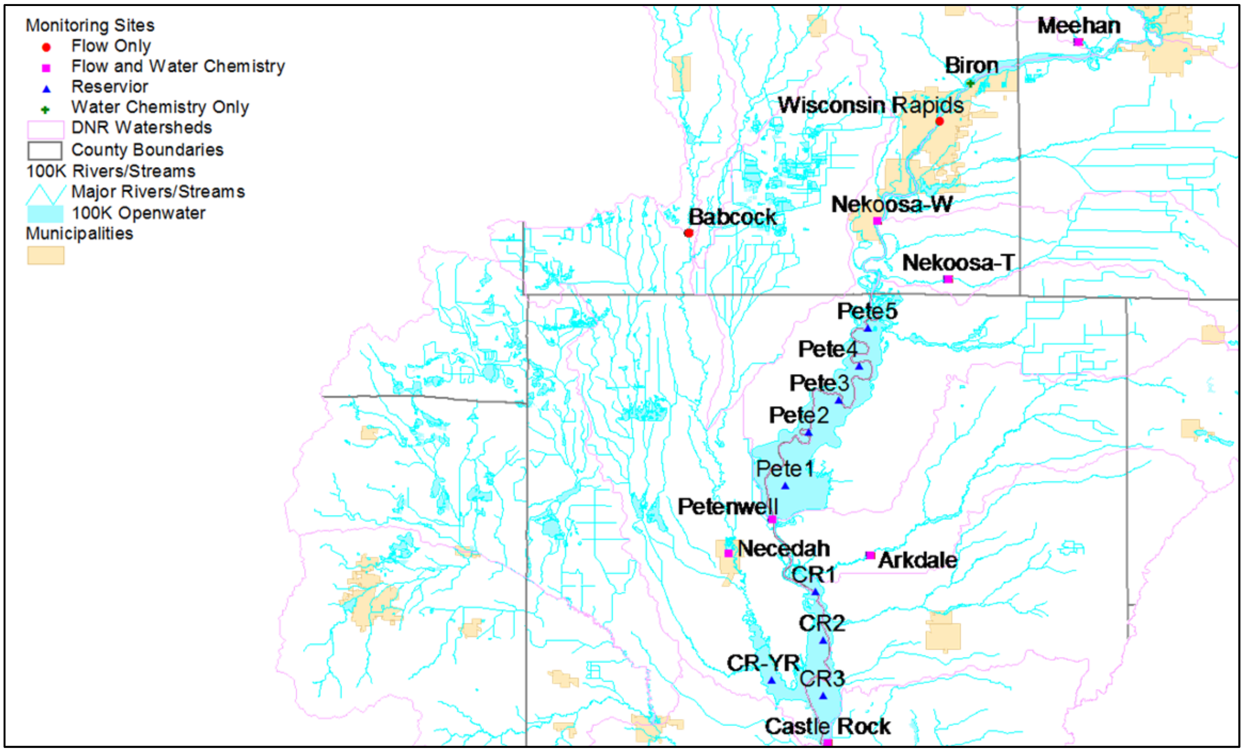

Figure 11 – Petenwell and Castle Rock water quality and flow monitoring stations

In addition to in-pool water quality sampling, sediment sampling will be completed in the fall of 2013 for laboratory-controlled estimation of sediment oxygen demand, rates of ammonium and nitrate fluxes and rates of phosphorus release. These rates will be used in the W2 model to describe SOD and sediment nutrient releases.

Table 17 shows two possible options for sampling stations and incubation conditions for measuring phosphorus release, and Table 16 shows the sampling stations and incubation conditions that will be used to estimate sediment oxygen demand and rates of ammonium and nitrate fluxes.

Table 17 – Sampling stations and incubation conditions for sediment cores collected in Petenwell and Castle Rock Lakes. Numbers represent the replicates for each condition

Lake	Location	Anoxic	Condition	
			Oxic pH ~8	Oxic pH ~9
Petenwell	PL-2 Thalweg	3	3	
	PL-4 Thalweg	3	3	3
	PL-4 ~15 ft. contour		3	3
Castle Rock	CRL-WI R. 1 ~20 ft. contour	3	3	
	CRL-WI R. 3 ~ 10-15 ft. contour	3	3	3
	CRL-Yellow R. 4 ~10-15 ft. contour		3	3

Table 18 – Sampling stations and incubation conditions for sediment cores collected in Petenwell and Castle Rock Lakes. Numbers represent the replicates for each condition

Lake	Location	Sediment Oxygen Demand	Oxic Ammonium and Nitrate Flux	Anoxic Ammonium and Nitrate Flux
Petenwell	PL-2 Thalweg	2	2	2
	PL-4 Thalweg	2	2	2
Castle Rock	CRL-WI R. 1 ~20 ft. contour	2	2	2
	CRL-WI R. 3 ~ 10-15 ft. contour	2	2	2
	CRL-Yellow R. 4 ~10-15 ft. contour	2	2	2

5.4.4 CE-QUAL-W2 Sensitivity Analysis

W2 model sensitivity analysis will be conducted to determine the influence a set of parameters had on predicting flow and water quality. Various sensitivity analysis methods have been used to identify model parameters that significantly affect model prediction uncertainty and the water quality constituents. First Order Variance Analysis (FOVA) (Porter et al. 1999) will be used in this study. Based on the model calibration process, the sensitive input variables will be selected for the analysis. The output variables for the sensitivity analyses may include dissolved oxygen, ammonium, nitrate, total nitrogen, orthophosphate, total phosphorus and chlorophyll *a*.

The dimensionless sensitivity coefficient, S_i is the index describing the sensitivity of the output result Y for input x_i. Thus, when x_i varies 1%, the output F will be changed S_i%. The equation (1) is formed as:

$$S_i^{Y_{x_i=x_{i0}}} \equiv \left\{\left[\frac{\partial Y}{\partial x_i}\right] / \left[\frac{Y(x_i)}{x_i}\right]\right\}_{x_i=x_{i0}} \quad (1)$$

or computed numerically as:

$$S_i = \left[\frac{Y(x_{i0}+\Delta x_i)-Y(x_{i0})}{Y(x_{i0})}\right] / \left[\frac{\Delta x_i}{(x_{i0})}\right] \quad (2)$$

where x_{i0} is the unperturbed, or calibrated value of the variable x_i.
The uncertainty of the model outputs can be estimated based on the standard deviation σ_Y for the output variable Y:

$$\sigma_Y^2 \equiv var(Y) \approx \sum_{i=1}^{p} \left[\frac{\partial Y}{\partial x_i}\bigg|_{x_i=x_{i0}} \sigma_i\right]^2 \quad (3)$$

where σ_i and σ_Y are the standard deviations of the basic parameter x_i and output variable Y, respectively. ∂Y is determined as the difference between the disturbed and undisturbed output variable Y, and ∂x is determined as the difference between the disturbed and undisturbed input variable x.

5.4.5 CE-QUAL-W2 Calibration and Validation

Observed data records are fundamental during the calibration and validation phases of W2 model. Calibration and validation of W2 will be based on a balanced, split-sample approach. Available historical data will be divided into two datasets: 2 years for calibration and 2 years for validation.

The model calibration is a critical step in ensuring the W2 model will properly simulate the WI River. Without adequate calibration/validation, the results of any model cannot be relied upon. W2 model calibration involves successive runs of the model by adjusting calibration parameters until the model results are in agreement with the observed data. Calibration of the W2 model requires simultaneous measurement of flow and water quality.

After the W2 model is calibrated to produce results that closely agreed to observed data for the calibration period, the model needs to be validated using additional observed data sets. The validation is used to evaluate the reliability of a calibrated model. The primary goal of model validation is to confirm that the W2 model can be used to simulate WR flow and water quality and be able to apply to other magnitudes.

Both calibration and validation require a goodness of fit measure to quantify how well the model matches the target data and determine the quality and reliability of the model simulations. Two evaluation criteria will be used to assess model results simulated by W2. The first criteria are visual comparisons of plots of modeled and observed values. The second evaluation criteria involved error statistics that quantitatively measured the agreement between modeled and observed values. Coefficient of determination (R^2), Nashe-Sutcliffe efficiency (NSE), Percent error (PBIAS), and the ratio of the root mean square error (RMSE) to observations standard deviation (RSR) are used as evaluators of model performance (Equations 4 – 7).

$$R^2 = \frac{\left(\sum_i (OV_i - \overline{OV})(MV_i - \overline{MV})\right)^2}{\sum_i (OV_i - \overline{OV})^2 \sum_i (MV_i - \overline{MV})^2} \tag{4}$$

$$NSE = 1.0 - \frac{\sum_i (OV_i - MV_i)^2}{\sum_i (OV_i - \overline{OV})^2} \tag{5}$$

$$PBIAS = \frac{\sum_i \left(OV_i - MV_i\right)}{\sum_i OV_i} * 100 \tag{6}$$

$$RSR = \frac{\sqrt{\frac{1}{n}\sum_i (OV_i - MV_i)^2}}{\sqrt{\frac{1}{n}\sum_i (OV_i - \overline{OV})^2}} \quad (7)$$

where *n* is the number of observations during the simulation period, OV_i is the observed value at the i time step, $\overline{OV}$ is the mean observed value for the time period, MV_i = modeled value at the i time step, $\overline{MV}$ is the mean modeled value for the time period.

5.4.6 CE-QUAL-W2 Outputs

The W2 model can output all hydrodynamic, thermal and any active water quality state variables at any segment and layer at any specified time increment. The format of the output data can be specified as profiles, time series, contours, vectors, spreadsheets or withdrawals. For calibration purposes, profiles and withdrawal data will be used to compare in-pool water temperature and water quality data and downstream flow, temperature and water quality data.

6.0 Model Integration Database

The model integration database will utilize the Microsoft Access database platform to integrate the outputs from the SWAT, BATHTUB, WinSLAMM, and CE-QUAL-W2 models along with data from permitted discharges on a reach by reach basis. The model outputs and permitted discharge data will be used in the database to determine the TMDL allocations for each stream segment throughout the TMDL study area. This approach is similar to what was used in the WDNR Rock River TMDL as a link between model outputs and TMDL allocations. A detailed description of model integration and TMDL allocation procedures is expected to be developed in late 2014.

7.0 Technical Education and Outreach

The WDNR and USACE water quality modeling staff will take steps to provide transparency and education to the public during the development of the landscape and reservoir models. The following activities will allow for timely updates and data access:

- The details of this technical scope will be discussed among technical stakeholders at two meetings with technical stakeholders that will take place on November 6 and November 13, 2013 near Stevens Point, WI.

- A final modeling report which will detail the aspects of the scopes of work and model results will be available upon completion of all modeling efforts. With respect to the watershed modeling, during the model development and calibration process, technical memos will be drafted outlining the steps used to complete certain tasks.

- The USACE will provide technical training to WDNR staff regarding the CE-QUAL-W2 modeling effort that will include
    - A copy of the modeling report
    - All the required software and model files
    - Instruction on the model setup and simulation
    - Instruction on running scenarios
    - Inputting SWAT loadings

- Upon completion of the modeling, WDNR will make all model files available

- Frequent presentations will be made at various venues including the annual Wisconsin River Water Quality Improvement Symposium, North Central Wisconsin Stormwater Coalition, etc.

- Individual in-person meetings between WDNR staff and affected stakeholders are available upon request.

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