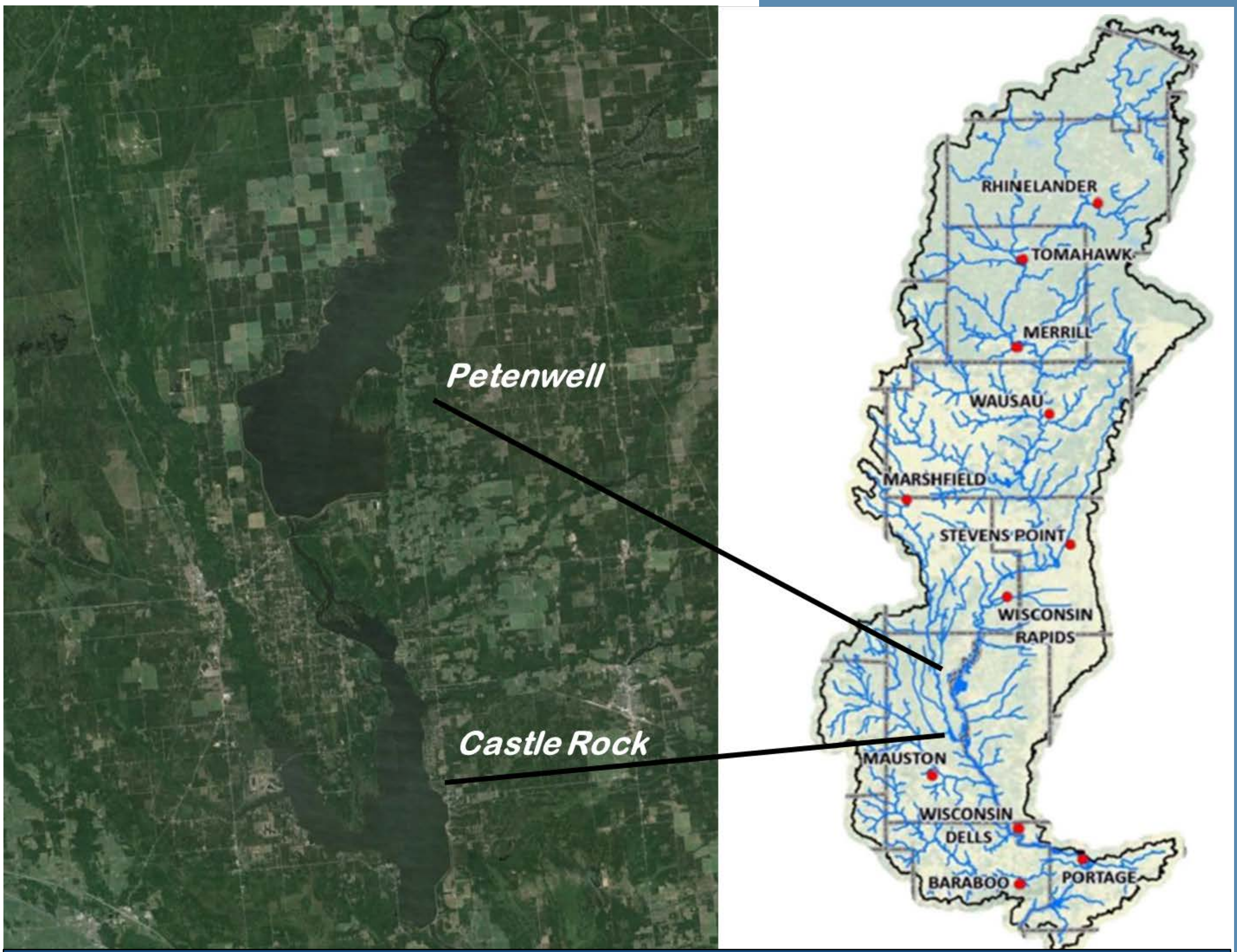

CE-QUAL-W2 Lake Response Modeling of Petenwell and Castle Rock Reservoirs for the Wisconsin River TMDL

Prepared for:

U.S. EPA Region 5

EPA Contract No: EP-BPA-13-R5-0003

EPA Task Order No: EP-B145-00008

Under Subcontract to:

RTI International

June 2016

LimnoTech

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1 Introduction

1.1 Background and Objectives

The purpose of this report is to present the development of a mechanistic water quality response model, CE-QUAL-W2, for Petenwell and Castle Rock reservoirs, for use in the development of the Wisconsin River total maximum daily load (TMDL) for total phosphorus. Petenwell and Castle Rock reservoirs are located in central Wisconsin on the mainstem of the Wisconsin River. The Wisconsin River TMDL study area drains 9,156 square miles of Wisconsin's central corridor from the basin's headwaters in Vilas County to Lake Wisconsin in Columbia County (Figure 1.1). Approximately 5,964 square miles drain to Petenwell and 6,962 square miles drain to Castle Rock. Petenwell Reservoir is 23,173 acres with a maximum depth of 44 feet. Castle Rock is 12,981 acres with a maximum depth of 36 feet.

The designated uses for these water bodies include fish and aquatic life uses designated in Wisconsin Administrative Code Chapter NR 102.04(3), specifically warm water sport fish communities designated in NR 102.04(3)(b), and recreational uses designated in NR 102.04(5). NR 102.06 includes Wisconsin's water quality standards for phosphorus, which for lakes and reservoirs depend upon the nature of stratification of the water body. Petenwell and Castle Rock reservoirs both meet the definition of a "Reservoir" in NR 102.06(2)(f) and do not meet the definition of a stratified reservoir in NR 102.06(2)(g). NR 102.06(4)(a) identifies a total phosphorus criterion of 40 micrograms per liter (µg/L) for reservoirs that are not stratified for the protection of aquatic life and recreational uses.

These reservoirs have a long history of impaired water quality conditions and are currently listed on the state and federal impaired waters list due to degraded habitat, algal problems, eutrophication, or a combination of these. Section 303(d)(1)(C) of the Clean Water Act (CWA) and its associated policy and program requirements for water quality planning, management, and implementation (Title 40 of the Code of Federal Regulations Part 130) require the establishment of a TMDL for the achievement of state water quality standards when a water body is impaired. The excessive nutrient loading to Petenwell and Castle Rock reservoirs results in low levels of dissolved oxygen and severe algal blooms. The phosphorus loads come from a combination of natural sources such as wetlands and forests, runoff from the agricultural landscape, municipal and industrial wastewater treatment plants, and urban runoff (http://dnr.wi.gov/topic/TMDLs/documents/WisconsinRiver/WQIPTMDL.pdf).

These reservoirs are important recreational, industrial, and natural resources, so 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. For this purpose, the CE-QUAL-W2 model was selected to assess the response of Petenwell and Castle Rock to phosphorus loads. The model will be used to inform the development of the TMDL to support the restoration and protection of beneficial surface water uses in Petenwell and Castle Rock reservoirs. This project was conducted to accomplish the following objectives:

- Develop CE-QUAL-W2 models of existing conditions in Petenwell and Castle Rock reservoirs;
- Calibrate the models with available monitoring data from 2010–2013; and
- Determine the quantity of total phosphorous load reduction needed in each reservoir to achieve numeric water quality standards for the purpose of establishing a TMDL.

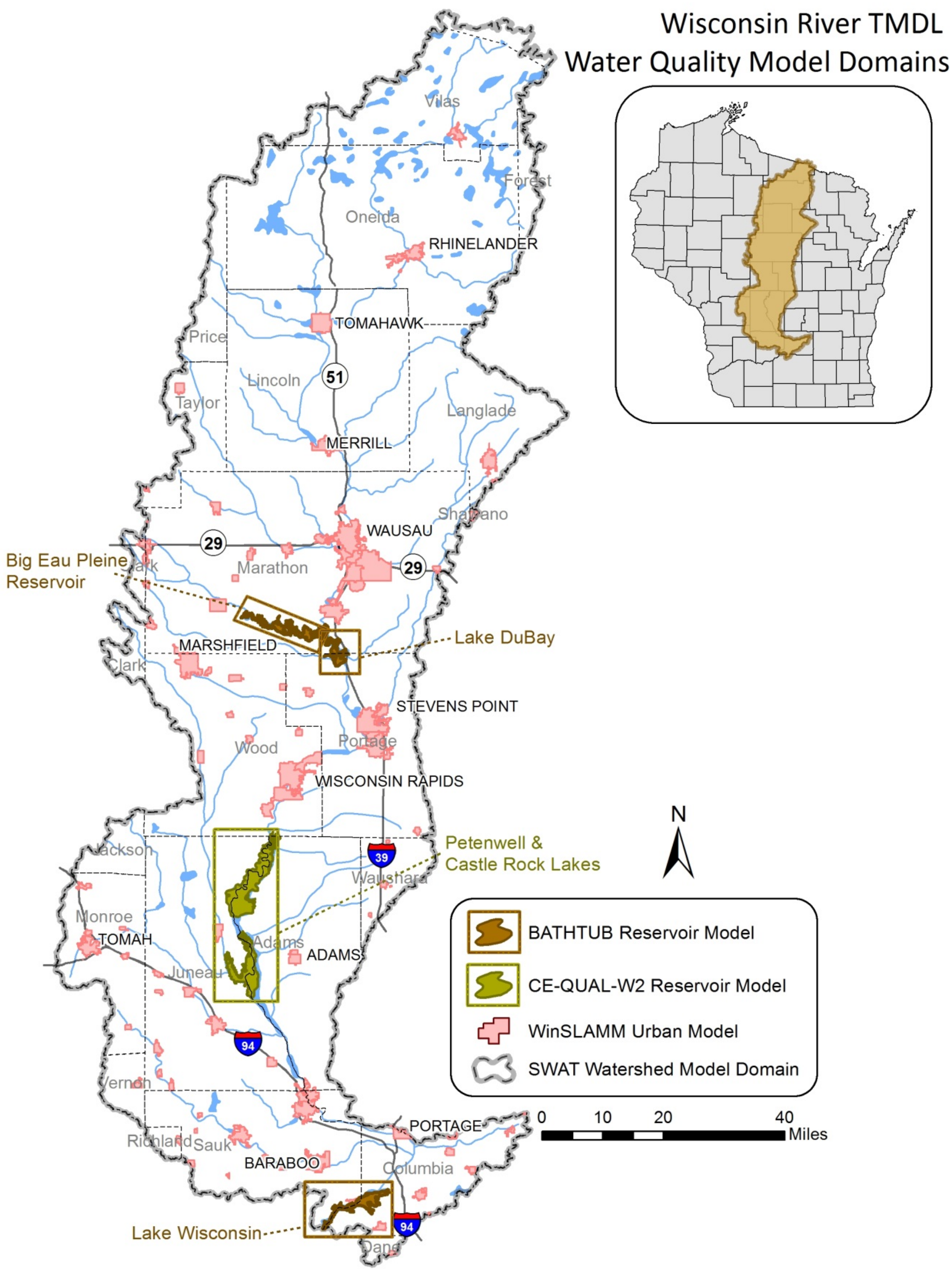

Figure 1.1. Wisconsin River TMDL Study Area and Model Domains

1.2 Project and Report Organization

The U.S. Environmental Protection Agency (EPA) Region 5 provided the funding for this project. EPA Region 5 also provided technical advice, oversight and contract administration. The Wisconsin Department of Natural Resources (WDNR) is the beneficiary of this work and provided technical guidance and state-level information. RTI International is a fiduciary of the EPA funding through a task order (TO) under an EPA contract titled Technical Support for the EPA Region 5 Watershed Program for the Mississippi River Basin and the EPA/State Work Share Initiative (EP-BPA-13-R5-0003). LimnoTech, under subcontract to RTI, performed the technical analysis supporting model development. Work performed under this contract was conducted consistent with the project Quality Assurance Project Plan (QAPP, LimnoTech, January 30, 2015).

The remainder of this report is organized as follows:

- Section 2. CE-QUAL-W2 Description;
- Section 3. Model Input Development;
- Section 4. Integration of SWAT Model Results;
- Section 5. Water Mass Balance;
- Section 6. Model Calibration; and
- Section 7. Load Reduction Scenarios.

2 CE-QUAL-W2 Description

The WDNR selected the CE-QUAL-W2 model to simulate the water quality response of Petenwell and Castle Rock reservoirs to phosphorus loads. CE-QUAL-W2 is a two-dimensional, laterally averaged hydrodynamic and water quality model maintained by the U.S. Army Corps of Engineers (USACE) (Cole and Wells, 2013). CE-QUAL-W2 predicts variations in water movement, temperature, and water quality constituents longitudinally and vertically. Lateral variations are assumed to be minor compared to longitudinal and vertical variations such that average water quality conditions across the width of the reservoir are assumed. This is generally a valid assumption in many reservoir systems.

CE-QUAL-W2 was originally developed in the 1970s as a hydrodynamic model, the Laterally Averaged Reservoir Model (Edinger and Buchak, 1975). Development of the model by the USACE and Portland State University (PSU) has continued over the past several decades. Subsequent revisions have added the capability to simulate multiple arms of a reservoir, multiple water bodies in series, and water quality kinetics to the original water movement and temperature predictions. CE-QUAL-W2 Version 3.71, released by PSU, was used in this project to model Petenwell and Castle Rock reservoirs.

CE-QUAL-W2 is based upon a finite difference solution of the laterally averaged equations of fluid motion including:

- Free water surface;
- Hydrostatic pressure;
- Horizontal momentum;
- Continuity;
- Constituent transport; and
- An equation of state relating density and constituents including temperature and solids concentrations.

The hydrodynamic component of the CE-QUAL-W2 model can simulate the water balance and the heat balance of the lake. The water balance can be verified with a combination of measured flow inputs, flow outputs, and water surface elevation data if it is available. The heat balance can be verified with observed water temperature data.

The water quality component of the CE-QUAL-W2 model can be utilized to simulate eutrophication processes in response to nutrient loading. The model is capable of simulating a number of water quality constituents and these can be included or excluded depending on modeling objectives.

Nutrient release from the sediments can be simulated in a relatively simple manner, where it is assumed to be proportional to a specified sediment oxygen demand rate. Nutrient release is restricted to conditions when dissolved oxygen concentrations are below a specified threshold value.

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3 Model Input Development

3.1 Overview

The CE-QUAL-W2 model input development for Petenwell and Castle Rock reservoirs encompasses the following components:

- Meteorological conditions;
- Bathymetry and model segmentation;
- Upstream and tributary boundary conditions;
- Flows
- Water quality
- Point source discharges; and
- Initial conditions for water levels and water quality.

This section summarizes the development of these model inputs. Data from 2009 through 2013 were reviewed to assess their adequacy to support model development and calibration. The limited amount of observed data in 2009 did not support model input development. Therefore, the model inputs were developed to start on November 1, 2009 and run through December 31, 2013. November 1, 2009 through the end of 2009 was considered a model “spin-up” period to reduce the influence of initial conditions, although data through April 2010 were also relatively sparse. The available data for 2010–2013 were used for the calibration process and were determined to be sufficient to support a quantitative assessment of model calibration.

3.2 Meteorological Conditions

CE-QUAL-W2 requires a description of meteorological conditions that can affect water temperature and biological processes such as photosynthesis. The University of Wisconsin (UW)—Extension Hancock agricultural research station is located approximately 22 miles east of Petenwell Lake and near interstate highway I-39 (LAT 44.12, LON -89.53). UW maintains a meteorological station at this location that has been in operation since 1985. The data were downloaded from the UW Extension Ag Weather website (http://agwx.soils.wisc.edu/uwex_agwx/awon/). Figure 3.1 depicts the location of the Hancock weather station relative to Petenwell reservoir.

Thirty minute records were available for the required meteorological parameters for the simulation period, except for cloud cover (reported as percent clear sky), which was available on a daily basis. The available 30-minute data includes air temperature, dew point temperature, wind speed, wind direction and solar radiation. The Hancock station meteorological records were reviewed for completeness and quality, found to be adequate to support modeling, and then processed into a format suitable for model input development.

The wind meter height was set to 10 meters following confirmation from staff at the Hancock station that the anemometer is at the top of a 30' tower.

Figure 3.1. Location of Hancock Meteorological Station

3.3 Bathymetry and Model Segmentation

A model segmentation scheme was constructed by USACE for the two reservoirs in cooperation with WDNR prior to the work performed under the EPA contract by RTI and LimnoTech. The segmentation scheme was based on bathymetric data provided by Fishing Hot Spots, Inc. The bathymetric data are not available to be freely disseminated due to the requirements of a limited use agreement with Fishing Hot Spots. LimnoTech verified the USACE segmentation with the Fishing Hot Spots bathymetry data and concluded that the segmentation was sufficient to support the modeling. Figure 3.2 presents the model segmentation schematic and segment numbering. Each surface segment is underlain by multiple layers. The USACE assigned a depth of 0.98 meters in Petenwell for all layers. In Castle Rock, the USACE assigned a depth of 0.5 meters in the top seven layers, and a depth of 1 meter in the lower layers. A representation of the longitudinal profile of the segmentation layers are presented in Figures 3.3 and 3.4; however, these figures are not shown to scale. Also note that the depth of the top layer in the CE-QUAL-W2 model varies to account for changes in water surface elevation.

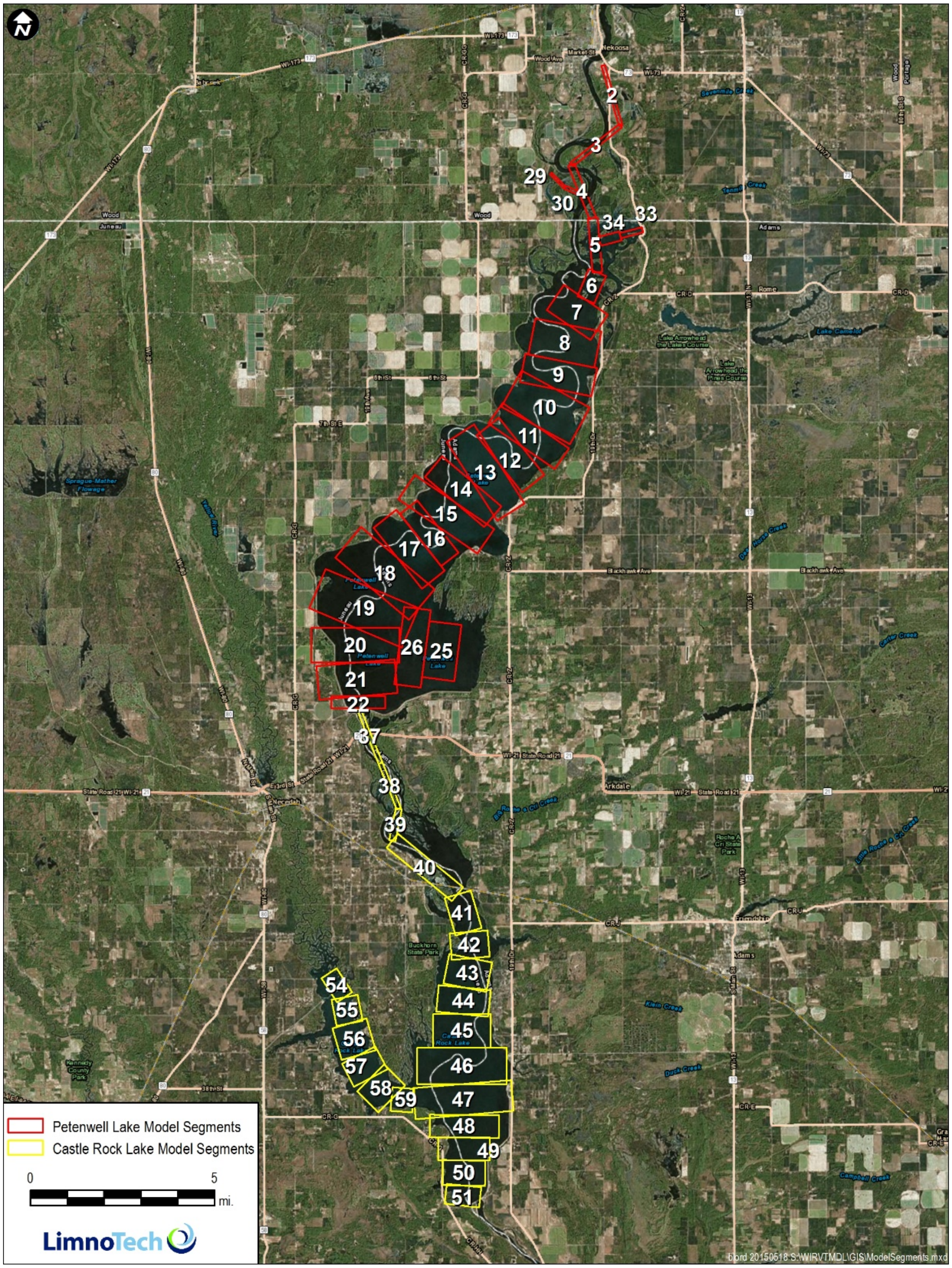

Figure 3.2. Model Segmentation Schematic

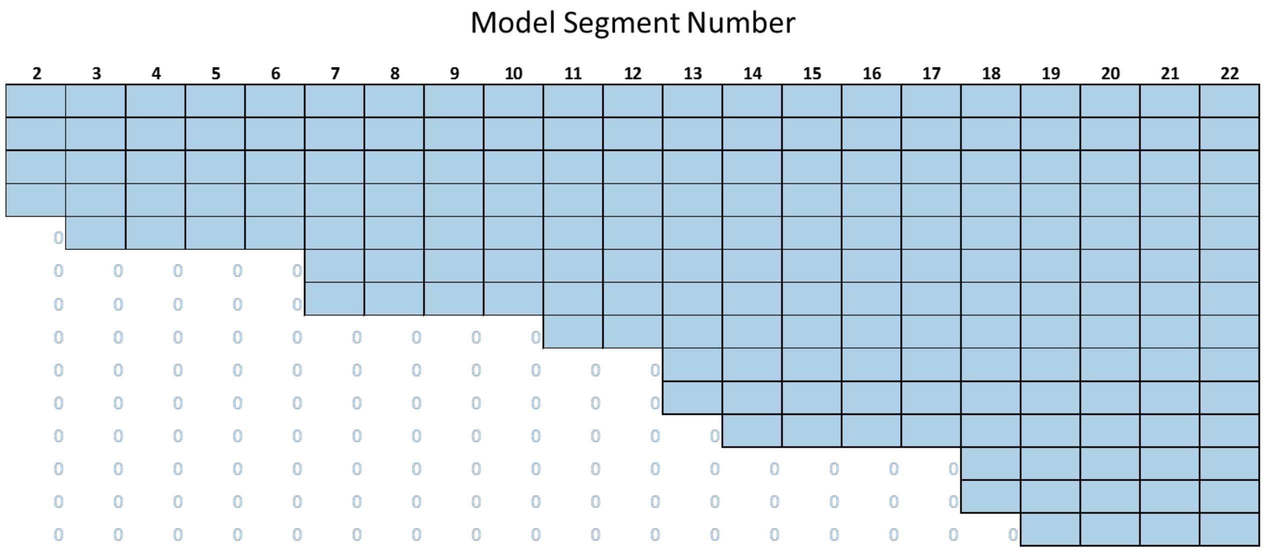

Figure 3.3. Petenwell Longitudinal Profile

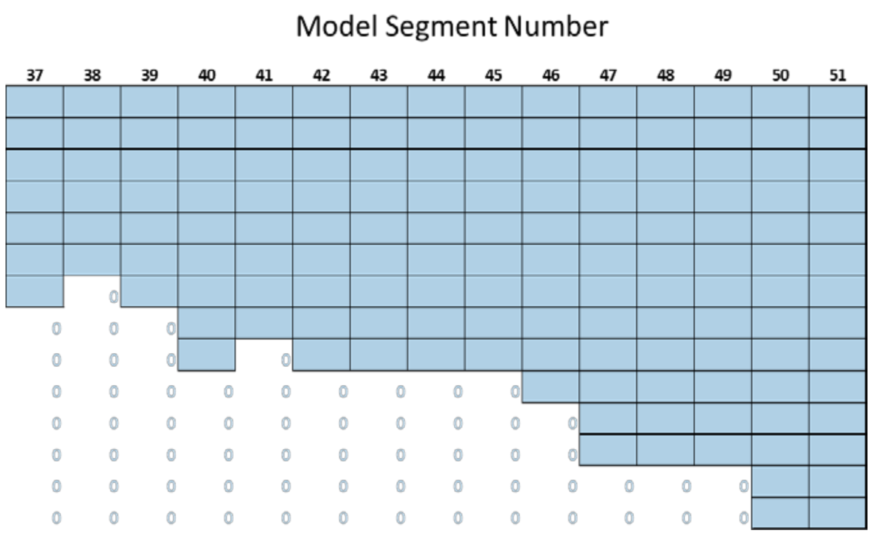

Figure 3.4. Castle Rock Longitudinal Profile

3.4 Upstream and Tributary Boundary Conditions

Model inputs describing the flows and water quality entering the reservoirs during the model simulation period were needed. This information was developed using measurements of flow and water quality, where available, to characterize the required model inputs. Where measurements were not available, estimates were developed using the best available information. Numerous flow gauges were operational and a comprehensive water quality sampling program was conducted during the model simulation period. These monitoring locations are presented in Figures 3.5 and 3.6.

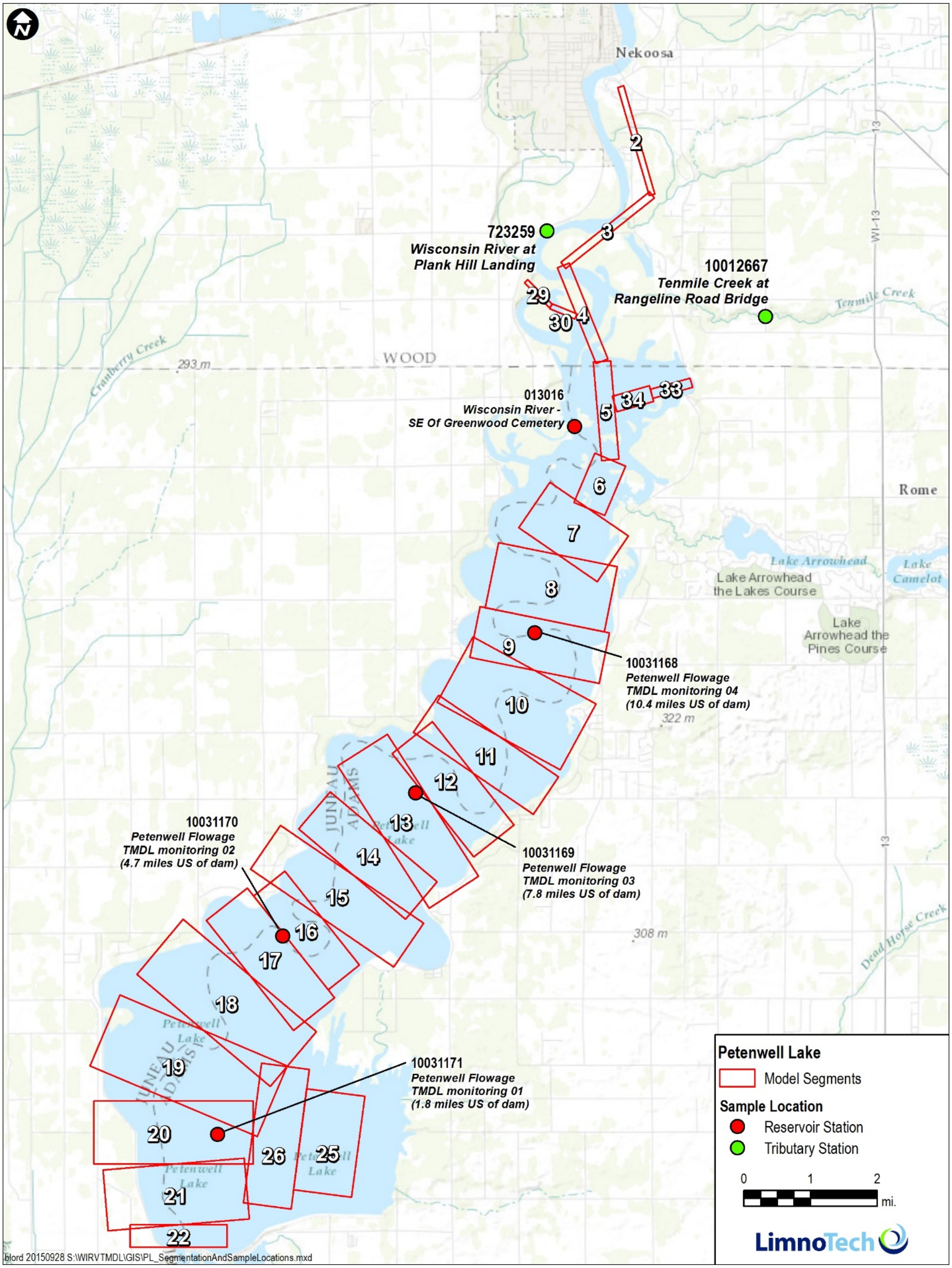

Figure 3.5. Petenwell Monitoring Stations

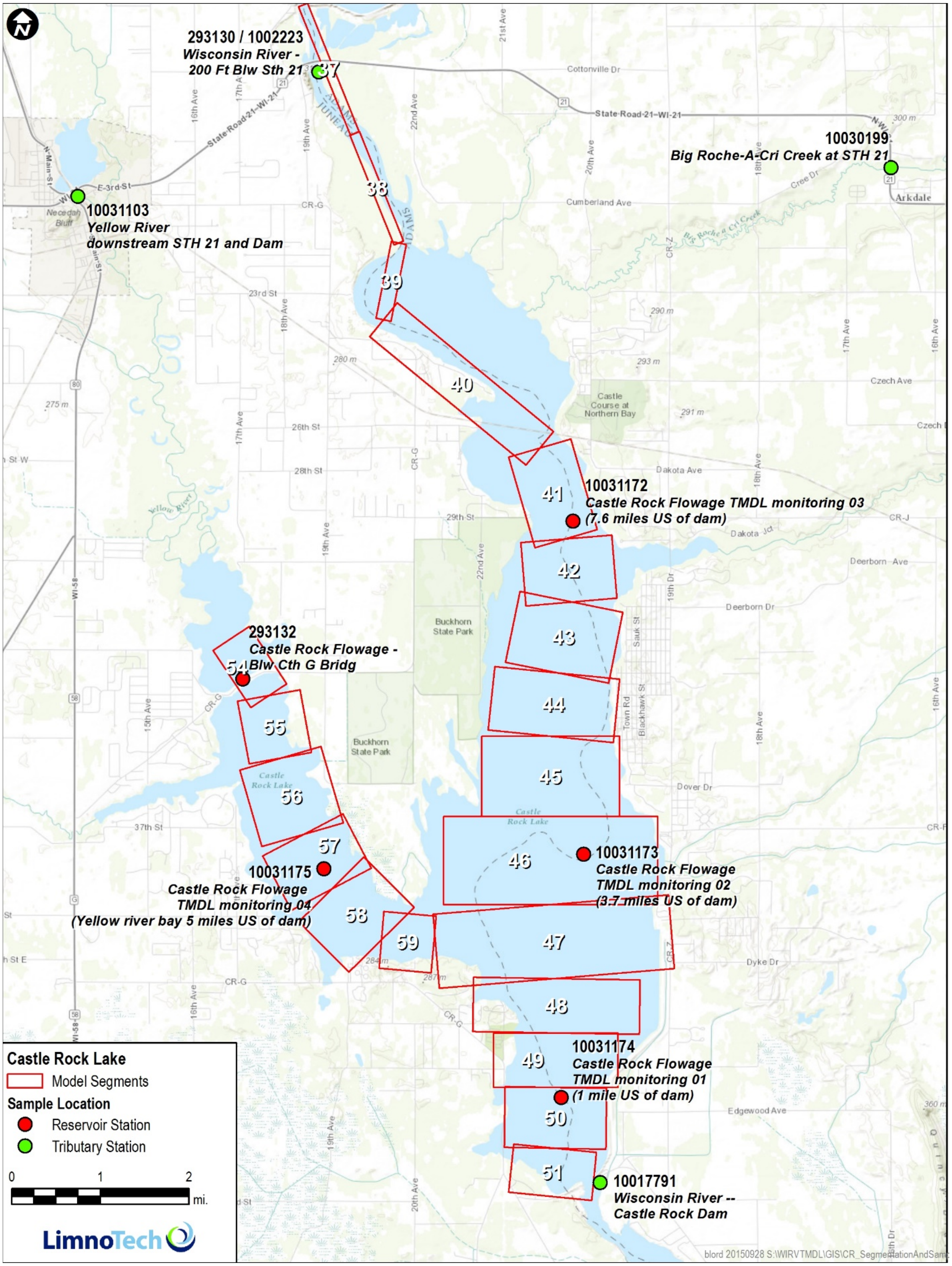

Figure 3.6. Castle Rock Monitoring Locations

3.4.1 Flows

Upstream and major tributary daily discharge data were available for most of the modeling simulation period (November 1, 2009–December 31, 2013) at specific tributary monitoring locations as shown in Figure 3.5 and Figure 3.6. These stations include the following: U.S. Geological Survey (USGS) gauge #05400980 on the Wisconsin River at Nekoosa Dam; USGS gauge #05401050 on Tenmile Creek near Nekoosa; USGS gauge #05401556 on Big Roche A Cri Creek at State Hwy 21 near Arkdale; and USGS gauge #05403000 on the Yellow River at Necedah.

Upstream flows to Petenwell were available for the Wisconsin River at Nekoosa Dam (Station 723259, USGS gauge #05400980) for the entire simulation period. Tributary flows to Petenwell were also available for Ten Mile Creek near Nekoosa (Station 10012667, USGS gauge #05401050) for the entire simulation period. Tributary flows into Castle Rock were available from May 1, 2010 through 2013 for Big Roche A Cri Creek at Hwy 21 (Station 10030199, USGS gauge #05401556) and Yellow River at Hwy 21 (Station 10031103, USGS gauge #05403000). November 2009 through April 2010 flows for these two tributary stations were estimated based on correlating the available daily flows at these locations to other stations to fill this 6-month data gap, with the specific method described in the following paragraphs.

Daily flows for Big Roche A Cri Creek exhibited a strong correlation ($r^2 = 0.81$) with Ten Mile Creek flows using an exponential relationship for the period of available overlapping records (May 1, 2010, through December 31, 2013). A strong linear correlation ($r^2 = 0.77$) was also found.

Daily flows for Yellow River at Hwy 21 exhibited a strong correlation ($r^2 = 0.85$) with flows at an upstream location (Yellow River at Babcock—USGS gauge #05402000, downloaded from USGS) using a power function relationship for the period of available overlapping records (May 1, 2010, through December 31, 2013). Adding travel times between the stations (1 day or more) failed to improve the correlation, and linear relationships between the two stations were not strong (e.g., $r^2 < 0.4$).

While application of drainage area ratios between these tributary stations and the Ten Mile Creek (or other) station could be used to roughly estimate daily flows, the selected nonlinear correlations provide a reasonable basis for filling the November 2009–April 2010 flow data gap. These tributaries represent less than 12% of the total flow entering the reservoirs, exclusive of direct drainage inflows which were also estimated as discussed below. The selected estimation approach to fill this data gap did not impact the modeling effort in any significant way, since the flows are relatively small and are estimated for only the first 6 months of the model simulation, inclusive of the spin-up period. The resulting correlations are as follows:

$$Q_{Big\ Roche\ A\ Cri} = 50.304827 * e^{0.010435 * QTenMile}$$

$$Q_{YellowRiver} = 5.982572 * Q_{YellowRiver@Babcock}^{0.835365}$$

Where

$Q_{Big\ Roche\ A\ Cri}$ = Stream flow at Big Roche A Cri Creek (cms)

$Q_{TenMile}$ = Stream flow at Ten Mile Creek (cms)

$Q_{YellowRiver}$ = Stream flow for Yellow River at Hwy 21 (cms)

$Q_{YellowRiverr@Babcock}$ = Stream flow for Yellow River at Babcock (cms)

3.4.1.a Ungauged Tributary and Direct Drainage Inflows

Ungauged tributary and direct drainage inflows to the reservoirs were estimated using available tributary station daily flow time series, with scaling factors applied based on the ratio of each drainage area relative to an assigned tributary station drainage area. The tributary and direct drainage areas where this method was used, and the corresponding assigned tributary stations and drainage area ratios, are summarized in Tables 3.1 and 3.2. The ungauged estimated flows are approximately 7% of the total flows entering the reservoirs. Therefore, the precision of the estimation method is not critical.

3.4.1.b Dam Outflow

Petenwell and Castle Rock dam operation records supplied by WDNR covered 2009–2012 and were supplemented by records provided by the Wisconsin Public Service power company for 2013 to provide continuous data on flows through the dams at hourly intervals. Both generator and gate flow records were available to use in the modeling effort. These flows were processed to daily averages for consistency with the available upstream and tributary flow records, but are still reflective of significant flow variations that occur seasonally or due to runoff events.

Table 3.1. Petenwell Direct Drainage Adjustments

Drainage Area	SWAT Subbasin(s)	Monitored Station	Surrogate Station	Area Coverage (acres)	Drainage Area Ratio	Receiving Model Segment
Upstream Wisconsin River	All upstream subbasins	Flow at 05400980 Nekoosa Dam and Water Quality at 723259 Plank Hill	N/A	Upstream of Station: 3,601,317	1.00	2
Ten Mile Creek	142, 255	Flow and Water Quality at 10012667 Ten Mile Creek	N/A	Upstream of Station: 65,477 Downstream of Station: 3,362	1.05	4
Lake Arrowhead and Lake Sherwood	76, 77	N/A	Flow and Water Quality at 10012667 Ten Mile Creek	65,392	0.999	6
Direct Drainage, Petenwell	74, 143	N/A	Flow and Water Quality at 10012667 Ten Mile Creek	58,062	0.905	13

Table 3.2. Castle Rock Direct Drainage Adjustments

Drainage Area	SWAT Subbasin(s)	Monitored Station	Surrogate Station	Area Coverage (acres)	Drainage Area Ratio	Receiving Model Segment
West Petenwell Ditch	73	N/A	Flow and Water Quality at 10031103 Yellow River	11,081	0.032	37
Big Roche A Cri Creek	141, 254	Flow and Water Quality at 1030199 Big Roche A Cri	N/A	Upstream of Station: 91,498 Downstream of Station: 7,394	1.08	40
Little Roche A Cri Creek	311, 75, 202, 253	N/A	Flow and Water Quality at 1030199 Big Roche A Cri	87,807	0.96	42
Klein Creek	251	N/A	Flow and Water Quality at 1030199 Big Roche A Cri	21,419	0.23	46
Direct Drainage, Castle Rock Lake	59	N/A	Flow and Water Quality at 1030199 Big Roche A Cri	35,092	0.38	45
Yellow River	275, 71, 70, 69, 68, 66, 307, 314, 201, 62, 313, 72, 67, 65, 200, 64, 63, 140, 61, 199, 60	Flow and Water Quality at 10031103 Yellow River	N/A	Upstream of Station: 342,935 Downstream of Station: 28,817	1.08	54

3.4.2 Water Quality

Water quality parameter time series boundary conditions were developed based on two key sources:

- WDNR's monitoring program (grab and continuous sampling data) for this TMDL study; and
- USGS FLUXMASTER daily loading estimates developed for the upstream and tributary stations.

Incorporation of three different types of data (grab, continuous, and USGS daily load estimates) resulted in boundary conditions with varying frequency (daily to weekly to seasonal) by location and parameter. Additionally, some degree of extrapolation and approximation assumptions were used to estimate beginning (i.e., November 1, 2009) and ending (i.e., December 31, 2013) values for some parameters where needed. Lastly, both the observed and estimated (e.g., USGS loads) data did not directly correspond to each CE-QUAL-W2 model state variable that was simulated to assess in-lake eutrophication. Development of the required state variable values from available data is described in the following subsections.

Addressing the combination of different data types to form boundary conditions was relatively straightforward. Where available for a particular water quality constituent, USGS-estimated daily loads were utilized to specify daily concentrations. On days where grab sample data supporting the load estimates were available, the observed data were used instead of USGS load estimates. However, USGS FLUXMASTER load estimates for Big Roche A Cri Creek at Hwy 21 (Station 10030199) and Yellow River at Hwy 21 (Station 10031103) did not begin until May 1, 2010. For the period from November 1, 2009 through April 30, 2010 at the beginning of the model simulation, grab sample data were used when available to construct interpolated daily estimates for input of these boundary conditions to the model.

Initial boundary condition values for November 1, 2009 were based either on available USGS-estimated loads or estimated based on median concentrations of available daily data (load estimates or grab sample). In either case, the significance of this assumption is nominal given that the first few months of the simulation is a spin-up period for the model calibration effort. Ending values (December 31, 2013) were also estimated since water quality sampling by WDNR ended in October 2013. Ending values were either based on the available USGS daily load estimates or simply assumed to be the same as the beginning values. The significance of this assumption (as noted previously) is again nominal, at least with respect to model calibration (e.g., no model-data comparisons can be conducted beyond the monitoring period).

The above methodology for model boundary condition inputs applies to all CE-QUAL-W2 state variables other than water temperature and dissolved oxygen (DO). Both grab sample and continuous monitoring data were available for these two parameters, but not USGS loading estimates. In this case, continuous data daily averages were filtered to remove obvious errors (e.g., large temperature or DO deviations from nearby grab sampling results, which sometimes occurred towards the end of a few metering deployments). The daily averages from continuous metering were utilized when available to specify temperature and DO boundary conditions. Grab sampling data were used to fill gaps either within or outside of the continuous meter deployments. Any remaining gaps in time for these data were retained, as was done for other water quality constituents to allow for interpolation to daily time series estimates to fill these gaps within the model calibration period. Beginning values for temperature boundary conditions were based on sampling on November 17, 2009 near the start of the simulation (November 1, 2009) and set at 8.0°C. DO concentrations were assumed to be 90% of saturation (approximate average saturation of the available data). In either case, the significance of this assumption is nominal given that the first few months represent a spin-up period for the model simulation. Ending (December 31, 2013) values for temperature and DO were simply assumed to be the same as the beginning values because sampling ended in October 2013. The significance of this assumption (as noted previously) is again nominal, at least with respect to model calibration (e.g., no model-data comparisons can be made beyond the monitoring period).

3.4.2.a Algal Biomass

The development of boundary conditions for algal biomass was based on both chlorophyll-a (Chl-a) measurements and initial model calibration parameter assumptions. Algal biomass (and its associated carbon content) must be estimated to develop concentrations for organic matter carbon state variables.

Three functional algal groups were simulated in the CE-QUAL-W2 model for Petenwell and Castle Rock reservoirs. Wisconsin DNR provided LimnoTech with phytoplankton data measured at five reservoir stations (13016, 10031169, 1003117, 10031175, and 10031173) and two mainstem stations (72359 and 293130) for the years 2010–2013. Phytoplankton taxa were identified to the lowest taxonomic level, which was genus or species in most cases. The following phyla were represented in the data:

- Phylum Bacillariophyta (diatoms);
- Phylum Chlorophyta (green algae);
- Phylum Cryptophyta (cryptomonads);
- Phylum Cyanophyta (blue-green algae);
- Phylum Euglenophyta (euglenoids); and
- Phylum Pyrrophyta (dinoflagellates).

For each sample, taxa abundance (cells/mL) and total biovolume (mm^3/L) are reported.

Phyla Euglenophyta and Pyrrophyta are not well represented spatially and temporally in Petenwell and Castle Rock reservoirs, whereas the other phyla are well distributed in space and time. Consequently, the following functional algal groups were selected for model simulation:

- ALG1: Blue-green algae (all representative taxa in phylum Cyanophyta);
- ALG2: Diatoms (all representative taxa in phylum Bacillariophyta); and
- ALG3: Other assemblage (phyla Chlorophyta and Cryptophyta).

Data-based algal biomass estimates assigned to one of three algal assemblages were evaluated for Station 723259 (Wisconsin River at Nekoosa Dam) in relation to corresponding reported total Chl-a observations to develop the requisite algal state variable (blue-greens [ALG1], diatoms [ALG2], and other [ALG3]) biomass concentration upstream boundary conditions for the CE-QUAL-W2 model simulation period. The model calibration target was observed Chl-a at monitoring locations in Petenwell and Castle Rock reservoirs, not algal biomass. Therefore, the fractional contribution to Chl-a of each modeled algal group at Station 723259 was estimated for each sampling date. This estimate was based on model parameterization assumptions described in the project QAPP (e.g., ALGC—an algal carbon to biomass ratio of 0.45 mg C/mg dry weight [d.w.] for all algal forms) along with initial algal group-specific model parameterization assumptions that were used in modeling Lake Pepin (50 mg C/mg Chl-a for diatoms, and 33 mg C/mg Chl-a for blue-greens and other).

Additionally, algae and Chl-a sampling events primarily occurred during spring, summer and fall conditions beginning in 2010, so assumptions regarding algal biomass concentrations during cold winter periods were applied to fill this data gap as needed. Specifically, it was assumed that wintertime algal biomass was low (0.111 mg d.w./L) and had order of magnitude dominance (similar to spring conditions) in order of diatoms (0.1 mg d.w./L) to other (0.01 mg d.w./L) and to blue-greens (0.001 mg d.w./L). The Chl-a concentration corresponding to this assumed wintertime biomass is negligible (approximately 1 µg/L), so the impact of this assumption with respect to the direct external loading of algal biomass to the lakes during these data gap periods is minimal relative to that occurring during the monitored spring through fall periods. A daily time series of estimated biomass concentrations was developed based upon these assumptions by linearly interpolating between sampling event or data gap-filling dates. Figure 3.7 presents the estimated algal group upstream boundary condition time series in terms of Chl-a and the related Chl-a-constrained algal biomass concentrations.

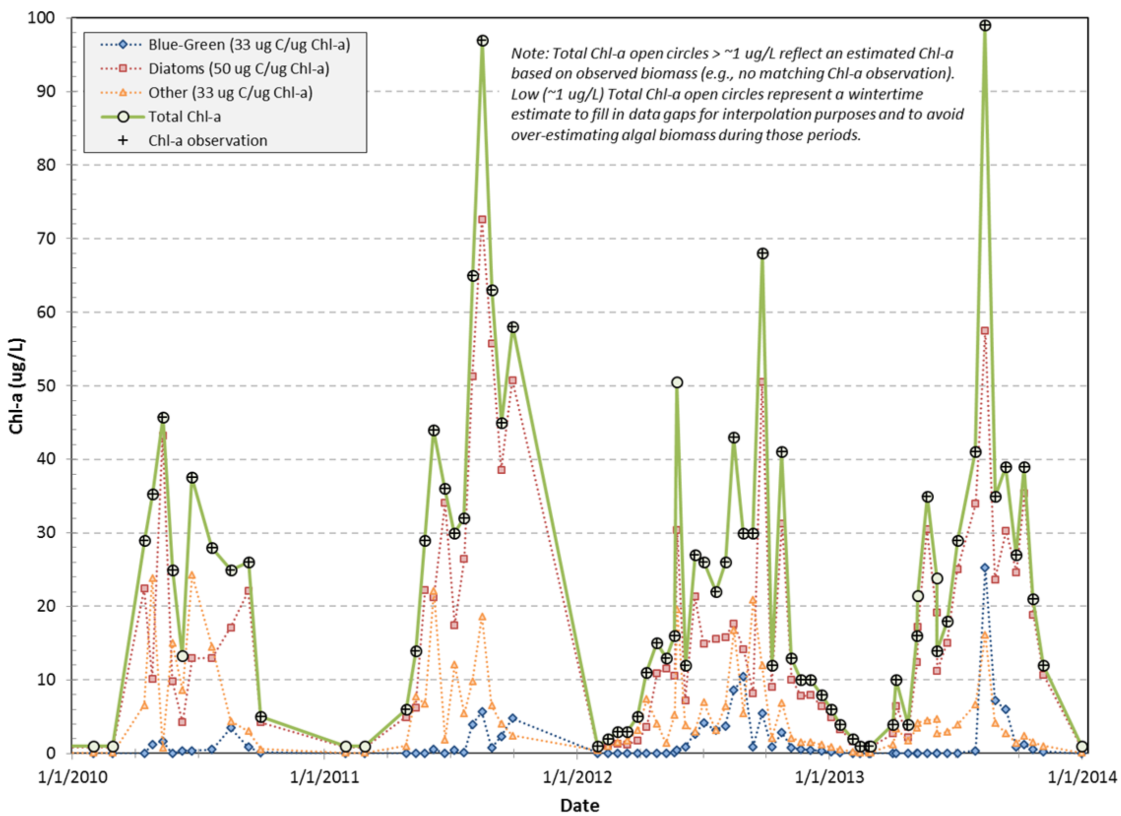

Figure 3.7. Estimated Algal Group Chl-a Based on Algal Biomass Fractions and Assumed Carbon to Chl-a Ratios for Petenwell Upstream Boundary (Station 723259)

Seasonal algal inputs from tributaries were developed by WDNR using available Chl-a data from Wisconsin streams with, and without, upstream reservoirs, as tributary data for Chl-a in the study area was limited (i.e., a total of three observations). A summary of the seasonal algal inputs for tributaries is presented in Table 3.3. The low and high values of algal inputs were based on a WDNR assessment of available data. Low values apply to tributaries without an upstream reservoir. High values apply to tributaries with an upstream reservoir. The algal suspended solids, phosphorus and nitrogen components of algal biomass were accounted for in each boundary condition value. These seasonal average Chl-a values were assigned to each day for which observations were not available to serve as both a boundary condition for algal biomass and to support computation of boundary conditions for the organic carbon state variables. The overall average estimated biomass was split among the three algal groups based on the average observed distribution at Station 723259 (~5% blue-greens, ~78% diatoms, and ~17% other).

Table 3.3. Seasonal Algal Inputs for Tributaries

Season	Low Chl-a (µg/L)	High Chl-a (µg/L)
Winter (Dec-Mar)	1.5	1.5
Spring (Apr-May)	2.9	12
Summer (Jun-Sep)	2.1	8.9
Fall (Oct-Nov)	1.5	6.4

3.4.2.b Boundary Conditions for Model State Variables Not Directly Measured

A number of the CE-QUAL-W2 model state variables are directly input based on measured data, but this was not feasible in all cases. The relationship between measured and imputed water quality constituents required for the Petenwell and Castle Rock eutrophication modeling is described by Table 3.4. Imputed water quality constituents were determined through subtraction between measured or estimated (e.g., USGS FLUXMASTER loads) constituents in some instances, resulting in an infrequent potential for negative concentrations (e.g., measured DOC > TOC). All negative imputed water quality constituent concentrations were set to zero for the development of the model boundary conditions.

Table 3.4. Determination of CE-QUAL-W2 State Variables Based on Observed Water Quality Parameters

CE-QUAL-W2 State Variable	CE-QUAL-W2 State Variable Description	Directly Measured?	Measured Parameters Used to Estimate State Variable	Model Coefficients Used to Estimate State Variable	Other Initial Assumptions to Estimate State Variable
TEMP (deg C)	Water Temperature	Yes	---	---	---
DO (mg/L)	Dissolved Oxygen	Yes	---	---	---
ALG (mg/L)[1]	Algal Biomass	No	ALG = Chl-a * ACHLA	ACHLA[2]	---
ISS (mg/L)	Inorganic Suspended Solids	No	ISS = TSS - ALG -POM	ACHLA[2]	---
LDOM-C (mg/L)	Labile Dissolved Organic Carbon (OC)	No	DOC	---	15% labile
RDOM-C (mg/L)	Refractory Dissolved OC	No	DOC	---	85% refractory
LPOM-C (mg/L)	Labile Particulate OC	No	POC = TOC - DOC - ALG*ALGC	ACHLA[2], ALGC[3]	15% labile
RPOM-C (mg/L)	Refractory Particulate OC	No	POC = TOC - DOC - ALG*ALGC	ACHLA[2], ALGC[3]	85% refractory
NH4-N (mg/L)	Ammonia Nitrogen	Yes	---	---	---
NOX-N (mg/L)	Nitrate + Nitrite Nitrogen	Yes	---	---	---
LDOM-N (mg/L)	Labile Dissolved Organic Nitrogen (ON)	No	TON = TKN - NH4-N - ALG*ALGN	---	15% labile, 60% dissolved
RDOM-N (mg/L)	Refractory Dissolved ON	No		---	85% refractory, 40% particulate
LPOM-N (mg/L)	Labile Particulate ON	No		---	15% labile, 60% dissolved
RPOM-N (mg/L)	Refractory Particulate ON	No		---	85% refractory, 40% particulate
PO4-P (mg/L)	Dissolved Ortho-Phosphate	Yes	---	---	---
LDOM-P (mg/L)	Labile Dissolved Organic Phosphorus (OP)	No	TOP = TP - PO4-P - ALG*ALGP	---	15% labile, 20% dissolved
RDOM-P (mg/L)	Refractory Dissolved OP	No		---	85% refractory, 20% dissolved
LPOM-P (mg/L)	Labile Particulate OP	No		---	15% labile, 80% particulate
RPOM-P (mg/L)	Refractory Particulate OP	No		---	85% refractory, 80% particulate
CBOD (mg/L)	Point Source CBOD	Yes	---	---	---

Notes:

1. ALG = three separate algal groups were simulated (blue-greens, diatoms and other assemblage)
2. ACHLA = algal biomass to Chl-a ratio = 0.1 mg algae/ug Chl-a (see modeling QAPP)
3. ALGC = carbon to algal biomass ratio = 0.45 mg C/mg algae (see modeling QAPP)

3.5 Point Source(s)

The O'Dell Bay Sanitation District wastewater treatment plant (WWTP) discharges in the Yellow River Arm of Castle Rock. Reported monthly point source flows and water quality constituent concentrations for the O'Dell Bay Sanitation District WWTP were provided by WDNR for 2009–2013. These data were processed in a manner consistent with the treatment of the development of water quality state variable boundary conditions, except that the carbonaceous biochemical oxygen demand (CBOD) for this point source was incorporated as a separate state variable in the CE-QUAL-W2 model, rather than as estimated organic matter carbon constituents. DO and temperature data for the WWTP were not available, so the discharge was assumed to have a constant DO concentration of 6 mg/L and a nominal temperature of 20°C. These simplistic assumptions have a negligible impact on the modeling results, since the effluent discharge for the O'Dell Bay plant is quite small with an average flowrate of 0.0377 million gallons per day during the simulation period.

3.6 Initial Conditions

Petenwell and Castle Rock water surface elevations recorded by Wisconsin Power on November 1, 2009 were 923.60' in relation to the National Geodetic Vertical Datum (NGVD) and 881.80' NGVD, respectively, and were used to set the initial pool levels for the CE-QUAL-W2 model calibration. These are near the normal pool level for each reservoir which are 923.5' NGVD for Petenwell and 881.5' NGVD for Castle Rock.

Initial water quality condition inputs for the CE-QUAL-W2 modeling of Petenwell and Castle Rock reservoirs were developed based on WDNR reservoir water quality monitoring data from November 17, 2009, to be reflective of the November 1, 2009 model simulation start date. Grab sampling data across all stations in both reservoirs were analyzed to characterize representative initial conditions. Median values for the representative observations were then processed in the same manner used for the development of the water quality state variable boundary conditions. Table 3.5 presents the resulting water quality initial conditions that were used for the CE-QUAL-W2 model calibration. The table also indicates which sampling events or sampling event periods were utilized in developing the initial conditions for each water quality model state variable. Because a spin-up period was used to initiate the modeling period, a uniform characterization of water quality conditions in the reservoirs for the initial conditions was sufficient to meet the modeling needs of the TMDL study.

Table 3.5. Development of CE-QUAL-W2 Initial Conditions

Water Quality Parameter	Initial Condition	Sampling Events
Water Temperature, TEMP (deg C)	8.0	11/17/2009
Dissolved Oxygen, DO (mg/L)	12.3	11/17/2009
Inorganic Suspended Solids, ISS (mg/L)	7.8	All Events (TSS)
Algal Biomass for each group, ALG1, ALG2 and ALG3 (mg/L)	0.25	All November Events
Labile Dissolved Organic Carbon, LDOM-C (mg/L)	2.10	All Events (TOC, DOC)
Refractory Dissolved Organic Carbon, RDOM-C (mg/L)	11.90	All Events (TOC, DOC)
Labile Particulate Organic Carbon, LPOM-C (mg/L)	0.38	All Events (TOC, DOC)
Refractory Particulate Organic Carbon, RPOM-C (mg/L)	2.18	All Events (TOC, DOC)
Ammonia Nitrogen, NH4-N (mg/L)	0.16	11/17/2009
Nitrate + Nitrite Nitrogen, NOX-N (mg/L)	0.2645	11/17/2009
Labile Dissolved Organic Nitrogen, LDOM-N (mg/L)	0.0837	11/17/2009
Refractory Dissolved Organic Nitrogen, RDOM-N (mg/L)	0.4746	11/17/2009
Labile Particulate Organic Nitrogen, LPOM-N (mg/L)	0.0558	11/17/2009
Refractory Particulate Organic Nitrogen, RPOM-N (mg/L)	0.3164	11/17/2009
Dissolved Ortho-Phosphate, PO4-P (mg/L)	0.008	11/17/2009
Labile Dissolved Organic Phosphorus, LDOM-P (mg/L)	0.0016	11/17/2009
Refractory Dissolved Organic Phosphorus, RDOM-P (mg/L)	0.0090	11/17/2009
Labile Particulate Organic Phosphorus, LPOM-P (mg/L)	0.0064	11/17/2009
Refractory Particulate Organic Phosphorus, RPOM-P (mg/L)	0.0360	11/17/2009

4 Integration of SWAT Model Results

In parallel with the development of the model inputs described in Section 3, WDNR was conducting Soil and Water Assessment Tool (SWAT) modeling of the watersheds contributing to Petenwell and Castle Rock reservoirs. The initial reservoir model development and calibration was conducted before the SWAT results were available. However, once calibrated SWAT model results became available, they were integrated into the CE-QUAL-W2 model. Total suspended solids (TSS) and total phosphorus (TP) loads from SWAT were incorporated into the CE-QUAL-W2 model, replacing some of the USGS FLUXMASTER loads discussed in Section 3. Also, flows for the Yellow River simulated using SWAT were incorporated into the CE-QUAL-W2 model. This section summarizes the approach taken to integrate SWAT results.

Calibrated SWAT modeling results were provided to LimnoTech by WDNR, in late September 2015. Revised results for the Yellow River were provided by WDNR on February 29, 2016. The results included daily flow and mass load predictions for tributaries and direct drainage subbasins into Petenwell and Castle Rock reservoirs for the period from January 1, 2002, through December 31, 2013. The model outputs included values for flow, sediment, organic phosphorus, and mineral phosphorus. Subbasin outputs also included soluble phosphorus. WDNR noted that SWAT was calibrated to flow, TSS, and TP, and not individual components of sediment and phosphorus. LimnoTech's review of the SWAT results for direct drainage areas indicated much lower sediment and phosphorus loads for these areas than the estimates using USGS FLUXMASTER results and drainage area ratio adjustments. WDNR's further review of the SWAT results indicated possible issues related to rounding, resulting in lower loads for direct drainage subbasins surrounding the reservoir. Therefore, SWAT results for the direct drainages were not used; however, SWAT results for tributary inputs were used as previously planned.

4.1 Integration of SWAT Tributary Flows

The previously described CE-QUAL-W2 inputs were replaced with daily flows predicted by SWAT for each tributary in an initial test simulation. The resulting water mass balance was reviewed to determine how significantly the revised flows impacted the water balance. The results of this test simulation indicated that the water balance would need to be redone if SWAT flows were used. Given the significant effort required to redo the water balance, the decision was made to maintain the existing flows based on available USGS gauge data and drainage-area ratio adjustments in CE-QUAL-W2 for the final calibration, for all tributaries except the Yellow River. The Yellow River is the largest tributary and significantly impacts conditions in the Yellow River Arm of Castle Rock. Therefore, the SWAT flows were incorporated into CE-QUAL-W2 for the Yellow River and the water balance was revised for Castle Rock Reservoir to reflect that one change to the model integration approach. For all other tributaries, the initial flow inputs were maintained. This approach was not anticipated to impact the utility of the model since the difference in flows is only 4%. This approach has been used in similar studies conducted with the CE-QUAL-W2 model, including in the development of the Lake Travis water quality model for the Lower Colorado River Authority (Anchor QEA, 2009). Further discussion of the water balance is presented in Section 5 of this report.

4.2 Integration of SWAT Tributary Loads

Daily CE-QUAL-W2 tributary inputs of sediment and total phosphorus loads were adjusted to reflect SWAT loads, as described in the following subsections.

4.2.1 Sediment Loads

For sediment loads, the daily CE-QUAL-W2 input of inorganic suspended solids (ISS) at each tributary and direct drainage input was recalculated on a daily basis using SWAT output as follows:

$$\text{Adjusted ISS (kg/day)} = \text{SWAT Sediment} - \text{ALG1} - \text{ALG2} - \text{ALG3} - \text{LPOM} - \text{RPOM}$$

This resulted in the TSS load to CE-QUAL-W2 from tributaries equaling the SWAT output each day of the simulation period. The only exception being days when the derived ISS value was less than zero; on such days ISS was set to zero. Reductions to particulate organic matter (POM; RPOM and LPOM) daily concentration boundary condition estimates were implemented, as necessary, to ensure that the model TSS boundary conditions matched either SWAT or FLUXMASTER daily TSS estimates. These adjustments were typically small and frequently not required, but are significant at times because the boundary conditions were developed by various methods (as necessitated by available data).

4.2.2 Phosphorus Loads

For phosphorus loads, the ratio of the daily TP SWAT output to the existing TP input to CE-QUAL-W2 for individual tributaries was applied to adjust each phosphorus fraction input to CE-QUAL-W2. Each phosphorus fraction (PO4, LDOM-P, RDOM-P, LPOM-P, and RPOM-P) was recalculated as follows:

$$\text{Adjusted Phosphorus Fraction } \left(\frac{\text{kg}}{\text{day}}\right)$$
$$= \frac{\text{SWAT Total Phosphorus}}{\text{Existing CE} - \text{QUAL} - \text{W2 Total Phosphorus}} \times \text{Existing Phosphorus Fraction}$$

This resulted in the total phosphorus load to CE-QUAL-W2 from tributaries equaling the SWAT total phosphorus output each day of the simulation period.

A summary of each tributary or direct drainage input to the CE-QUAL-W2 model and the basis for the input is presented in Table 4.1.

Table 4.1. Basis for Tributary and Direct Drainage Inputs

Input	CE-QUAL-W2 Input Segment	SWAT Reach or Subbasin	Basis for Solids and Phosphorus Load Input to CE-QUAL-W2	Algal Load
Wisconsin River Mainstem	2	Not applicable	FLUXMASTER	Available data
Petenwell Reservoir				
Ten Mile Creek	4	Reach 255	SWAT	Low
Lake Arrowhead and Lake Sherwood	6	Reach 76	SWAT	Low
Direct Drainage (includes Nekoosa subbasin)	10	Subbasins 74 and 143	FLUXMASTER	Zero
Castle Rock Reservoir				
West Petenwell Ditch	37	Subbasin 73	FLUXMASTER	Zero
Big Roche A Cri Creek	40	Reach 254	SWAT	High
Little Roche A Cri Creek	42	Reach 253	SWAT	Low
Klein Creek	46	Reach 251	SWAT	Low
Direct Drainage	45	Subbasin 59	FLUXMASTER	Zero
Yellow River	54	Reach 60	SWAT	High
Little Yellow River	56	Reach 252	SWAT	Low

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5
Water Mass Balance

5.1 Methodology

The CE-QUAL-W2 model for Petenwell and Castle Rock is driven by the amount of flow going into and discharged from each reservoir. The model is run with the flow inputs and dam discharges and simulates the change in water surface elevations as a result of water mass balances. Specifically, the models include the following forcing functions, or model inputs, for flows:

- Mainstem upstream flows above Petenwell Reservoir based on USGS gauge data;
- Tributary and direct drainage flow inputs to Petenwell and Castle Rock reservoirs based on USGS gauge data and drainage area ratio adjustments; and
- Flows discharging from Petenwell and Castle Rock dams based on records of dam operations and estimated flows.

Measured water surface elevation data were available at the headwater of each dam and the simulated water surface elevations were compared to measured water surface elevations. Discrepancies between the simulated and measured water surface elevations were then evaluated and adjustments made to modify the water balance to result in an acceptable simulation of water surface elevations. Adjustments to the flows account for potential unaccounted for inputs or outputs of flow from the reservoirs, such as evaporation, direct precipitation, and groundwater interactions, as well as potential inaccuracies in the measured and estimated mainstem and tributary flow inputs to the reservoirs and the measured discharges from each reservoir.

The initial CE-QUAL-W2 results, prior to water balance efforts, produced simulated water surface elevations that deviated by as much as 10 meters from the observed water surface elevations (Figure 5.1). The USACE's water balance utility for CE-QUAL-W2 (waterbal_ivf37.exe) was used to adjust the flows and resolve the water surface discrepancies. The adjusted inflows and outflows calculated by the water balance utility were incorporated into the model as distributed tributary inputs for Branch 1 (main stem of Petenwell) and Branch 5 (main stem of Castle Rock), meaning the adjustments to flow were equally distributed among each model grid cell along the main branch of the reservoirs. The water balance utility calculated adjustments to account for discrepancies resulting from long-term trends and minor runoff events, but was unable to correct larger discrepancies occurring during periods when the reservoirs were drawn down in the spring to manage snowmelt runoff and during large storm events. Running multiple iterations of the water balance utility did not improve the results and in some cases made the discrepancies in water surface elevation greater during periods of larger flow variation. This necessitated manual adjustment of the distributed tributary flows.

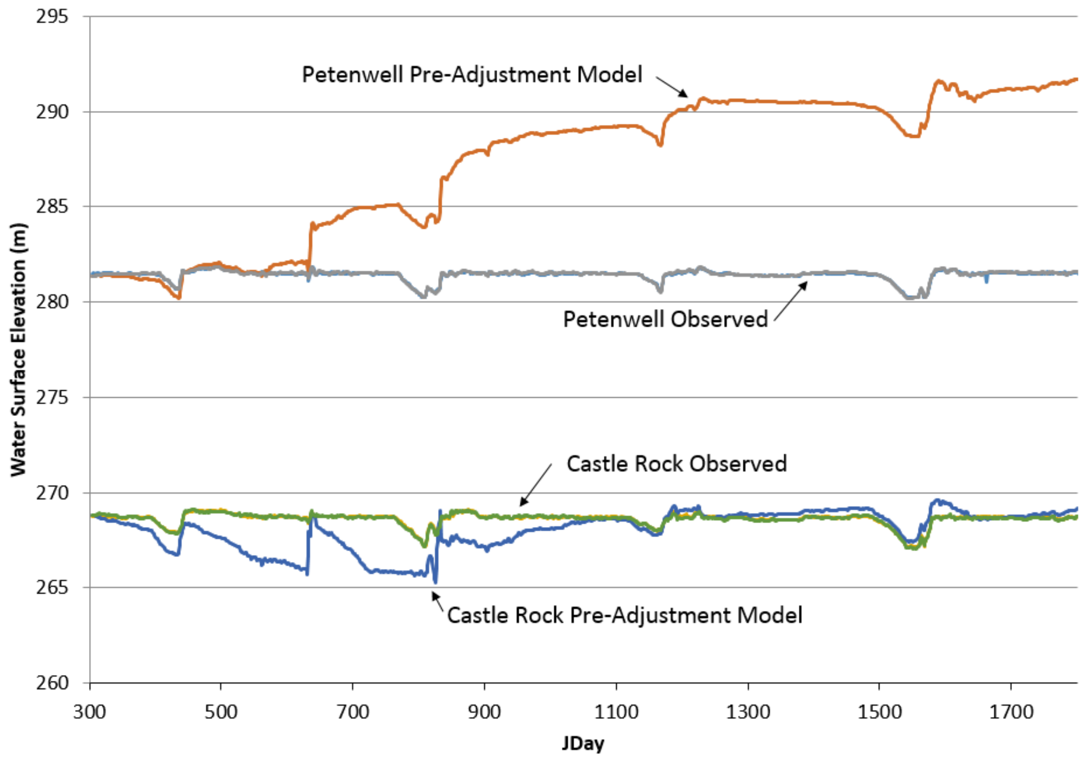

Figure 5.1. Water Surface Elevation Time Series for the Initial Predicted and Observed Headwater, November 1, 2009 through December 31, 2013

The water balance adjustments were made (via the distributed tributary files) iteratively with a general goal of producing a predicted water surface within 15 cm of the observed water surface. The manual water balance adjustment consisted of four techniques listed below in order of preference:

1. Make no adjustment whenever possible;
2. Use the water balance utility fine-scale adjustments;
3. Make smaller, continuous adjustments for several days to alleviate a diverging trend in observed versus simulated water surface elevations; and
4. Make larger, short duration adjustments to alleviate discrepancies related to larger swings in water surface elevations.

5.2 Results

The Petenwell and Castle Rock measured water surface elevations at the headwater of the dams along with the pre- and post-adjustment model predictions are provided in Figure 5.2. The observed water surface for each reservoir fluctuates by about ±1 meter throughout the 4-year model simulation period. This represents a small portion of the total volume, roughly 4% in Petenwell and 5% in Castle Rock. The targeted goal for the water balance was to achieve a simulated water surface elevation within 15 cm of the observed water surface elevation, or a deviation of approximately 0.6% of the volume in Petenwell and 0.8% of the volume in Castle Rock. This goal was achieved 99.6% of the time in Petenwell and 99.7% of the time in Castle Rock during the simulation period (November 1, 2009–December 31, 2013).

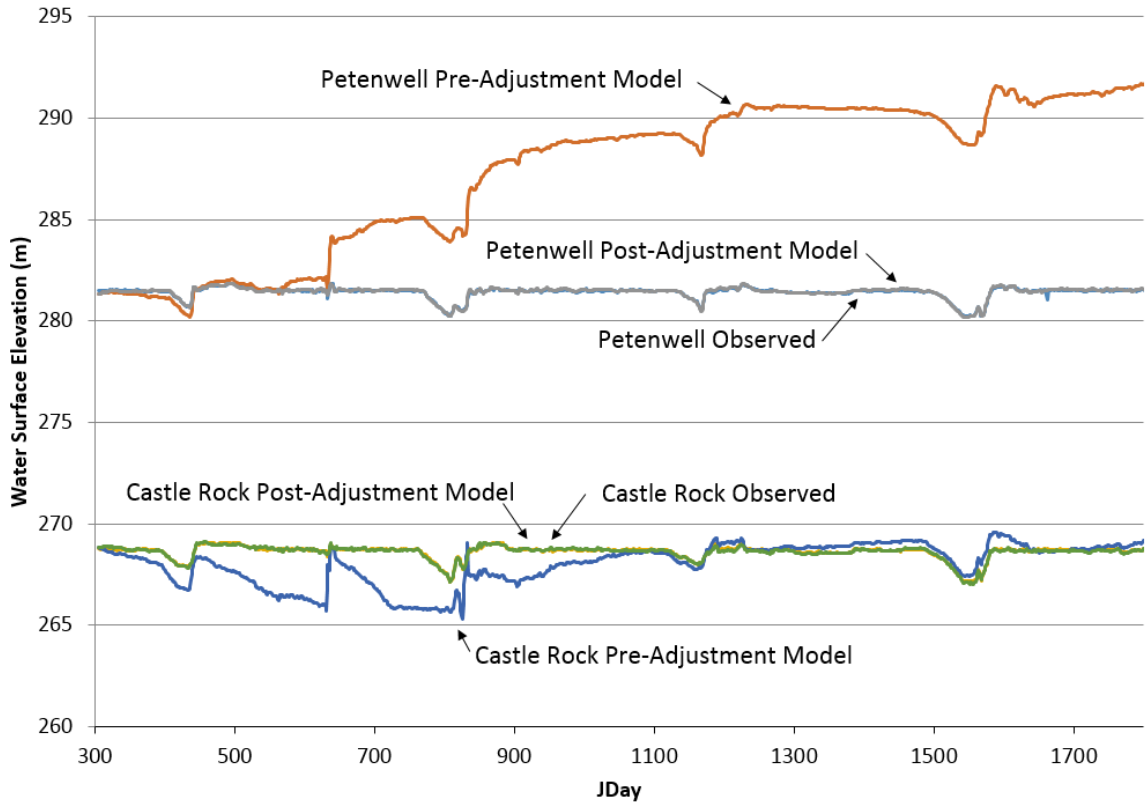

Figure 5.2. Water Surface Elevation Time Series for the Pre- and Post-Adjustment Predicted and Observed Headwater, November 1, 2009 through December 31, 2013

In general, the greatest flow adjustments were required during runoff events and acted to shift the hydrograph forward slightly and reduce what appears to be an overestimation of the peak discharge in the measured dam discharge records. The largest daily flow adjustments are presented in Table 5.1. While large flow adjustments were needed on some days, the relative volume of those adjustments compared to the reservoir volume is small.

Table 5.1. Daily Flow Adjustments for Water Mass Balance

Reservoir	Maximum Inflow Adjustment (cms)	Percent of Reservoir Volume	Maximum Outflow Adjustment (cms)	Percent of Reservoir Volume
Petenwell	300	1.2%	600	2.4%
Castle Rock	111	1.1%	205	2.0%

Note: cms = cubic meters per second

On the whole, the total volume of flow adjusted is relatively small compared to the total flow inputs and outputs. The water balance components are summarized in the table below. The adjustments in each reservoir as a percent of total inflow or outflow range from 1.8% to 6.4%.

Table 5.2. Water Balance Components

Reservoir	Reservoir Volume at Normal Pool	Total Inflows (Simulation Period)			Total Outflows (Simulation Period)	
		Mainstem	Tributaries	Adjustments	Dam Discharge	Adjustments
Petenwell	2.19×10^{9}	1.697×10^{10}	7.118×10^{8}	3.293×10^{8}	1.675×10^{10}	1.143×10^{9}
Castle Rock	9.01×10^{8}	1.675×10^{10}	1.375×10^{9}	5.300×10^{8}	1.995×10^{10}	5.990×10^{8}

*all values in m^3

The flow adjustments incorporated for each reservoir resulted in an acceptable simulation of water surface elevations. Additionally, the magnitude of the required flow adjustments were of a magnitude that does not significantly impact the simulation of water quality conditions in the reservoirs.

6 Model Calibration

6.1 Overview

This section presents the calibration of the CE-QUAL-W2 model of Petenwell and Castle Rock reservoirs to measured water quality data. The calibration process included an initial hydrodynamic calibration, an initial water quality calibration, and a final calibration. In the initial calibration, tributary inputs were based on USGS-generated FLUXMASTER estimates. The final calibration integrated results from the SWAT watershed modeling effort into the CE-QUAL-W2 model.

6.2 Model Evaluation Criteria

CE-QUAL-W2 model results were assessed using graphical techniques (observed vs. predicted and time series graphs) as well as statistical measures. The statistical measures used to verify model simulated results as compared to observed water quality data include mean absolute error (MAE), percent bias (PBIAS), and the relative percent error (Rel%Err). The equations used to calculate these metrics are listed below.

MAE is a measure of the average magnitude of deviation of the simulated results to the observed data and is defined as:

$$MAE = \sum_{i=1}^{n} \frac{|O_i - S_i|}{n}$$

where O represents observed values and S represents model simulated values.

PBIAS measures the average tendency of the simulated results to be larger or smaller than the observed data (Gupta et al., 1999; Moriasi et al., 2007). The optimal value of PBIAS is 0%, with low values indicating an unbiased model simulation. Positive values indicate that the model has an underestimation bias, and negative values indicate that the model has an overestimation bias (Gupta et al., 1999; Moriasi et al., 2007). PBIAS is calculated based on the following equation:

$$PBIAS = \left[\frac{\sum_{i=1}^{n}(O_i - S_i) \times (100)}{\sum_{i=1}^{n}(O_i)}\right]$$

Rel%Err is the average of the differences between observed values and simulated values relative to the observed value and is reported as a percentage. It is a measure of the average relative deviation of the simulated results to the observed values. The optimal value of Rel%Err is 0%. Positive values indicate that the model generally underestimates the observed data, and negative values indicate that the model generally overestimates the observed data. Rel%Err is calculated using the following equation:

$$Rel\%Err = 100 \times \frac{\left[\sum_{i=1}^{n} \frac{(O_i - S_i)}{O_i}\right]}{n}$$

The calibration targets were initially based on targets used for CE-QUAL-W2 applications to Texas reservoirs (Dean, 2007) and then refined based on an assessment of the magnitude and variability of the state variable values in the Wisconsin River system. An emphasis was put on the MAE as the primary calibration statistic. PBIAS and Rel%Err were used to further inform the calibration. Results were initially assessed on a system-wide basis with statistics calculated for the main body sampling locations collectively. Statistics for each reservoir and then each sampling location were also calculated and evaluated. Meeting calibration targets at each individual location was not expected, but analysis by individual station provides further insight into model response and potential adjustments to improve the calibration. The targets for MAE for each parameter are presented in Table 6.1. In applying the target, the goal of the calibration is to be at or below these error values for each parameter.

Table 6.1. Calibration Targets

Model State Variables	Mean Absolute Error
Primary Calibration State Variables	
Temperature	1°C
Total Phosphorus	0.02 mg/L
Chlorophyll a	4 µg/L
Dissolved Oxygen	2 mg/L
Secondary Calibration State Variables	
Total Organic Carbon	5 mg/L
Total Nitrogen	0.5 mg/L
Total Kjeldahl Nitrogen	0.4 mg/L
Ammonia Nitrogen	0.03 mg/L
Nitrate and Nitrite	0.1 mg/L
Orthophosphate	0.01 mg/L

These model performance statistics were used not as absolute criteria for acceptance of the calibration, but rather as targets within part of a "weight of evidence" approach to supplement visual inspection of model-data comparison plots and as a quantitative basis of comparison between model simulations to determine appropriate endpoints for calibration of the model. Given the lack of a general consensus for defining quantitative model performance criteria (and the ability of modelers to influence statistical results via potentially inappropriate adjustment of model inputs), absolute adherence to these data quality objectives for model acceptance or rejection is not appropriate.

6.3 Calibration Methodology

Calibration is critical to ensuring the CE-QUAL-W2 model will properly represent water quality conditions in the Wisconsin River reservoirs of interest. The calibration process involves successive runs of the model by adjusting model parameters until the model results are in agreement with the observed data.

Calibration activities were conducted in accordance with the project QAPP (LimnoTech, January 30, 2015). In general, model calibration consists of an adjustment of model parameters within an acceptable range until the difference between model computations and measured state variables meets the evaluation criteria.

The CE-QUAL-W2 model was applied to continuously simulate the period from November 1, 2009, through December 31, 2013, for the model calibration effort. The period from November 1, 2009, to December 31, 2009, is considered a model spin-up period. The model was calibrated to observed water quality (surface and depth) for the entire 2010–2013 dataset concurrently. The calibration consisted of adjusting a range of parameters over the course of numerous model simulations. The calibration effort resulted in the following adjustments to model parameters:

- Manning's n (FRICT) adjusted from initial value of 0.035 to 0.020. This adjustment was required to provide sufficient vertical mixing to improve the model representation of water temperature in deeper layers.
- Extinction coefficient for pure water (EXH20) adjusted to 0.25/m and reflects the default setting for this coefficient in CE-QUAL-W2.
- Surface layer solar radiation absorption (BETA) adjusted from default value of 0.45 to 0.35.
- Wind sheltering coefficient (WSC) adjusted from initial value of 1 to 1.2.
- Algal rates including maximum algal growth rates (AG), maximum algal respiration rates (AR), maximum algal excretion rates (AE), maximum algal mortality rates (AM), and algal settling rates (AS). Adjusted from initial values to final values reflective of typical literature values for the growth and loss characteristics of each algal group and to improve the calibration.
- Algal half-saturation for nitrogen limited growth (AHSN) adjusted from 0.014 g/m^3 to 0 g/m^3 for the blue-green algal functional group to effectively allow for nitrogen-fixation under the assumption that a significant fraction of the blue-green algal forms are capable of nitrogen fixation. Specifying a zero value for AHSN is the method by which the CE-QUAL-W2 model allows nitrogen-fixation to occur for a given algal group, since nitrogen uptake is not limited by the available nitrogen concentration in the water column.
- Light saturation intensity at maximum photosynthetic rate (ASAT) adjusted from 70 W/m^2 to 100 W/m^2 for all algal groups as a calibration change within the acceptable range for ASAT.
- Algal temperature rate coefficients including lower temperature for algal growth (ATT1) for diatoms adjusted from 5°C to 10°C; upper temperature for maximum algal growth (AT3) for diatoms adjusted from 20°C to 25°C and for "other" from 30°C to 25°C; and upper temperature for algal growth (AT4) for diatoms adjusted from 25°C to 30°C and for "other" from 35°C to 30°C. The temperature rate coefficients were initially set to reflect algal group-specific optimal temperature ranges, but further adjustments to better reflect the relative seasonal dominance of each algal group to improve the calibration.
- Stoichiometric equivalent between algal biomass and nitrogen (ALGN) adjusted from 0.05 to 0.08 for all algal functional groups to improve the calibration.
- Algal half saturation constant for ammonium preference (ANPR) for all algal groups adjusted from 0.001 to 0.01 and within the typical accepted range to improve the calibration.
- Sediment release rate of phosphorus (PO4R) adjusted from 0.01 as a fraction of sediment oxygen demand (SOD) to 0.005 to approximately reflect sediment flux measurements for the draft calibration, but was then increased back to the default fraction of 0.01 for the final calibration.

- Sediment release rate of ammonium (NH4R) adjusted from 0.001 as a fraction of SOD to 0.005 to approximately reflect sediment flux measurements.
- Ammonium decay rate (NH4DK) adjusted from 0.12/day to 0.1/day to improve the calibration.

Model parameters with beginning and ending calibration values are presented in Table 6.2.

Table 6.2. Model Parameters for Final Calibration

Parameter Description	Beginning Value	Ending Value
Hydrodynamic and Thermal		
Coefficient in wind speed effects on heat BFW exchange, AFW	9.2	9.2
Coefficient in wind speed effects on heat BFW exchange, BFW	0.46	0.46
Coefficient in wind speed effects on heat BFW exchange, CFW	2	2
Wind meter height above surface, WINDH, m	10	10
Time weighting for vertical advection scheme, THETA	0.55	0.55
Longitudinal eddy viscosity, AX, m^2/sec	1	1
Longitudinal eddy viscosity, DX, m^2/sec	1	1
Coefficient of bottom heat exchange, CBHE, W/m^2/sec	0.3	0.3
Bottom temperature, TSED, ^oC	8	8
Interfacial friction factor, FI	0.01	0.01
Heat lost to sediments that is added back to water column, TSEDF	1	1
Bottom friction solution, MANN or CHEZY, FRICC	MANN	MANN
Manning's N, FRICT	0.035	0.02
Form of vertical turbulence closure algorithm, NICK, PARAB, RNG, W2, W2N, or TKE, AZC	W2	W2
Specified either implicit, IMP, or explicit, EXP, treatment of the vertical eddy viscosity in the longitudinal momentum equation, AZSLC	IMP	IMP
Maximum value for vertical eddy viscosity, AZMAX, m^2/sec	0.001	0.001
Wind sheltering coefficient, WSC	1	1.2
Solar radiation absorbed in surface layer, BETA	0.45	0.35
Extinction coefficient for pure water, EXH2O, /m	0.35	0.25
Extinction due to inorganic suspended solids, EXSS, /m	0.01	0.01
Extinction due to organic suspended solids, EXOM, /m	0.2	0.2
Algal light extinction, EXA, /m/gm^3		
blue-green functional group	0.2	0.2
diatom functional group	0.2	0.2
"other" functional group	0.2	0.2

Table 6.2. Model Parameters for Final Calibration (cont.)

Parameter Description	Beginning Value	Ending Value
Algal Rates		
Maximum algal growth rate, AG, /day		
blue-green functional group	1.5	1.5
diatom functional group	2.5	2
"other" functional group	2	1.8
Maximum algal respiration rate, AR, /day		
blue-green functional group	0.04	0.1
diatom functional group	0.04	0.1
"other" functional group	0.04	0.1
Maximum algal excretion rate, AE, /day		
blue-green functional group	0.04	0.05
diatom functional group	0.04	0.05
"other" functional group	0.04	0.05
Maximum algal mortality rate, AM, /day		
blue-green functional group	0.1	0.08
diatom functional group	0.1	0.1
"other" functional group	0.1	0.1
Algal settling rate, AS, m/day		
blue-green functional group	0.05	0
diatom functional group	0.1	0.3
"other" functional group	0.1	0.2
Algal half-saturation for phosphorus limited growth, AHSP, g/m		
blue-green functional group	0.003	0.003
diatom functional group	0.003	0.003
"other" functional group	0.003	0.003
Algal half-saturation for nitrogen limited growth, AHSN, g/m		
blue-green functional group	0.014	0
diatom functional group	0.014	0.014
"other" functional group	0.014	0.014
Light saturation intensity at maximum photosynthetic rate, ASAT, W/m		
blue-green functional group	70	100
diatom functional group	70	100
"other" functional group	70	100

Table 6.2. Model Parameters for Final Calibration (cont.)

Parameter Description	Beginning Value	Ending Value
Algal Temperature Rate Coefficients		
Lower temperature for algal growth, ATT1, °C		
blue-green functional group	10	10
diatom functional group	5	10
"other" functional group	10	10
Lower temperature for maximum algal growth, ATT2, °C		
blue-green functional group	25	25
diatom functional group	15	15
"other" functional group	20	20
Upper temperature for maximum algal growth, AT3, °C		
blue-green functional group	35	35
diatom functional group	20	25
"other" functional group	30	25
Upper temperature for algal growth, AT4, °C		
blue-green functional group	40	40
diatom functional group	25	30
"other" functional group	35	30
Fraction of algal growth rate at AT1, AK1		
blue-green functional group	0.1	0.1
diatom functional group	0.1	0.1
"other" functional group	0.1	0.1
Fraction of maximum algal growth rate at AT2, AK2		
blue-green functional group	0.99	0.99
diatom functional group	0.99	0.99
"other" functional group	0.99	0.99
Fraction of maximum algal growth rate at AT3, AK3		
blue-green functional group	0.99	0.99
diatom functional group	0.99	0.99
"other" functional group	0.99	0.99
Fraction of algal growth rate at AT4, AK4		
blue-green functional group	0.1	0.1
diatom functional group	0.1	0.1
"other" functional group	0.1	0.1

Table 6.2. Model Parameters for Final Calibration (cont.)

Parameter Description	Beginning Value	Ending Value
Algal Stoichiometry		
Stoichiometric equivalent between algal biomass and phosphorus, ALGP		
blue-green functional group	0.005	0.005
diatom functional group	0.005	0.005
"other" functional group	0.005	0.005
Stoichiometric equivalent between algal biomass and nitrogen, ALGN		
blue-green functional group	0.05	0.08
diatom functional group	0.05	0.08
"other" functional group	0.05	0.08
Stoichiometric equivalent between algal biomass and carbon, ALGC		
blue-green functional group	0.45	0.45
diatom functional group	0.45	0.45
"other" functional group	0.45	0.45
Ratio between algal biomass and chlorophyll- a, ALCHLA		
blue-green functional group	0.07333	0.07333
diatom functional group	0.11111	0.11111
"other" functional group	0.07333	0.07333
Fraction of algal biomass that is converted to particulate organic matter when algae die, ALPOM		
blue-green functional group	0.8	0.8
diatom functional group	0.8	0.8
"other" functional group	0.8	0.8
Equation number for algal ammonium preference (either 1 or 2), ALEQN		
blue-green functional group	2	2
diatom functional group	2	2
"other" functional group	2	2
Algal half saturation constant for ammonium preference, ANPR		
blue-green functional group	0.001	0.01
diatom functional group	0.001	0.01
"other" functional group	0.001	0.01

Table 6.2. Model Parameters for Final Calibration (cont.)

Parameter Description	Beginning Value	Ending Value
Dissolved Organic Matter		
Labile DOM decay rate, LDOMDK, /day	0.05	0.05
Refractory DOM decay rate, RDOMDK, /day	0.001	0.001
Labile to refractory DOM decay rate, LRDDK, /day	0.01	0.01
Particulate Organic Matter		
Labile POM decay rate, LPOMDK, /day	0.08	0.08
Refractory POM decay rate, RPOMDK, /day	0.001	0.001
Labile to refractory POM decay rate, LRPDK, /day	0.01	0.01
POM settling rate. POMS, m/day	0.1	0.1
Organic Matter Stoichiometry		
Stoichiometric equivalent between organic matter and phosphorus, ORGP	0.005	0.005
Stoichiometric equivalent between organic matter and nitrogen, ORGN	0.08	0.08
Stoichiometric equivalent between organic matter and carbon, ORGC	0.45	0.45
Organic Matter Temperature Rate Coefficients		
Lower temperature for organic matter decay, OMT1, ^{o}C	4	4
Upper temperature for organic matter decay, OMT2, ^{o}C	25	25
Fraction of organic matter decay rate at OMT1, OMK1	0.1	0.1
Fraction of organic matter decay rate at OMT2, OMK2	0.99	0.99
Inorganic Phosphorus		
Sediment release rate of phosphorus, PO4R, fraction of SOD	0.01	0.01
Phosphorus partitioning coefficient for suspended solids, PARTP	0	0
Ammonium		
Sediment release rate of ammonium, NH4R, Fraction of SOD	0.001	0.005
Ammonium decay rate, NH4DK	0.12	0.1
Ammonium Temperature Rate Coefficients		
Lower temperature for ammonia decay NH4T1, ^{o}C	5	5
Lower temperature for maximum ammonia decay, NH4T2, ^{o}C	25	25
Fraction of nitrification at NH4T1, NH4K1	0.1	0.1
Fraction of nitrification at NH4T2, NH4K2	0.99	0.99

Table 6.2.Model Parameters for Final Calibration (cont.)

Parameter Description	Beginning Value	Ending Value
Nitrate		
Nitrate decay rate, NO3DK, /day	0.03	0.1
Denitrification rate from sediments, NO3S, m/day	0.01	0.05
Nitrate Temperature Rate Coefficients		
Lower temperature for nitrate decay, NO3T1, ^oC	5	5
Lower temperature for maximum nitrate decay, NO3T2, ^oC	25	25
Fraction of denitrification rate at NO3T1, NO3K1	0.1	0.1
Fraction of denitrification rate at NO3T2, NO3K2	0.99	0.99
Oxygen Stoichiometry		
Oxygen stoichiometry for nitrification, O2NH4	4.57	4.57
Oxygen stoichiometry for organic matter decay, O2OM	1.4	1.4
Oxygen Stoichiometry 2		
Oxygen stoichiometry for algal respiration, O2AR	1.1	1.1
Oxygen stoichiometry for algal primary production, O2AG	1.6	1.6
Oxygen Limit		
Dissolved oxygen half- saturation constant, KDO, g/m^3	0.1	1
SOD Temperature Rate Coefficients		
Fraction of the zero- order SOD rate used, FSOD	1	1
Lower temperature for zero-order SOD or first- order sediment decay, SODT1, ^oC	4	4
Upper temperature for zero-order SOD or first- order sediment decay, SODT2, ^oC	25	25
Fraction of SOD or sediment decay rate at lower temperature, SODK1	0.1	0.1
Fraction of SOD or sediment decay rate at upper temperature, SODK2	0.99	0.99
Zero-Order Sediment Oxygen Demand		
Zero-order sediment oxygen demand for each segment, SOD, $gO2/m^2/day$	0.8	n/a
Petenwell (WB 1)	0.8	1.2
Castle Rock (WB 2)	0.8	0.94
Reaeration		
Waterbody type, TYPE	Lake	Lake
Reaeration formulation, EQN#	2	2

6.4 Calibration Results

Model results were compared to observed data at all reservoir stations and depths for which measurements were available. Some problems were noted with the observed dataset including periods when the temperature sensors were exposed to the atmosphere. The suspect data were removed from the dataset. Graphical and statistical comparisons of model results versus observed data are described below.

6.4.1 Graphical Comparisons of Model Results to Observed Data

Plots comparing observed data, both continuous and grab sampling data, to model simulations for each sampling station and at each depth of measurement can be viewed using an online tool at http://ltiweb02.limno.com/WIRVTMDL/CEQUALW2_viewer.vbhtml. Please note that when selecting a new plot from the pull down menus, there is a momentary lag as the appropriate information is located and the graphics are generated. Updating a newly selected plot may take a few seconds. Maps of the sampling station locations and the model grid cells are shown in Figures 3.5 and 3.6.

6.4.2 Statistical Measures of Model-Data Comparisons

Model results were assessed against the observed data at each individual sampling station, grouped by main body stations on each reservoir and the Yellow River arm of Castle Rock, as well as an overall main body grouping. Error statistics are reported for each monitoring station and for the 2010–2013 period. A summary of the statistics is presented in Appendix A. Table 6.3 presents a summary of the main body sampling stations (10031168, 10031169, 10031170, 10031171, 10031172, 10031173, and 10031174). Table 6.4 presents the MAE for total phosphorus when model-data pairs are aggregated on a monthly average basis for each sampling station, as well as when data and model results are averaged across groups of sampling stations. Statistics calculated for all months or a year-round basis are presented, as well as statistics for summer months only (June–September).

Table 6.3. Calibration Statistics—Main Body Sampling Stations

Model State Variable	Count (#)	Median of Observed Data	Median of Matched Model Results	MAE	PBIAS (%)	Rel%Err (%)
Year-round Statistics						
Temperature (°C)	202,725	20.72	20.82	0.60	-1	-1
Total Phosphorus (mg/L)	666	0.081	0.084	0.028	-2	-11
Chlorophyll-a (µg/L)	650	12	14	13.6	21	-169
Dissolved Oxygen (mg/L)	2,481	7.72	7.75	1.43	1	-16
Total Organic Carbon (mg/L)	665	17	17	3.00	1	-5
Total Nitrogen (mg/L)	666	1.42	1.37	0.27	6	1
Total Kjeldahl Nitrogen (mg/L)	666	1.078	1.068	0.28	6	-6
Ammonia Nitrogen (mg/L)	667	0.045	0.070	0.075	0	-219
Nitrate and Nitrite (mg/L)	667	0.176	0.177	0.161	7	-75
Orthophosphate (mg/L)	667	0.017	0.019	0.023	-25	-130
Summer Statistics (June–September)						
Temperature (°C)	170,349	22.06	22.23	0.61	-0.72	-0.83
Total Phosphorus (mg/L)	507	0.087	0.088	0.030	0.89	-8.6
Chlorophyll-a (µg/L)	492	14.03	15.98	14.53	25	-122
Dissolved Oxygen (mg/L)	1,847	7.10	7.11	1.48	1.3	-19
Total Organic Carbon (mg/L)	508	17.95	17.27	2.97	5.2	1.1
Total Nitrogen (mg/L)	507	1.41	1.31	0.30	11	4.6
Total Kjeldahl Nitrogen (mg/L)	507	1.14	1.14	0.30	7.0	-6.9
Ammonia Nitrogen (mg/L)	508	0.043	0.075	0.075	-8.3	-245
Nitrate and Nitrite (mg/L)	508	0.124	0.121	0.148	32	-87
Orthophosphate (mg/L)	508	0.019	0.019	0.024	-15	-93

Table 6.4. Monthly Aggregate Total Phosphorus Mean Absolute Error

Station	TP MAE (mg/L)	Summer TP MAE (mg/L)
13016	0.016	0.017
10031168	0.022	0.024
10031169	0.035	0.042
10031170	0.019	0.021
10031171	0.028	0.031
293130	0.016	0.023
10031172	0.014	0.014
10031173	0.019	0.022
10031174	0.018	0.020
10017791	0.017	0.022
293132	0.039	0.044
10031175	0.029	0.037
Petenwell Main Body	0.017	0.018
Castle Rock Main Body	0.015	0.017
Yellow River Arm	0.031	0.039
All Main Body Stations	0.015	0.016

6.4.3 Assessment of Model-Data Comparisons

The main body sampling stations generally compare well to the calibration targets for MAE, as well as providing generally good results for PBIAS and Rel%Err. While all initial calibration targets were not achieved, sufficient sensitivity analyses were conducted to conclude that the current model framework will not achieve these targets in the absence of finer spatial resolution, refinement of model boundary conditions, or both. The model's ability to represent an individual water quality sample will always be limited as a result of the spatial averaging represented in the model. While a measured data point represents a very specific location in the reservoir, the model simulates average conditions within each model segment and later. A sampling location in the middle of each reservoir transect may not represent variation across the segment. Small or large scale three-dimensional circulation patterns that involve lateral variation cannot be represented by the CE-QUAL-W2 model framework.

Model state variables that did not meet the initial calibration targets were investigated and indicate potential limitations of the model. These are discussed further below.

- **Total Phosphorus:** The total phosphorus MAE on an individual sample basis (Table 6.3) is 0.028 mg/L compared to the target of 0.02 mg/L. However, results for PBIAS and Rel%Err are very good. The MAE for Petenwell main body stations is 0.032 mg/L while the MAE for Castle Rock main body stations is 0.022 mg/L (Appendix A). The MAE target is met when comparing the average monthly observed data and matched model results on a reservoir-wide basis, with an MAE of 0.017 mg/L in Petenwell main body stations and 0.015 mg/L in Castle Rock main body stations (Table 6.4). The largest MAE at an individual reservoir station occurs at Petenwell station 10031169 where the MAE is 0.038 mg/L. The model tends to underestimate total phosphorus during late summer conditions in the surface.

Various potential means of improving the total phosphorus model-data comparison were considered and discussed with WDNR. These are discussed below.

- The model does not capture high concentrations of algae at the surface on some summer days, particularly at the sampling locations in the middle and lower end of Petenwell. On many sampling dates the DO profiles indicate what could be described as a "micro-stratification" layer with much higher DO in the upper 1–2 meters of the water column. When this occurs, the surface TP and Chl-a values are typically much higher than those collected deeper in the epilimnion. This may be expected on calmer days, which may also be days when sampling is more likely to occur on large reservoirs. The model does not reproduce this micro-stratification and tends to represent the epilimnion as fairly well mixed. The existing model is not configured to be able to potentially capture such a micro-stratification at the surface. A much finer vertical resolution would be needed, and possibly going to a three-dimensional approach adding in a lateral dimension. Even then, we are not certain the model would simulate the observed DO gradient at the locations and dates it is observed. The data do not consistently exhibit the gradient, so a model forcing input, such as wind or lack thereof would need to "drive" the model simulation of the gradient. Sensitivity analyses were run with the model to test the impact of assigning a negative settling velocity for blue-green algae, but this did not improve the model-data comparison.
- Errors in the estimated boundary loads could contribute to model-data disagreement. There are periods where FLUXMASTER-estimated concentrations are significantly different than grab samples (e.g., summer 2012), which suggests that the estimated concentrations between these samples may be erroneous. These errors would propagate downstream through the reservoirs.
- Sensitivity analyses were also run on increased sediment release rates of phosphorus. The final calibrated rates for sediment phosphorus release performed well in matching total phosphorus concentrations at depth. Higher rates of sediment phosphorus release resulted in much worse model-data comparisons at bottom and mid-depth with limited improvements in the model-data comparison at the surface.
- The assumptions applied for the various forms of phosphorus may not accurately reflect actual conditions. As presented in Section 3, the model state variables for the various forms of organic phosphorus were not directly measured. Therefore, assumptions were made based on previous modeling experience. This included assumptions of 15% labile and 85% refractory and 20% dissolved and 80% particulate. Further testing of these assumptions could improve model calibration.

Given the limitations of the model in regard to the surface gradient issues, and constraints of working with the existing phosphorus dataset and project budget and timeline, TMDL efforts will move forward with the current calibration, recognizing that it is a starting point for WDNR to explore further model refinements.

- **Chlorophyll-a**: The Chl-a MAE of 12.8 μg/L exceeds the preliminary target of 4 μg/L. However, the PBIAS value is good. The Rel%Err of -173% is outside typical targets of ±50–100%. The graphical model-data comparisons generally look good with the model missing some peak concentrations and generally overpredicting the lower concentrations. Comparison of MAE values to targets are made challenging by the high degree of heterogeneity in observed concentrations. An example of this is shown by duplicate sample at station 10031171 on August 3, 2010, where the two available Chl-a measurements differed by 99 µg/L.

- **Ammonia Nitrogen:** The ammonia nitrogen MAE of 0.065 mg/L exceeds the preliminary target of 0.03 mg/L. The model is overestimating ammonia with a PBIAS of 19% and a Rel%Err of 130%. This is generally a result of the model overestimating the lowest observed values. Calibration for ammonia is challenging given the large range in this parameter and the significant seasonal variability. Significant efforts were made in the calibration process to achieve a better fit. The model-data fit for ammonia is not expected to have a significant impact on the model's ability to support the TMDL.
- **Nitrate and Nitrite:** The nitrate and nitrite MAE is 0.166 mg/L and exceeds the preliminary target of 0.1 mg/L. The PBIAS of 10% is very good and the Rel%Err of 76% is fair. As with ammonia, this is generally a result of the model overestimating the lowest observed values. This is not expected to have a significant impact on the model's ability to support the TMDL.
- **Orthophosphate:** The orthophosphate MAE is 0.018 mg/L and exceeds the preliminary target of 0.01 mg/L. The PBIAS of 21% is good as is the Rel%Err of 50%.

6.4.4 Considerations for Further Model Refinement

Should further refinement of the model be pursued, the following are recommended items to consider:

- Modify the upstream boundary conditions from FLUXMASTER to improve the trends between measured data points;
- Assess the sensitivity of the model predictions to the assumptions for the forms of organic phosphorus (15% labile and 85% refractory and 20% dissolved and 80% particulate); and
- Test refinement of the vertical resolution of the layers.

6.5 Mass Balance Assessment

The total phosphorus mass balance was assessed for each reservoir individually. A mass balance assessment provides understanding of the fate and transport of a state variable through a water body and can be used as a quality assurance check on the general acceptance of a calibrated model. A mass balance can also be used to inform pollutant reduction strategies. The method for calculating the mass balance and the results are described below.

External loads were calculated based on the model inputs for the upstream, tributary, and point source loads. An updated version of CE-QUAL-W2, version 4.0, became available at the end of the project and included a mass balance output capability. LimnoTech ran version 4.0 with the calibrated model inputs. The mass balance output file includes a summary of the release of phosphorus from the sediments and the total phosphorus mass outflow for each reservoir. Tables 6.5 and 6.6 present the mass balance outputs for Petenwell and Castle Rock, respectively. Trapping efficiency was calculated for each reservoir by subtracting the outflow from the total external load and dividing by the external load.

The upstream load was quite similar for three of the four years ranging from 479 metric tons to 522 metric tons, with a much lower load in 2012 at 241 metric tons. In comparison to the other years, 2012 was a low-flow year. The tributary loads in Petenwell were much smaller than the upstream load contributing only 2%–3% of the total phosphorus load. This is a contrast with Castle Rock, which had 15%–22% of the loads coming from tributaries, primarily the Yellow River. The one point source in the model domain is not a significant contributor of total phosphorus. The annual trapping efficiency of

Petenwell ranges from 14% to 24%, while in Castle Rock the annual trapping efficiency ranges from 11% to 18%. Finally, the internal release of phosphorus from bottom sediments in Petenwell accounts for 9% to 16% of the annual load to the reservoir. In Castle Rock the internal release of phosphorus from the bottom sediments accounts for 2% to 4% of the annual load to the reservoir.

Outflows estimated by USGS FLUXMASTER results below Petenwell Dam (Station 293130) and Castle Rock Dam (Station 10017791) were compared to the mass balance outputs for outflow from each reservoir. These comparisons are shown in Table 6.7. Percent differences range from -1% to 20% for Petenwell and -2% to 20% for Castle Rock, demonstrating a reasonable comparison between results.

Table 6.5. Annual Total Phosphorus Mass Balance for Petenwell Reservoir in Metric Tons/Year

Total Phosphorus Mass Balance Components (all values in metric tons/year)	2010	2011	2012	2013
External Loads				
Wisconsin River Mainstem	483	522	241	479
Tributaries and Direct Drainage	10.5	11.8	6.8	8.7
Point Sources	0	0	0	0
Total External Load	**494**	**534**	**248**	**487**
Internal Load—Sediment Release	**51**	**52**	**48**	**47**
Outflow	**405**	**459**	**188**	**399**
Trapping Efficiency	***18%***	***14%***	***24%***	***18%***

Table 6.6. Annual Total Phosphorus Mass Balance for Castle Rock Reservoir in Metric Tons/Year

Total Phosphorus Mass Balance Components (all values in metric tons/year)	2010	2011	2012	2013
External Loads				
Outflow from Petenwell	405	459	188	399
Tributaries and Direct Drainage	87	81	52	78
Point Sources	0.19	0.12	0.17	0.10
Total External Load	**492**	**540**	**240**	**477**
Internal Load—Sediment Release	**11**	**12**	**10**	**9**
Outflow	**425**	**480**	**198**	**425**
Trapping Efficiency	***14%***	***11%***	***18%***	***11%***

Table 6.7. Comparison of Estimated and Simulated Outflows from Each Reservoir

Reservoir Outflow (all values in metric tons/year)	2010	2011	2012	2013
Petenwell				
USGS FLUXMASTER	410	389	187	333
CE-QUAL-W2 Mass Balance Outflow	405	459	188	399
% Difference	*-1%*	*18%*	*1%*	*20%*
Castle Rock				
USGS FLUXMASTER	433	399	183	392
CE-QUAL-W2 Mass Balance Outflow	425	480	198	425
% Difference	*-2%*	*20%*	*8%*	*9%*

6.6 Summary

The water quality calibration includes the integration of SWAT results for tributary loadings. A comprehensive dataset was available to inform model development and calibration. The model performed well in representing the measured temperature and dissolved oxygen data. The model performed fair in representing the individual measurements of total phosphorus and chlorophyll-a. However, when aggregating measurements on a monthly basis across the reservoir, the model performed well. The monthly, spatially aggregated comparisons are more applicable to the seasonal water quality assessment for attaining the nutrient goals in the reservoirs.

The primary model coefficients impacting the fate and transport of phosphorus were varied sufficiently to inform their final values. However, there are limitations to the model's ability to simulate the observed range of phosphorus and Chl-a values in some surface segments, as noted previously in this section.

In the context of developing a TMDL for Petenwell and Castle Rock reservoirs, the model, as configured and calibrated, provides a reasonable tool for estimating the reductions in total phosphorus loads needed to comply with the seasonal phosphorus targets. Given constraints of working with the existing dataset, and project budget and timeline, the current calibration provides a starting point for WDNR to explore further model refinements.

7 Load Reduction Scenarios

7.1 Overview

The purpose of this section is to present the results of applying the calibrated model to determine the magnitude of the pollutant load reduction of total phosphorus needed to achieve the in-lake phosphorus goal. This section is organized as follows:

- In-Lake Phosphorus Goals;
- Flow Conditions during Simulation Period;
- Loading Adjustments Evaluated; and
- Scenario Application Results.

7.2 In-Lake Phosphorus Goals

Petenwell and Castle Rock are considered unstratified reservoirs by WDNR (NR 102.06(2)(g)). The applicable water quality criterion for unstratified reservoirs is 40 µg/L total phosphorus (NR 102.06(4)(a)). WDNR provided the basis for assessment of this criterion for Petenwell and Castle Rock reservoirs in an April 15, 2016, memorandum (*Defining in-lake phosphorus goals for Petenwell and Castle Rock Scenarios for CE-QUAL-W2*). The assessment was based on a geometric mean of daily total phosphorus model outputs for the growing season of June 1 through September 15 across all four years of the model simulation period (2010–2013). Model outputs representing the upper two meters of the water column were used. This was done by averaging the results from the top two model layers in Petenwell segments (each layer is 0.98 meters deep) and the top four layers in Castle Rock segments (each layer is 0.5 meters deep). The top layer varies in depth so consideration was made for depth-weighting the results. However, the differences in the assessment results were determined to be negligible so straight averages across the assessment layers were used. Model results were grouped to assess Petenwell, Castle Rock, and the Yellow River Arm of Castle Rock individually. The segment groupings were used:

Group 1: Petenwell (main body)

- Upper Middle Petenwell—Station 10021168; model segment 9
- Middle Petenwell—Station 10031169; model segment 13
- Lower Middle Petenwell—Station 10031170; model segment 17
- Lower Petenwell—Station 10031171; model segment 20

Group 2: Castle Rock (main body)

- Main Upper Castle Rock—Station 10021172; model segment 41
- Main Middle Castle Rock—Station 10031173; model segment 46
- Main Lower Castle Rock—Station 10031174; model segment 50

Group 3: Castle Rock (Yellow River arm)

- Yellow River Arm—Station 10031175; model segment 57

Maps showing these monitoring locations and model segments are included as Figure 3.5 and Figure 3.6 in this report. WDNR developed this approach to be consistent with the Wisconsin 2016 Consolidated Assessment and Listing Methodology (WisCALM), which is available at http://dnr.wi.gov/topic/surfacewater/assessments.html.

7.3 Flow Conditions during Simulation Period

The ability of the model simulation period to represent longer term variability in stream flow was assessed by plotting flow duration curves for the simulation period (2010–2013) and the most recent 30 years (1985–2015) for the Wisconsin River at Wisconsin Rapids (USGS site 05400760). Flow duration curves plot discharge against the percent of time exceeded, and were plotted for both the summer period (June 1–September 15) and for the entire year (Figure 7.1). The curve based on all data indicates that typical flows (20^{th}–80^{th} percentile) were slightly lower and high flows were slightly higher during 2010–2013 than during 1985–2015. In other words, flows were slightly more variable than normal during the model simulation period. The curve based on the summer data indicates that the full range of flows was slightly above normal during the model simulation period. Based on these comparisons, the simulation period can be considered representative of longer term patterns and should produce representative predictions of water quality conditions as assessed by the method described in Section 7.2.

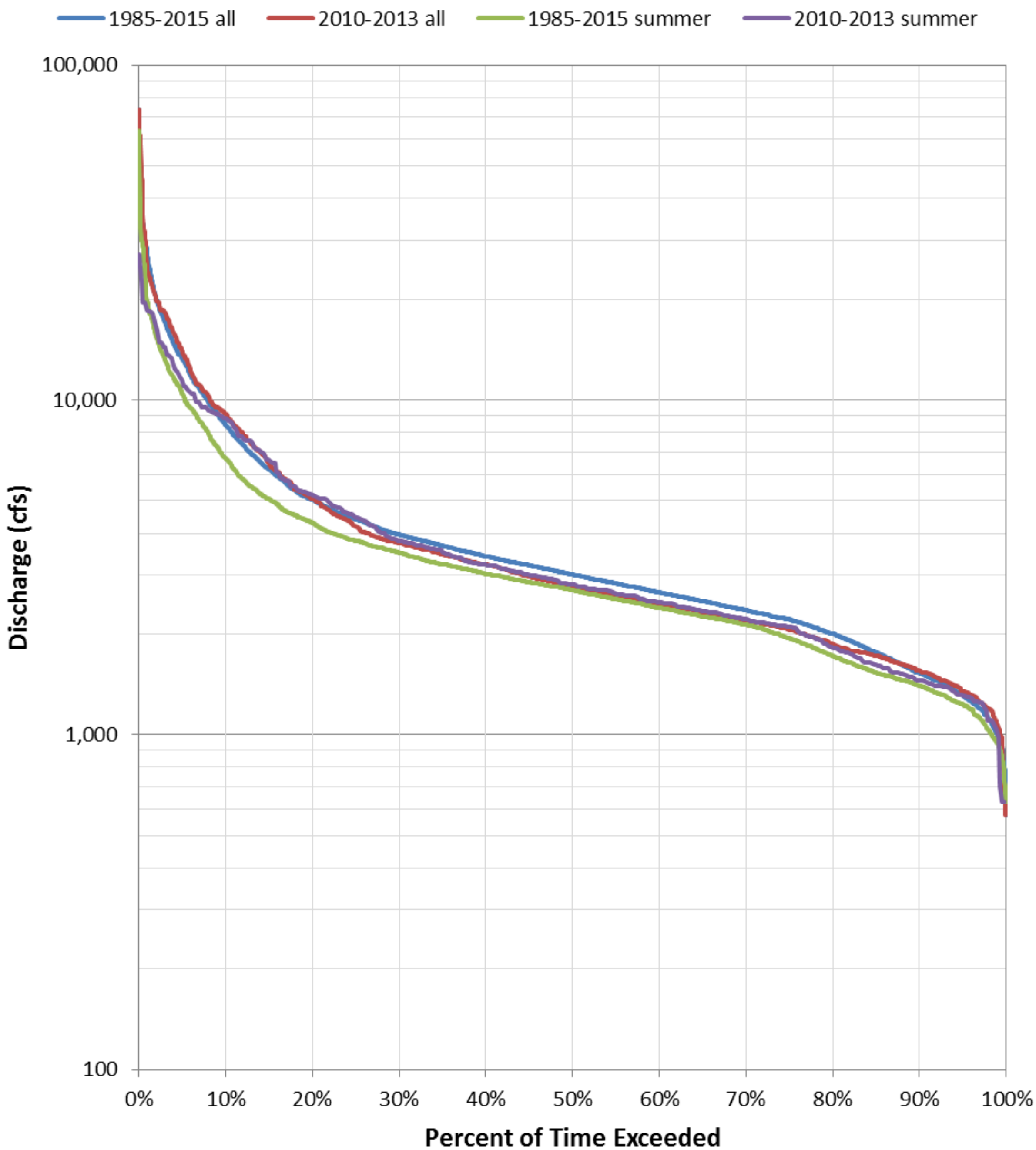

Figure 7.1. Flow Duration Curves for the Wisconsin River at Wisconsin Rapids, WI (USGS site ID 05400760) for the Model Simulation Period (2010–2013) and the Most Recent 30 Years (1985–2015), for Both the Summer Period (June 1–September 15) and the Entire Year

7.4 Loading Adjustments Evaluated

Load reduction scenarios were run to determine conditions needed to attain the in-lake phosphorus goal. Total phosphorus loads were reduced from external loading sources, including the upstream, tributary and direct drainage loads. Scenarios were run iteratively to bracket attainment of the in-lake phosphorus goal within a 5% increment in terms of percent reduction. Additional sensitivity scenarios were run that assessed reductions in the release of phosphorus from the bottom sediments.

All phosphorus fractions represented in the model that collectively comprise total phosphorus were reduced proportionately by the same percentage. This includes orthophosphate (PO4), labile dissolved organic matter-phosphorus (LDOM-P), refractory dissolved organic matter phosphorus (RDOM-P), labile particulate organic matter phosphorus (LPOM-P), refractory particulate organic matter phosphorus (RPOM-P), and external algal biomass loads for each of the three algal groups represented in the model.

It is expected that future reduction in external phosphorus loads will lead to reductions in internal sediment release, but this mechanism is not explicitly considered in the current version of CE-QUAL-W2. Additional sensitivity scenarios were run that included manually specified reductions in the flux of phosphorus from the bottom sediments. This was accomplished by adjustment of the PO4R parameter, which represents the release of phosphate from the sediments as a fraction of the SOD value. The final calibrated value of PO4R was 0.01. The assumed amount of reduction is explained later in this section.

7.5 Scenario Application Results

The results of the scenario applications are presented in Appendix B. A summary of the results are presented in Figure 7.2. The results show that the greatest reduction is needed to achieve the in-lake phosphorus goal of 40 µg/L (0.040 mg/L) in Petenwell at a 55% reduction in the external load. Under this scenario, the goal is also achieved in Castle Rock and the Yellow River Arm. The in-lake phosphorus goal for Castle Rock is achieved at a 49% reduction, and in the Yellow River Arm at approximately a 42% reduction.

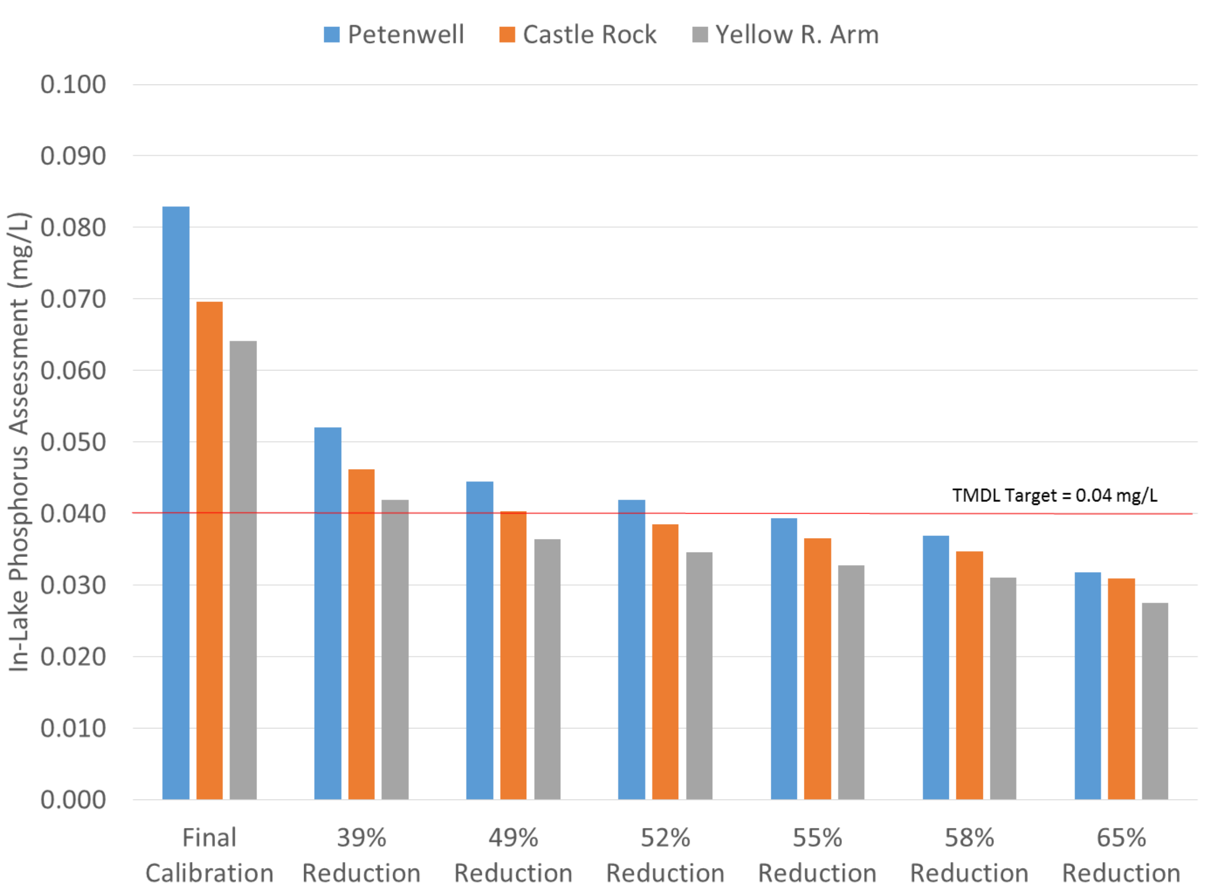

Figure 7.2. Assessment of Attainment of In-Lake Phosphorus Goal for Different Levels of Reduction of the External Phosphorus Load

7.6 Sensitivity of Results to Reductions in Sediment Flux

Sensitivity analyses were run on the TP reduction scenarios to examine the potential improvements associated with a decrease in the phosphorus release from sediments associated with reductions in external loads. Something less than a 1-to-1 ratio in the reduction of sediment release of phosphorus to reductions in external loads of phosphorus would be expected. Therefore, 25% and 50% reductions in sediment phosphorus release were simulated by reducing the PO4R parameter by 25% (from 0.01 to 0.0075) and 50% (from 0.01 to 0.005).

The results of these simulations are shown in Figure 7.3 for Petenwell. These simulations indicate that a 51% reduction in the external phosphorus load combined with a 25% reduction in the sediment release of phosphorus results in achieving the in-lake phosphorus goal of 0.04 mg/L. Also, a 49% reduction in the external phosphorus load combined with a 52% reduction in the sediment release of phosphorus results in achieving the in-lake phosphorus goal of 0.04 mg/L. The sensitivity of the in-lake phosphorus assessment for Castle Rock and the Yellow River Arm to reductions in sediment release are shown in Figures 7.4 and 7.5.

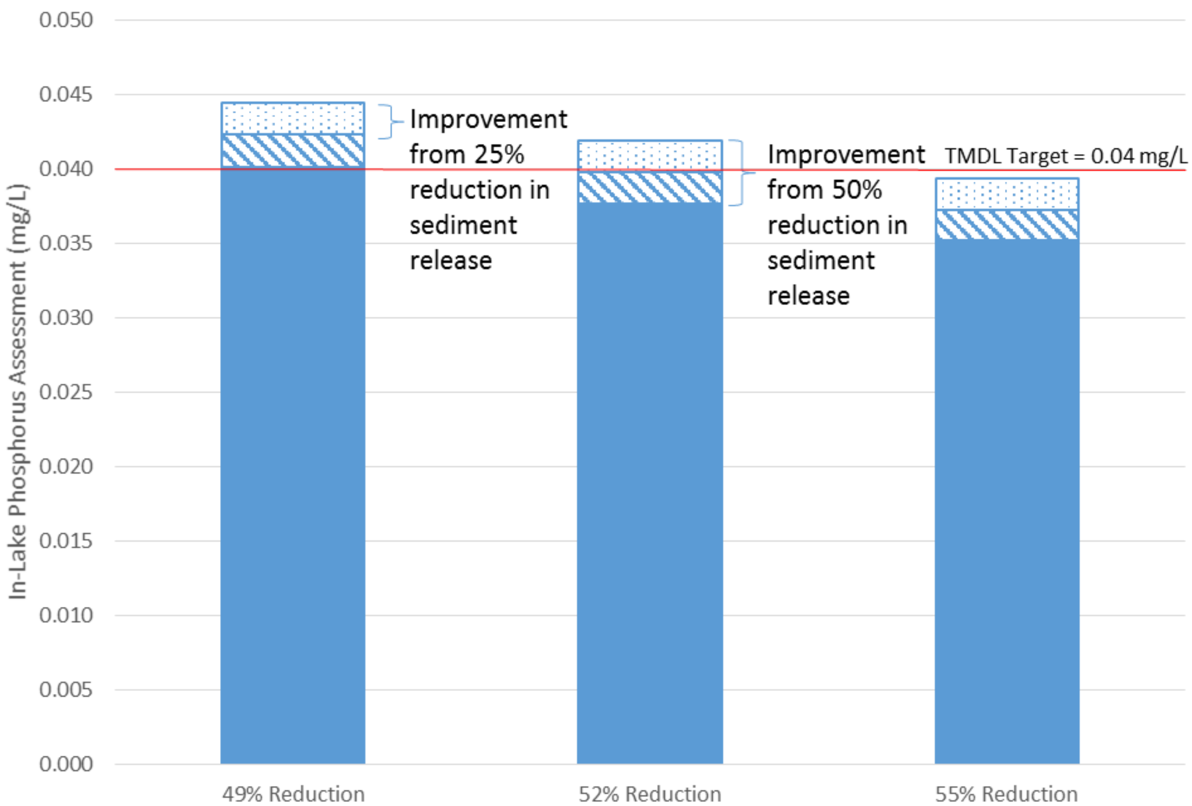

Figure 7.3. Petenwell Sensitivity to Reductions in Sediment Release

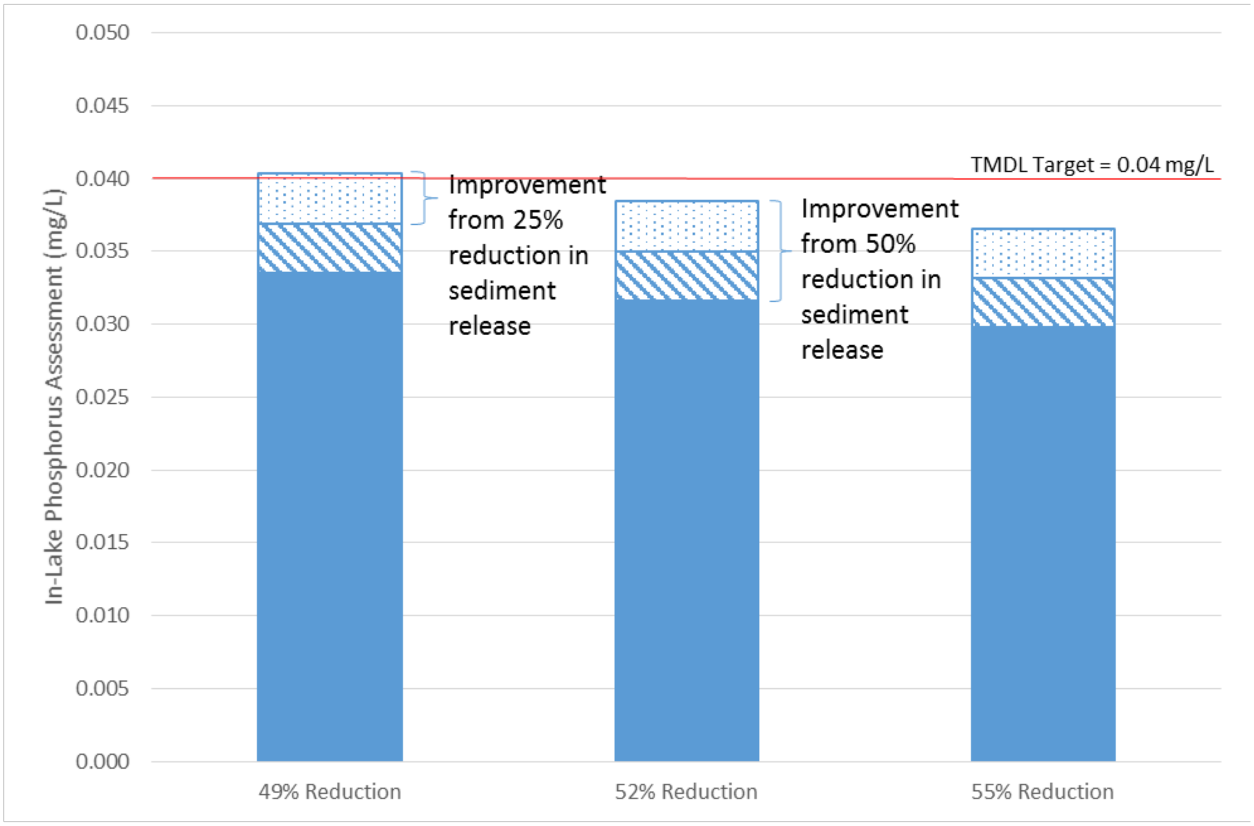

Figure 7.4. Castle Rock Sensitivity to Reductions in Sediment Release

Figure 7.5. Yellow River Arm Sensitivity to Reduction in Sediment Release

7.7 Conclusion

The results of the scenario analysis indicate that a large percentage reduction is needed in the external phosphorus load to achieve the in-lake phosphorus goals. The required reductions are approximately 55% for Petenwell, 49% for Castle Rock, and 42% for the Yellow River Arm. If sediment release of phosphorus is reduced in response to this level of external load reduction, then a somewhat smaller external load reduction may be needed. A 25% reduction in sediment release changes the required load reduction for Petenwell from 55% to 52%, while a 50% reduction in sediment release changes the required load reduction to 49%.

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Additional Project Memoranda

LimnoTech. (2015, September 22). Memorandum. To: Vilma Rivera-Carrero, EPA; From: Holmberg, H. P., Lofton, D. D., & Eddy, M. Subject: Functional Algal Group Determination.

LimnoTech. (2016, January 20). Memorandum. To: Vilma Rivera-Carrero, EPA; From: Hinz, S. C., Holmberg, H. P., Lofton, D. D., & Dilks, D. W. Subject: Task 3b—Initial Water Quality Calibration Task 3b—Initial Water Quality Calibration.

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Appendix A
Goodness of Fit Statistics

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Temperature Statistics

	Location	Station Number	Years with Data	Count	Med_data deg. C	Med_ model deg. C	MAE deg. C	PBIAS %	Rel%Err %
Grab Samples	Petenwell Lake—Wisconsin River	013016	2010-2013	330	20.26	20.25	0.92	1	0
	Petenwell Lake—Main Body	10031168	2010-2013	313	20.28	20.16	0.97	0	0
	Petenwell Lake—Main Body	10031169	2010-2013	441	19.68	19.50	1.07	1	0
	Petenwell Lake—Main Body	10031170	2010-2013	640	19.73	19.47	0.90	1	1
	Petenwell Lake—Main Body	10031171	2010-2013	753	19.13	18.96	1.05	1	0
	Castle Rock Lake—below Petenwell Dam	293130	2010-2013	96	7.42	7.49	0.75	1	-7
	Castle Rock Lake—Main Body	10031172	2010-2013	388	19.65	19.69	0.82	0	-1
	Castle Rock Lake—Main Body	10031173	2010-2013	519	19.72	19.53	0.64	1	1
	Castle Rock Lake—Main Body	10031174	2010-2013	529	19.26	19.03	0.70	2	1
	Wisconsin River—Castle Rock Dam	10017791	2010-2013	96	7.31	7.65	1.34	6	-19
	Castle Rock Lake—Yellow River Arm	293132	2010-2013	436	19.88	19.48	1.04	2	2
	Castle Rock Lake—Yellow River Arm	10031175	2010-2013	409	20.09	19.90	0.73	1	1

Temperature Statistics (continued)

	Location	Station Number	Years with Data	Count	Med_data deg. C	Med_model deg. C	MAE deg. C	PBIAS %	Rel%Err %
Time Series	Petenwell Lake—Wisconsin River	013016 TS	2011-2013	14706	22.27	22.09	0.63	1	-1
	Petenwell Lake—Main Body	10031168 TS	2010-2012	12293	20.45	20.72	0.67	-1	1
	Petenwell Lake—Main Body	10031169 TS	2010-2013	27243	20.95	21.28	0.69	-2	2
	Petenwell Lake—Main Body	10031170 TS	2010-2013	46967	20.37	20.54	0.59	-1	1
	Petenwell Lake—Main Body	10031171 TS	2010-2013	48624	20.20	20.43	0.55	-1	1
	Castle Rock Lake—below Petenwell Dam	293130 TS	2010-2013	9610	14.49	13.15	1.45	0	-4
	Castle Rock Lake—Main Body	10031172 TS	2011-2013	16396	21.21	20.90	0.66	2	-1
	Castle Rock Lake—Main Body	10031173 TS	2011-2013	18850	21.53	21.43	0.55	0	0
	Castle Rock Lake—Main Body	10031174 TS	2011-2013	28769	21.43	21.32	0.52	0	0
	Wisconsin River—Castle Rock Dam	10017791 TS	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
	Castle Rock Lake—Yellow River Arm	293132 TS	2011-2012	11890	20.90	20.32	0.90	3	-3
	Castle Rock Lake—Yellow River Arm	10031175 TS	2011-2012	13612	21.39	21.13	0.59	1	-1
Station Groups	Petenwell Main Body Stations	10031168, 10031169, 10031170, 10031171		*137274*	*20.42*	*20.64*	*0.61*	*-1*	*-1*
	Castle Rock Main Body Stations	10031172, 10031173, 10031174		*65451*	*21.36*	*21.20*	*0.57*	*1*	*1*
	Yellow River Arm Stations	293132, 10031175		*26347*	*21.12*	*20.72*	*0.74*	*2*	*2*
	All Main Body			*202725*	*20.72*	*20.82*	*0.60*	*-1*	*-1*

Total Phosphorus Statistics

	Location	Station Number	Years with Data	Count	Med_data mg/L	Med_model mg/L	MAE mg/L	PBIAS %	Rel%Err %
Grab Samples	Petenwell Lake—Wisconsin River	013016	2010-2013	44	0.091	0.105	0.018	-14	-17
	Petenwell Lake—Main Body	10031168	2010-2013	43	0.102	0.099	0.026	2	-2
	Petenwell Lake—Main Body	10031169	2010-2013	85	0.107	0.092	0.038	17	6
	Petenwell Lake—Main Body	10031170	2010-2013	131	0.090	0.091	0.028	1	-8
	Petenwell Lake—Main Body	10031171	2010-2013	136	0.072	0.096	0.033	-36	-41
	Castle Rock Lake—below Petenwell Dam	293130	2010-2013	99	0.072	0.069	0.019	6	0
	Castle Rock Lake—Main Body	10031172	2010-2013	45	0.072	0.079	0.016	-10	-13
	Castle Rock Lake—Main Body	10031173	2010-2013	92	0.074	0.068	0.022	11	3
	Castle Rock Lake—Main Body	10031174	2010-2013	134	0.070	0.071	0.023	2	-8
	Wisconsin River—Castle Rock Dam	10017791	2010-2013	99	0.059	0.067	0.020	-12	-21
	Castle Rock Lake—Yellow River Arm	293132	2010-2013	46	0.105	0.077	0.044	26	19
	Castle Rock Lake—Yellow River Arm	10031175	2010-2013	89	0.088	0.066	0.034	29	19
Station Groups	Petenwell Main Body Stations	10031168, 10031169, 10031170, 10031171		*395*	*0.088*	*0.094*	*0.032*	*-5*	*-15*
	Castle Rock Main Body Stations	10031172, 10031173, 10031174		*271*	*0.072*	*0.071*	*0.022*	*3*	*-5*
	Yellow River Arm Stations	293132, 10031175		*135*	*0.094*	*0.069*	*0.037*	*27*	*19*
	All Main Body			*666*	*0.081*	*0.084*	*0.028*	*-2*	*-11*

Chlorophyll-a Statistics

	Location	Station Number	Years with Data	Count	Med_data ug/L	Med_model ug/L	MAE ug/L	PBIAS %	Rel%Err %
Grab Samples	Petenwell Lake—Wisconsin River	013016	2010-2013	44	26	29	9.9	-3	-27
	Petenwell Lake—Main Body	10031168	2010-2013	42	27	22	14.7	30	-10
	Petenwell Lake—Main Body	10031169	2010-2013	82	18	16	17.0	34	-77
	Petenwell Lake—Main Body	10031170	2010-2013	129	9	12	13.0	22	-217
	Petenwell Lake—Main Body	10031171	2010-2013	136	7	11	12.1	20	-261
	Castle Rock Lake—below Petenwell Dam	293130	2010-2013	67	7	7	6.6	13	-87
	Castle Rock Lake—Main Body	10031172	2010-2013	43	13	16	13.3	6	-172
	Castle Rock Lake—Main Body	10031173	2010-2013	88	14	17	13.5	15	-159
	Castle Rock Lake—Main Body	10031174	2010-2013	130	12	15	13.4	15	-142
	Wisconsin River—Castle Rock Dam	10017791	2010-2013	68	9	8	10.2	25	-89
	Castle Rock Lake—Yellow River Arm	293132	2010-2013	45	16	17	10.4	11	-48
	Castle Rock Lake—Yellow River Arm	10031175	2010-2013	87	13	20	13.3	-14	-162
Station Groups	Petenwell Main Body Stations	10031168, 10031169, 10031170, 10031171		*389*	*11*	*13*	*13.7*	*26*	*-180*
	Castle Rock Main Body Stations	10031172, 10031173, 10031174		*261*	*13*	*16*	*13.4*	*14*	*-152*
	Yellow River Arm Stations	293132, 10031175		*132*	*14*	*19*	*12.3*	*-5*	*-123*
	All Main Body			*650*	*12*	*14*	*13.6*	*21*	*-169*

Dissolved Oxygen Statistics

	Location	Station Number	Years with Data	Count	Med_ data mg/L	Med_ model mg/L	MAE mg/L	PBIAS %	Rel%Err %
Grab Samples	Petenwell Lake—Wisconsin River	013016	2010-2013	216	8.74	8.31	1.23	6	3
	Petenwell Lake—Main Body	10031168	2010-2013	197	8.51	8.07	1.74	6	-6
	Petenwell Lake—Main Body	10031169	2010-2013	288	7.83	7.53	1.94	5	-22
	Petenwell Lake—Main Body	10031170	2010-2013	419	7.13	7.08	1.50	3	-29
	Petenwell Lake—Main Body	10031171	2010-2013	490	7.26	7.04	1.25	2	-2
	Castle Rock Lake—below Petenwell Dam	293130	2010-2013	95	9.19	8.71	1.21	4	4
	Castle Rock Lake—Main Body	10031172	2010-2013	271	8.32	8.21	1.20	2	0
	Castle Rock Lake—Main Body	10031173	2010-2013	369	8.36	8.82	1.31	-3	-10
	Castle Rock Lake—Main Body	10031174	2010-2013	447	7.57	8.15	1.35	-4	-31
	Wisconsin River—Castle Rock Dam	10017791	2010-2013	95	9.62	8.74	1.37	6	7
	Castle Rock Lake—Yellow River Arm	293132	2010-2013	276	7.78	8.32	1.06	-6	-8
	Castle Rock Lake—Yellow River Arm	10031175	2010-2013	303	7.38	8.90	1.57	-14	-146
Time Series	Castle Rock Lake—below Petenwell Dam	293130 TS	2011-2013	5271	6.96	6.25	1.46	13	31
Station Groups	Petenwell Main Body Stations	10031168, 10031169, 10031170, 10031171		*1394*	*7.50*	*7.29*	*1.54*	*4*	*-15*
	Castle Rock Main Body Stations	10031172, 10031173, 10031174		*1087*	*8.01*	*8.39*	*1.30*	*-2*	*-16*
	Yellow River Arm Stations	293132, 10031175		*579*	*7.57*	*8.62*	*1.32*	*-10*	*-80*
	All Main Body			*2481*	*7.72*	*7.75*	*1.43*	*1*	*-16*

Total Organic Carbon Statistics

	Location	Station Number	Years with Data	Count	Med_data mg/L	Med_model mg/L	MAE mg/L	PBIAS %	Rel%Err %
Grab Samples	Petenwell Lake—Wisconsin River	013016	2010-2013	43	19	21	2.50	-6	-9
	Petenwell Lake—Main Body	10031168	2010-2013	43	20	19	3.08	2	-1
	Petenwell Lake—Main Body	10031169	2010-2013	85	19	18	4.24	8	1
	Petenwell Lake—Main Body	10031170	2010-2013	132	18	17	3.13	4	-2
	Petenwell Lake—Main Body	10031171	2010-2013	136	16	17	2.74	-3	-8
	Castle Rock Lake—below Petenwell Dam	293130	2010-2013	39	16	16	2.43	5	1
	Castle Rock Lake—Main Body	10031172	2010-2013	45	16	17	2.38	-5	-9
	Castle Rock Lake—Main Body	10031173	2010-2013	90	16	16	2.69	0	-5
	Castle Rock Lake—Main Body	10031174	2010-2013	134	15	16	2.74	-2	-7
	Wisconsin River—Castle Rock Dam	10017791	2010-2013	39	16	15	1.70	5	4
	Castle Rock Lake—Yellow River Arm	293132	2010-2013	45	16	15	3.78	5	2
	Castle Rock Lake—Yellow River Arm	10031175	2010-2013	89	16	16	3.21	-1	-6
Station Groups	Petenwell Main Body Stations	10031168, 10031169, 10031170, 10031171		*396*	*18*	*18*	*3.23*	*2*	*-4*
	Castle Rock Main Body Stations	10031172, 10031173, 10031174		*269*	*16*	*16*	*2.66*	*-2*	*-7*
	Yellow River Arm Stations	293132, 10031175		*134*	*16*	*16*	*3.42*	*1*	*-3*
	All Main Body			*665*	*17*	*17*	*3.00*	*1*	*-5*

Total Nitrogen Statistics

	Location	Station Number	Years with Data	Count	Med_data mg/L	Med_ model mg/L	MAE mg/L	PBIAS %	Rel%Err %
Grab Samples	Petenwell Lake—Wisconsin River	013016	2010-2013	44	1.62	1.75	0.186	-7	-8
	Petenwell Lake—Main Body	10031168	2010-2013	43	1.67	1.61	0.204	5	3
	Petenwell Lake—Main Body	10031169	2010-2013	85	1.66	1.46	0.420	17	8
	Petenwell Lake—Main Body	10031170	2010-2013	131	1.48	1.41	0.324	9	2
	Petenwell Lake—Main Body	10031171	2010-2013	136	1.34	1.35	0.220	1	-2
	Castle Rock Lake—below Petenwell Dam	293130	2010-2013	98	1.52	1.37	0.268	11	8
	Castle Rock Lake—Main Body	10031172	2010-2013	45	1.37	1.35	0.192	3	0
	Castle Rock Lake—Main Body	10031173	2010-2013	92	1.37	1.33	0.267	5	0
	Castle Rock Lake—Main Body	10031174	2010-2013	134	1.30	1.30	0.222	2	-2
	Wisconsin River—Castle Rock Dam	10017791	2010-2013	98	1.45	1.41	0.199	3	1
	Castle Rock Lake—Yellow River Arm	293132	2010-2013	46	1.20	1.08	0.300	13	6
	Castle Rock Lake—Yellow River Arm	10031175	2010-2013	89	1.23	1.19	0.232	5	1
Station Groups	Petenwell Main Body Stations	10031168, 10031169, 10031170, 10031171		*395*	*1.49*	*1.41*	*0.301*	*8*	*2*
	Castle Rock Main Body Stations	10031172, 10031173, 10031174		*271*	*1.34*	*1.32*	*0.234*	*3*	*-1*
	Yellow River Arm Stations	293132, 10031175		*135*	*1.22*	*1.15*	*0.257*	*8*	*3*
	All Main Body			*666*	*1.42*	*1.37*	*0.274*	*6*	*1*

Total Kjeldahl Nitrogen Statistics

	Location	Station Number	Years with Data	Count	Med_data mg/L	Med_model mg/L	MAE mg/L	PBIAS %	Rel%Err %
Grab Samples	Petenwell Lake—Wisconsin River	013016	2010-2013	44	1.194	1.347	0.201	-12	-14
	Petenwell Lake—Main Body	10031168	2010-2013	43	1.334	1.260	0.194	7	4
	Petenwell Lake—Main Body	10031169	2010-2013	85	1.354	1.155	0.402	21	11
	Petenwell Lake—Main Body	10031170	2010-2013	131	1.171	1.097	0.298	11	3
	Petenwell Lake—Main Body	10031171	2010-2013	136	1.001	1.057	0.208	-4	-8
	Castle Rock Lake—below Petenwell Dam	293130	2010-2013	100	0.994	0.869	0.218	14	10
	Castle Rock Lake—Main Body	10031172	2010-2013	45	0.952	1.017	0.185	-5	-12
	Castle Rock Lake—Main Body	10031173	2010-2013	92	0.991	1.007	0.294	5	-14
	Castle Rock Lake—Main Body	10031174	2010-2013	134	0.957	1.002	0.249	1	-16
	Wisconsin River—Castle Rock Dam	10017791	2010-2013	100	0.946	0.825	0.195	12	10
	Castle Rock Lake—Yellow River Arm	293132	2010-2013	46	0.869	0.967	0.318	10	-272
	Castle Rock Lake—Yellow River Arm	10031175	2010-2013	89	0.931	1.028	0.244	0	-55
Station Groups	Petenwell Main Body Stations	10031168, 10031169, 10031170, 10031171		*395*	*1.161*	*1.114*	*0.288*	*9*	*0*
	Castle Rock Main Body Stations	10031172, 10031173, 10031174		*271*	*0.967*	*1.005*	*0.255*	*2*	*-15*
	Yellow River Arm Stations	293132, 10031175		*135*	*0.909*	*1.003*	*0.272*	*4*	*-128*
	All Main Body			*666*	*1.078*	*1.068*	*0.275*	*6*	*-6*

Ammonia Statistics

	Location	Station Number	Years with Data	Count	Med_data mg/L	Med_model mg/L	MAE mg/L	PBIAS %	Rel%Err %
Grab Samples	Petenwell Lake—Wisconsin River	013016	2010-2013	44	0.0187	0.0446	0.0323	-90	-231
	Petenwell Lake—Main Body	10031168	2010-2013	43	0.0255	0.0708	0.0608	-61	-348
	Petenwell Lake—Main Body	10031169	2010-2013	85	0.0614	0.0779	0.0955	21	-191
	Petenwell Lake—Main Body	10031170	2010-2013	132	0.0693	0.0949	0.0938	11	-211
	Petenwell Lake—Main Body	10031171	2010-2013	136	0.0465	0.0969	0.0833	-38	-324
	Castle Rock Lake—below Petenwell Dam	293130	2010-2013	100	0.1012	0.1027	0.0679	16	-78
	Castle Rock Lake—Main Body	10031172	2010-2013	45	0.0229	0.0376	0.0481	-7	-193
	Castle Rock Lake—Main Body	10031173	2010-2013	92	0.0330	0.0423	0.0512	18	-127
	Castle Rock Lake—Main Body	10031174	2010-2013	134	0.0457	0.0612	0.0636	9	-167
	Wisconsin River—Castle Rock Dam	10017791	2010-2013	100	0.0827	0.0923	0.0573	9	-80
	Castle Rock Lake—Yellow River Arm	293132	2010-2013	46	0.0179	0.0298	0.0288	-58	-180
	Castle Rock Lake—Yellow River Arm	10031175	2010-2013	89	0.0412	0.0345	0.0681	37	-95
Station Groups	Petenwell Main Body Stations	10031168, 10031169, 10031170, 10031171		*396*	*0.0528*	*0.0887*	*0.0870*	*-4*	*-261*
	Castle Rock Main Body Stations	10031172, 10031173, 10031174		*271*	*0.0365*	*0.0498*	*0.0568*	*10*	*-158*
	Yellow River Arm Stations	293132, 10031175		*135*	*0.0310*	*0.0329*	*0.0547*	*23*	*-124*
	All Main Body			*667*	*0.0454*	*0.0702*	*0.0747*	*0*	*-219*

Nitrate and Nitrite Statistics

	Location	Station Number	Years with Data	Count	Med_data mg/L	Med_model mg/L	MAE mg/L	PBIAS %	Rel%Err %
Grab Samples	Petenwell Lake—Wisconsin River	013016	2010-2013	44	0.369	0.375	0.130	8	-16
	Petenwell Lake—Main Body	10031168	2010-2013	43	0.201	0.297	0.171	-5	-168
	Petenwell Lake—Main Body	10031169	2010-2013	85	0.153	0.219	0.159	-6	-148
	Petenwell Lake—Main Body	10031170	2010-2013	132	0.175	0.214	0.135	-1	-91
	Petenwell Lake—Main Body	10031171	2010-2013	136	0.214	0.177	0.160	19	-34
	Castle Rock Lake—below Petenwell Dam	293130	2010-2013	98	0.342	0.338	0.144	6	-47
	Castle Rock Lake—Main Body	10031172	2010-2013	45	0.235	0.210	0.183	21	-36
	Castle Rock Lake—Main Body	10031173	2010-2013	92	0.160	0.152	0.176	4	-50
	Castle Rock Lake—Main Body	10031174	2010-2013	134	0.147	0.135	0.160	5	-52
	Wisconsin River—Castle Rock Dam	10017791	2010-2013	98	0.302	0.316	0.144	-12	-34
	Castle Rock Lake—Yellow River Arm	293132	2010-2013	46	0.068	0.071	0.162	29	-126
	Castle Rock Lake—Yellow River Arm	10031175	2010-2013	89	0.091	0.055	0.202	26	-82
Station Groups	Petenwell Main Body Stations	10031168, 10031169, 10031170, 10031171		*396*	*0.185*	*0.199*	*0.155*	*7*	*-91*
	Castle Rock Main Body Stations	10031172, 10031173, 10031174		*271*	*0.163*	*0.150*	*0.170*	*7*	*-52*
	Yellow River Arm Stations	293132, 10031175		*135*	*0.082*	*0.053*	*0.182*	*27*	*-80*
	All Main Body			*667*	*0.176*	*0.177*	*0.161*	*7*	*-75*

Orthophosphate Statistics

	Location	Station Number	Years with Data	Count	Med_data mg/L	Med_model mg/L	MAE mg/L	PBIAS %	Rel%Err %
Grab Samples	Petenwell Lake—Wisconsin River	013016	2010-2013	44	0.0087	0.0129	0.0098	-5	-125
	Petenwell Lake—Main Body	10031168	2010-2013	43	0.0098	0.0164	0.0161	-57	-223
	Petenwell Lake—Main Body	10031169	2010-2013	85	0.0198	0.0189	0.0240	-10	-100
	Petenwell Lake—Main Body	10031170	2010-2013	132	0.0235	0.0249	0.0256	-9	-102
	Petenwell Lake—Main Body	10031171	2010-2013	136	0.0212	0.0298	0.0324	-68	-185
	Castle Rock Lake—below Petenwell Dam	293130	2010-2013	100	0.0245	0.0278	0.0148	-8	-38
	Castle Rock Lake—Main Body	10031172	2010-2013	45	0.0144	0.0181	0.0160	-25	-113
	Castle Rock Lake—Main Body	10031173	2010-2013	92	0.0121	0.0097	0.0133	8	-68
	Castle Rock Lake—Main Body	10031174	2010-2013	134	0.0131	0.0139	0.0200	-11	-138
	Wisconsin River—Castle Rock Dam	10017791	2010-2013	100	0.0142	0.0273	0.0202	-71	-215
	Castle Rock Lake—Yellow River Arm	293132	2010-2013	46	0.0175	0.0169	0.0189	20	-53
	Castle Rock Lake—Yellow River Arm	10031175	2010-2013	89	0.0153	0.0086	0.0224	48	-62
Station Groups	Petenwell Main Body Stations	10031168, 10031169, 10031170, 10031171		*396*	*0.0199*	*0.0238*	*0.0266*	*-33*	*-143*
	Castle Rock Main Body Stations	10031172, 10031173, 10031174		*271*	*0.0130*	*0.0128*	*0.0171*	*-8*	*-110*
	Yellow River Arm Stations	293132, 10031175		*135*	*0.0160*	*0.0109*	*0.0212*	*38*	*-59*
	All Main Body			*667*	*0.0167*	*0.0185*	*0.0227*	*-25*	*-130*

Total Dissolved Solids Statistics

	Location	Station Number	Years with Data	Count	Med_data mg/L	Med_model mg/L	MAE mg/L	PBIAS %	Rel%Err %
Grab Samples	Petenwell Lake—Wisconsin River	013016	2010-2013	44	143	151	16.1	-4	-8
	Petenwell Lake—Main Body	10031168	2010-2013	43	140	148	17.1	-5	-9
	Petenwell Lake—Main Body	10031169	2010-2013	85	132	142	18.1	-6	-11
	Petenwell Lake—Main Body	10031170	2010-2013	132	128	139	18.2	-7	-11
	Petenwell Lake—Main Body	10031171	2010-2013	136	125	138	16.7	-10	-12
	Castle Rock Lake—below Petenwell Dam	293130	2010-2013	52	135	144	14.8	-6	-8
	Castle Rock Lake—Main Body	10031172	2010-2013	45	126	140	18.2	-10	-13
	Castle Rock Lake—Main Body	10031173	2010-2013	92	124	140	20.1	-12	-14
	Castle Rock Lake—Main Body	10031174	2010-2013	134	121	137	18.0	-12	-14
	Wisconsin River—Castle Rock Dam	10017791	2010-2013	52	129	144	18.9	-10	-13
	Castle Rock Lake—Yellow River Arm	293132	2010-2013	46	98	109	18.3	-11	-14
	Castle Rock Lake—Yellow River Arm	10031175	2010-2013	89	108	121	18.5	-11	-14
Station Groups	Petenwell Main Body Stations	10031168, 10031169, 10031170, 10031171		*396*	*129*	*140*	*17.6*	*-7*	*-11*
	Castle Rock Main Body Stations	10031172, 10031173, 10031174		*271*	*123*	*139*	*18.7*	*-12*	*-14*
	Yellow River Arm Stations	293132, 10031175		*135*	*104*	*116*	*18.5*	*-11*	*-14*
	All Main Body			*667*	*127*	*140*	*18.0*	*-9*	*-12*

Appendix B
Load Reduction Scenario Results

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Total Phosphorus Assessment Method Applied to Calibration Run H49

Assessment/Growing Season (June 1 - September 15) Geometric Mean TP (mg/L) for 2010-2013

	Group 1	*Group 2*	*Group 3*	Petenwell Lake (top 2 layers)				Castle Rock Lake (top 4 layers)			Yellow River Arm (top 4 layers)
Layer	**Petenwell**	**Castle Rock**	**Yellow R. Arm**	**Seg 9**	**Seg 13**	**Seg 17**	**Seg 20**	**Seg 41**	**Seg 46**	**Seg 50**	**Seg 57**
Assessment	0.0829	0.0696	0.0641	0.0926	0.0820	0.0791	0.0755	0.0801	0.0654	0.0629	0.0641
L1	0.0824	0.0693	0.0638	0.0920	0.0816	0.0787	0.0752	0.0797	0.0650	0.0625	0.0638
L2	0.0833	0.0695	0.0640	0.0931	0.0825	0.0795	0.0757	0.0800	0.0653	0.0628	0.0640
L3	0.0842	0.0697	0.0642	0.0946	0.0832	0.0804	0.0764	0.0802	0.0655	0.0630	0.0642
L4	0.0858	0.0700	0.0644	0.0976	0.0844	0.0816	0.0775	0.0804	0.0657	0.0632	0.0644

Assessment/Growing Season (June 1 - September 15) Mean TP (mg/L) for 2010-2013

	Group 1	*Group 2*	*Group 3*	Petenwell Lake (top 2 layers)				Castle Rock Lake (top 4 layers)			Yellow River Arm (top 4 layers)
Layer	**Petenwell**	**Castle Rock**	**Yellow R. Arm**	**Seg 9**	**Seg 13**	**Seg 17**	**Seg 20**	**Seg 41**	**Seg 46**	**Seg 50**	**Seg 57**
Assessment	0.0843	0.0713	0.0653	0.0944	0.0842	0.0812	0.0774	0.0822	0.0673	0.0644	0.0653
L1	0.0839	0.0709	0.0650	0.0939	0.0837	0.0808	0.0771	0.0818	0.0669	0.0640	0.0650
L2	0.0847	0.0712	0.0652	0.0950	0.0846	0.0816	0.0777	0.0821	0.0672	0.0643	0.0652
L3	0.0856	0.0714	0.0654	0.0965	0.0854	0.0824	0.0782	0.0823	0.0674	0.0645	0.0654
L4	0.0873	0.0716	0.0656	0.0998	0.0865	0.0835	0.0794	0.0825	0.0676	0.0647	0.0656

Assessment/Growing Season (June 1 - September 15) Median TP (mg/L) for 2010-2013

	Group 1	*Group 2*	*Group 3*	Petenwell Lake (top 2 layers)				Castle Rock Lake (top 4 layers)			Yellow River Arm (top 4 layers)
Layer	**Petenwell**	**Castle Rock**	**Yellow R. Arm**	**Seg 9**	**Seg 13**	**Seg 17**	**Seg 20**	**Seg 41**	**Seg 46**	**Seg 50**	**Seg 57**
Assessment	0.0861	0.0732	0.0619	0.0910	0.0828	0.0826	0.0810	0.0864	0.0683	0.0641	0.0619
L1	0.0858	0.0727	0.0619	0.0906	0.0823	0.0825	0.0809	0.0860	0.0679	0.0638	0.0619
L2	0.0863	0.0732	0.0620	0.0917	0.0833	0.0831	0.0814	0.0862	0.0683	0.0640	0.0620
L3	0.0863	0.0732	0.0620	0.0922	0.0837	0.0844	0.0825	0.0865	0.0684	0.0642	0.0620
L4	0.0875	0.0732	0.0621	0.0940	0.0851	0.0858	0.0833	0.0867	0.0685	0.0646	0.0621

Assessment/Growing Season (June 1 - September 15) 90th Percentile TP (mg/L) for 2010-2013

	Group 1	*Group 2*	*Group 3*	Petenwell Lake (top 2 layers)				Castle Rock Lake (top 4 layers)			Yellow River Arm (top 4 layers)
Layer	**Petenwell**	**Castle Rock**	**Yellow R. Arm**	**Seg 9**	**Seg 13**	**Seg 17**	**Seg 20**	**Seg 41**	**Seg 46**	**Seg 50**	**Seg 57**
Assessment	0.1037	0.0892	0.0811	0.1226	0.1115	0.1017	0.0945	0.1018	0.0874	0.0812	0.0811
L1	0.1035	0.0888	0.0805	0.1216	0.1106	0.1015	0.0945	0.1013	0.0868	0.0808	0.0805
L2	0.1041	0.0890	0.0807	0.1233	0.1120	0.1023	0.0950	0.1016	0.0872	0.0810	0.0807
L3	0.1062	0.0894	0.0811	0.1254	0.1124	0.1028	0.0963	0.1021	0.0875	0.0814	0.0811
L4	0.1093	0.0896	0.0817	0.1295	0.1134	0.1043	0.0974	0.1024	0.0878	0.0818	0.0817

Total Phosphorus Assessment Method Applied to TP Load Reduction Scenario 02 - 39% Reduction of External TP, PO4R@Calibration (H49)

Assessment/Growing Season (June 1 - September 15) Geometric Mean TP (mg/L) for 2010-2013

	Group 1	*Group 2*	*Group 3*	Petenwell Lake (top 2 layers)				Castle Rock Lake (top 4 layers)			Yellow River Arm (top 4 layers)
Layer	**Petenwell**	**Castle Rock**	**Yellow R. Arm**	**Seg 9**	**Seg 13**	**Seg 17**	**Seg 20**	**Seg 41**	**Seg 46**	**Seg 50**	**Seg 57**
Assessment	0.0521	0.0461	0.0419	0.0565	0.0514	0.0503	0.0487	0.0537	0.0430	0.0413	0.0419
L1	0.0518	0.0459	0.0417	0.0562	0.0511	0.0501	0.0485	0.0534	0.0428	0.0411	0.0417
L2	0.0523	0.0461	0.0418	0.0569	0.0516	0.0506	0.0488	0.0536	0.0429	0.0412	0.0418
L3	0.0529	0.0462	0.0420	0.0579	0.0521	0.0511	0.0492	0.0537	0.0430	0.0413	0.0420
L4	0.0541	0.0464	0.0421	0.0600	0.0529	0.0519	0.0500	0.0539	0.0432	0.0415	0.0421

Assessment/Growing Season (June 1 - September 15) Mean TP (mg/L) for 2010-2013

	Group 1	*Group 2*	*Group 3*	Petenwell Lake (top 2 layers)				Castle Rock Lake (top 4 layers)			Yellow River Arm (top 4 layers)
Layer	**Petenwell**	**Castle Rock**	**Yellow R. Arm**	**Seg 9**	**Seg 13**	**Seg 17**	**Seg 20**	**Seg 41**	**Seg 46**	**Seg 50**	**Seg 57**
Assessment	0.0527	0.0471	0.0425	0.0572	0.0522	0.0514	0.0499	0.0551	0.0441	0.0421	0.0425
L1	0.0524	0.0469	0.0423	0.0569	0.0520	0.0512	0.0497	0.0549	0.0439	0.0419	0.0423
L2	0.0530	0.0471	0.0424	0.0576	0.0525	0.0517	0.0500	0.0550	0.0440	0.0421	0.0424
L3	0.0535	0.0472	0.0425	0.0586	0.0530	0.0522	0.0504	0.0552	0.0442	0.0422	0.0425
L4	0.0547	0.0473	0.0427	0.0611	0.0538	0.0529	0.0511	0.0554	0.0443	0.0424	0.0427

Assessment/Growing Season (June 1 - September 15) Median TP (mg/L) for 2010-2013

	Group 1	*Group 2*	*Group 3*	Petenwell Lake (top 2 layers)				Castle Rock Lake (top 4 layers)			Yellow River Arm (top 4 layers)
Layer	**Petenwell**	**Castle Rock**	**Yellow R. Arm**	**Seg 9**	**Seg 13**	**Seg 17**	**Seg 20**	**Seg 41**	**Seg 46**	**Seg 50**	**Seg 57**
Assessment	0.0545	0.0483	0.0413	0.0558	0.0529	0.0531	0.0510	0.0560	0.0436	0.0415	0.0413
L1	0.0543	0.0481	0.0409	0.0554	0.0528	0.0528	0.0509	0.0556	0.0435	0.0414	0.0409
L2	0.0549	0.0482	0.0411	0.0561	0.0531	0.0535	0.0511	0.0558	0.0436	0.0415	0.0411
L3	0.0556	0.0483	0.0414	0.0566	0.0534	0.0542	0.0514	0.0561	0.0437	0.0415	0.0414
L4	0.0563	0.0484	0.0415	0.0580	0.0537	0.0550	0.0522	0.0563	0.0439	0.0420	0.0415

Assessment/Growing Season (June 1 - September 15) 90th Percentile TP (mg/L) for 2010-2013

	Group 1	*Group 2*	*Group 3*	Petenwell Lake (top 2 layers)				Castle Rock Lake (top 4 layers)			Yellow River Arm (top 4 layers)
Layer	**Petenwell**	**Castle Rock**	**Yellow R. Arm**	**Seg 9**	**Seg 13**	**Seg 17**	**Seg 20**	**Seg 41**	**Seg 46**	**Seg 50**	**Seg 57**
Assessment	0.0616	0.0594	0.0514	0.0702	0.0648	0.0617	0.0620	0.0700	0.0580	0.0534	0.0514
L1	0.0613	0.0592	0.0507	0.0697	0.0644	0.0616	0.0621	0.0698	0.0579	0.0532	0.0507
L2	0.0618	0.0594	0.0509	0.0707	0.0653	0.0617	0.0620	0.0699	0.0580	0.0534	0.0509
L3	0.0623	0.0595	0.0515	0.0724	0.0654	0.0620	0.0622	0.0701	0.0581	0.0535	0.0515
L4	0.0639	0.0596	0.0519	0.0753	0.0662	0.0623	0.0622	0.0703	0.0581	0.0536	0.0519

Total Phosphorus Assessment Method Applied to TP Load Reduction Scenario 06 - 49% Reduction of External TP, PO4R@Calibration (H49)

Assessment/Growing Season (June 1 - September 15) Geometric Mean TP (mg/L) for 2010-2013

	Group 1	*Group 2*	*Group 3*	Petenwell Lake (top 2 layers)				Castle Rock Lake (top 4 layers)			Yellow River Arm (top 4 layers)
Layer	**Petenwell**	**Castle Rock**	**Yellow R. Arm**	**Seg 9**	**Seg 13**	**Seg 17**	**Seg 20**	**Seg 41**	**Seg 46**	**Seg 50**	**Seg 57**
Assessment	0.0445	0.0404	0.0364	0.0476	0.0438	0.0432	0.0421	0.0472	0.0375	0.0360	0.0364
L1	0.0443	0.0402	0.0363	0.0473	0.0436	0.0430	0.0420	0.0469	0.0373	0.0358	0.0363
L2	0.0447	0.0403	0.0364	0.0478	0.0440	0.0435	0.0422	0.0471	0.0374	0.0360	0.0364
L3	0.0452	0.0404	0.0365	0.0487	0.0444	0.0439	0.0426	0.0472	0.0376	0.0361	0.0365
L4	0.0462	0.0406	0.0366	0.0506	0.0451	0.0446	0.0433	0.0474	0.0377	0.0362	0.0366

Assessment/Growing Season (June 1 - September 15) Mean TP (mg/L) for 2010-2013

	Group 1	*Group 2*	*Group 3*	Petenwell Lake (top 2 layers)				Castle Rock Lake (top 4 layers)			Yellow River Arm (top 4 layers)
Layer	**Petenwell**	**Castle Rock**	**Yellow R. Arm**	**Seg 9**	**Seg 13**	**Seg 17**	**Seg 20**	**Seg 41**	**Seg 46**	**Seg 50**	**Seg 57**
Assessment	0.0449	0.0412	0.0369	0.0480	0.0444	0.0442	0.0432	0.0485	0.0384	0.0367	0.0369
L1	0.0447	0.0410	0.0367	0.0477	0.0442	0.0440	0.0431	0.0483	0.0382	0.0366	0.0367
L2	0.0452	0.0412	0.0368	0.0483	0.0446	0.0444	0.0433	0.0485	0.0384	0.0367	0.0368
L3	0.0457	0.0413	0.0369	0.0492	0.0450	0.0448	0.0436	0.0486	0.0385	0.0368	0.0369
L4	0.0467	0.0414	0.0371	0.0514	0.0457	0.0454	0.0442	0.0487	0.0386	0.0369	0.0371

Assessment/Growing Season (June 1 - September 15) Median TP (mg/L) for 2010-2013

	Group 1	*Group 2*	*Group 3*	Petenwell Lake (top 2 layers)				Castle Rock Lake (top 4 layers)			Yellow River Arm (top 4 layers)
Layer	**Petenwell**	**Castle Rock**	**Yellow R. Arm**	**Seg 9**	**Seg 13**	**Seg 17**	**Seg 20**	**Seg 41**	**Seg 46**	**Seg 50**	**Seg 57**
Assessment	0.0466	0.0416	0.0360	0.0470	0.0458	0.0446	0.0431	0.0487	0.0380	0.0362	0.0360
L1	0.0464	0.0414	0.0357	0.0467	0.0455	0.0443	0.0430	0.0486	0.0378	0.0361	0.0357
L2	0.0468	0.0415	0.0359	0.0472	0.0460	0.0448	0.0433	0.0487	0.0380	0.0362	0.0359
L3	0.0474	0.0416	0.0361	0.0479	0.0462	0.0456	0.0435	0.0488	0.0381	0.0363	0.0361
L4	0.0482	0.0417	0.0362	0.0491	0.0464	0.0463	0.0442	0.0488	0.0381	0.0364	0.0362

Assessment/Growing Season (June 1 - September 15) 90th Percentile TP (mg/L) for 2010-2013

	Group 1	*Group 2*	*Group 3*	Petenwell Lake (top 2 layers)				Castle Rock Lake (top 4 layers)			Yellow River Arm (top 4 layers)
Layer	**Petenwell**	**Castle Rock**	**Yellow R. Arm**	**Seg 9**	**Seg 13**	**Seg 17**	**Seg 20**	**Seg 41**	**Seg 46**	**Seg 50**	**Seg 57**
Assessment	0.0516	0.0521	0.0440	0.0575	0.0533	0.0530	0.0549	0.0629	0.0512	0.0466	0.0440
L1	0.0514	0.0520	0.0438	0.0570	0.0530	0.0529	0.0549	0.0628	0.0510	0.0465	0.0438
L2	0.0518	0.0521	0.0440	0.0578	0.0534	0.0531	0.0549	0.0628	0.0511	0.0466	0.0440
L3	0.0522	0.0521	0.0441	0.0595	0.0540	0.0532	0.0547	0.0630	0.0513	0.0467	0.0441
L4	0.0535	0.0522	0.0445	0.0615	0.0546	0.0534	0.0548	0.0633	0.0513	0.0467	0.0445

Total Phosphorus Assessment Method Applied to TP Load Reduction Scenario b6 - 49% Reduction of External TP, PO4R@0.0075 vs. Calibration (H49) Factor of 0.010

Assessment/Growing Season (June 1 - September 15) Geometric Mean TP (mg/L) for 2010-2013

	Group 1	***Group 2***	***Group 3***	**Petenwell Lake (top 2 layers)**				**Castle Rock Lake (top 4 layers)**			**Yellow River Arm (top 4 layers)**
Layer	**Petenwell**	**Castle Rock**	**Yellow R. Arm**	**Seg 9**	**Seg 13**	**Seg 17**	**Seg 20**	**Seg 41**	**Seg 46**	**Seg 50**	**Seg 57**
Assessment	0.0423	0.0369	0.0344	0.0465	0.0417	0.0407	0.0393	0.0429	0.0343	0.0330	0.0344
L1	0.0421	0.0367	0.0343	0.0462	0.0415	0.0405	0.0392	0.0427	0.0341	0.0329	0.0343
L2	0.0425	0.0368	0.0344	0.0467	0.0420	0.0409	0.0394	0.0428	0.0343	0.0330	0.0344
L3	0.0430	0.0369	0.0345	0.0475	0.0423	0.0413	0.0397	0.0430	0.0344	0.0331	0.0345
L4	0.0439	0.0370	0.0346	0.0492	0.0429	0.0419	0.0403	0.0431	0.0345	0.0332	0.0346

Assessment/Growing Season (June 1 - September 15) Mean TP (mg/L) for 2010-2013

	Group 1	***Group 2***	***Group 3***	**Petenwell Lake (top 2 layers)**				**Castle Rock Lake (top 4 layers)**			**Yellow River Arm (top 4 layers)**
Layer	**Petenwell**	**Castle Rock**	**Yellow R. Arm**	**Seg 9**	**Seg 13**	**Seg 17**	**Seg 20**	**Seg 41**	**Seg 46**	**Seg 50**	**Seg 57**
Assessment	0.0427	0.0375	0.0350	0.0470	0.0424	0.0415	0.0401	0.0439	0.0351	0.0337	0.0350
L1	0.0425	0.0374	0.0348	0.0467	0.0422	0.0413	0.0400	0.0437	0.0349	0.0335	0.0348
L2	0.0429	0.0375	0.0349	0.0473	0.0426	0.0417	0.0402	0.0438	0.0350	0.0336	0.0349
L3	0.0434	0.0376	0.0350	0.0481	0.0430	0.0420	0.0405	0.0439	0.0351	0.0337	0.0350
L4	0.0443	0.0377	0.0351	0.0500	0.0436	0.0426	0.0411	0.0440	0.0352	0.0338	0.0351

Assessment/Growing Season (June 1 - September 15) Median TP (mg/L) for 2010-2013

	Group 1	***Group 2***	***Group 3***	**Petenwell Lake (top 2 layers)**				**Castle Rock Lake (top 4 layers)**			**Yellow River Arm (top 4 layers)**
Layer	**Petenwell**	**Castle Rock**	**Yellow R. Arm**	**Seg 9**	**Seg 13**	**Seg 17**	**Seg 20**	**Seg 41**	**Seg 46**	**Seg 50**	**Seg 57**
Assessment	0.0440	0.0382	0.0345	0.0460	0.0424	0.0430	0.0410	0.0447	0.0349	0.0331	0.0345
L1	0.0437	0.0380	0.0342	0.0458	0.0424	0.0427	0.0408	0.0444	0.0348	0.0330	0.0342
L2	0.0443	0.0381	0.0344	0.0463	0.0427	0.0432	0.0412	0.0445	0.0349	0.0331	0.0344
L3	0.0445	0.0382	0.0346	0.0467	0.0429	0.0437	0.0415	0.0447	0.0350	0.0331	0.0346
L4	0.0450	0.0383	0.0346	0.0480	0.0436	0.0444	0.0422	0.0448	0.0351	0.0333	0.0346

Assessment/Growing Season (June 1 - September 15) 90th Percentile TP (mg/L) for 2010-2013

	Group 1	***Group 2***	***Group 3***	**Petenwell Lake (top 2 layers)**				**Castle Rock Lake (top 4 layers)**			**Yellow River Arm (top 4 layers)**
Layer	**Petenwell**	**Castle Rock**	**Yellow R. Arm**	**Seg 9**	**Seg 13**	**Seg 17**	**Seg 20**	**Seg 41**	**Seg 46**	**Seg 50**	**Seg 57**
Assessment	0.0499	0.0464	0.0436	0.0570	0.0524	0.0492	0.0491	0.0546	0.0448	0.0416	0.0436
L1	0.0497	0.0461	0.0434	0.0566	0.0522	0.0492	0.0490	0.0545	0.0445	0.0413	0.0434
L2	0.0500	0.0463	0.0435	0.0572	0.0527	0.0493	0.0490	0.0546	0.0447	0.0415	0.0435
L3	0.0503	0.0464	0.0436	0.0587	0.0531	0.0497	0.0490	0.0546	0.0450	0.0416	0.0436
L4	0.0515	0.0465	0.0437	0.0607	0.0536	0.0500	0.0492	0.0547	0.0451	0.0418	0.0437

Total Phosphorus Assessment Method Applied to TP Load Reduction Scenario c6 - 49% Reduction of External TP, PO4R@0.005 vs. Calibration (H49) Factor of 0.010

Assessment/Growing Season (June 1 - September 15) Geometric Mean TP (mg/L) for 2010-2013

	Group 1	***Group 2***	***Group 3***	**Petenwell Lake (top 2 layers)**				**Castle Rock Lake (top 4 layers)**			**Yellow River Arm (top 4 layers)**
Layer	**Petenwell**	**Castle Rock**	**Yellow R. Arm**	**Seg 9**	**Seg 13**	**Seg 17**	**Seg 20**	**Seg 41**	**Seg 46**	**Seg 50**	**Seg 57**
Assessment	0.0401	0.0335	0.0325	0.0454	0.0397	0.0382	0.0365	0.0386	0.0313	0.0302	0.0325
L1	0.0400	0.0333	0.0324	0.0452	0.0395	0.0380	0.0364	0.0385	0.0312	0.0301	0.0324
L2	0.0403	0.0334	0.0325	0.0457	0.0399	0.0383	0.0366	0.0386	0.0313	0.0302	0.0325
L3	0.0407	0.0335	0.0325	0.0463	0.0402	0.0387	0.0369	0.0387	0.0314	0.0303	0.0325
L4	0.0415	0.0336	0.0326	0.0478	0.0407	0.0393	0.0374	0.0388	0.0314	0.0303	0.0326

Assessment/Growing Season (June 1 - September 15) Mean TP (mg/L) for 2010-2013

	Group 1	***Group 2***	***Group 3***	**Petenwell Lake (top 2 layers)**				**Castle Rock Lake (top 4 layers)**			**Yellow River Arm (top 4 layers)**
Layer	**Petenwell**	**Castle Rock**	**Yellow R. Arm**	**Seg 9**	**Seg 13**	**Seg 17**	**Seg 20**	**Seg 41**	**Seg 46**	**Seg 50**	**Seg 57**
Assessment	0.0406	0.0340	0.0332	0.0460	0.0404	0.0389	0.0371	0.0393	0.0320	0.0308	0.0332
L1	0.0404	0.0339	0.0331	0.0458	0.0402	0.0387	0.0370	0.0392	0.0318	0.0306	0.0331
L2	0.0408	0.0340	0.0332	0.0463	0.0406	0.0390	0.0372	0.0393	0.0320	0.0307	0.0332
L3	0.0412	0.0341	0.0333	0.0470	0.0410	0.0394	0.0375	0.0394	0.0320	0.0308	0.0333
L4	0.0420	0.0342	0.0334	0.0485	0.0415	0.0399	0.0380	0.0395	0.0321	0.0309	0.0334

Assessment/Growing Season (June 1 - September 15) Median TP (mg/L) for 2010-2013

	Group 1	***Group 2***	***Group 3***	**Petenwell Lake (top 2 layers)**				**Castle Rock Lake (top 4 layers)**			**Yellow River Arm (top 4 layers)**
Layer	**Petenwell**	**Castle Rock**	**Yellow R. Arm**	**Seg 9**	**Seg 13**	**Seg 17**	**Seg 20**	**Seg 41**	**Seg 46**	**Seg 50**	**Seg 57**
Assessment	0.0413	0.0340	0.0321	0.0451	0.0398	0.0395	0.0380	0.0406	0.0322	0.0300	0.0321
L1	0.0412	0.0338	0.0319	0.0448	0.0396	0.0393	0.0379	0.0404	0.0320	0.0298	0.0319
L2	0.0414	0.0339	0.0321	0.0452	0.0400	0.0397	0.0382	0.0405	0.0321	0.0299	0.0321
L3	0.0418	0.0341	0.0322	0.0456	0.0402	0.0403	0.0387	0.0407	0.0322	0.0300	0.0322
L4	0.0424	0.0341	0.0323	0.0469	0.0406	0.0409	0.0392	0.0408	0.0324	0.0301	0.0323

Assessment/Growing Season (June 1 - September 15) 90th Percentile TP (mg/L) for 2010-2013

	Group 1	***Group 2***	***Group 3***	**Petenwell Lake (top 2 layers)**				**Castle Rock Lake (top 4 layers)**			**Yellow River Arm (top 4 layers)**
Layer	**Petenwell**	**Castle Rock**	**Yellow R. Arm**	**Seg 9**	**Seg 13**	**Seg 17**	**Seg 20**	**Seg 41**	**Seg 46**	**Seg 50**	**Seg 57**
Assessment	0.0487	0.0416	0.0432	0.0568	0.0516	0.0476	0.0441	0.0476	0.0409	0.0387	0.0432
L1	0.0485	0.0415	0.0430	0.0563	0.0515	0.0474	0.0438	0.0474	0.0405	0.0384	0.0430
L2	0.0489	0.0416	0.0432	0.0569	0.0520	0.0477	0.0442	0.0476	0.0408	0.0386	0.0432
L3	0.0494	0.0416	0.0433	0.0579	0.0522	0.0479	0.0442	0.0476	0.0409	0.0387	0.0433
L4	0.0505	0.0418	0.0434	0.0598	0.0529	0.0483	0.0449	0.0477	0.0410	0.0387	0.0434

Total Phosphorus Assessment Method Applied to TP Load Reduction Scenario 03 - 52% Reduction of External TP, PO4R@Calibration (H49)

Assessment/Growing Season (June 1 - September 15) Geometric Mean TP (mg/L) for 2010-2013

	Group 1	*Group 2*	*Group 3*	Petenwell Lake (top 2 layers)				Castle Rock Lake (top 4 layers)			Yellow River Arm (top 4 layers)
Layer	**Petenwell**	**Castle Rock**	**Yellow R. Arm**	**Seg 9**	**Seg 13**	**Seg 17**	**Seg 20**	**Seg 41**	**Seg 46**	**Seg 50**	**Seg 57**
Assessment	0.0419	0.0385	0.0346	0.0446	0.0413	0.0409	0.0399	0.0450	0.0357	0.0343	0.0346
L1	0.0417	0.0383	0.0345	0.0443	0.0410	0.0407	0.0398	0.0448	0.0355	0.0341	0.0345
L2	0.0421	0.0384	0.0346	0.0448	0.0415	0.0411	0.0400	0.0449	0.0356	0.0342	0.0346
L3	0.0426	0.0385	0.0347	0.0456	0.0418	0.0415	0.0404	0.0451	0.0357	0.0343	0.0347
L4	0.0436	0.0387	0.0348	0.0475	0.0425	0.0422	0.0410	0.0452	0.0359	0.0344	0.0348

Assessment/Growing Season (June 1 - September 15) Mean TP (mg/L) for 2010-2013

	Group 1	*Group 2*	*Group 3*	Petenwell Lake (top 2 layers)				Castle Rock Lake (top 4 layers)			Yellow River Arm (top 4 layers)
Layer	**Petenwell**	**Castle Rock**	**Yellow R. Arm**	**Seg 9**	**Seg 13**	**Seg 17**	**Seg 20**	**Seg 41**	**Seg 46**	**Seg 50**	**Seg 57**
Assessment	0.0424	0.0393	0.0350	0.0449	0.0418	0.0418	0.0410	0.0463	0.0366	0.0350	0.0350
L1	0.0422	0.0391	0.0349	0.0446	0.0416	0.0416	0.0409	0.0461	0.0364	0.0348	0.0349
L2	0.0426	0.0392	0.0350	0.0452	0.0420	0.0419	0.0411	0.0463	0.0365	0.0349	0.0350
L3	0.0430	0.0393	0.0351	0.0461	0.0424	0.0423	0.0414	0.0464	0.0366	0.0350	0.0351
L4	0.0440	0.0395	0.0352	0.0482	0.0430	0.0429	0.0420	0.0465	0.0367	0.0351	0.0352

Assessment/Growing Season (June 1 - September 15) Median TP (mg/L) for 2010-2013

	Group 1	*Group 2*	*Group 3*	Petenwell Lake (top 2 layers)				Castle Rock Lake (top 4 layers)			Yellow River Arm (top 4 layers)
Layer	**Petenwell**	**Castle Rock**	**Yellow R. Arm**	**Seg 9**	**Seg 13**	**Seg 17**	**Seg 20**	**Seg 41**	**Seg 46**	**Seg 50**	**Seg 57**
Assessment	0.0438	0.0394	0.0340	0.0440	0.0430	0.0419	0.0405	0.0462	0.0360	0.0344	0.0340
L1	0.0434	0.0391	0.0338	0.0438	0.0427	0.0416	0.0404	0.0460	0.0358	0.0341	0.0338
L2	0.0439	0.0393	0.0340	0.0442	0.0433	0.0423	0.0407	0.0461	0.0360	0.0343	0.0340
L3	0.0445	0.0394	0.0341	0.0449	0.0437	0.0427	0.0409	0.0463	0.0361	0.0344	0.0341
L4	0.0453	0.0395	0.0343	0.0462	0.0440	0.0435	0.0416	0.0463	0.0362	0.0346	0.0343

Assessment/Growing Season (June 1 - September 15) 90th Percentile TP (mg/L) for 2010-2013

	Group 1	*Group 2*	*Group 3*	Petenwell Lake (top 2 layers)				Castle Rock Lake (top 4 layers)			Yellow River Arm (top 4 layers)
Layer	**Petenwell**	**Castle Rock**	**Yellow R. Arm**	**Seg 9**	**Seg 13**	**Seg 17**	**Seg 20**	**Seg 41**	**Seg 46**	**Seg 50**	**Seg 57**
Assessment	0.0485	0.0498	0.0417	0.0531	0.0498	0.0509	0.0523	0.0604	0.0489	0.0445	0.0417
L1	0.0484	0.0497	0.0416	0.0527	0.0494	0.0509	0.0522	0.0601	0.0486	0.0442	0.0416
L2	0.0487	0.0497	0.0416	0.0535	0.0501	0.0512	0.0522	0.0602	0.0489	0.0444	0.0416
L3	0.0490	0.0498	0.0416	0.0552	0.0502	0.0512	0.0522	0.0605	0.0488	0.0445	0.0416
L4	0.0500	0.0499	0.0419	0.0570	0.0506	0.0514	0.0523	0.0606	0.0490	0.0446	0.0419

Total Phosphorus Assessment Method Applied to TP Load Reduction Scenario b3 - 52% Reduction of External TP, PO4R@0.0075 vs. Calibration (H49) Factor of 0.010

Assessment/Growing Season (June 1 - September 15) Geometric Mean TP (mg/L) for 2010-2013

	Group 1	*Group 2*	*Group 3*	Petenwell Lake (top 2 layers)				Castle Rock Lake (top 4 layers)			Yellow River Arm (top 4 layers)
Layer	**Petenwell**	**Castle Rock**	**Yellow R. Arm**	**Seg 9**	**Seg 13**	**Seg 17**	**Seg 20**	**Seg 41**	**Seg 46**	**Seg 50**	**Seg 57**
Assessment	0.0398	0.0350	0.0326	0.0435	0.0392	0.0384	0.0371	0.0408	0.0325	0.0313	0.0326
L1	0.0396	0.0348	0.0325	0.0433	0.0391	0.0382	0.0370	0.0406	0.0324	0.0312	0.0325
L2	0.0400	0.0350	0.0326	0.0437	0.0394	0.0386	0.0373	0.0407	0.0325	0.0313	0.0326
L3	0.0404	0.0351	0.0327	0.0445	0.0398	0.0389	0.0375	0.0408	0.0326	0.0314	0.0327
L4	0.0413	0.0352	0.0328	0.0461	0.0403	0.0395	0.0381	0.0410	0.0327	0.0315	0.0328

Assessment/Growing Season (June 1 - September 15) Mean TP (mg/L) for 2010-2013

	Group 1	*Group 2*	*Group 3*	Petenwell Lake (top 2 layers)				Castle Rock Lake (top 4 layers)			Yellow River Arm (top 4 layers)
Layer	**Petenwell**	**Castle Rock**	**Yellow R. Arm**	**Seg 9**	**Seg 13**	**Seg 17**	**Seg 20**	**Seg 41**	**Seg 46**	**Seg 50**	**Seg 57**
Assessment	0.0402	0.0356	0.0332	0.0439	0.0398	0.0391	0.0379	0.0417	0.0332	0.0319	0.0332
L1	0.0400	0.0354	0.0330	0.0437	0.0396	0.0389	0.0378	0.0415	0.0331	0.0317	0.0330
L2	0.0404	0.0356	0.0331	0.0442	0.0400	0.0393	0.0380	0.0416	0.0332	0.0319	0.0331
L3	0.0408	0.0357	0.0332	0.0449	0.0403	0.0396	0.0383	0.0418	0.0333	0.0319	0.0332
L4	0.0417	0.0358	0.0333	0.0467	0.0409	0.0402	0.0388	0.0419	0.0334	0.0321	0.0333

Assessment/Growing Season (June 1 - September 15) Median TP (mg/L) for 2010-2013

	Group 1	*Group 2*	*Group 3*	Petenwell Lake (top 2 layers)				Castle Rock Lake (top 4 layers)			Yellow River Arm (top 4 layers)
Layer	**Petenwell**	**Castle Rock**	**Yellow R. Arm**	**Seg 9**	**Seg 13**	**Seg 17**	**Seg 20**	**Seg 41**	**Seg 46**	**Seg 50**	**Seg 57**
Assessment	0.0414	0.0363	0.0327	0.0431	0.0403	0.0402	0.0385	0.0421	0.0330	0.0315	0.0327
L1	0.0413	0.0361	0.0325	0.0429	0.0401	0.0400	0.0384	0.0420	0.0328	0.0313	0.0325
L2	0.0416	0.0363	0.0327	0.0432	0.0404	0.0404	0.0386	0.0421	0.0329	0.0314	0.0327
L3	0.0422	0.0364	0.0327	0.0438	0.0405	0.0409	0.0389	0.0421	0.0330	0.0315	0.0327
L4	0.0427	0.0365	0.0327	0.0450	0.0411	0.0415	0.0396	0.0424	0.0332	0.0315	0.0327

Assessment/Growing Season (June 1 - September 15) 90th Percentile TP (mg/L) for 2010-2013

	Group 1	*Group 2*	*Group 3*	Petenwell Lake (top 2 layers)				Castle Rock Lake (top 4 layers)			Yellow River Arm (top 4 layers)
Layer	**Petenwell**	**Castle Rock**	**Yellow R. Arm**	**Seg 9**	**Seg 13**	**Seg 17**	**Seg 20**	**Seg 41**	**Seg 46**	**Seg 50**	**Seg 57**
Assessment	0.0464	0.0440	0.0412	0.0527	0.0486	0.0461	0.0464	0.0522	0.0424	0.0394	0.0412
L1	0.0463	0.0438	0.0412	0.0524	0.0484	0.0462	0.0464	0.0520	0.0423	0.0392	0.0412
L2	0.0465	0.0439	0.0412	0.0531	0.0487	0.0463	0.0463	0.0521	0.0424	0.0393	0.0412
L3	0.0468	0.0440	0.0413	0.0544	0.0492	0.0464	0.0463	0.0522	0.0424	0.0394	0.0413
L4	0.0480	0.0441	0.0414	0.0560	0.0497	0.0467	0.0464	0.0523	0.0427	0.0396	0.0414

Total Phosphorus Assessment Method Applied to TP Load Reduction Scenario c3 - 52% Reduction of External TP, PO4R@0.005 vs. Calibration (H49) Factor of 0.010

Assessment/Growing Season (June 1 - September 15) Geometric Mean TP (mg/L) for 2010-2013

	Group 1	*Group 2*	*Group 3*	Petenwell Lake (top 2 layers)				Castle Rock Lake (top 4 layers)			Yellow River Arm (top 4 layers)
Layer	**Petenwell**	**Castle Rock**	**Yellow R. Arm**	**Seg 9**	**Seg 13**	**Seg 17**	**Seg 20**	**Seg 41**	**Seg 46**	**Seg 50**	**Seg 57**
Assessment	0.0377	0.0316	0.0307	0.0425	0.0372	0.0359	0.0344	0.0366	0.0296	0.0285	0.0307
L1	0.0375	0.0315	0.0306	0.0422	0.0370	0.0357	0.0343	0.0364	0.0294	0.0284	0.0306
L2	0.0378	0.0316	0.0307	0.0427	0.0374	0.0360	0.0345	0.0365	0.0295	0.0285	0.0307
L3	0.0382	0.0317	0.0308	0.0433	0.0377	0.0364	0.0347	0.0366	0.0296	0.0286	0.0308
L4	0.0389	0.0318	0.0309	0.0447	0.0382	0.0369	0.0352	0.0367	0.0297	0.0287	0.0309

Assessment/Growing Season (June 1 - September 15) Mean TP (mg/L) for 2010-2013

	Group 1	*Group 2*	*Group 3*	Petenwell Lake (top 2 layers)				Castle Rock Lake (top 4 layers)			Yellow River Arm (top 4 layers)
Layer	**Petenwell**	**Castle Rock**	**Yellow R. Arm**	**Seg 9**	**Seg 13**	**Seg 17**	**Seg 20**	**Seg 41**	**Seg 46**	**Seg 50**	**Seg 57**
Assessment	0.0381	0.0322	0.0314	0.0430	0.0378	0.0365	0.0349	0.0372	0.0302	0.0291	0.0314
L1	0.0379	0.0320	0.0313	0.0427	0.0376	0.0363	0.0348	0.0371	0.0300	0.0289	0.0313
L2	0.0382	0.0321	0.0314	0.0432	0.0380	0.0367	0.0350	0.0372	0.0301	0.0290	0.0314
L3	0.0386	0.0322	0.0315	0.0438	0.0383	0.0370	0.0353	0.0373	0.0302	0.0291	0.0315
L4	0.0393	0.0323	0.0316	0.0453	0.0388	0.0375	0.0358	0.0374	0.0303	0.0292	0.0316

Assessment/Growing Season (June 1 - September 15) Median TP (mg/L) for 2010-2013

	Group 1	*Group 2*	*Group 3*	Petenwell Lake (top 2 layers)				Castle Rock Lake (top 4 layers)			Yellow River Arm (top 4 layers)
Layer	**Petenwell**	**Castle Rock**	**Yellow R. Arm**	**Seg 9**	**Seg 13**	**Seg 17**	**Seg 20**	**Seg 41**	**Seg 46**	**Seg 50**	**Seg 57**
Assessment	0.0387	0.0320	0.0304	0.0421	0.0374	0.0374	0.0358	0.0384	0.0302	0.0283	0.0304
L1	0.0386	0.0319	0.0303	0.0419	0.0373	0.0372	0.0358	0.0382	0.0301	0.0282	0.0303
L2	0.0389	0.0320	0.0303	0.0423	0.0374	0.0375	0.0359	0.0384	0.0302	0.0283	0.0303
L3	0.0392	0.0321	0.0304	0.0428	0.0377	0.0378	0.0364	0.0385	0.0302	0.0283	0.0304
L4	0.0397	0.0322	0.0305	0.0440	0.0381	0.0382	0.0370	0.0385	0.0304	0.0283	0.0305

Assessment/Growing Season (June 1 - September 15) 90th Percentile TP (mg/L) for 2010-2013

	Group 1	*Group 2*	*Group 3*	Petenwell Lake (top 2 layers)				Castle Rock Lake (top 4 layers)			Yellow River Arm (top 4 layers)
Layer	**Petenwell**	**Castle Rock**	**Yellow R. Arm**	**Seg 9**	**Seg 13**	**Seg 17**	**Seg 20**	**Seg 41**	**Seg 46**	**Seg 50**	**Seg 57**
Assessment	0.0452	0.0392	0.0410	0.0524	0.0478	0.0441	0.0412	0.0449	0.0384	0.0363	0.0410
L1	0.0450	0.0390	0.0409	0.0520	0.0477	0.0439	0.0411	0.0448	0.0381	0.0361	0.0409
L2	0.0454	0.0391	0.0409	0.0525	0.0480	0.0443	0.0412	0.0449	0.0383	0.0363	0.0409
L3	0.0458	0.0392	0.0411	0.0537	0.0483	0.0444	0.0412	0.0449	0.0385	0.0363	0.0411
L4	0.0468	0.0393	0.0413	0.0555	0.0490	0.0451	0.0421	0.0451	0.0386	0.0364	0.0413

Total Phosphorus Assessment Method Applied to TP Load Reduction Scenario 04 - 55% Reduction of External TP, PO4R@Calibration (H49)

Assessment/Growing Season (June 1 - September 15) Geometric Mean TP (mg/L) for 2010-2013

	Group 1	*Group 2*	*Group 3*	Petenwell Lake (top 2 layers)				Castle Rock Lake (top 4 layers)			Yellow River Arm (top 4 layers)
Layer	**Petenwell**	**Castle Rock**	**Yellow R. Arm**	**Seg 9**	**Seg 13**	**Seg 17**	**Seg 20**	**Seg 41**	**Seg 46**	**Seg 50**	**Seg 57**
Assessment	0.0394	0.0366	0.0328	0.0416	0.0387	0.0385	0.0377	0.0428	0.0339	0.0325	0.0328
L1	0.0392	0.0364	0.0327	0.0413	0.0385	0.0383	0.0376	0.0426	0.0337	0.0324	0.0327
L2	0.0396	0.0365	0.0328	0.0418	0.0389	0.0387	0.0378	0.0428	0.0338	0.0325	0.0328
L3	0.0400	0.0366	0.0329	0.0426	0.0393	0.0391	0.0381	0.0429	0.0339	0.0326	0.0329
L4	0.0410	0.0367	0.0330	0.0444	0.0399	0.0397	0.0388	0.0430	0.0340	0.0327	0.0330

Assessment/Growing Season (June 1 - September 15) Mean TP (mg/L) for 2010-2013

	Group 1	*Group 2*	*Group 3*	Petenwell Lake (top 2 layers)				Castle Rock Lake (top 4 layers)			Yellow River Arm (top 4 layers)
Layer	**Petenwell**	**Castle Rock**	**Yellow R. Arm**	**Seg 9**	**Seg 13**	**Seg 17**	**Seg 20**	**Seg 41**	**Seg 46**	**Seg 50**	**Seg 57**
Assessment	0.0398	0.0373	0.0332	0.0418	0.0392	0.0394	0.0388	0.0442	0.0347	0.0332	0.0332
L1	0.0396	0.0372	0.0330	0.0416	0.0390	0.0392	0.0387	0.0440	0.0345	0.0330	0.0330
L2	0.0400	0.0373	0.0331	0.0421	0.0394	0.0395	0.0389	0.0441	0.0347	0.0331	0.0331
L3	0.0404	0.0374	0.0332	0.0429	0.0397	0.0399	0.0391	0.0442	0.0348	0.0332	0.0332
L4	0.0414	0.0375	0.0333	0.0450	0.0403	0.0404	0.0397	0.0443	0.0349	0.0333	0.0333

Assessment/Growing Season (June 1 - September 15) Median TP (mg/L) for 2010-2013

	Group 1	*Group 2*	*Group 3*	Petenwell Lake (top 2 layers)				Castle Rock Lake (top 4 layers)			Yellow River Arm (top 4 layers)
Layer	**Petenwell**	**Castle Rock**	**Yellow R. Arm**	**Seg 9**	**Seg 13**	**Seg 17**	**Seg 20**	**Seg 41**	**Seg 46**	**Seg 50**	**Seg 57**
Assessment	0.0406	0.0370	0.0325	0.0411	0.0402	0.0395	0.0380	0.0438	0.0341	0.0324	0.0325
L1	0.0404	0.0368	0.0322	0.0409	0.0399	0.0394	0.0379	0.0437	0.0339	0.0321	0.0322
L2	0.0409	0.0370	0.0324	0.0413	0.0404	0.0398	0.0382	0.0438	0.0340	0.0324	0.0324
L3	0.0417	0.0371	0.0326	0.0418	0.0406	0.0401	0.0384	0.0439	0.0341	0.0325	0.0326
L4	0.0424	0.0372	0.0326	0.0432	0.0412	0.0406	0.0389	0.0440	0.0342	0.0327	0.0326

Assessment/Growing Season (June 1 - September 15) 90th Percentile TP (mg/L) for 2010-2013

	Group 1	*Group 2*	*Group 3*	Petenwell Lake (top 2 layers)				Castle Rock Lake (top 4 layers)			Yellow River Arm (top 4 layers)
Layer	**Petenwell**	**Castle Rock**	**Yellow R. Arm**	**Seg 9**	**Seg 13**	**Seg 17**	**Seg 20**	**Seg 41**	**Seg 46**	**Seg 50**	**Seg 57**
Assessment	0.0457	0.0473	0.0396	0.0488	0.0462	0.0492	0.0499	0.0581	0.0463	0.0422	0.0396
L1	0.0455	0.0471	0.0394	0.0484	0.0460	0.0491	0.0500	0.0579	0.0464	0.0420	0.0394
L2	0.0458	0.0472	0.0395	0.0491	0.0463	0.0494	0.0498	0.0580	0.0464	0.0422	0.0395
L3	0.0460	0.0473	0.0397	0.0506	0.0465	0.0494	0.0497	0.0581	0.0462	0.0423	0.0397
L4	0.0473	0.0475	0.0399	0.0523	0.0472	0.0496	0.0500	0.0584	0.0464	0.0425	0.0399

Total Phosphorus Assessment Method Applied to TP Load Reduction Scenario b4 - 55% Reduction of External TP, PO4R@0.0075 vs. Calibration (H49) Factor of 0.010

Assessment/Growing Season (June 1 - September 15) Geometric Mean TP (mg/L) for 2010-2013

	Group 1	*Group 2*	*Group 3*	Petenwell Lake (top 2 layers)				Castle Rock Lake (top 4 layers)			Yellow River Arm (top 4 layers)
Layer	**Petenwell**	**Castle Rock**	**Yellow R. Arm**	**Seg 9**	**Seg 13**	**Seg 17**	**Seg 20**	**Seg 41**	**Seg 46**	**Seg 50**	**Seg 57**
Assessment	0.0373	0.0331	0.0309	0.0405	0.0367	0.0361	0.0350	0.0387	0.0308	0.0296	0.0309
L1	0.0371	0.0330	0.0307	0.0403	0.0366	0.0359	0.0349	0.0385	0.0306	0.0295	0.0307
L2	0.0375	0.0331	0.0308	0.0407	0.0369	0.0362	0.0351	0.0386	0.0307	0.0296	0.0308
L3	0.0379	0.0332	0.0309	0.0414	0.0372	0.0366	0.0354	0.0387	0.0308	0.0297	0.0309
L4	0.0387	0.0333	0.0310	0.0430	0.0378	0.0371	0.0359	0.0388	0.0309	0.0298	0.0310

Assessment/Growing Season (June 1 - September 15) Mean TP (mg/L) for 2010-2013

	Group 1	*Group 2*	*Group 3*	Petenwell Lake (top 2 layers)				Castle Rock Lake (top 4 layers)			Yellow River Arm (top 4 layers)
Layer	**Petenwell**	**Castle Rock**	**Yellow R. Arm**	**Seg 9**	**Seg 13**	**Seg 17**	**Seg 20**	**Seg 41**	**Seg 46**	**Seg 50**	**Seg 57**
Assessment	0.0376	0.0337	0.0314	0.0409	0.0372	0.0367	0.0357	0.0396	0.0314	0.0302	0.0314
L1	0.0375	0.0335	0.0312	0.0406	0.0370	0.0365	0.0356	0.0394	0.0313	0.0300	0.0312
L2	0.0378	0.0337	0.0313	0.0411	0.0374	0.0369	0.0358	0.0395	0.0314	0.0301	0.0313
L3	0.0382	0.0338	0.0314	0.0418	0.0377	0.0372	0.0361	0.0396	0.0315	0.0302	0.0314
L4	0.0390	0.0339	0.0315	0.0435	0.0382	0.0377	0.0366	0.0397	0.0316	0.0303	0.0315

Assessment/Growing Season (June 1 - September 15) Median TP (mg/L) for 2010-2013

	Group 1	*Group 2*	*Group 3*	Petenwell Lake (top 2 layers)				Castle Rock Lake (top 4 layers)			Yellow River Arm (top 4 layers)
Layer	**Petenwell**	**Castle Rock**	**Yellow R. Arm**	**Seg 9**	**Seg 13**	**Seg 17**	**Seg 20**	**Seg 41**	**Seg 46**	**Seg 50**	**Seg 57**
Assessment	0.0388	0.0342	0.0309	0.0402	0.0379	0.0373	0.0360	0.0398	0.0310	0.0299	0.0309
L1	0.0386	0.0340	0.0308	0.0399	0.0375	0.0371	0.0359	0.0396	0.0309	0.0297	0.0308
L2	0.0391	0.0341	0.0309	0.0403	0.0379	0.0375	0.0360	0.0398	0.0310	0.0298	0.0309
L3	0.0396	0.0342	0.0310	0.0408	0.0382	0.0380	0.0364	0.0399	0.0311	0.0299	0.0310
L4	0.0402	0.0343	0.0310	0.0422	0.0386	0.0387	0.0369	0.0399	0.0312	0.0300	0.0310

Assessment/Growing Season (June 1 - September 15) 90th Percentile TP (mg/L) for 2010-2013

	Group 1	*Group 2*	*Group 3*	Petenwell Lake (top 2 layers)				Castle Rock Lake (top 4 layers)			Yellow River Arm (top 4 layers)
Layer	**Petenwell**	**Castle Rock**	**Yellow R. Arm**	**Seg 9**	**Seg 13**	**Seg 17**	**Seg 20**	**Seg 41**	**Seg 46**	**Seg 50**	**Seg 57**
Assessment	0.0430	0.0417	0.0391	0.0485	0.0448	0.0432	0.0439	0.0497	0.0401	0.0372	0.0391
L1	0.0428	0.0415	0.0389	0.0480	0.0445	0.0431	0.0439	0.0496	0.0400	0.0371	0.0389
L2	0.0430	0.0417	0.0390	0.0487	0.0449	0.0433	0.0440	0.0497	0.0401	0.0372	0.0390
L3	0.0432	0.0417	0.0392	0.0500	0.0454	0.0434	0.0440	0.0498	0.0401	0.0373	0.0392
L4	0.0445	0.0418	0.0393	0.0515	0.0458	0.0436	0.0442	0.0501	0.0403	0.0374	0.0393

Total Phosphorus Assessment Method Applied to TP Load Reduction Scenario c4 - 55% Reduction of External TP, PO4R@0.005 vs. Calibration (H49) Factor of 0.010

Assessment/Growing Season (June 1 - September 15) Geometric Mean TP (mg/L) for 2010-2013

	Group 1	***Group 2***	***Group 3***	**Petenwell Lake (top 2 layers)**				**Castle Rock Lake (top 4 layers)**			**Yellow River Arm (top 4 layers)**
Layer	**Petenwell**	**Castle Rock**	**Yellow R. Arm**	**Seg 9**	**Seg 13**	**Seg 17**	**Seg 20**	**Seg 41**	**Seg 46**	**Seg 50**	**Seg 57**
Assessment	0.0352	0.0298	0.0290	0.0395	0.0347	0.0336	0.0322	0.0345	0.0278	0.0269	0.0290
L1	0.0350	0.0297	0.0289	0.0393	0.0346	0.0334	0.0321	0.0344	0.0277	0.0268	0.0289
L2	0.0353	0.0298	0.0290	0.0397	0.0349	0.0337	0.0323	0.0344	0.0278	0.0269	0.0290
L3	0.0357	0.0299	0.0290	0.0403	0.0352	0.0340	0.0326	0.0345	0.0279	0.0269	0.0290
L4	0.0364	0.0299	0.0291	0.0415	0.0356	0.0345	0.0330	0.0346	0.0279	0.0270	0.0291

Assessment/Growing Season (June 1 - September 15) Mean TP (mg/L) for 2010-2013

	Group 1	***Group 2***	***Group 3***	**Petenwell Lake (top 2 layers)**				**Castle Rock Lake (top 4 layers)**			**Yellow River Arm (top 4 layers)**
Layer	**Petenwell**	**Castle Rock**	**Yellow R. Arm**	**Seg 9**	**Seg 13**	**Seg 17**	**Seg 20**	**Seg 41**	**Seg 46**	**Seg 50**	**Seg 57**
Assessment	0.0355	0.0303	0.0296	0.0399	0.0352	0.0341	0.0328	0.0351	0.0284	0.0274	0.0296
L1	0.0354	0.0301	0.0295	0.0397	0.0351	0.0340	0.0327	0.0349	0.0283	0.0272	0.0295
L2	0.0357	0.0302	0.0296	0.0401	0.0354	0.0343	0.0329	0.0350	0.0284	0.0273	0.0296
L3	0.0360	0.0303	0.0297	0.0407	0.0357	0.0346	0.0331	0.0351	0.0284	0.0274	0.0297
L4	0.0367	0.0304	0.0298	0.0421	0.0362	0.0350	0.0335	0.0352	0.0285	0.0275	0.0298

Assessment/Growing Season (June 1 - September 15) Median TP (mg/L) for 2010-2013

	Group 1	***Group 2***	***Group 3***	**Petenwell Lake (top 2 layers)**				**Castle Rock Lake (top 4 layers)**			**Yellow River Arm (top 4 layers)**
Layer	**Petenwell**	**Castle Rock**	**Yellow R. Arm**	**Seg 9**	**Seg 13**	**Seg 17**	**Seg 20**	**Seg 41**	**Seg 46**	**Seg 50**	**Seg 57**
Assessment	0.0360	0.0303	0.0287	0.0391	0.0349	0.0352	0.0335	0.0361	0.0283	0.0265	0.0287
L1	0.0359	0.0302	0.0286	0.0390	0.0348	0.0350	0.0335	0.0360	0.0282	0.0265	0.0286
L2	0.0362	0.0302	0.0287	0.0394	0.0351	0.0353	0.0336	0.0361	0.0282	0.0266	0.0287
L3	0.0365	0.0303	0.0288	0.0398	0.0353	0.0355	0.0340	0.0362	0.0283	0.0266	0.0288
L4	0.0371	0.0304	0.0288	0.0410	0.0356	0.0360	0.0348	0.0363	0.0285	0.0267	0.0288

Assessment/Growing Season (June 1 - September 15) 90th Percentile TP (mg/L) for 2010-2013

	Group 1	***Group 2***	***Group 3***	**Petenwell Lake (top 2 layers)**				**Castle Rock Lake (top 4 layers)**			**Yellow River Arm (top 4 layers)**
Layer	**Petenwell**	**Castle Rock**	**Yellow R. Arm**	**Seg 9**	**Seg 13**	**Seg 17**	**Seg 20**	**Seg 41**	**Seg 46**	**Seg 50**	**Seg 57**
Assessment	0.0417	0.0368	0.0387	0.0480	0.0441	0.0407	0.0386	0.0425	0.0359	0.0341	0.0387
L1	0.0415	0.0367	0.0386	0.0477	0.0439	0.0407	0.0385	0.0422	0.0356	0.0339	0.0386
L2	0.0418	0.0368	0.0387	0.0482	0.0442	0.0409	0.0387	0.0424	0.0358	0.0340	0.0387
L3	0.0421	0.0368	0.0388	0.0493	0.0445	0.0410	0.0388	0.0425	0.0360	0.0342	0.0388
L4	0.0430	0.0369	0.0390	0.0508	0.0450	0.0417	0.0393	0.0426	0.0361	0.0342	0.0390

Total Phosphorus Assessment Method Applied to TP Load Reduction Scenario 05 - 58% Reduction of External TP, PO4R@Calibration (H49)

Assessment/Growing Season (June 1 - September 15) Geometric Mean TP (mg/L) for 2010-2013

	Group 1	*Group 2*	*Group 3*	Petenwell Lake (top 2 layers)				Castle Rock Lake (top 4 layers)			Yellow River Arm (top 4 layers)
Layer	**Petenwell**	**Castle Rock**	**Yellow R. Arm**	**Seg 9**	**Seg 13**	**Seg 17**	**Seg 20**	**Seg 41**	**Seg 46**	**Seg 50**	**Seg 57**
Assessment	0.0369	0.0347	0.0310	0.0386	0.0362	0.0362	0.0355	0.0407	0.0321	0.0308	0.0310
L1	0.0367	0.0345	0.0309	0.0383	0.0360	0.0360	0.0354	0.0405	0.0319	0.0306	0.0309
L2	0.0370	0.0346	0.0310	0.0388	0.0364	0.0363	0.0357	0.0406	0.0320	0.0308	0.0310
L3	0.0375	0.0347	0.0311	0.0395	0.0367	0.0367	0.0359	0.0407	0.0321	0.0308	0.0311
L4	0.0384	0.0348	0.0312	0.0412	0.0373	0.0373	0.0365	0.0409	0.0322	0.0309	0.0312

Assessment/Growing Season (June 1 - September 15) Mean TP (mg/L) for 2010-2013

	Group 1	*Group 2*	*Group 3*	Petenwell Lake (top 2 layers)				Castle Rock Lake (top 4 layers)			Yellow River Arm (top 4 layers)
Layer	**Petenwell**	**Castle Rock**	**Yellow R. Arm**	**Seg 9**	**Seg 13**	**Seg 17**	**Seg 20**	**Seg 41**	**Seg 46**	**Seg 50**	**Seg 57**
Assessment	0.0372	0.0354	0.0314	0.0388	0.0366	0.0370	0.0366	0.0420	0.0329	0.0314	0.0314
L1	0.0371	0.0352	0.0312	0.0385	0.0364	0.0368	0.0365	0.0418	0.0327	0.0312	0.0312
L2	0.0374	0.0354	0.0313	0.0390	0.0368	0.0371	0.0367	0.0419	0.0328	0.0314	0.0313
L3	0.0378	0.0355	0.0314	0.0398	0.0371	0.0375	0.0369	0.0420	0.0329	0.0315	0.0314
L4	0.0387	0.0356	0.0315	0.0418	0.0377	0.0380	0.0374	0.0422	0.0330	0.0316	0.0315

Assessment/Growing Season (June 1 - September 15) Median TP (mg/L) for 2010-2013

	Group 1	*Group 2*	*Group 3*	Petenwell Lake (top 2 layers)				Castle Rock Lake (top 4 layers)			Yellow River Arm (top 4 layers)
Layer	**Petenwell**	**Castle Rock**	**Yellow R. Arm**	**Seg 9**	**Seg 13**	**Seg 17**	**Seg 20**	**Seg 41**	**Seg 46**	**Seg 50**	**Seg 57**
Assessment	0.0377	0.0348	0.0307	0.0383	0.0373	0.0372	0.0355	0.0417	0.0320	0.0308	0.0307
L1	0.0376	0.0347	0.0306	0.0382	0.0371	0.0369	0.0353	0.0415	0.0319	0.0305	0.0306
L2	0.0379	0.0348	0.0307	0.0385	0.0375	0.0374	0.0355	0.0416	0.0320	0.0306	0.0307
L3	0.0386	0.0349	0.0308	0.0389	0.0377	0.0376	0.0356	0.0418	0.0321	0.0308	0.0308
L4	0.0394	0.0351	0.0309	0.0401	0.0383	0.0381	0.0362	0.0419	0.0322	0.0309	0.0309

Assessment/Growing Season (June 1 - September 15) 90th Percentile TP (mg/L) for 2010-2013

	Group 1	*Group 2*	*Group 3*	Petenwell Lake (top 2 layers)				Castle Rock Lake (top 4 layers)			Yellow River Arm (top 4 layers)
Layer	**Petenwell**	**Castle Rock**	**Yellow R. Arm**	**Seg 9**	**Seg 13**	**Seg 17**	**Seg 20**	**Seg 41**	**Seg 46**	**Seg 50**	**Seg 57**
Assessment	0.0438	0.0451	0.0374	0.0445	0.0428	0.0475	0.0475	0.0559	0.0438	0.0400	0.0374
L1	0.0435	0.0450	0.0372	0.0442	0.0426	0.0473	0.0475	0.0558	0.0438	0.0398	0.0372
L2	0.0440	0.0451	0.0374	0.0448	0.0430	0.0476	0.0472	0.0559	0.0437	0.0400	0.0374
L3	0.0441	0.0452	0.0375	0.0461	0.0432	0.0477	0.0469	0.0559	0.0438	0.0401	0.0375
L4	0.0448	0.0453	0.0375	0.0477	0.0437	0.0478	0.0473	0.0559	0.0438	0.0402	0.0375

Total Phosphorus Assessment Method Applied to TP Load Reduction Scenario 01 - 65% Reduction of External TP, PO4R@Calibration (H49)

Assessment/Growing Season (June 1 - September 15) Geometric Mean TP (mg/L) for 2010-2013

	Group 1	*Group 2*	*Group 3*	Petenwell Lake (top 2 layers)				Castle Rock Lake (top 4 layers)			Yellow River Arm (top 4 layers)
Layer	**Petenwell**	**Castle Rock**	**Yellow R. Arm**	**Seg 9**	**Seg 13**	**Seg 17**	**Seg 20**	**Seg 41**	**Seg 46**	**Seg 50**	**Seg 57**
Assessment	0.0318	0.0309	0.0275	0.0325	0.0311	0.0314	0.0312	0.0363	0.0285	0.0274	0.0275
L1	0.0316	0.0307	0.0273	0.0323	0.0310	0.0313	0.0311	0.0362	0.0283	0.0272	0.0273
L2	0.0319	0.0308	0.0274	0.0327	0.0313	0.0316	0.0313	0.0363	0.0284	0.0273	0.0274
L3	0.0323	0.0309	0.0275	0.0334	0.0315	0.0319	0.0315	0.0364	0.0285	0.0274	0.0275
L4	0.0331	0.0310	0.0276	0.0350	0.0321	0.0324	0.0320	0.0365	0.0286	0.0275	0.0276

Assessment/Growing Season (June 1 - September 15) Mean TP (mg/L) for 2010-2013

	Group 1	*Group 2*	*Group 3*	Petenwell Lake (top 2 layers)				Castle Rock Lake (top 4 layers)			Yellow River Arm (top 4 layers)
Layer	**Petenwell**	**Castle Rock**	**Yellow R. Arm**	**Seg 9**	**Seg 13**	**Seg 17**	**Seg 20**	**Seg 41**	**Seg 46**	**Seg 50**	**Seg 57**
Assessment	0.0321	0.0316	0.0278	0.0327	0.0315	0.0322	0.0322	0.0377	0.0292	0.0279	0.0278
L1	0.0320	0.0314	0.0276	0.0325	0.0313	0.0321	0.0322	0.0375	0.0290	0.0278	0.0276
L2	0.0323	0.0315	0.0277	0.0329	0.0316	0.0324	0.0323	0.0376	0.0291	0.0279	0.0277
L3	0.0326	0.0316	0.0278	0.0336	0.0319	0.0326	0.0325	0.0377	0.0292	0.0279	0.0278
L4	0.0335	0.0317	0.0279	0.0354	0.0324	0.0331	0.0330	0.0378	0.0293	0.0280	0.0279

Assessment/Growing Season (June 1 - September 15) Median TP (mg/L) for 2010-2013

	Group 1	*Group 2*	*Group 3*	Petenwell Lake (top 2 layers)				Castle Rock Lake (top 4 layers)			Yellow River Arm (top 4 layers)
Layer	**Petenwell**	**Castle Rock**	**Yellow R. Arm**	**Seg 9**	**Seg 13**	**Seg 17**	**Seg 20**	**Seg 41**	**Seg 46**	**Seg 50**	**Seg 57**
Assessment	0.0323	0.0306	0.0274	0.0327	0.0320	0.0314	0.0298	0.0371	0.0281	0.0270	0.0274
L1	0.0322	0.0304	0.0273	0.0325	0.0318	0.0313	0.0297	0.0370	0.0280	0.0269	0.0273
L2	0.0325	0.0306	0.0273	0.0330	0.0322	0.0315	0.0300	0.0370	0.0280	0.0269	0.0273
L3	0.0329	0.0306	0.0274	0.0334	0.0324	0.0318	0.0302	0.0371	0.0281	0.0270	0.0274
L4	0.0336	0.0307	0.0274	0.0343	0.0327	0.0323	0.0309	0.0372	0.0282	0.0271	0.0274

Assessment/Growing Season (June 1 - September 15) 90th Percentile TP (mg/L) for 2010-2013

	Group 1	*Group 2*	*Group 3*	Petenwell Lake (top 2 layers)				Castle Rock Lake (top 4 layers)			Yellow River Arm (top 4 layers)
Layer	**Petenwell**	**Castle Rock**	**Yellow R. Arm**	**Seg 9**	**Seg 13**	**Seg 17**	**Seg 20**	**Seg 41**	**Seg 46**	**Seg 50**	**Seg 57**
Assessment	0.0395	0.0406	0.0331	0.0360	0.0373	0.0440	0.0427	0.0516	0.0391	0.0356	0.0331
L1	0.0394	0.0404	0.0330	0.0357	0.0371	0.0436	0.0427	0.0514	0.0390	0.0354	0.0330
L2	0.0397	0.0406	0.0331	0.0362	0.0374	0.0440	0.0423	0.0514	0.0391	0.0355	0.0331
L3	0.0397	0.0407	0.0331	0.0371	0.0373	0.0441	0.0421	0.0517	0.0391	0.0357	0.0331
L4	0.0405	0.0410	0.0332	0.0398	0.0375	0.0442	0.0425	0.0517	0.0392	0.0359	0.0332