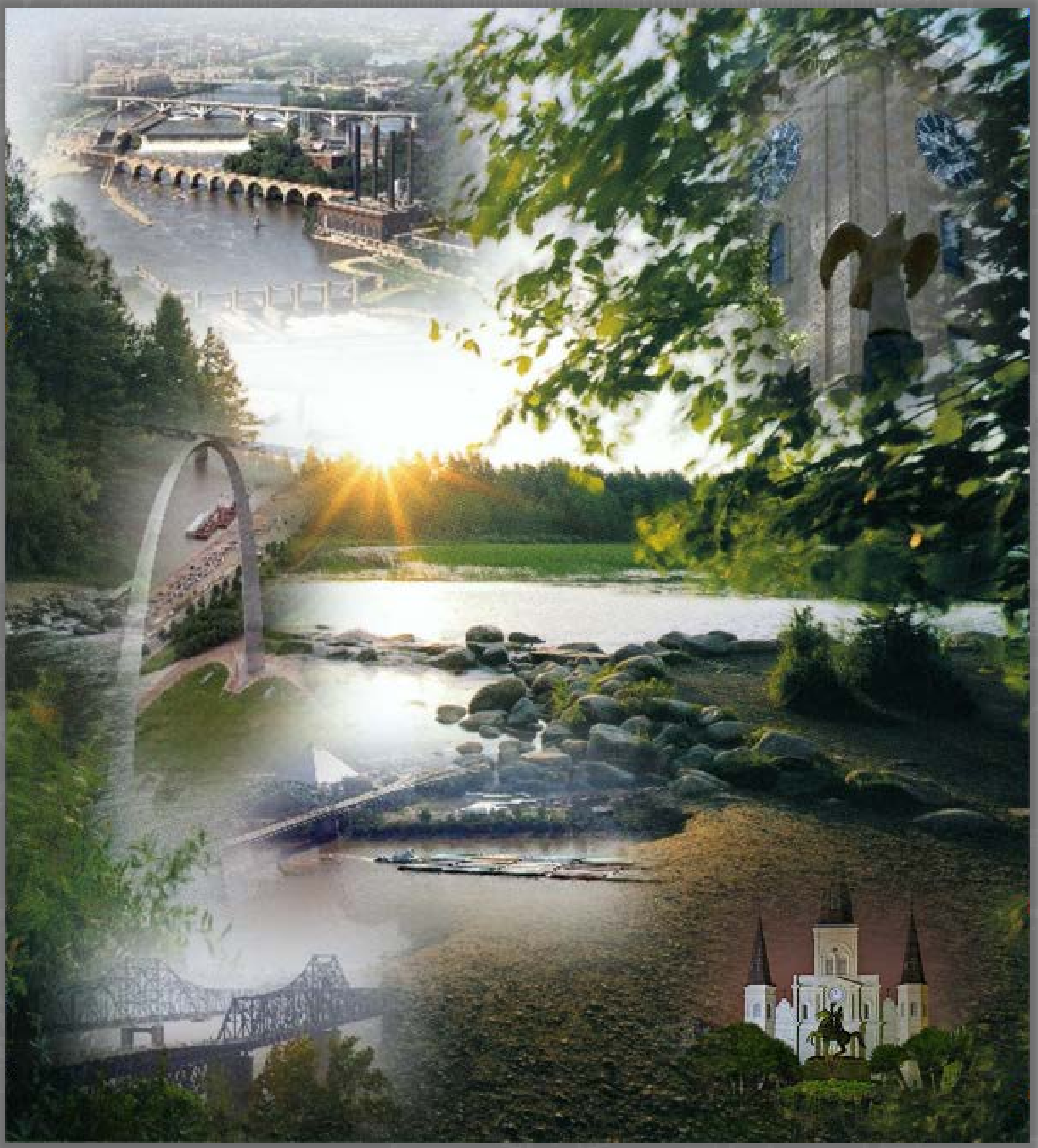
RED CEDAR CE-QUAL-W2 WATER QUALITY MODEL TAINTER LAKE - LAKE MENOMIN

Jim Noren
Red Cedar Watershed meeting
November 8, 2019
Menomonie, WI



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OUTLINE

- Study Background
- Purpose of the 2-D modeling of Lake Menomin and Tainter Lake
- Study Area
- Modeling Overview
- CE-Qual-W2 Design
- Model Inputs and monitoring data
- Model Calibration
- Scenario Results

BACKGROUND

CE-QUAL-W2 WQ model and report

- Part of a basin-wide project led by the West Central Wisconsin Regional Planning Commission (WCWRPC) to evaluate the significance of various social, economic and water quality aspects of the Red Cedar River to the surrounding region.

- Funding for this project is through a joint Wisconsin Department of Natural Resources' (WDNR) Lake Protection Grant and an US Army Corps of Engineers' (USACE) Section 22, planning assistance to states cost share agreement.

- Report is a companion document to the Draft Limnological Conditions in Tainter and Menomin Reservoirs: Interim Report 2018, (Bill James)

MODEL PURPOSE

CE-QUAL-W2 WQ model and report

- Assist the WDNR with refining phosphorus loading reduction scenarios originally derived from the 2012 Tainter Lake and Lake Menomin Phosphorus TMDL (1-D USACE BATHTUB model)

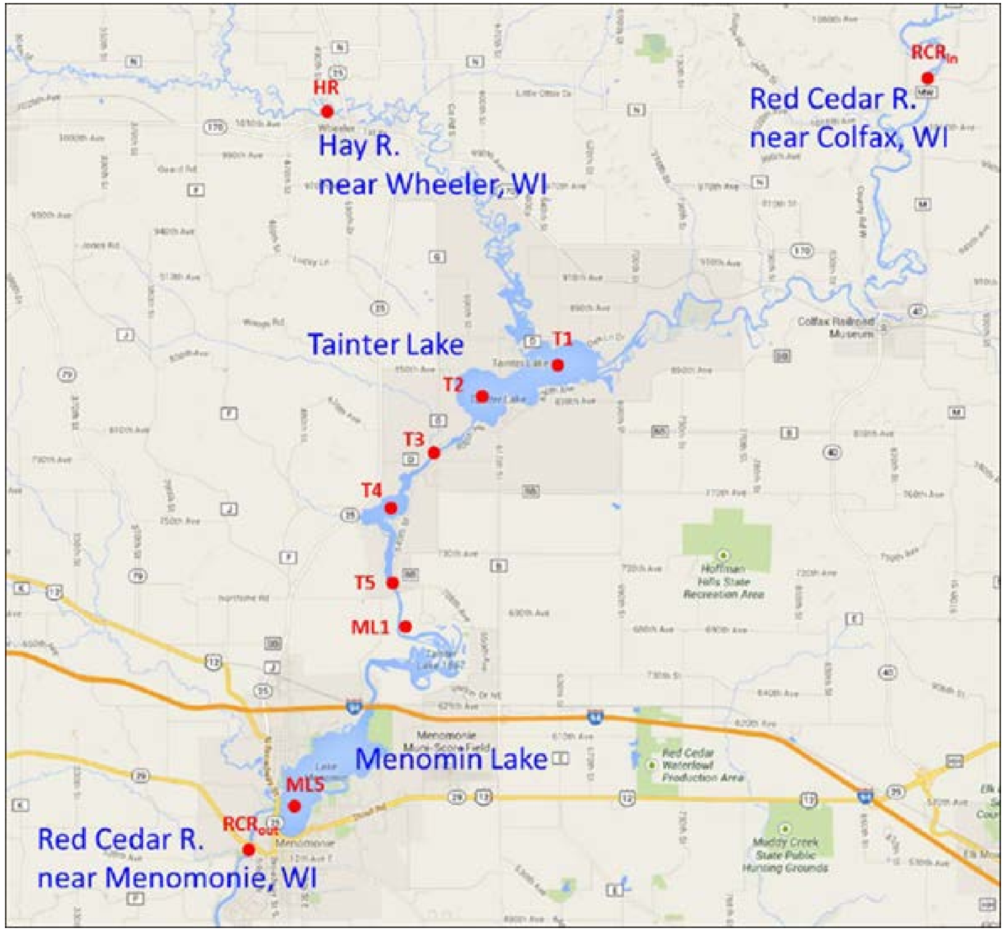
- Examine interrelationships between hydrology, advection (horizontal water movement), residence time and riverine nutrient (primarily phosphorus) delivery on cyanobacteria dynamics and potential cyanotoxicity in wet versus dry years

Leader telegram staff photo

STUDY SITE

Morphometric characteristics of Tainter and Menomin Lakes

Morphometric Variable	English			Metric		
	Tainter	Menomin	Unit	Tainter	Menomin	Unit
Surface area	1,608.2	1,325.4	ac	6,508,160	5,363,708	m^2
Volume	20,242.0	14,183.7	ac-ft	24,968,102	17,495,310	m^3
Mean depth	12.6	10.7	ft	3.84	3.26	m
Max depth	36.0	30.0	ft	10.97	9.14	m
Shoreline length	24.4	26.7	mi	39.30	42.97	km



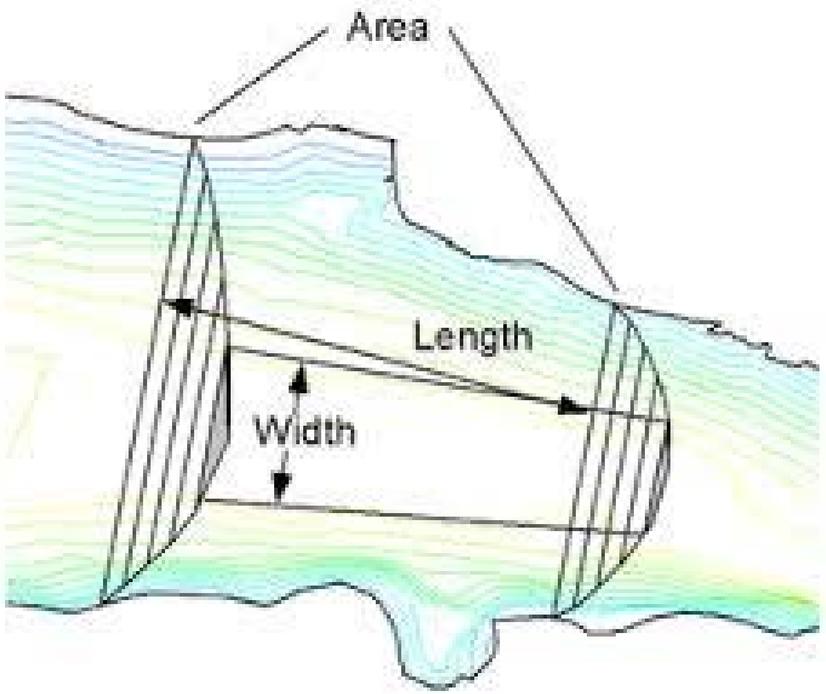
CE-QUAL-W2 MODEL OVERVIEW

- Longitudinal/vertical hydrodynamic and water quality model (2-D)
- Original model was known as LARM (Laterally Averaged Reservoir Model) developed by Edinger and Buchak (1975).
- Under continuous development since 1975
- Maintained by the US Corps of Engineers and Portland State University
- Includes algal/nutrient/dissolved oxygen interactions
- Has been applied to hundreds of rivers, lakes and reservoirs around the world.

CE-QUAL-W2 MODEL OVERVIEW

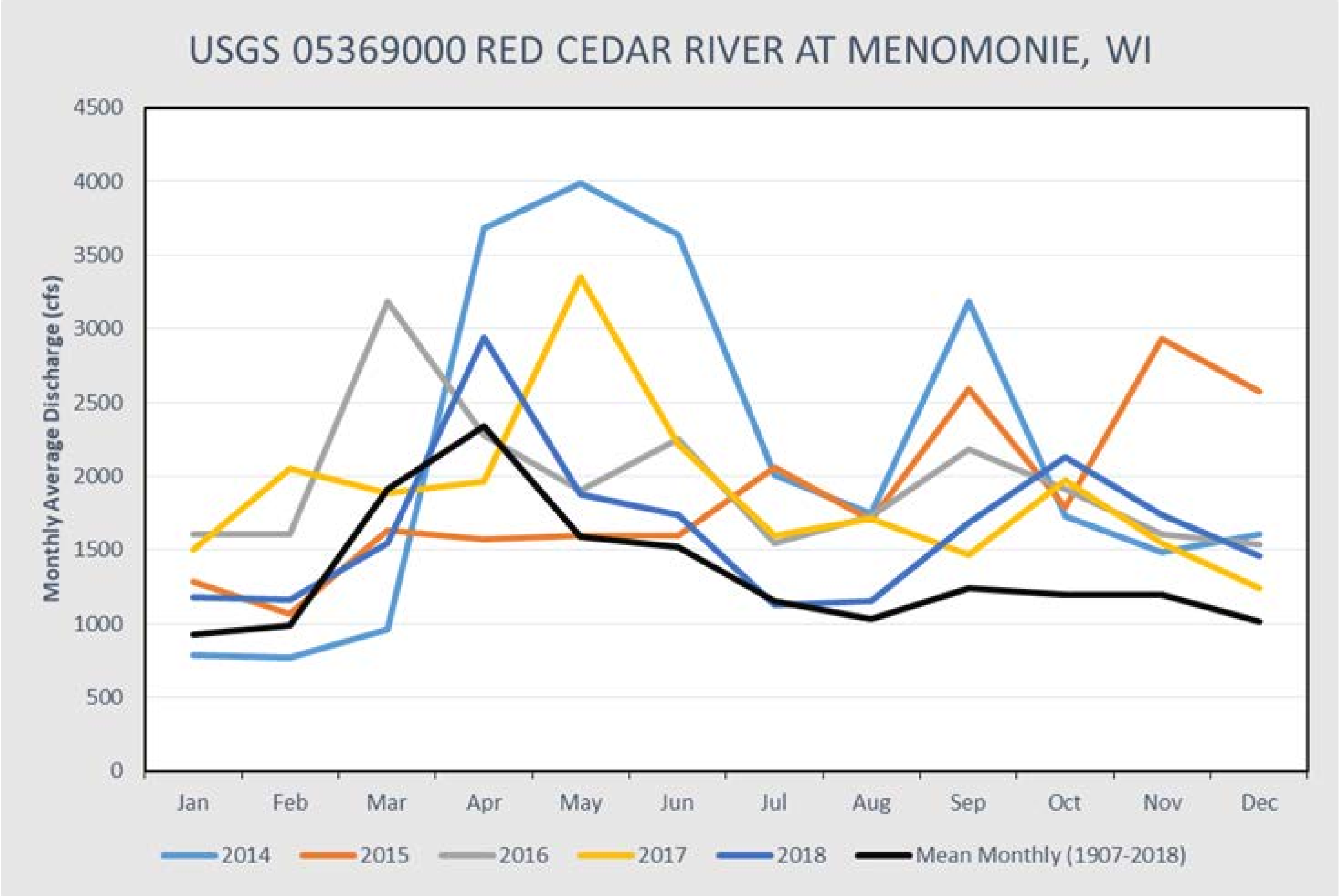
2-Dimensional Model

– Well-mixed in lateral direction CE-QUAL-W2 is a two dimensional reservoir model, thus all water quality parameters are averaged laterally across a segment. Each layer within a segment acts as a fully mixed reactor for each time step.



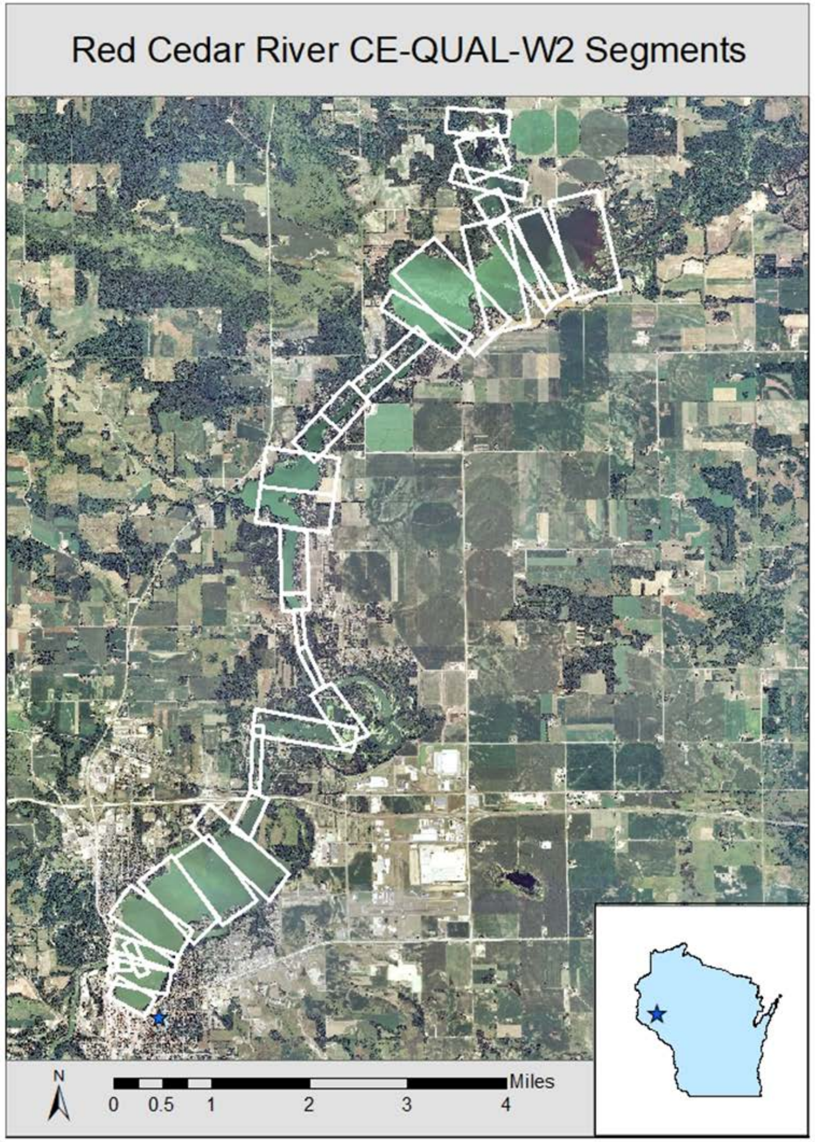
MODEL INPUTS

- Bathymetry
- Dam Outlet Structures
- Boundary conditions
- Calibration data
- Hydraulic parameters
- Kinetic parameters



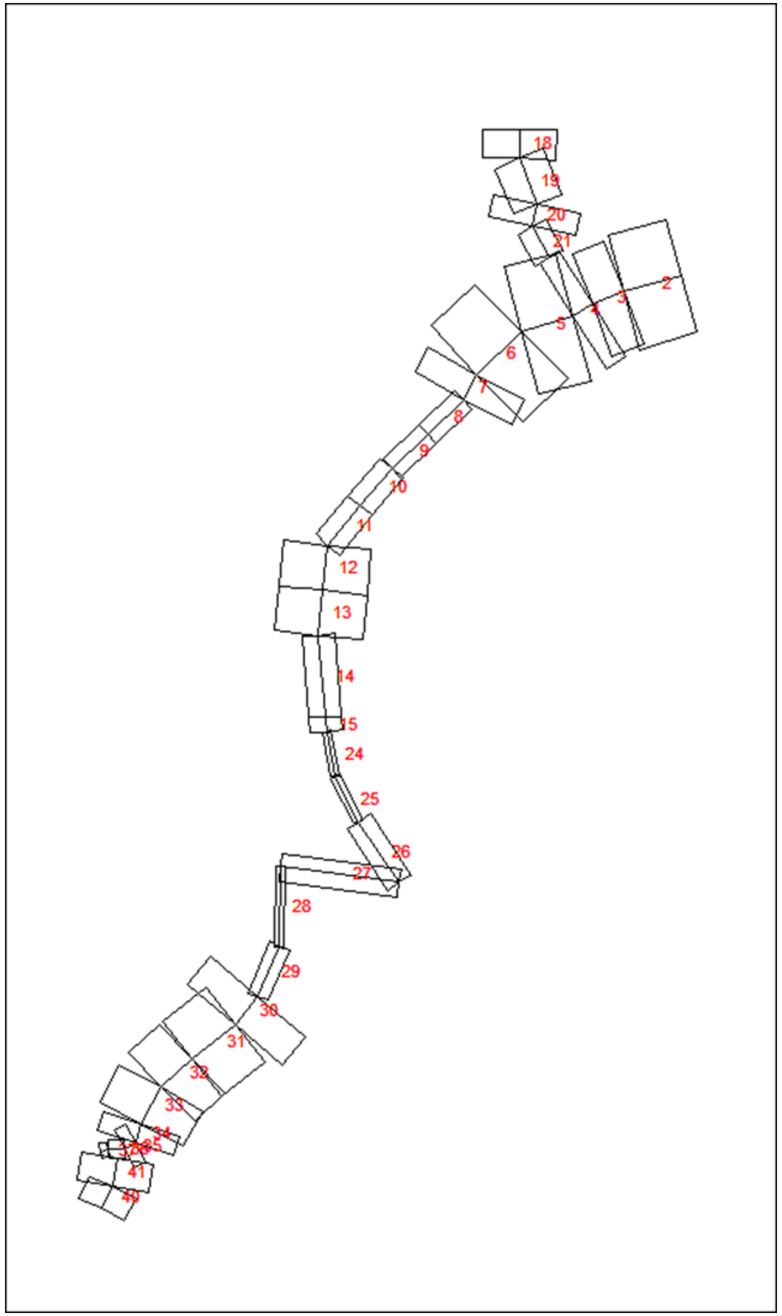
BATHYMETRY

- Developed from one meter GRID files from 2005-2007 bathymetric surveys done by Sean Hartnett at UW Eau Claire
- The grid files were converted to 5-meter DEMs and combined into one TIN file that was loaded into Watershed Modeling System (WMS) v10.1
- Two waterbodies (Tainter Lake and Lake Menomin) with two branches in each waterbody.



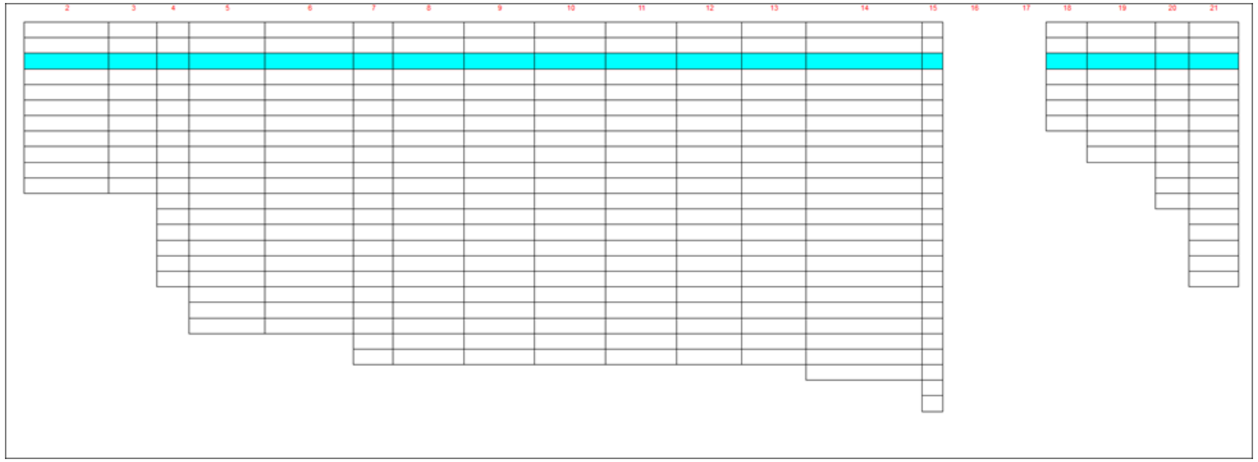
BATHYMETRY

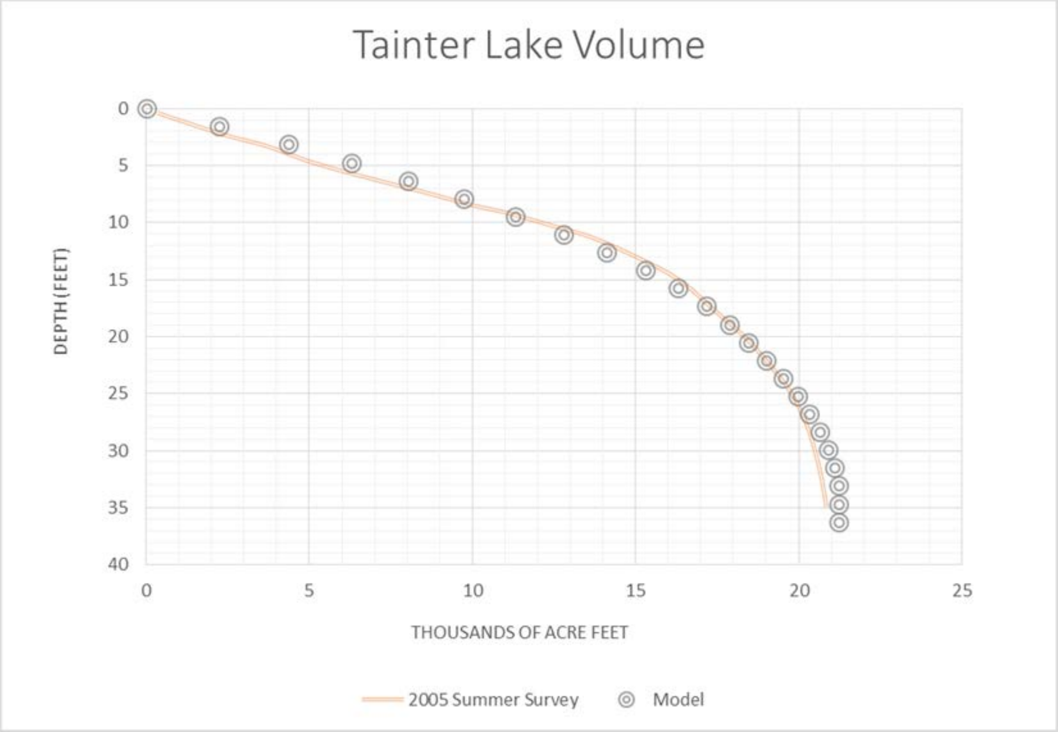
- Branch #1 represents the main branch in Tainter Lake
- Branch #2 represents the lower section of the Hay River as it enters Tainter Lake.
- Branch #3 is the main branch of Lake Menomin
- Branch #4 represents the lower portion of Lake Menomin that is south of the reservoir’s outlet.
- In total, there are 34 user-defined longitudinal segments of varying lengths (~100-1000m) in the model’s computational grid,



BATHYMETRY

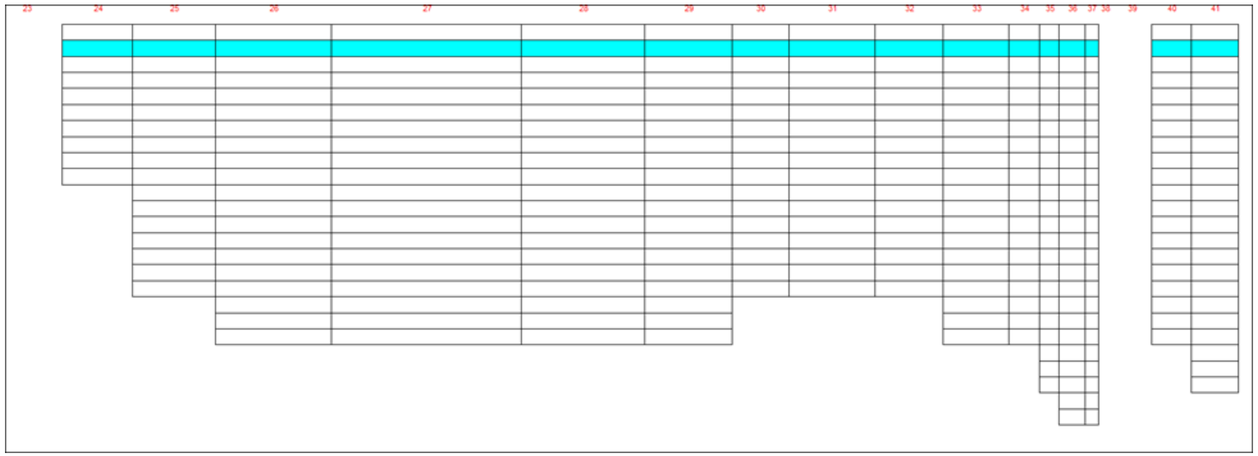
- Vertically, the model was split into 25 layers
- Tainter Lake's maximum depth of 11 meters (0.48 m/layer)
- Model Depth-Volume curves match observed data

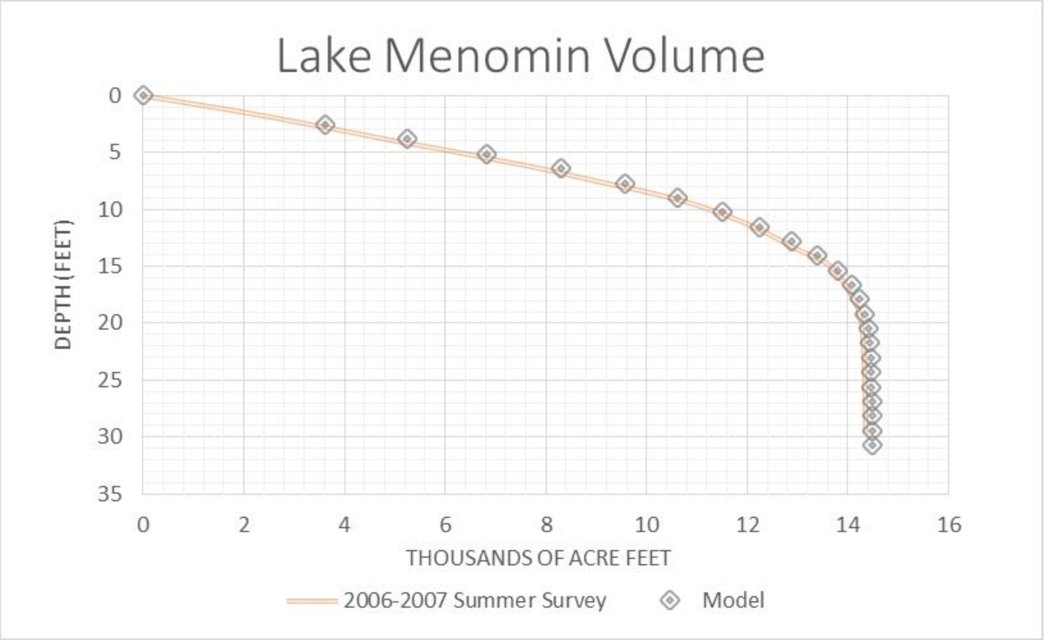




BATHYMETRY

- Lake Menomin’s maximum depth of 9.5 meters (0.39 m/layer).





DAM OUTLET STRUCTURES

Menomonie Hydroelectric Project and Cedar Falls Hydroelectric Project

- limited range of daily hydropower peaking and their Federal Energy Regulatory Commission licenses do not allow significant seasonal storage
- The impoundments have a maximum pool operation range of 0.5 feet (~run of river)
- Operators are at the plants daily, Monday through Friday and operated remotely by staff at Xcel's Wissota Hydro facility near Chippewa Falls, Wisconsin.
- Headwater and tailwater levels and their rates of change are monitored in addition to several operation conditions.
- Data courtesy of Xcel Energy (Matthew Miller)

DAM OUTLET STRUCTURES

Cedar Falls Hydroelectric Project

- For modeling purposes, the elevation of the normal water surface elevation of 265.8 meters (872.2 feet (NGVD 29)) was used as the starting elevation for Tainter Lake
- All discharge from the reservoir at the dam for power generation were placed at the centerline of the penstock inlet at 260.9 meters (855.8 feet).
- Excess flows were placed at the crest of the regulating tainter gate, which has a sill elevation of 264.4 meters (867.4 feet)

DAM OUTLET STRUCTURES

Menomonie Hydroelectric Project

- For modeling purposes, the elevation of the normal water surface elevation of 248.1 meters (814.0 feet (NGVD)) was used as the starting elevation for Lake Menomin
- All discharge from the reservoir at the dam for power generation were placed at the centerline of the penstock inlet at 240.3 meters (788.4 feet).
- Excess flows were placed at the crest of the regulating tainter gate, which measures 7.6 meters wide and 2.7 meters high with a sill elevation of 245.36 meters (805.0 feet)

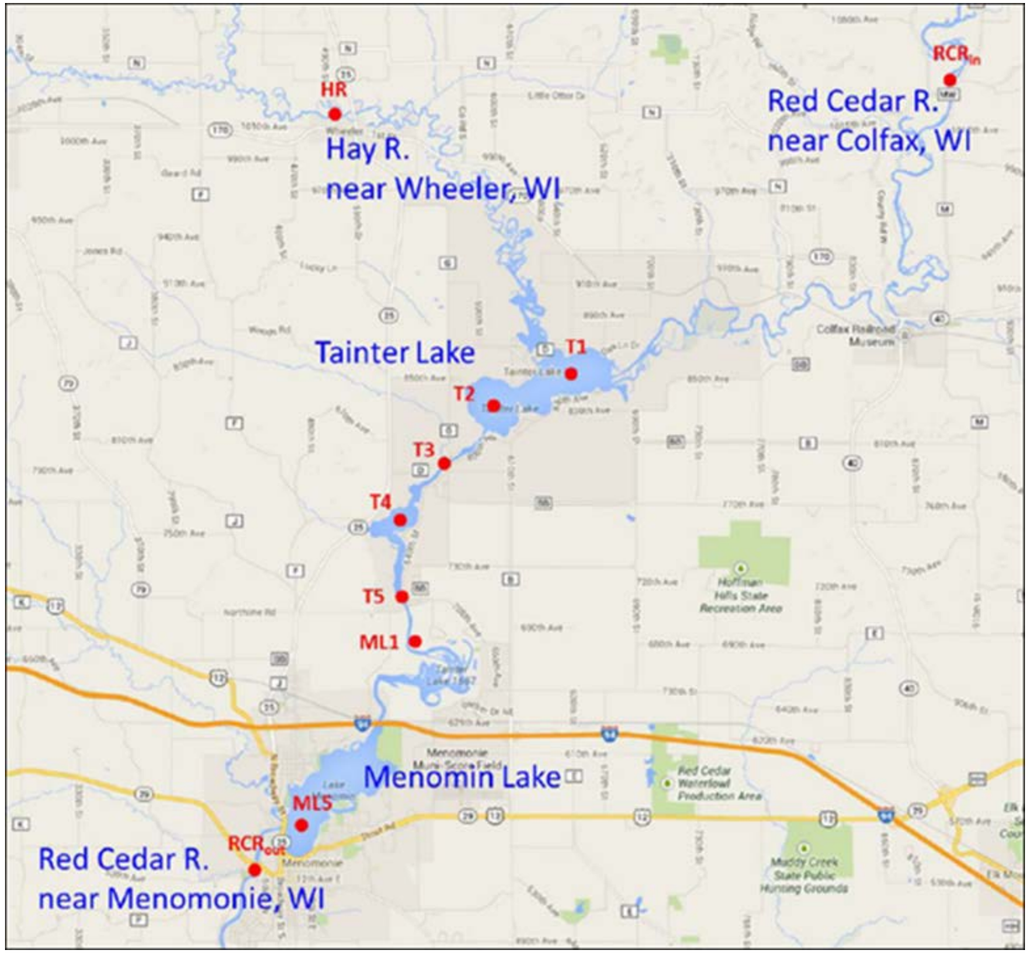
https://mapio.net/pic/p-89858029/

BOUNDARY CONDITIONS

Flow

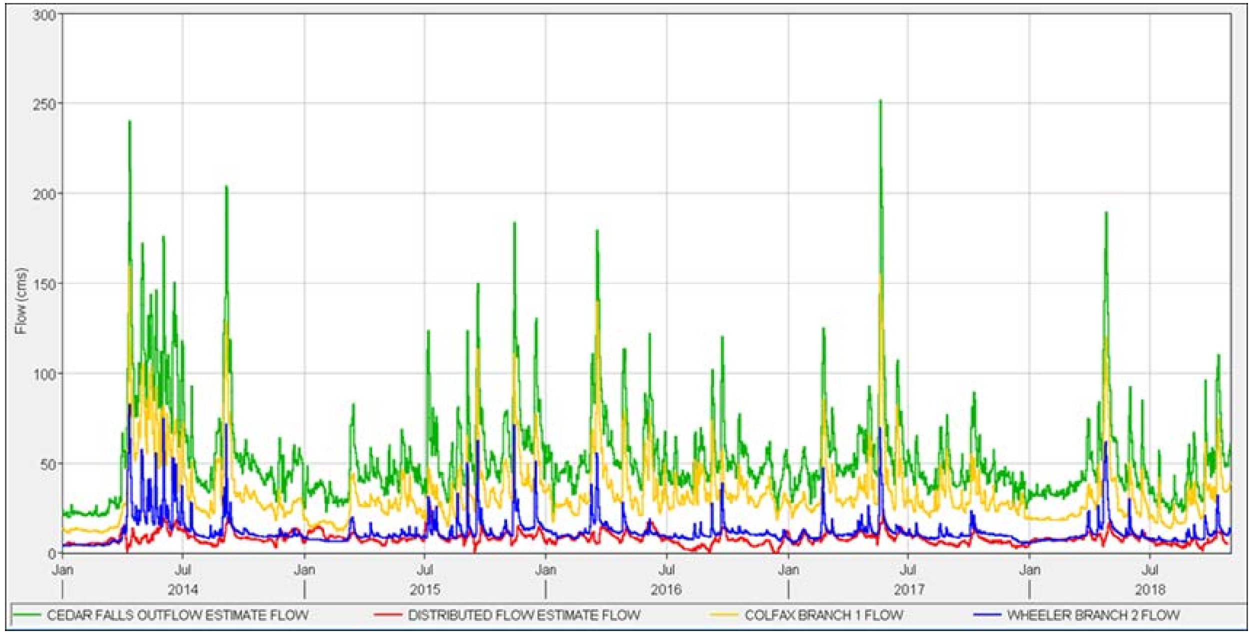
- Existing US Geological Survey flow gaging stations
- Daily Mean Flows

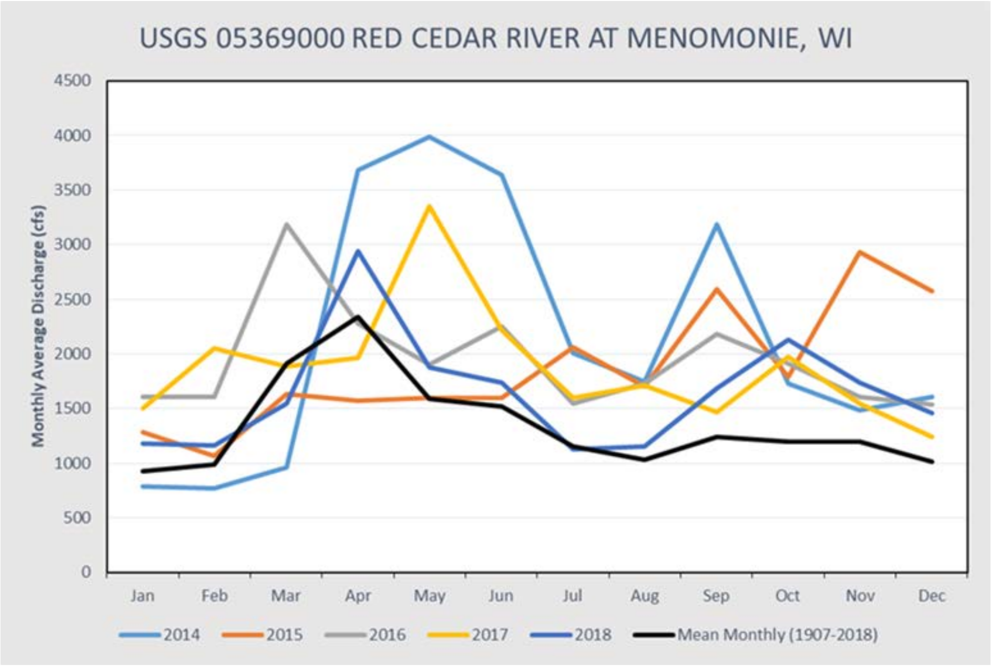
- Inflow
  - Hay River near Wheeler, WI, (05368000)
  - Red Cedar River near Colfax, WI (05367500)
- Outflow
  - Red Cedar River at Menomonie, WI (05369000)



BOUNDARY CONDITIONS

Flow 2014-2018

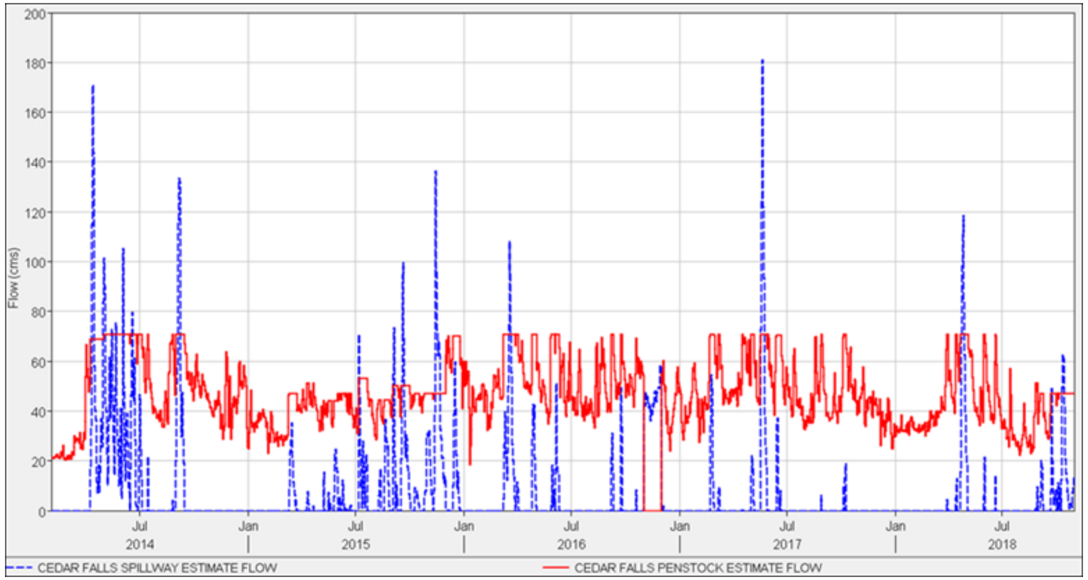




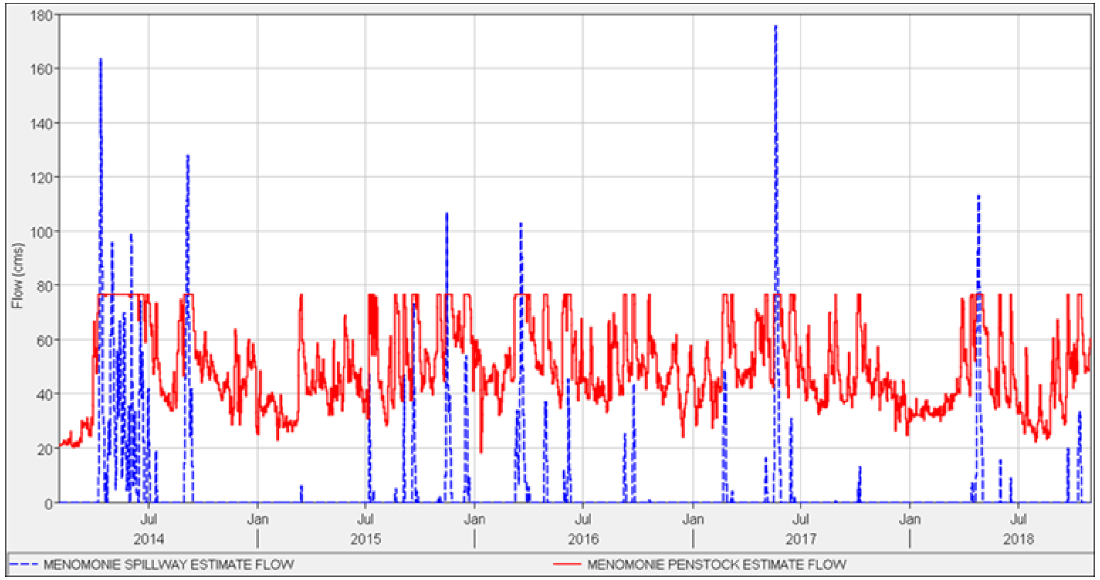
BOUNDARY CONDITIONS

Estimated Dam Discharge 2014-2018

Cedar Falls Dam



Menomonie Dam

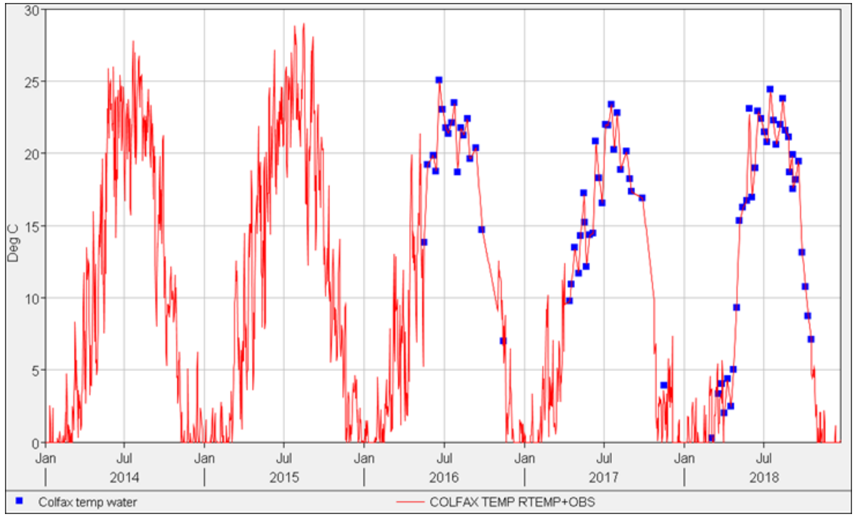


penstock discharge (red) and tainter gate discharge (blue).

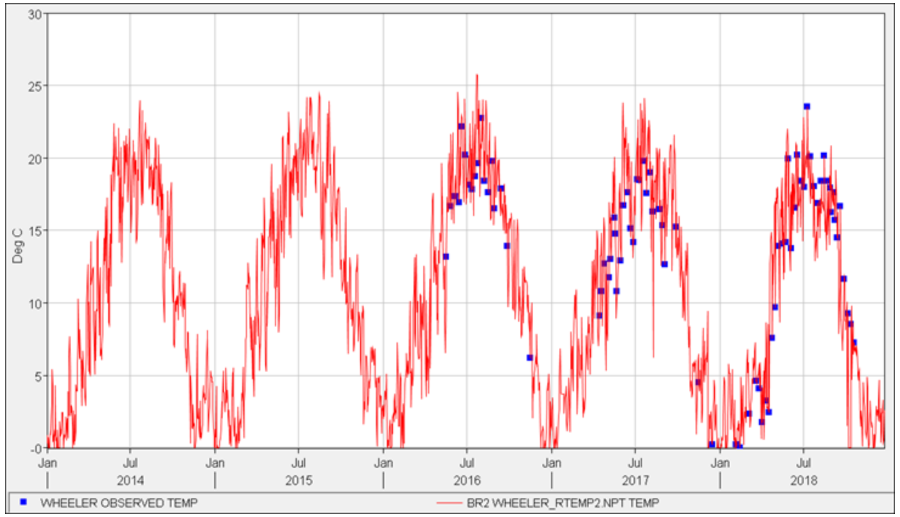
BOUNDARY CONDITIONS

Water Temperature (inflows)

- Critical in surface and sediment heat exchange, density functions that control water column stratification, temperature rate multipliers for chemical reactions, and algal growth cycle, etc.
- Response Temperature: a simple model of water temperature (rTemp) is a spreadsheet model developed by the Washington State Department of Ecology



Red Cedar River

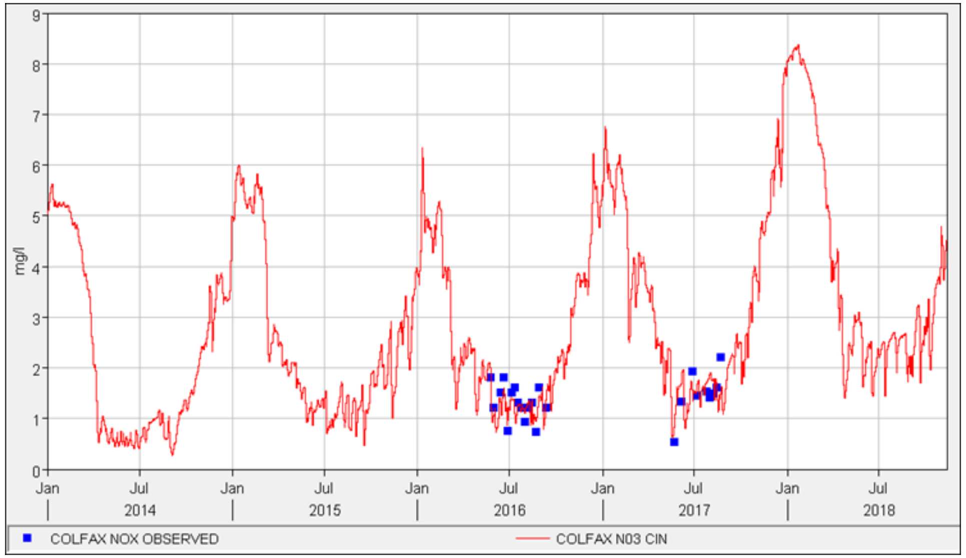


Hay River

BOUNDARY CONDITIONS

Water Quality (inflows) - Bill James

- Constituents measured include:
- total organic carbon (TOC),
- dissolved organic carbon (DOC),
- total kjeldahl nitrogen (TKN),
- ammonium-N (NHx),
- nitrate-nitrite-N (NOx),
- total phosphorus (TP),
- soluble reactive phosphorus (SRP)
- chlorophyll (CHLA).
- Annual and seasonal loadings (kg/y or kg/d) were estimated using the computer program FLUX. Daily concentrations of each constituent were back calculated from the loading estimates using mean daily flow.

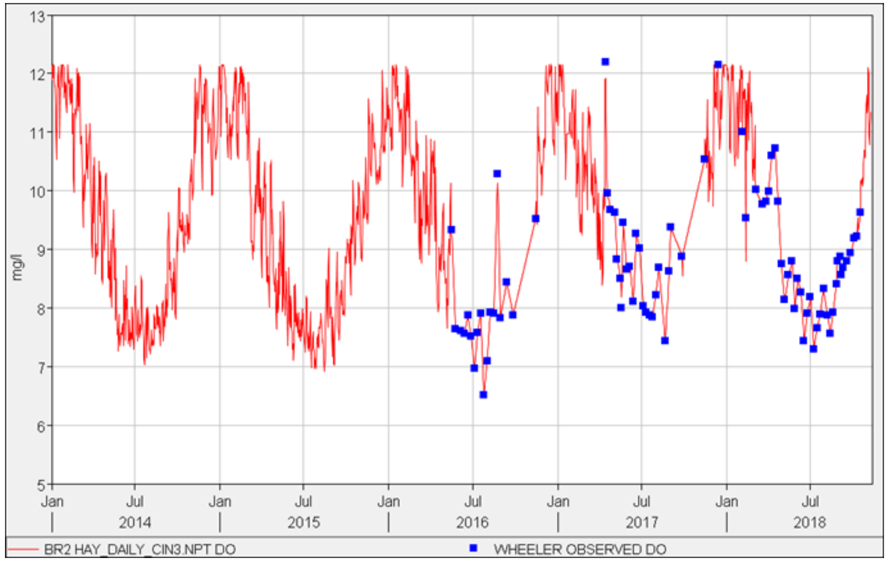


Nitrate-nitrite concentration input time-series used for branch 1

BOUNDARY CONDITIONS

Dissolved Oxygen (inflows)

- Oxygen is essential for higher forms of life, controls many chemical reactions through oxidation
- During the time-periods were DO were measured, a simple linearly interpolated daily time-series was used
- For time-periods not covered by observed data, DO concentrations were developed assuming 90% and 86% of the saturated DO concentrations for the Red Cedar River (05367500) and Hay River (05368000), respectively.



Dissolved Oxygen concentration input time-series used for branch 2

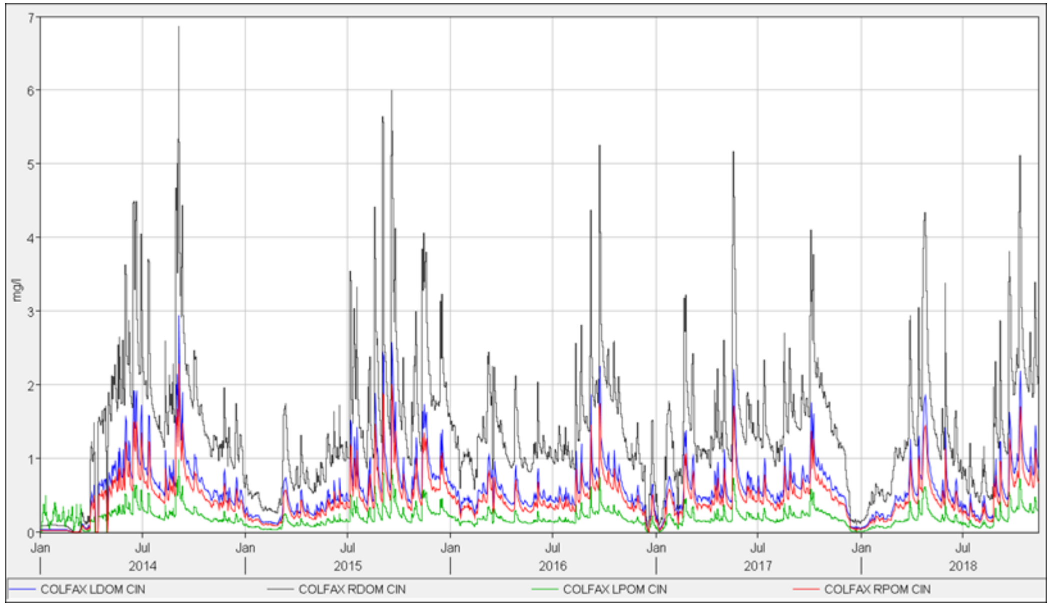
BOUNDARY CONDITIONS

Organic Matter (inflows)

- The decay of organic matter in the water column and sediments of reservoirs are important internal sources of nutrients and internal sinks for dissolved oxygen.

- LDOM= ((TOC -algae)* 0.75) * 0.30
- RDOM= ((TOC-algae) * 0.75) * 0.70
- LPOM = ((TOC-algae) * 0.25) * 0.30
- RPOM = ((TOC - algae) * 0.25) * 0.70

USACE (1999) Miscellaneous Paper EL-99-1, 13.



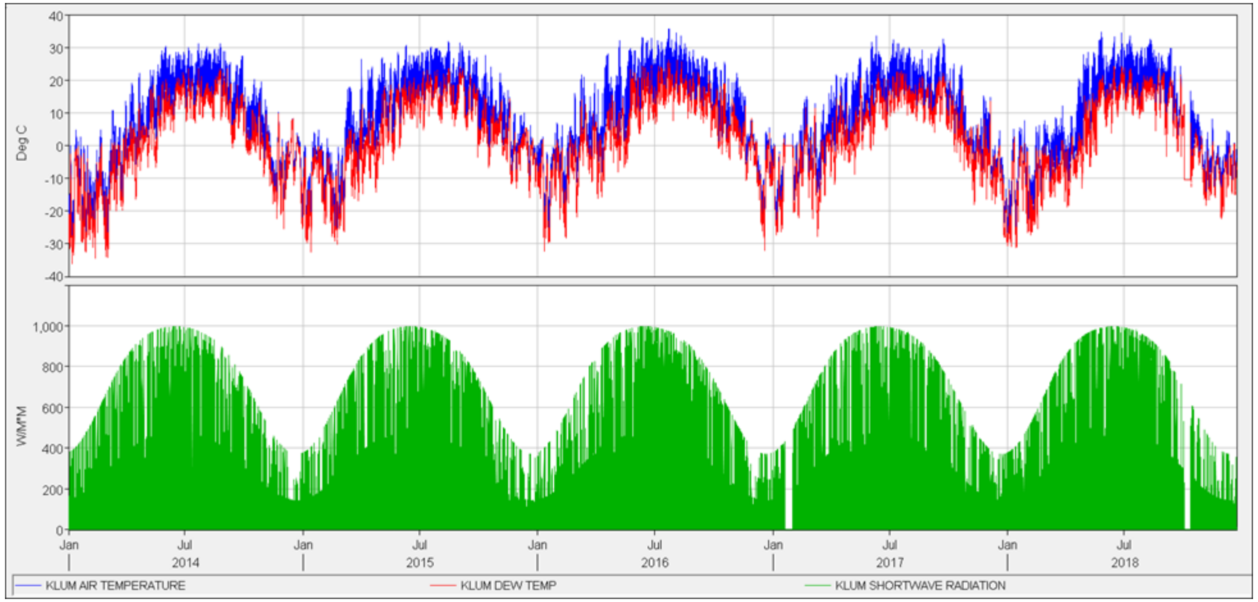
Organic matter (LDOM, RDOM, LPOM and RPOM) concentration input time-series used for branch 1 at Red Cedar River near Colfax, WI

BOUNDARY CONDITIONS

Meteorological Data

- Menomonie Municipal Airport-Score Field

- Hourly
  - air temperature,
  - dew point temperature
  - wind speed
  - wind direction
  - cloud cover
  - solar radiation



Hourly Air Temperature (blue), Dew Point Temperature(red) and Shortwave Radiation (green) reported from Menomonie Municipal Airport-Score Field (KLUM).

CALIBRATION DATA

In-Pool Data (Bill James)

- The model was calibrated using 2015-2018 summer observed in-pool data
- Five stations (TL1, TL2, TL3, TL4 and TL5) for Tainter Lake
- Two stations (ML1 and ML5) for Lake Menomin
- 2016-2018 Grab samples every two weeks (1-m integrated surface sample)
- 2015-2018 1-m profile data
  - pH
  - Conductivity
  - Temp
  - D.O.

Station	Coordinates North	Coordinates West	Total P (mg/L)	SRP (mg/L)	Chla (mg/L)	TKN (mg/L)	NHx (mg/L)	NOx (mg/L)	Phyto ID	Microcystin	AlkPAct (ug/g min)
Tainter Lake 1 (TL 1)	44.9889	-91.8361	X	X	X	X	X	X			
Tainter Lake 2 (TL 2)	44.9822	-91.8603	X	X	X	X	X	X			
Tainter Lake 3 (TL 3)	44.9657	-91.8783	X	X	X	X	X	X			
Tainter Lake 4 (TL 4)	44.9536	-91.8917	X	X	X	X	X	X			
Tainter Lake 5 (TL 5)	44.9384	-91.8913	X	X	X	X	X	X	X	X	X
Menomin Lake 1 (ML 1)	44.8808	-91.9239	X	X	X	X	X	X			
Menomin Lake 5 (ML 5)	44.9332	-91.8879	X	X	X	X	X	X	X	X	X

MODEL CALIBRATION

Water quality modeling is still very much an art with numerous parameters available for adjustment during model development (TM Cole - 2003)

For this Red Cedar W2 model, the calibration strategy was to use four years of monitoring data (2015-2018) to estimate a single set of pertinent hydraulic and water quality parameters that:

1) Minimizes the differences in computed and observed data for the simulated time-period of interest (May-Oct) and

2) Maximizes the model's predictive accuracy for testing a wide range of scenarios aimed at limiting cyanobacteria growth.

MODEL CALIBRATION

For minimizing the differences in computed and observed data the Red Cedar W2 model results were assessed using graphical techniques (observed vs. modeled profiles and time series graphs) as well as statistical measures.

statistical measures

- mean absolute error (MAE),
- percent bias (PBIAS),
- and the relative percent error (Rel%Err)

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

MAE is a measure of the average magnitude of deviation of the simulated results to the observed data

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

PBIAS measures the average tendency of the simulated results to be larger or smaller than the observed data

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

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.

MODEL CALIBRATION

Calibration targets,

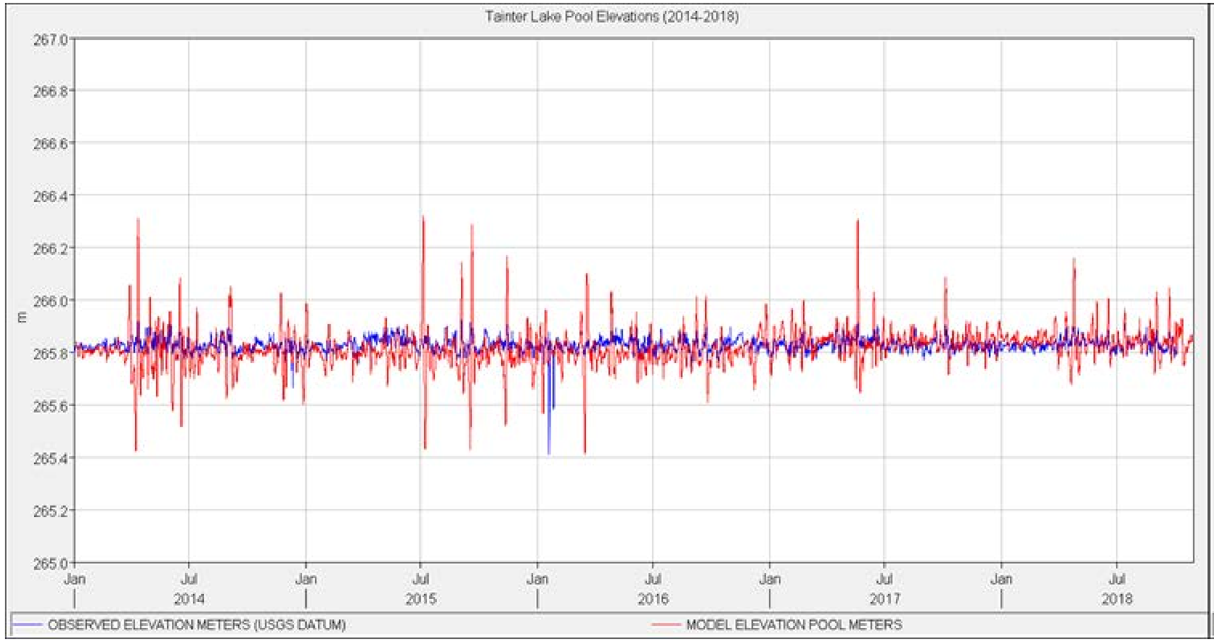
Based on targets used for a 2016 CE-QUAL-W2 model developed for the Wisconsin River TMDL (An emphasis was put on MAE as the primary calibration statistic)

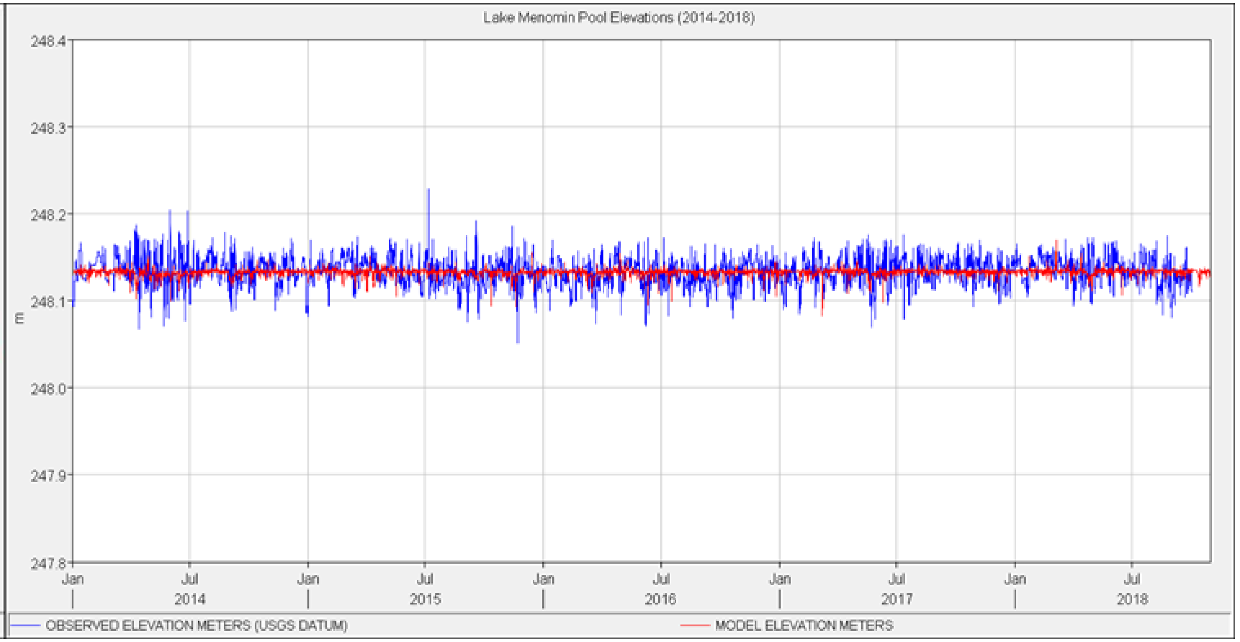
Primary Calibration State Variables	**Mean Absolute Error**
Temperature	1°C
Total Phosphorus	0.02 mg/L
Orthophosphate	0.01 mg/L
Dissolved Oxygen	2 mg/L
Secondary Calibration State Variables	**Mean Absolute Error**
Total Organic Carbon	5 mg/L
Chlorophyll a	4 µg/L
Total Kjeldahl Nitrogen	0.4 mg/L
Ammonia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

MODEL CALIBRATION

Flow/Water Surface Elevation

Reservoir pool elevation data were obtained from Xcel Energy





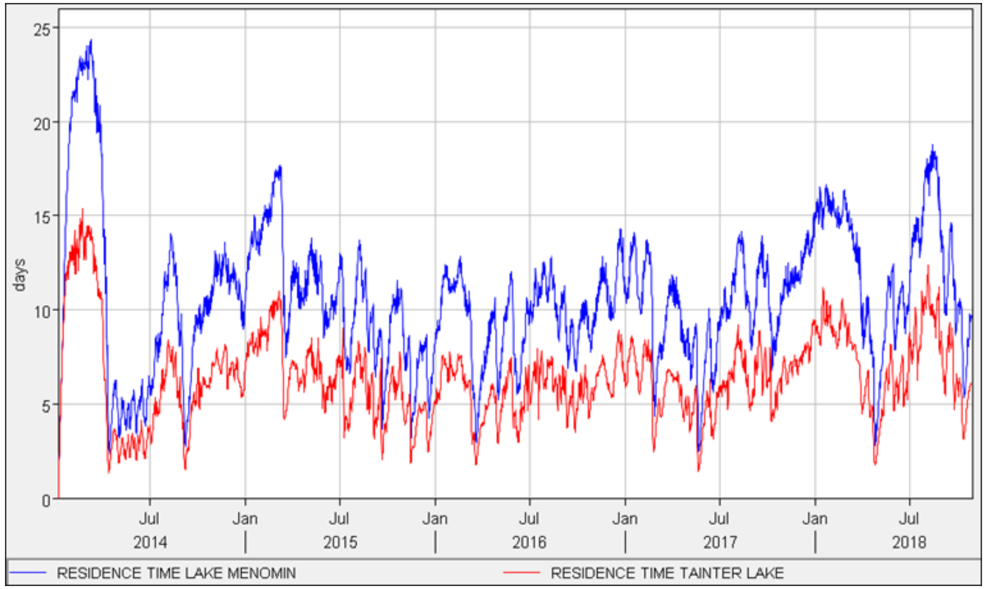
Tainter Lake.

Lake Menomin

Observed (blue) and computed (red) water surface elevations

MODEL CALIBRATION

Modeled Residence Times



Tainter Lake (red) and Tainter Lake + Lake Menomin (blue).

MODEL CALIBRATION

Water Temperature

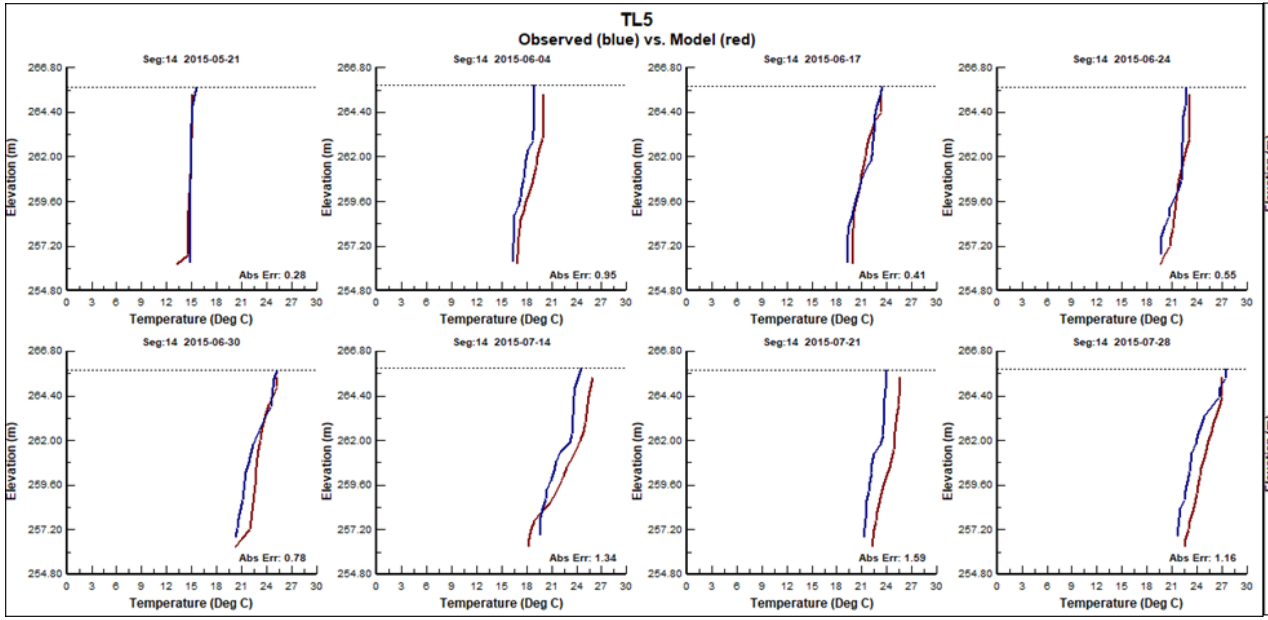
Temperature Calibration Coefficients

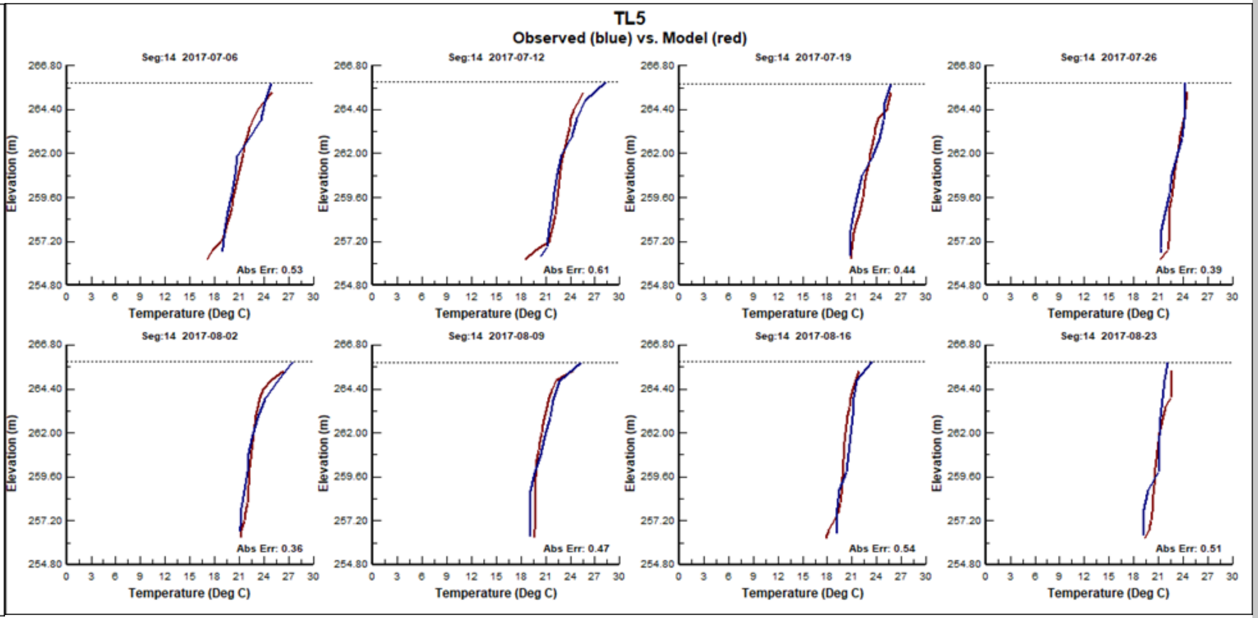
Temperature Calibration Coefficients	Variable	Default	Calibrated
Horizontal eddy viscosity (m2/s)	AX	1.0	1.0
Horizontal eddy diffusivity (m2/s)	DX	1.0	1.0
Bottom frictional resistance	MANN		0.03
Fraction of solar radiation absorbed at water surface	BETA	0.45	0.35
Solar radiation extinction - detritus	EXH2O	0.25	0.25
Solar radiation extinction - algae	EXA	0.2	0.2
Wind-sheltering coefficient	WSC	0.7-1.0	1.0
Sediment Temperature (Deg C)	TSED	10	8
Heat lost to sediments that is added back to water	TSEDF	1	1

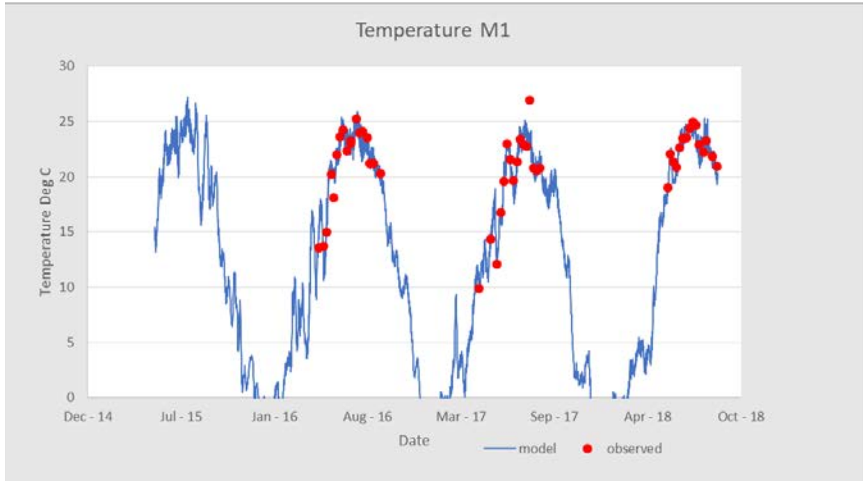
Temperature Mean Absolute Error (Deg C)					
Tainter Lake	**TL1**	**TL2**	**TL3**	**TL4**	**TL5**
0.75	0.85	0.74	0.64	0.74	0.79
Lake Menomin	**ML1**			**ML5**	
1.1	0.91			1.13	

MODEL CALIBRATION

Water Temperature



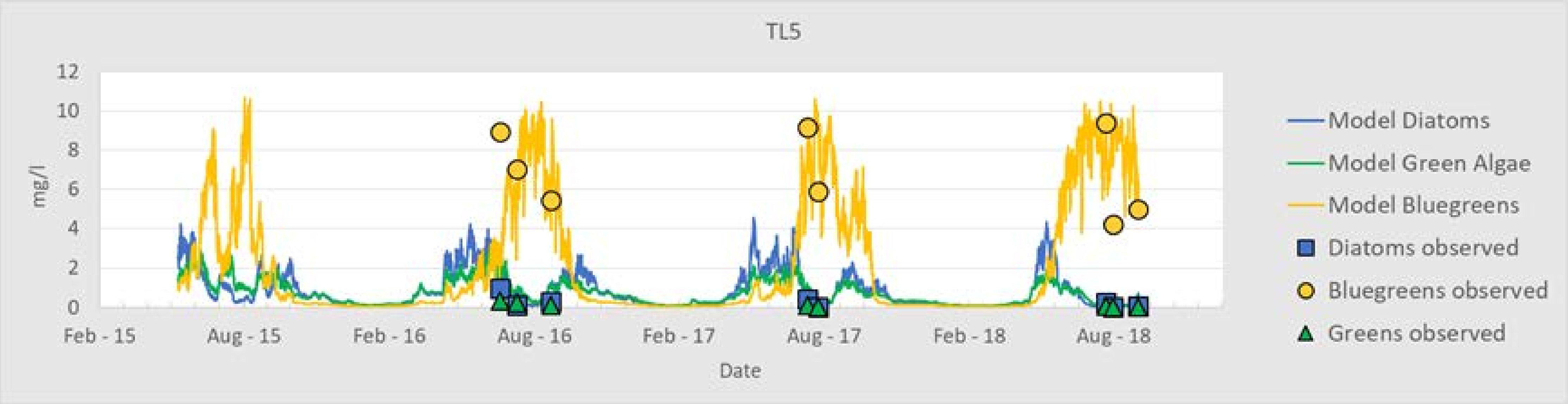




MODEL CALIBRATION

Algal groups representing diatoms, green algae, and blue-green algae are included in the Red Cedar River model

- Algae data were only collected at the surface (1-m) at TL5 and ML 5



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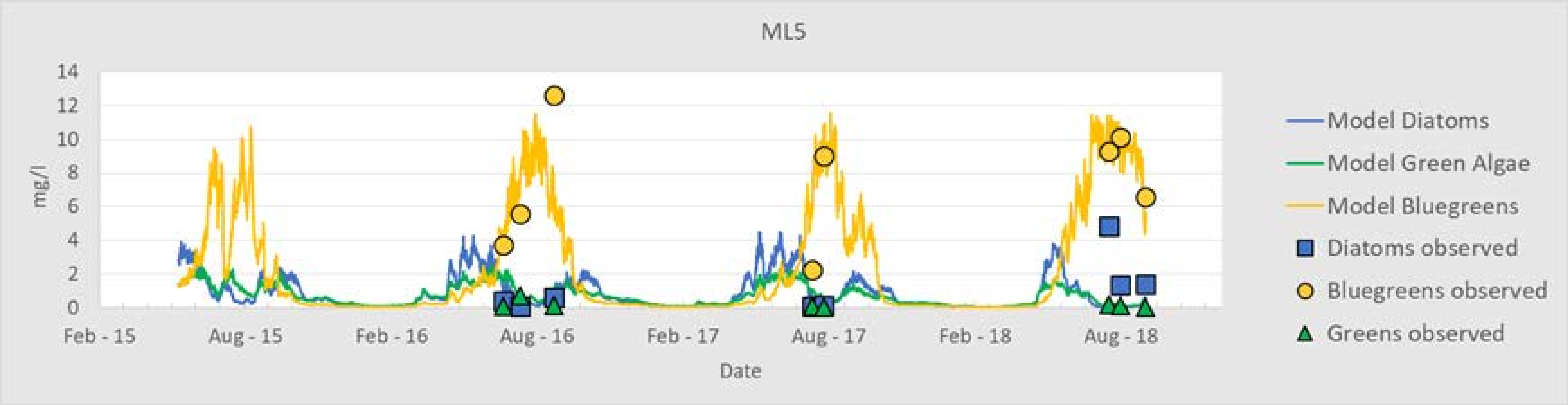


MODEL CALIBRATION

Algal Rates and Constants Parameter Description	ID	Diatoms	"Green"	"Bluegreens"
Maximum algal growth rate, 1/day	AG	1.5	1.2	1.5
Maximum algal respiration rate, 1/day	AR	0.04	0.04	0.04
Maximum algal excretion rate, 1/day	AE	0.05	0.05	0.05
Maximum algal mortality rate, 1/day	AM	0.1	0.1	0.08
Algal settling rate, 1/day	AS	0.3	0.2	0
Algal half-saturation for phosphorus limited growth, g/m	AHSP	0.003	0.003	0.003
Algal half-saturation for nitrogen limited growth, g/m	AHSN	0.014	0.014	0
Light saturation intensity at maximum photosynthetic rate, W/m	ASAT	100	100	100
Lower temperature for algal growth, DegC	AT1	10	10	10
Lower temperature for maximum algal growth, DegC	AT2	15	20	23
Upper temperature for maximum algal growth, DegC	AT3	22	25	30
Upper temperature for algal growth, DegC	AT4	28	30	40
Fraction of algal growth rate at AT1	AK1	0.1	0.1	0.1
Fraction of maximum algal growth rate at AT2	AK2	0.99	0.99	0.99
Fraction of maximum algal growth rate at AT3	AK3	0.99	0.99	0.99
Fraction of algal growth rate at AT4	AK4	0.1	0.1	0.1
Stoichiometric equivalent between algal biomass and phosphorus	ALGP	0.005	0.005	0.005
Stoichiometric equivalent between algal biomass and nitrogen	ALGN	0.08	0.08	0.08
Stoichiometric equivalent between algal biomass and carbon	ALGC	0.45	0.45	0.45
Ratio between algal biomass and chlorophyll- a	ALCHLA	0.15	0.25	0.07333
Fraction of algal biomass that is converted to particulate organic matter	ALPOM	0.8	0.8	0.8
Equation number for algal ammonium preference (1 or 2)	ALEQN	2	2	2
Algal half saturation constant for ammonium preference	ANPR	0.01	0.01	0.01
Oxygen equivalent for organic matter for algae growth	O2AR	1.1	1.1	1.1
Oxygen equivalent for organic matter for algae respiration	O2AG	1.4	1.4	1.4

MODEL CALIBRATION

Organic Matter

Organic Rates and Constants Parameter Description	Model ID	Tainter	Menomin
Dissolved Organic Matter			
Labile DOM decay, 1/day	LDOMDK	0.05	0.05
Labile to refractory decay rate, 1/day	RDOMDK	0.001	0.001
Maximum refractory decay rate, 1/day	LRDDK	0.05	0.05
Particulate Organic Matter			
Labile POM decay rate, 1/day	LPOMDK	0.08	0.08
Labile to refractory decay rate, 1/day	RPOMDK	0.001	0.001
Maximum refractory decay rate, 1/day	LRPDK	0.01	0.01
Settling rate, m/day	POMS	0.1	0.1
Organic Matter Stoichiometry			
Fraction P	ORGP	0.005	0.005
Fraction N	ORGN	0.08	0.08
Fraction C	ORGC	0.45	0.45
Organic Rate Multipliers			
Lower Temperature for OM decay	OMT1	4	4
Upper Temperature for OM decay	OMT2	25	25
Fraction of OM decay at OMT1	OMK1	0.1	0.1
Fraction of OM decay at OMT2	OMK2	0.99	0.99

MODEL CALIBRATION

Nutrients

Nutrient Rates and Constants Parameter Description	Model ID	Tainter	Menomin
Phosphorus			
Sediment release rate	PO4R	0.01	0.01
Ammonium			
Sediment release rate	NH4R	0.001	0.001
Ammonium decay rate, 1/day	NH4DK	0.265	0.265
Ammonium rate multipliers			
Lower temperature for ammonium decay	NH4T1	5	5
Upper temperature for ammonium decay	NH4T2	25	25
Fraction of nitrification rate at NH4T1	NH4K1	0.1	0.1
Fraction of nitrification rate at NH4T2	NH4K2	0.99	0.99
Nitrate			
Nitrate decay rate	ORGP	0.005	0.005
Nitrate sediment diffusion rate	ORGN	0.08	0.08
Fraction NO3 diffused converted to SedORGN	ORGC	0.45	0.45
Nitrate Rate Multipliers			
Lower Temperature for nitrate decay	NO3T1	4	4
Upper Temperature for nitrate decay	NO3T2	25	25
Fraction of denitrification rate at NO3T1	NO3K1	0.1	0.1
Fraction of denitrification rate at NO3T2	NO3K2	0.99	0.99

Sediment

SOD Rates and Constants Parameter Description	Model ID	Tainter	Menomin
Sediment			
Fraction SOD	FSOD	1	1
Zero order SOD, g/m^2/day	SOD	1	1
First order sediment decay	SEDC	ON	ON
SOD rate multipliers			
Lower temperature for sediment decay	SODT1	4	4
Upper temperature for sediment decay	SODT2	25	25
Fraction of sediment rate at SODT2	SODK1	0.1	0.1
Fraction of sediment rate at SODT2	SODK2	0.99	0.99

MODEL CALIBRATION

Chlorophyll a

Once the model was adjusted to adequately reproduce algal growth, observed chlorophyll a data was used to estimate appropriate ratios of chlorophyll a to algal biomass (ALCHLA) for each algal group

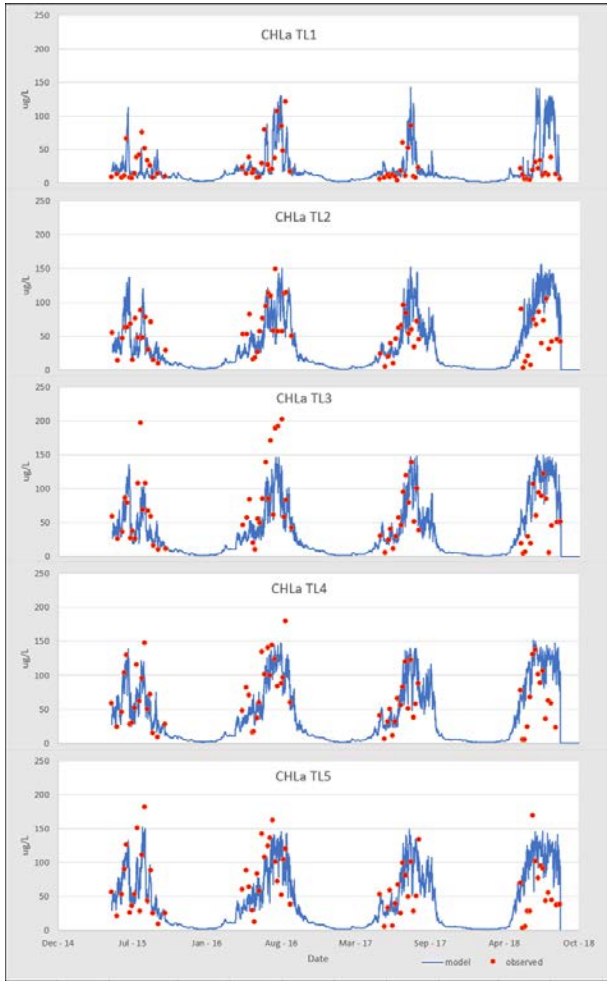
Ratios of 0.15, 0.25, and 0.07333 were used to generate the chlorophyll a concentrations for Tainter Lake and for Lake Menomin for diatoms, “greens” and cyanobacteria, respectively.

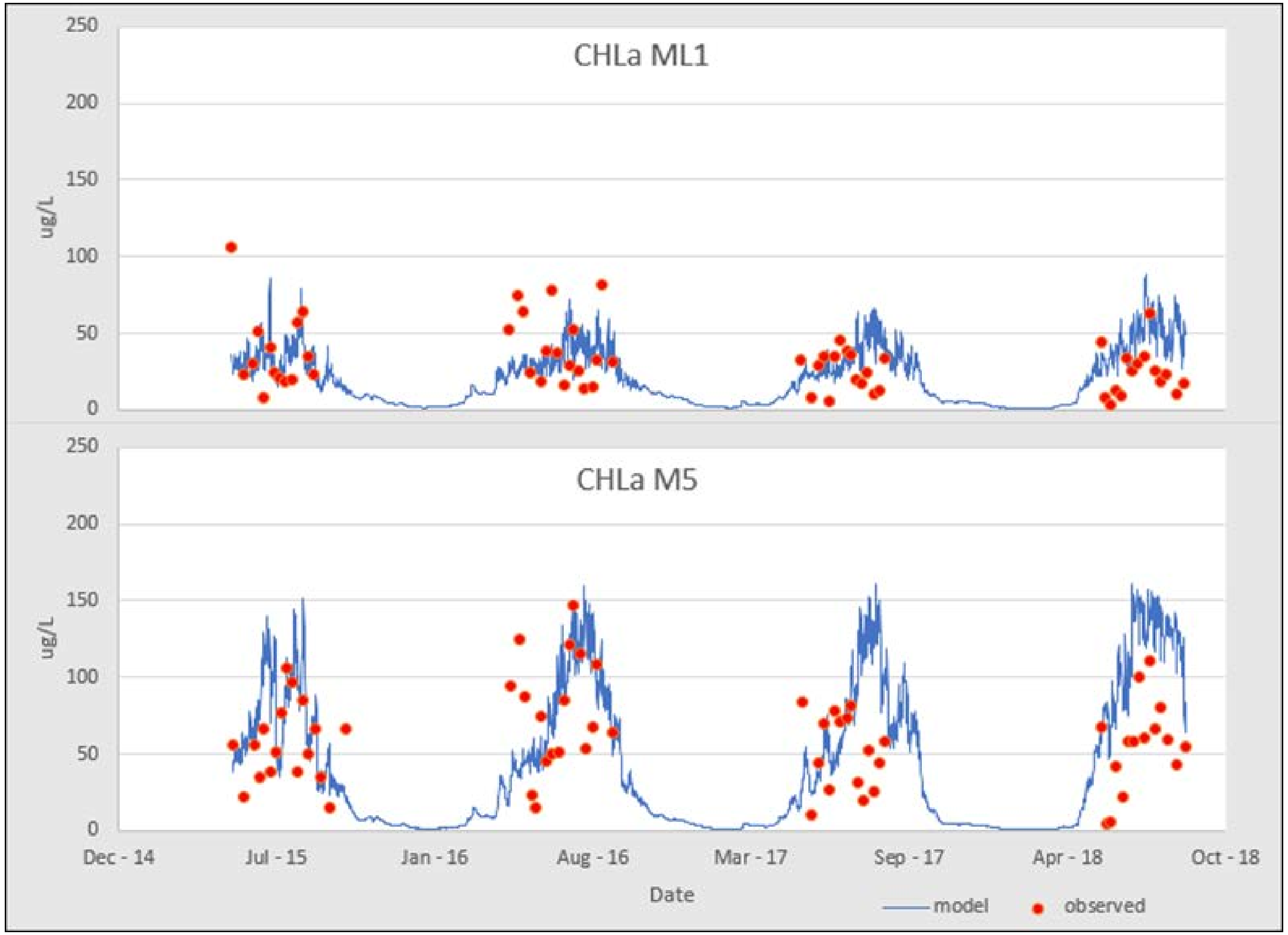
Chlorophyll a calibration statistics	TL1	TL2	TL3	TL4	TL5	**Tainter Lake**	ML1	ML5	**Lake Menomin**
Mean absolute error (MAE) =	21.66	35.59	32.61	31.49	39.60	**32.19**	20.92	40.60	**31.07**
Percent bias (PBIAS) =	-22.80	-13.42	7.66	-8.03	-2.40	**-5.44**	-11.36	-23.34	**-19.55**
Relative % Error (Rel%Err) =	-84.07	-88.99	-79.28	-93.91	-92.26	**-87.68**	-79.41	-91.72	**-85.76**

In addition to errors in estimating daily boundary conditions from bi-monthly sampling, simulated and observed chlorophyll a discrepancies are probably a result of the W2 model requiring the use of a static chlorophyll a to algal biomass ratio, where in reality this ratio may fluctuate depending on species abundance and environmental conditions

MODEL CALIBRATION

Chlorophyll a





MODEL CALIBRATION

Nutrients

Nutrient (MAE calibration target)	Statistic	TL1	TL2	TL3	TL4	TL5	Tainter Lake	ML1	ML5	Lake Menomin
PO4 (0.01 mg/l)	MAE	0.019	0.015	0.015	0.014	0.013	0.015	0.018	0.010	0.014
	PBIAS	11.06	-7.21	-13.35	-3.29	-15.94	-2.23	-32.90	-28.35	-31.41
	Rel%Err	3.27	-6.69	-63.94	-249.3	-291.78	-121.68	-59.09	-134.67	-96.88
TP (0.02 mg/l)	MAE	0.046	0.028	0.029	0.022	0.022	0.029	0.016	0.025	0.021
	PBIAS	32.31	20.56	22.87	14.74	13.21	21.61	8.45	5.36	6.88
	Rel%Err	29.79	15.71	19.21	9.47	6.94	16.27	4.06	-6.57	-1.42
NH4 (0.03 mg/l)	MAE	0.06	0.05	0.06	0.06	0.07	0.06	0.08	0.06	0.07
	PBIAS	43.71	3.43	10.77	-19.80	-34.23	13.40	34.32	-35.37	9.74
	Rel%Err	34.85	0.19	1.78	-34.50	-105.21	-37.50	0.74	-2.54	-39.35
Nitrate/Nitrite (0.1 mg/l)	MAE	0.30	0.40	0.47	0.53	0.53	0.45	0.27	0.45	0.36
	PBIAS	-12.39	-38.79	-49.05	-54.80	-57.46	-39.75	-23.29	-48.46	-29.85
	Rel%Err	-21.42	-55.64	-107.46	-108.83	-95.81	-77.83	-26.88	-36.49	-44.38
TKN (0.4 mg/l)	MAE	0.28	0.31	0.33	0.29	0.35	0.31	0.18	0.54	0.36
	PBIAS	6.78	-14.24	7.96	-15.39	-29.66	-8.94	-4.72	-36.61	-22.71
	Rel%Err	-6.48	-32.36	-12.12	-34.60	-24.45	-27.20	-13.37	-30.67	-45.87
TOC (5 mg/l)	MAE	1.83	1.42	1.43	2.03	1.32	1.61	1.80	3.39	1.61
	PBIAS	31.28	7.13	12.62	13.31	-1.37	12.30	34.96	-15.76	9.67
	Rel%Err	29.37	5.02	9.52	1.81	-4.89	1.64	32.13	-19.84	6.14

MODEL CALIBRATION

Dissolved Oxygen

Dissolved Oxygen Mean Absolute Error (mg/L)					
Tainter Lake	**TL1**	**TL2**	**TL3**	**TL4**	**TL5**
1.93	1.99	2.04	1.99	1.90	1.90
Lake Menomin	**ML1**		**ML5**		
2.0	1.08		2.18		

MODEL LIMITATIONS

- Additional observed data at a finer time interval would help validate the model calibration

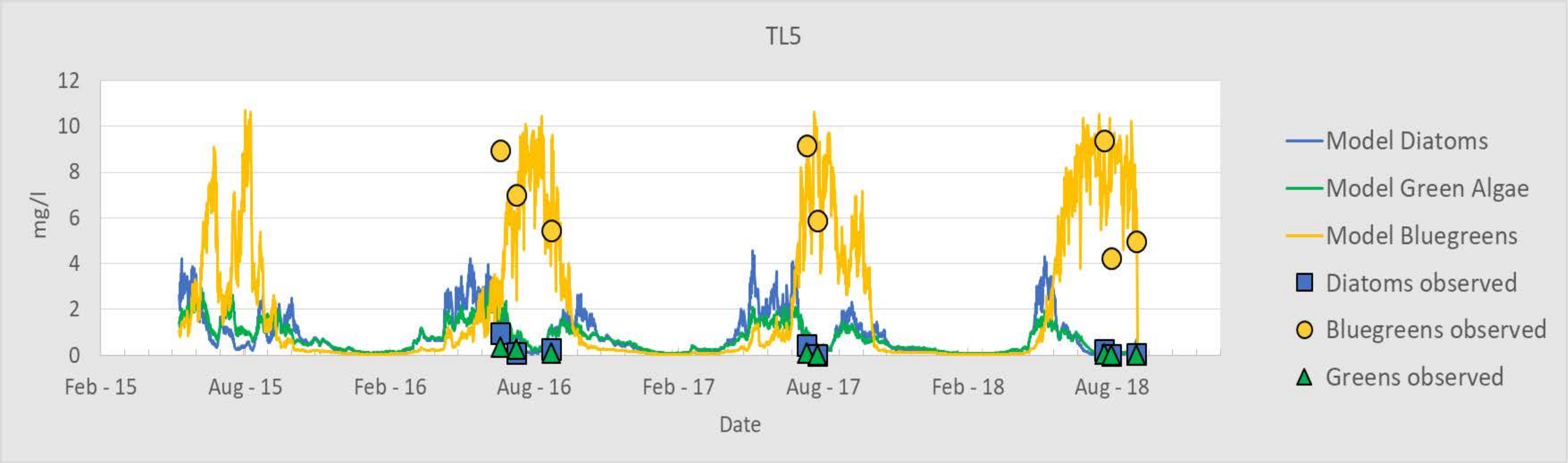
- Discharge flows from the hydroelectric dams were not directly measured and discharge elevations were estimated between penstock and tainter gate sill elevations based on monthly maintenance records

- The model was calibrated using water years that were all above average for the basin based on the gaged period of records

- based on a laterally averaged 2-D framework

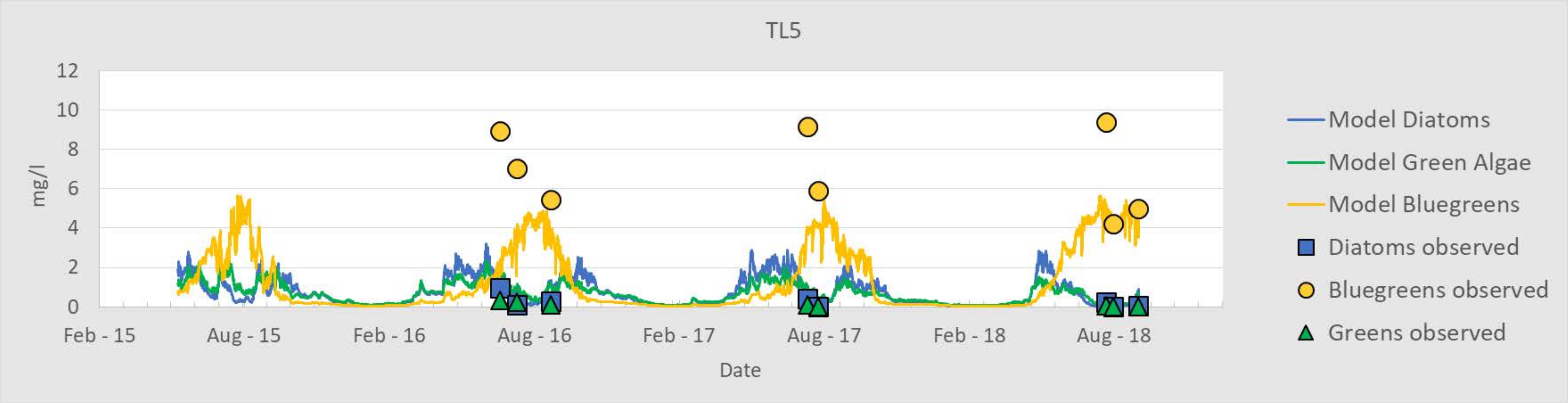
SCENARIOS

Existing Conditions



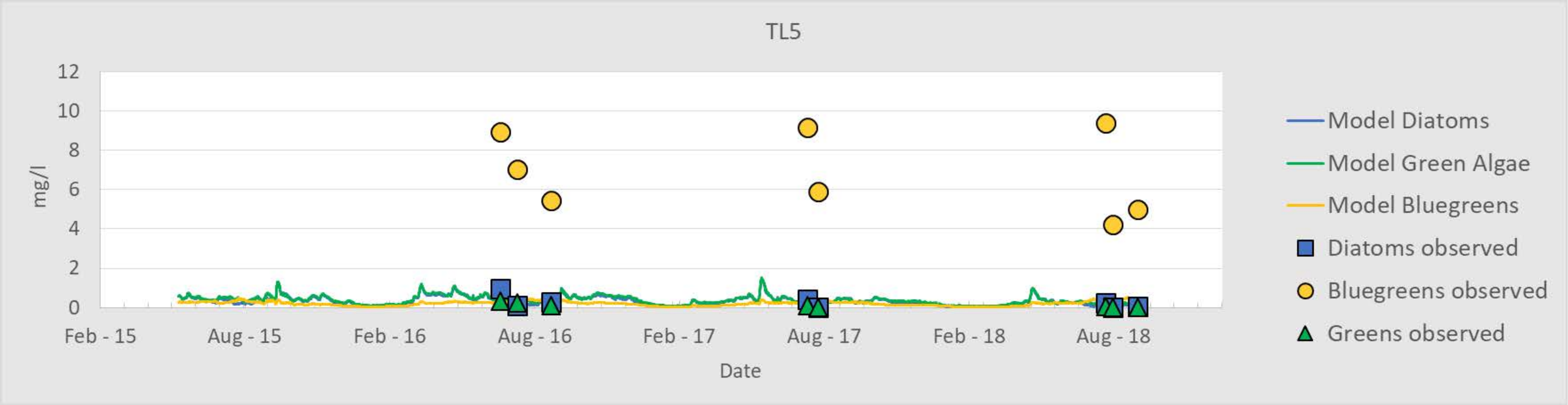
SCENARIOS

Half SRP inflows



SCENARIOS

No SRP inflows



CONCLUSIONS

- A CE-QAUL-W2 model was developed for the Red Cedar River for Tainter Lake and Lake Menomin, two west central Wisconsin reservoirs that are very nutrient-rich and have frequent and harmful algal blooms and low transparency

- Reasonable coefficients were derived through calibration successfully captures the major driving forces of cyanobacteria growth (e.g., nutrients, residence time, temperature) to allow for better prediction of reservoir responses to loading reducing scenarios that are needed to refine TMDL goals

- Scenarios results suggest that decreasing inflow SRP concentrations can be used to decrease in-pool chlorophyll and blue-green algal concentrations

- Geologic formations within the watershed that are “naturally” high in phosphorus may limit possible reductions in phosphorus inflows