A three-dimensional lake model to support total maximum daily load development for Lake Wister

J. Thad Scott, Erin Grantz, and Steve Patterson

@ScottBiogeochem

UNIVERSITY OF ARKANSAS
DALE BUMPERS COLLEGE
OF AGRICULTURAL, FOOD & LIFE SCIENCES

bioxdesign

UofA DIVISION OF AGRICULTURE
RESEARCH & EXTENSION
University of Arkansas System

Lake Wister

State of Oklahoma 303d List of Impaired Waterbodies:

- Chlorophyll-a
- Dissolved Oxygen
- Total Phosphorus
- Turbidity
- pH
- Mercury

2013 – Contracted with Poteau Valley Improvement Authority:

1. Sediment analysis
2. Water quality model

UNIVERSITY OF ARKANSAS
DALE BUMPERS COLLEGE
OF AGRICULTURAL, FOOD & LIFE SCIENCES

bioxdesign

DIVISION OF AGRICULTURE
RESEARCH & EXTENSION
University of Arkansas System

Presentation Overview

- History of modeling and water quality analyses
- Summary of existing watershed and in-lake data
- Model selection process
- Lake Wister ELCOM-CAEDYM model setup
- Lake Wister ELCOM-CAEDYM model calibration
- Lake Wister ELCOM-CAEDYM model planned simulations

Previous modeling efforts for Lake Wister:

Modeling approach (AMEC and Dynamic Solutions):

Watershed inputs – derived from modeling using the Water Quality Analysis Simulation Program (WASP 7)

WASP calibration – from USGS flow data and Oklahoma Conservation Commission in-stream WQ data

Lake Model – Environmental Fluid Dynamic Code (EFDC); 3D to simulate inflows and wind-driven mixing

EFDC calibration – measured data from summer 2001

Previous modeling efforts for Lake Wister:

Prepared for:

OKLAHOMA DEPARTMENT OF ENVIRONMENTAL QUALITY, WATER QUALITY DIVISION
Oklahoma City, Oklahoma

Prepared by:

AMEC Earth & Environmental, Inc.
Westford, Massachusetts
&
Dynamic Solutions
Knoxville, Tennessee

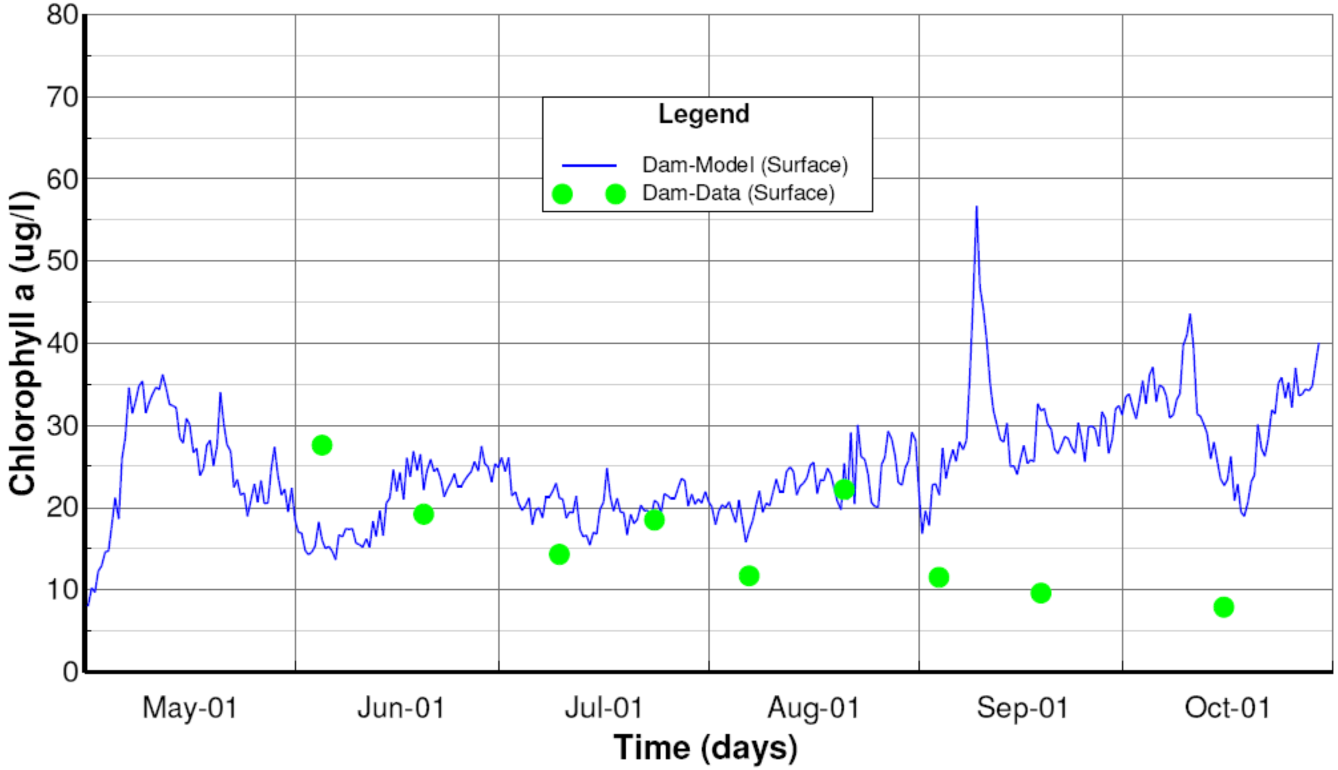


Figure 3-11. Lake Wister Water Quality Calibration: Chlorophyll-a Dam Site 1

Previous modeling efforts for Lake Wister:

Prepared for:
OKLAHOMA DEPARTMENT OF ENVIRONMENTAL QUALITY, WATER QUALITY DIVISION
Oklahoma City, Oklahoma

Prepared by:
nmental, Inc.
assachusetts
&
nic Solutions
e, Tennessee

Table 3-4. Summary of the Sediment Nutrient Fluxes for the Lake Wister Model

Benthic Zone	Benthic Flux Rates ($g/m^2/day$)					
	Phosphate	Ammonia	Nitrate	Silica	COD	SOD
Zone 1	0.03	0.2	0.06	0.00	0.00	-3.5
Zone 2	0.05	0.3	0.10	0.00	0.00	-5.0

Overestimated benthic flux resulted in underestimated watershed contribution

Table 3-6. Summary of the Lake Wister Base Case Average TN and TP Concentrations: Calibration Period

Water Quality Parameter	In Lake Concentration		Incoming Load			
			Fourche Maline Creek		Poteau River	
	Data	Model	(mg/l)	(% of Lake)	(mg/l)	(% of Lake)
TN	0.99	0.88	0.0169	1.7%	0.0251	2.5%
TP	0.16	0.09	0.0022	1.4%	0.0116	7.3%

UNIVERSITY OF ARKANSAS
DALE BUMPERS COLLEGE
OF AGRICULTURAL, FOOD & LIFE SCIENCES

bioxdesign

DIVISION OF AGRICULTURE
RESEARCH & EXTENSION
University of Arkansas System

Previous modeling efforts for Lake Wister:

Prepared for:

OKLAHOMA DEPARTMENT OF ENVIRONMENTAL QUALITY, WATER QUALITY DIVISION
Oklahoma City, Oklahoma

repared by:

nental, Inc.
sachusetts
&
c Solutions
Tennessee

Table 3-4. Summary of the Sediment Nutrient Fluxes for the Lake Wister Model

Benthic Zone	Benthic Flux Rates ($g/m^2/day$)					
	Phosphate	Ammonia	Nitrate	Silica	COD	SOD
Zone 1	0.03	0.2	0.06	0.00	0.00	-3.5
Zone 2	0.05	0.3	0.10	0.00	0.00	-5.0

Reservoir	Site Description	Aerobic Flux ($mg/m^2/d$)	Anaerobic Flux ($mg/m^2/d$)	Reference
Lake Wister, Oklahoma	Shallow Waters	50 (calibrated parameter)		AMEC (2008)
	Deep Waters	30 (calibrated parameter)		
Beaver Lake, Arkansas	Riverine Zone	0.13	0.85	Sen et al. (2007)
	Transition Zone	0.15	1.77	
	Lacustrine Zone	0.04	<0.01	
Lake Eucha, Oklahoma	Riverine Zone	1.14	4.70	Haggard et al. (2005)
	Transition Zone	1.01	2.46	
	Transition Zone	0.95	6.05	
Lake Frances, Arkansas – Oklahoma	Headwaters	0.37	14.53	Haggard and Soerens (2006)
	Near Dam	3.57	15.53	

Haggard, Scott, and Patterson. Lake and Reservoir Management 2012

UNIVERSITY OF ARKANSAS
DALE BUMPERS COLLEGE
OF AGRICULTURAL, FOOD & LIFE SCIENCES

bioxdesign

DIVISION OF AGRICULTURE
RESEARCH & EXTENSION
University of Arkansas System

Lake and Reservoir Management, 28:59–69, 2012

ISSN: 0743-8141 print / 1040-2381 online
DOI: 10.1080/07438141.2012.659376

Sediment phosphorus flux in an Oklahoma reservoir suggests reconsideration of watershed management planning

B.E. Haggard,[1,*] J.T. Scott,[2] and S. Patterson[3]
[1]Arkansas Water Resources Center, University of Arkansas, Fayetteville, AR
[2]Crop, Soil and Environmental Sciences Department, University of Arkansas, Fayetteville, AR
[3]BioxDesign, Poteau, OK

Table 2.-Mean soluble reactive phosphorus (SRP) release rates or flux (mg/m²/d) from intact sediment cores collected on 14 July 2010 from 3 sites in Lake Wister, OK.

Site	Treatment	Slope (mg/d)	R^2	P Value	Mean Flux* (mg/m²/d)
1	Aerobic	0.0024	0.41	0.17	0.75
1	Anaerobic	0.0048	0.78	0.02	1.52
2	Aerobic	0.0036	0.42	0.16	1.13
2	Anaerobic	0.0104	0.98	<0.01	3.30
3	Aerobic	0.0030	0.75	0.03	0.94
3	Anaerobic	–0.0007	0.42	0.16	–0.23

*Mean flux was reported as a numerical value even if the slope of the linear regression was not significantly different from zero ($P > 0.05$).

UNIVERSITY OF ARKANSAS
DALE BUMPERS COLLEGE
OF AGRICULTURAL, FOOD & LIFE SCIENCES

bioxdesign

DIVISION OF AGRICULTURE
RESEARCH & EXTENSION
University of Arkansas System

Previous modeling efforts for Lake Wister:

Prepared for:
OKLAHOMA DEPARTMENT OF ENVIRONMENTAL QUALITY, WATER QUALITY DIVISION
Oklahoma City, Oklahoma

Prepared by:
nmental, Inc.
assachusetts
&
nic Solutions
e, Tennessee

Table 3-4. Summary of the Sediment Nutrient Fluxes for the Lake Wister Model

Benthic Zone	Benthic Flux Rates ($g/m^2/day$)					
	Phosphate	Ammonia	Nitrate	Silica	COD	SOD
Zone 1	~~0.03~~ 0.003	0.2	0.06	0.00	0.00	-3.5
Zone 2	~~0.05~~ 0.001	0.3	0.10	0.00	0.00	-5.0

Overestimated benthic flux resulted in underestimated watershed contribution

Table 3-6. Summary of the Lake Wister Base Case Average TN and TP Concentrations: Calibration Period

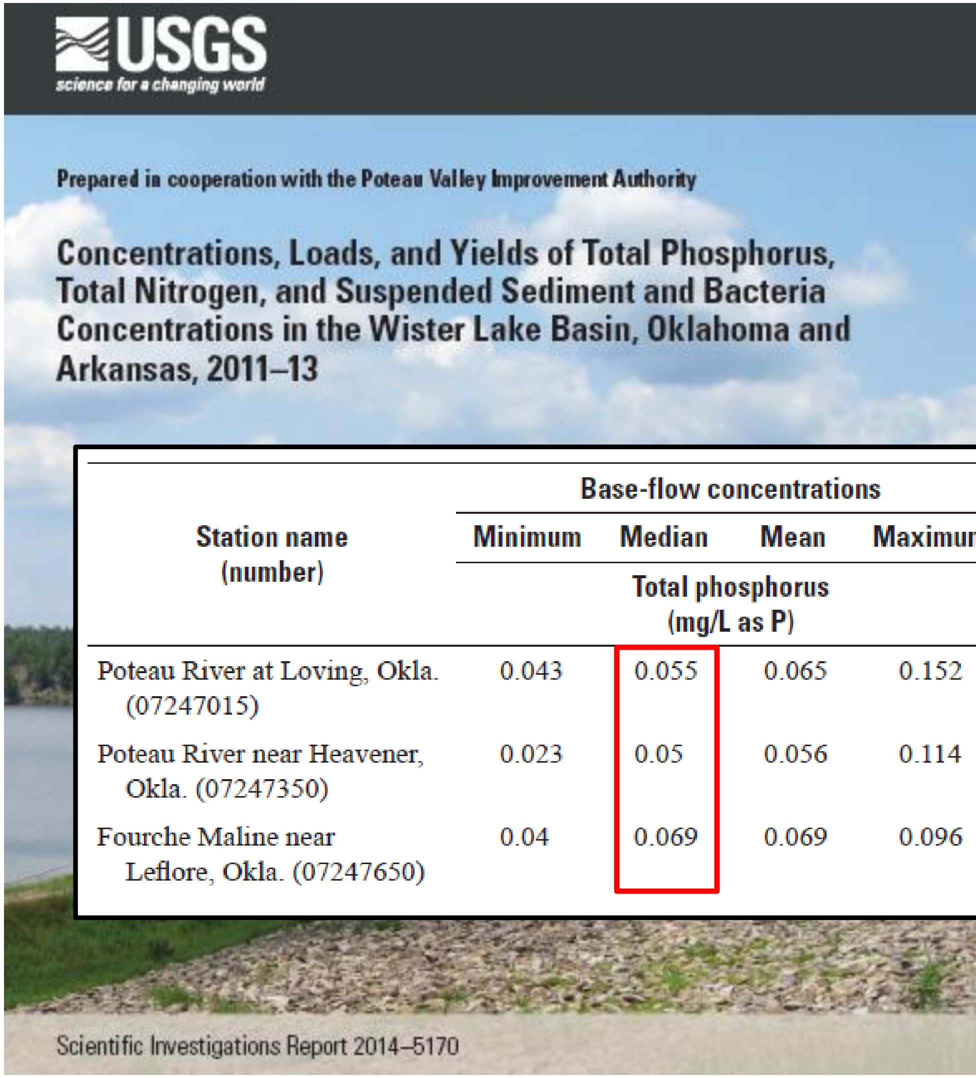
Water Quality Parameter	In Lake Concentration		Incoming Load			
			Fourche Maline Creek		Poteau River	
	Data	Model	(mg/l)	(% of Lake)	(mg/l)	(% of Lake)
TN	0.99	0.88	0.0169	1.7%	0.0251	2.5%
TP	0.16	0.09	0.0022	1.4%	0.0116	7.3%

UNIVERSITY OF ARKANSAS
DALE BUMPERS COLLEGE
OF AGRICULTURAL, FOOD & LIFE SCIENCES

bioxdesign

DIVISION OF AGRICULTURE
RESEARCH & EXTENSION
University of Arkansas System

Existing data for Lake Wister and watershed



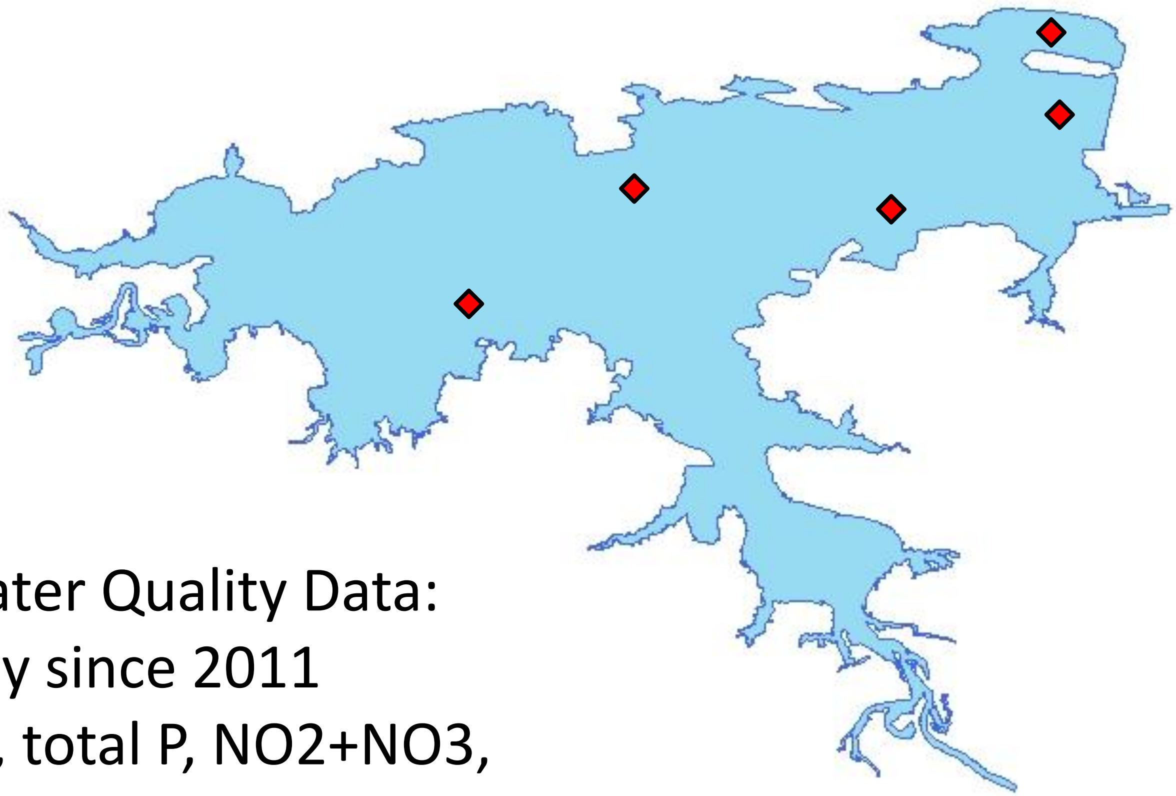
Station name (number)	Base-flow concentrations				obs.	Runoff concentrations				obs.
	Minimum	Median	Mean	Maximum		Minimum	Median	Mean	Maximum	
	Total phosphorus (mg/L as P)					Total phosphorus (mg/L as P)				
Poteau River at Loving, Okla. (07247015)	0.043	0.055	0.065	0.152	17	0.06	0.279	0.273	0.461	18
Poteau River near Heavener, Okla. (07247350)	0.023	0.05	0.056	0.114	15	0.051	0.205	0.196	0.378	22
Fourche Maline near Leflore, Okla. (07247650)	0.04	0.069	0.069	0.096	11	0.034	0.142	0.176	0.717	24

UNIVERSITY OF ARKANSAS
DALE BUMPERS COLLEGE
OF AGRICULTURAL, FOOD & LIFE SCIENCES

bioxdesign

DIVISION OF AGRICULTURE
RESEARCH & EXTENSION
University of Arkansas System

Existing data for Lake Wister and watershed



In-lake Water Quality Data:

- Monthly since 2011
- Total N, total P, NO2+NO3, NH4, SRP, chlorophyll-a, TSS

UNIVERSITY OF ARKANSAS
DALE BUMPERS COLLEGE
OF AGRICULTURAL, FOOD & LIFE SCIENCES

bioxdesign

DIVISION OF AGRICULTURE
RESEARCH & EXTENSION
University of Arkansas System

Model Selection Process

DIVISION OF AGRICULTURE
RESEARCH & EXTENSION
University of Arkansas System

UNIVERSITY OF ARKANSAS
DALE BUMPERS COLLEGE
OF AGRICULTURAL, FOOD & LIFE SCIENCES

Lake Wister Modeling Approach – Recommendations for the Development of a New Water Quality Model

April 10, 2014

Prepared for:
Poteau Valley Improvement Authority
25768 US Highway 270
Wister, OK 74966
918-655-7500

Prepared by:
J. Thad Scott, Ph.D.
Department of Crop, Soil, and Environmental Sciences
Division of Agriculture
University of Arkansas
jts004@uark.edu

and

Steven Patterson, Ph.D.
Bio x Design
Poteau, Oklahoma
spatterson@bioxdesign.com

bioxdesign
Environmental Consulting • Ecological Restoration • Ecosystem Design

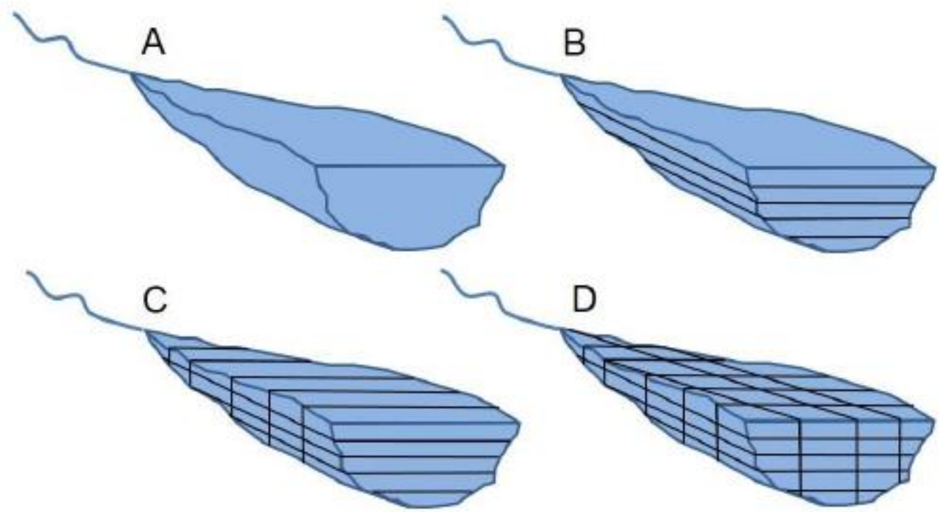


Figure 1. Spatial dimensions involved in hydrodynamic and water quality modeling of reservoirs: A) Zero-dimensional, B) One-dimensional, C) Two-dimensional, and D) Three-dimensional.

Two model options:

Environmental fluid dynamic code (EFDC)

- Open source (sort of…)
- Widely utilized by USEPA
- Standard internal diffusive flux model
- P adsorption/desorption with partitioning coefficients

Computational Aquatic Ecosystem Dynamic Model (CAEDYM)

- Proprietary (U Western Australia; Zephyr Systems)
- Rarely used by USEPA
- Standard internal diffusive flux model
- P adsorption/desorption using EPC_0

UNIVERSITY OF ARKANSAS
DALE BUMPERS COLLEGE
OF AGRICULTURAL, FOOD & LIFE SCIENCES

bioxdesign

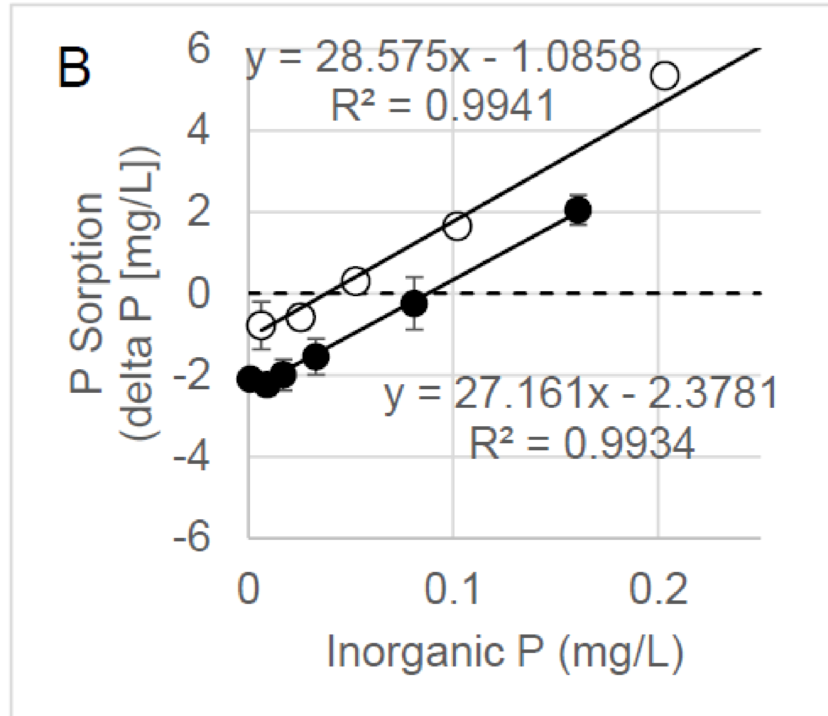
DIVISION OF AGRICULTURE
RESEARCH & EXTENSION
University of Arkansas System

Two model options:

Environmental fluid dynamic code (EFDC)

- Open source (sort of…)
- Widely utilized by USEP
- Standard internal diffusi
- P adsorption/desorptio

Computational Aquatic Eco (CAEDYM)



- Proprietary (U Western
- Rarely used by USEPA
- Standard internal diffusive flux model
- P adsorption/desorption using EPC_0

UNIVERSITY OF ARKANSAS DALE BUMPERS COLLEGE OF AGRICULTURAL, FOOD & LIFE SCIENCES

bioxdesign

DIVISION OF AGRICULTURE RESEARCH & EXTENSION University of Arkansas System

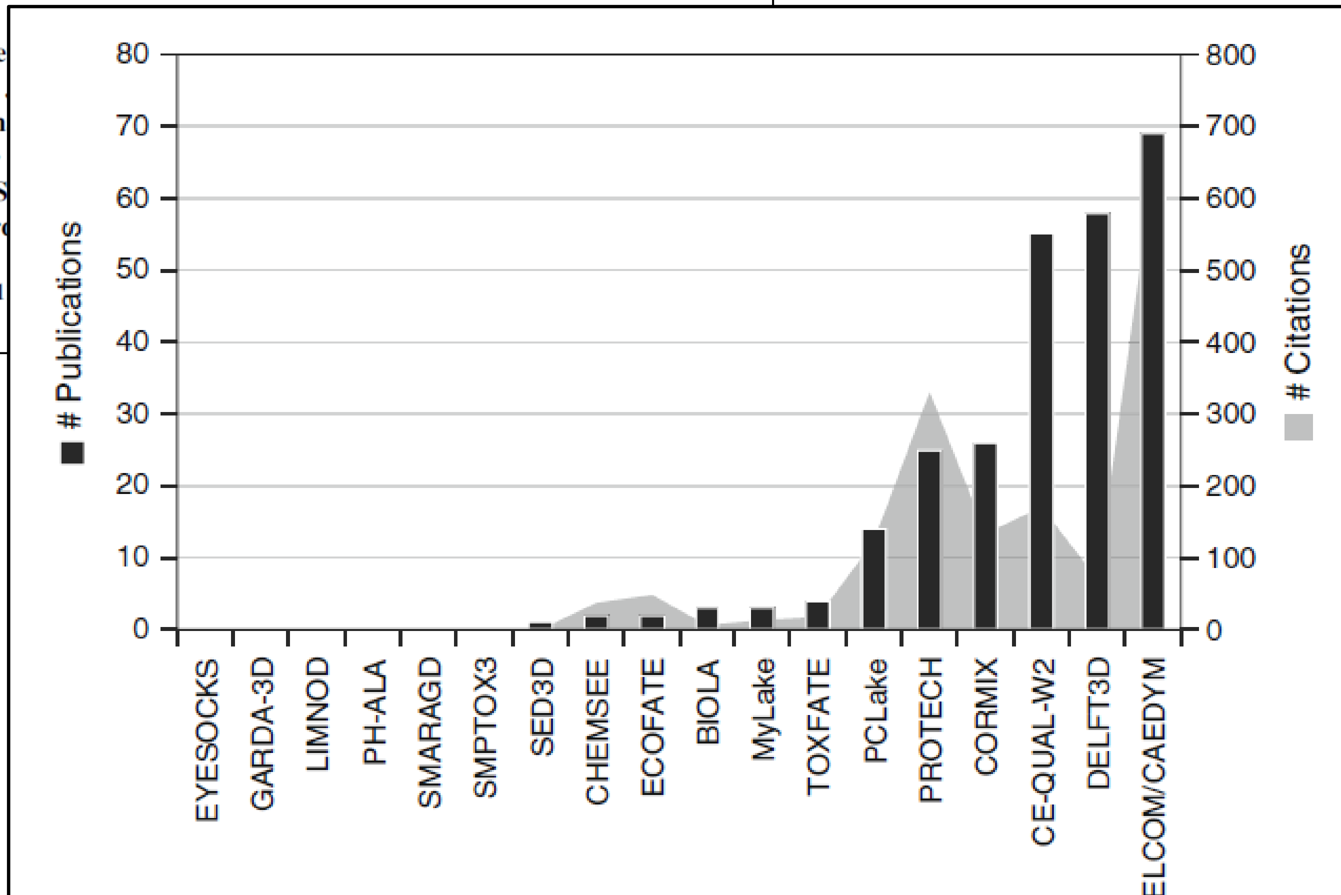
Hydrobiologia (2012) 683:25–34
DOI 10.1007/s10750-011-0957-0

OPINION PAPER

A community-based framework for aquatic ecosystem models

Dennis Trolle · David P. Hamilton · Matthe
Jorn Bruggeman · Wolf M. Mooij · Jan H.
J. Alex Elliott · Vardit Makler-Pick · Thom
Mogens R. Flindt · George B. Arhonditsis ·
Koji Tominaga · Jochem't Hoen · Andrea S
Carlos R. Fragoso Jr. · Martin Søndergaar

Received: 15 August 2011 / Revised: 1 November 201



UNIVERSITY OF ARKANSAS
DALE BUMPERS COLLEGE
OF AGRICULTURAL, FOOD & LIFE SCIENCES

bioxdesign

DIVISION OF AGRICULTURE
RESEARCH & EXTENSION
University of Arkansas System

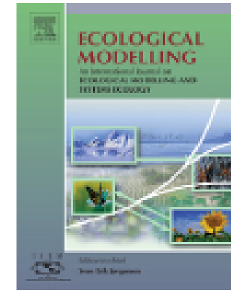
ECOLOGICAL MODELLING 211 (2008) 411–423

ELSEVIER

available at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/locate/ecolmodel



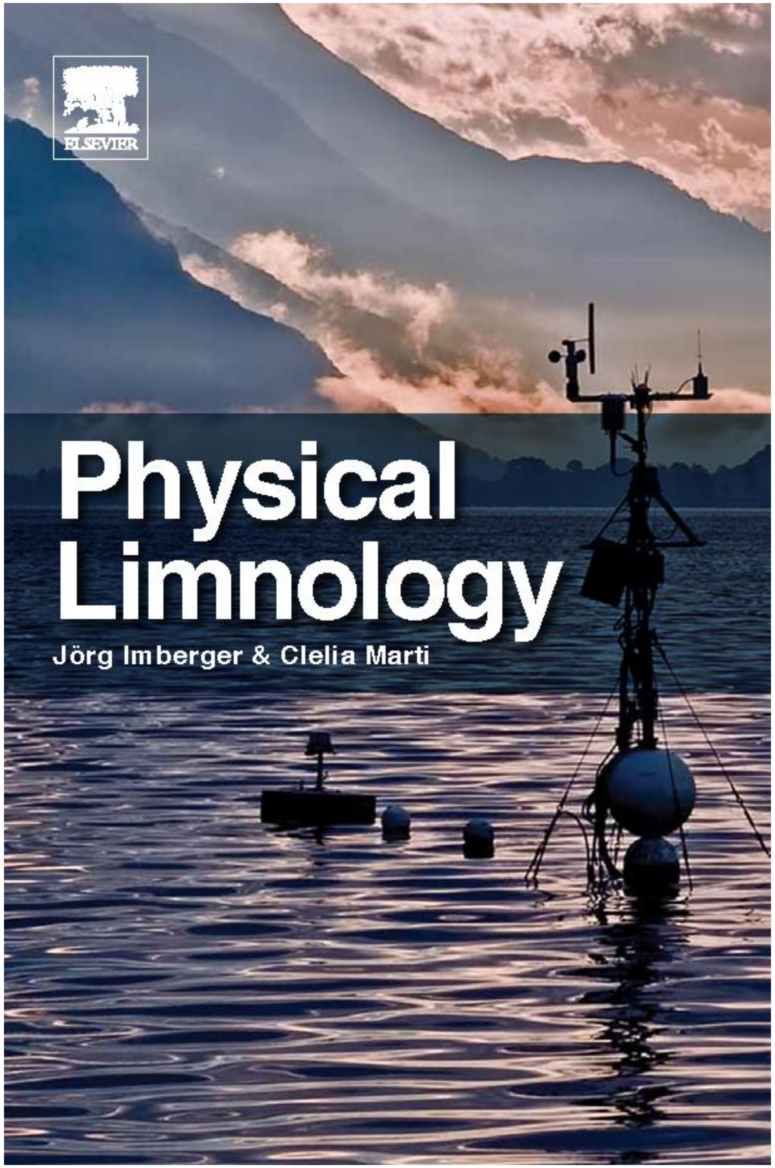
Modelling the relative importance of internal and external nutrient loads on water column nutrient concentrations and phytoplankton biomass in a shallow polymictic lake☆

David F. Burger, David P. Hamilton, Conrad A. Pilditch*

Centre for Biodiversity and Ecology Research, University of Waikato, Private Bag 3105, Hamilton, New Zealand

ELCOM-CAEDYM chosen as modeling platform for Lake Wister

ELCOM = estuarine, lake and coastal ocean model is a hydrodynamic model coupled to CAEDYM



Clelia Marti – U Western Australia

ELCOM-CAEDYM training in Fayetteville, AR –

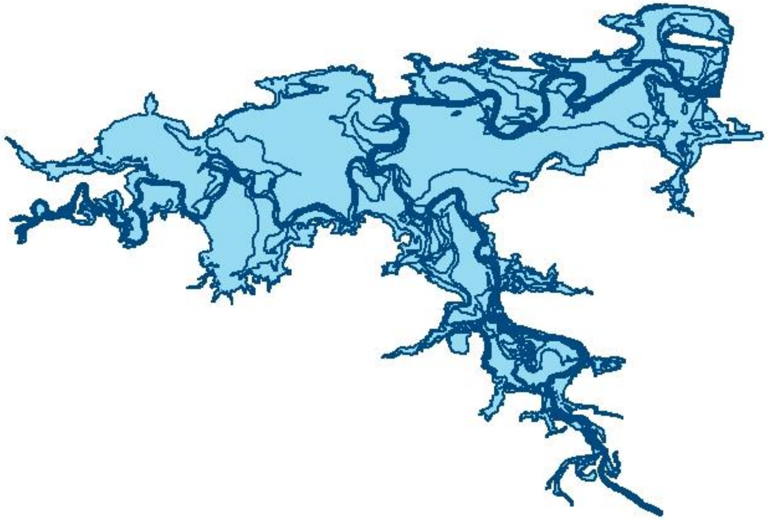
March 2015

UNIVERSITY OF ARKANSAS
DALE BUMPERS COLLEGE
OF AGRICULTURAL, FOOD & LIFE SCIENCES

bioxdesign

DIVISION OF AGRICULTURE
RESEARCH & EXTENSION
University of Arkansas System

Conservation Pool Bathymetry Measured by OWRB

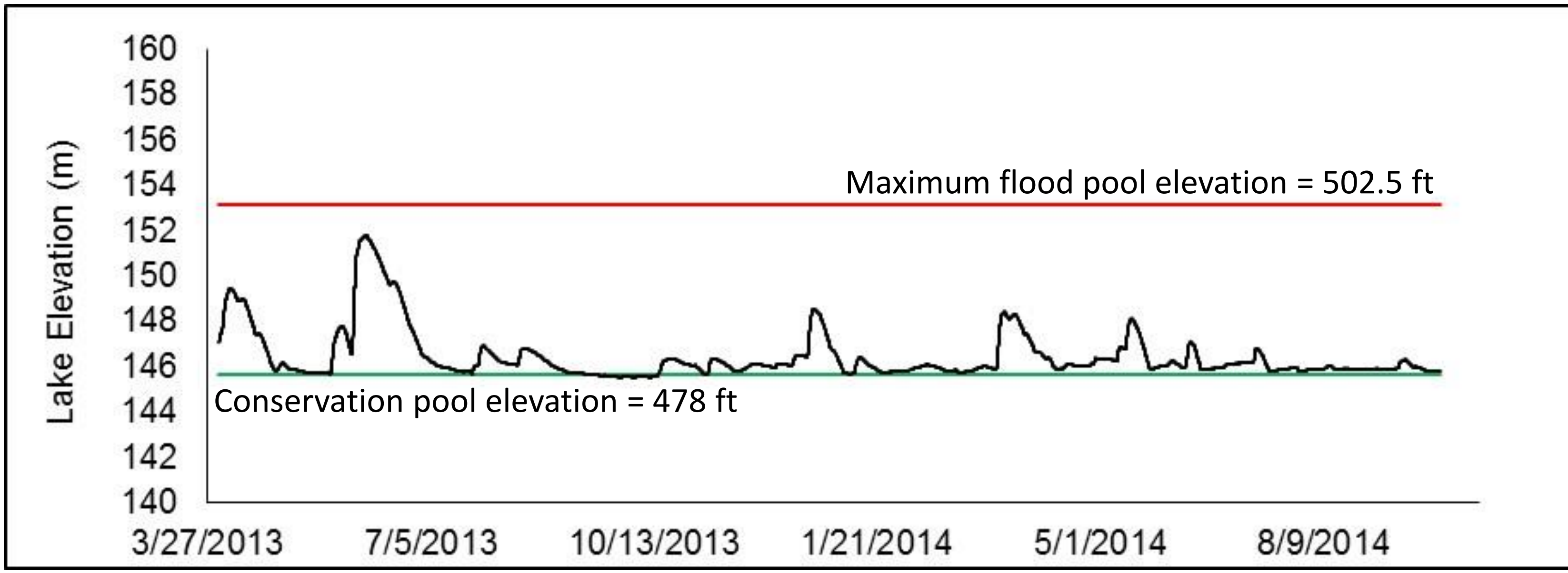


UNIVERSITY OF ARKANSAS
DALE BUMPERS COLLEGE
OF AGRICULTURAL, FOOD & LIFE SCIENCES

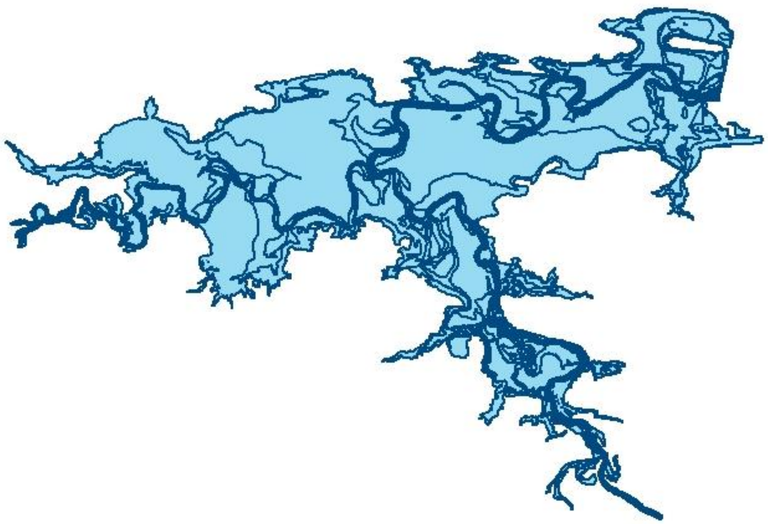
bioxdesign

DIVISION OF AGRICULTURE
RESEARCH & EXTENSION
University of Arkansas System

Lake Wister is NOT regularly at the conservation pool elevation



Integrated flood pool into continuous bathymetry for Lake Wister

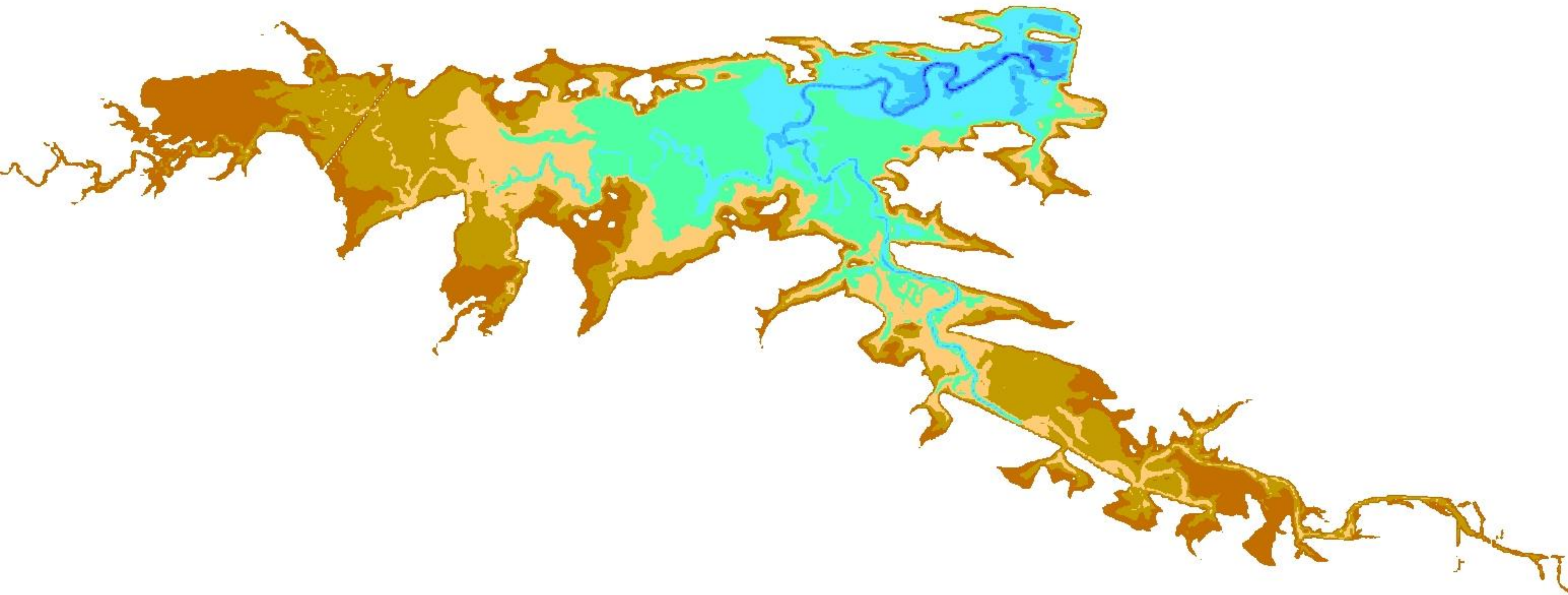


UNIVERSITY OF ARKANSAS
DALE BUMPERS COLLEGE
OF AGRICULTURAL, FOOD & LIFE SCIENCES

bioXdesign

UofA DIVISION OF AGRICULTURE
RESEARCH & EXTENSION
University of Arkansas System

Integrated flood pool into continuous bathymetry for Lake Wister



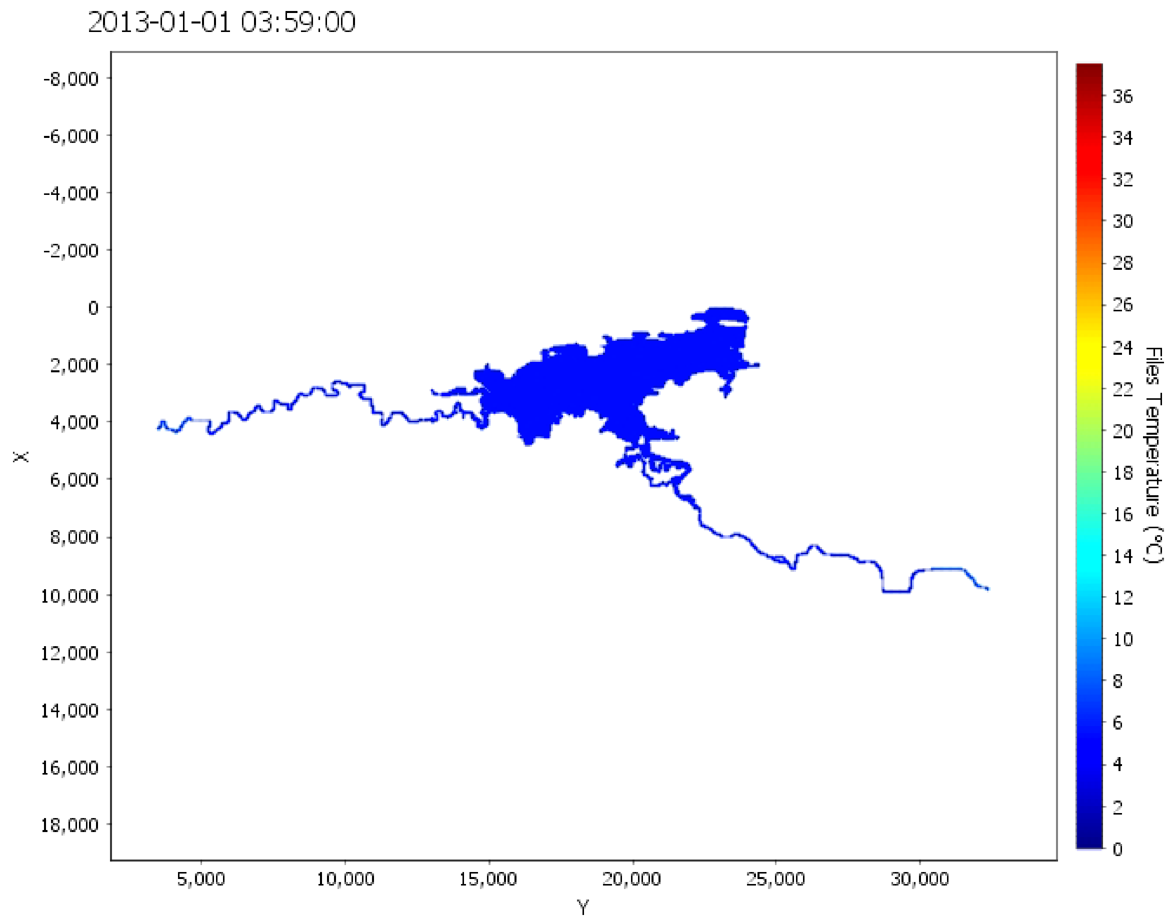
UNIVERSITY OF ARKANSAS
DALE BUMPERS COLLEGE
OF AGRICULTURAL, FOOD & LIFE SCIENCES

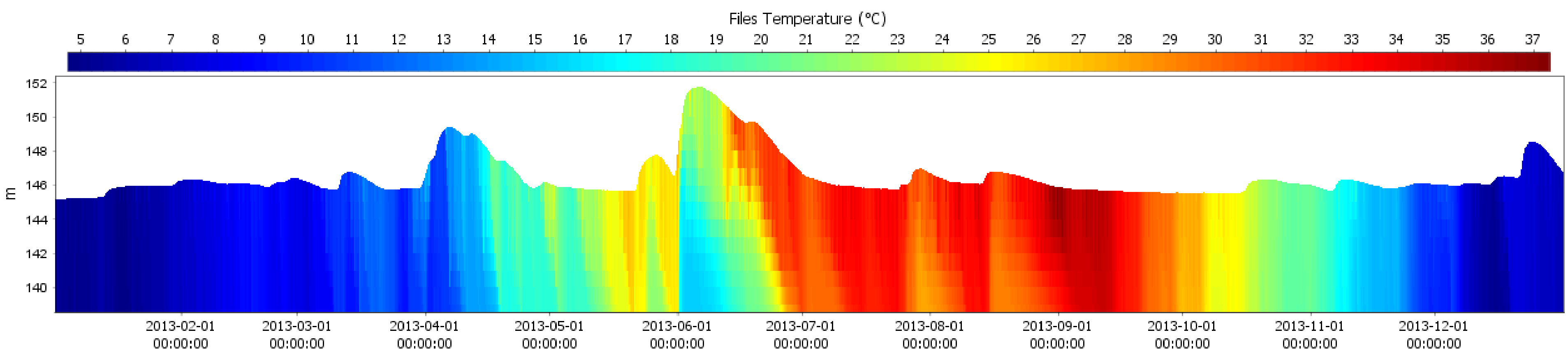
bioxdesign

DIVISION OF AGRICULTURE
RESEARCH & EXTENSION
University of Arkansas System

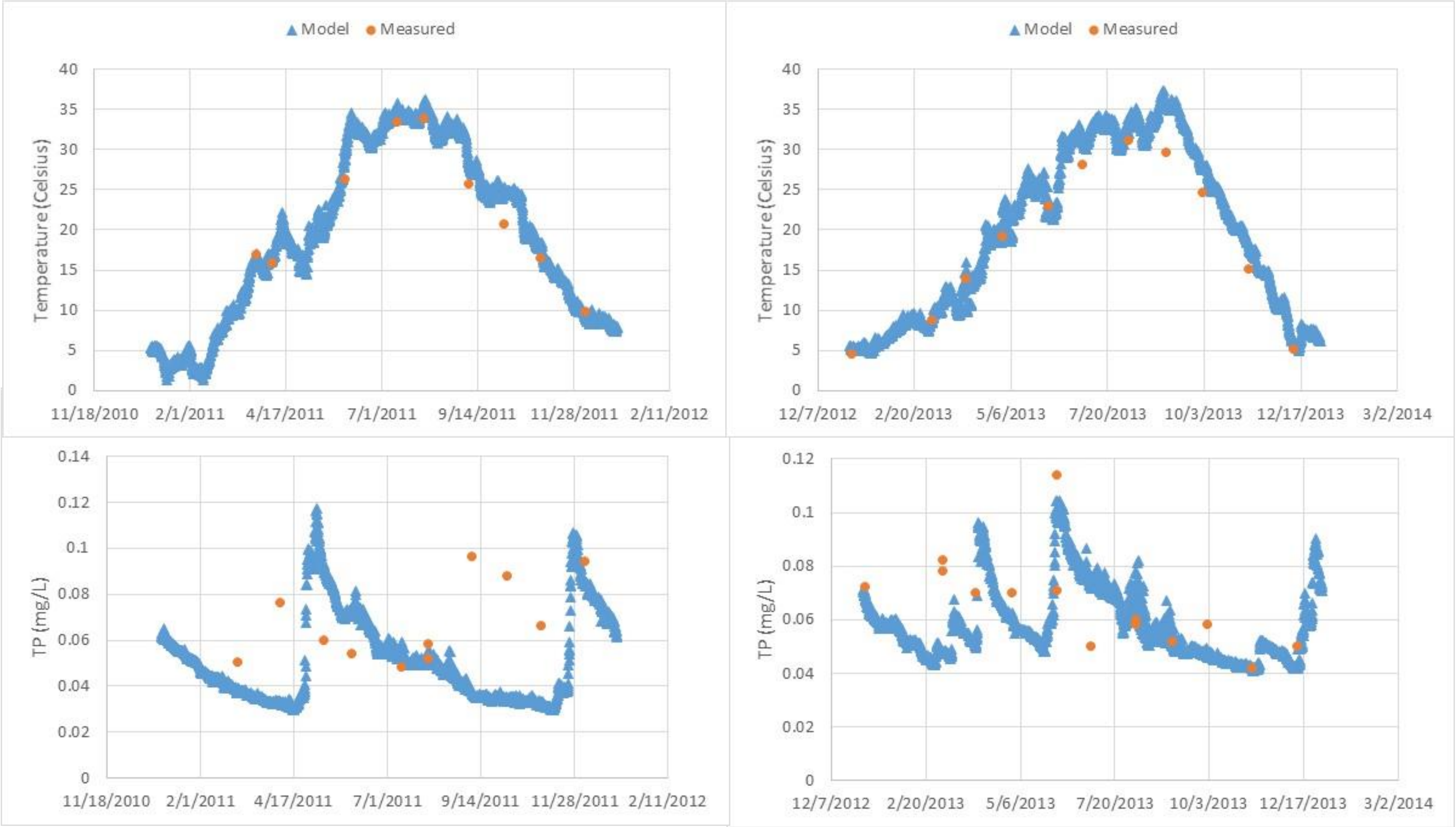
Conservation pool is not the norm

Thermal stratification is temporary





Model calibration ongoing



UNIVERSITY OF ARKANSAS
DALE BUMPERS COLLEGE
OF AGRICULTURAL, FOOD & LIFE SCIENCES

bioxdesign

DIVISION OF AGRICULTURE
RESEARCH & EXTENSION
University of Arkansas System

Model calibration ongoing

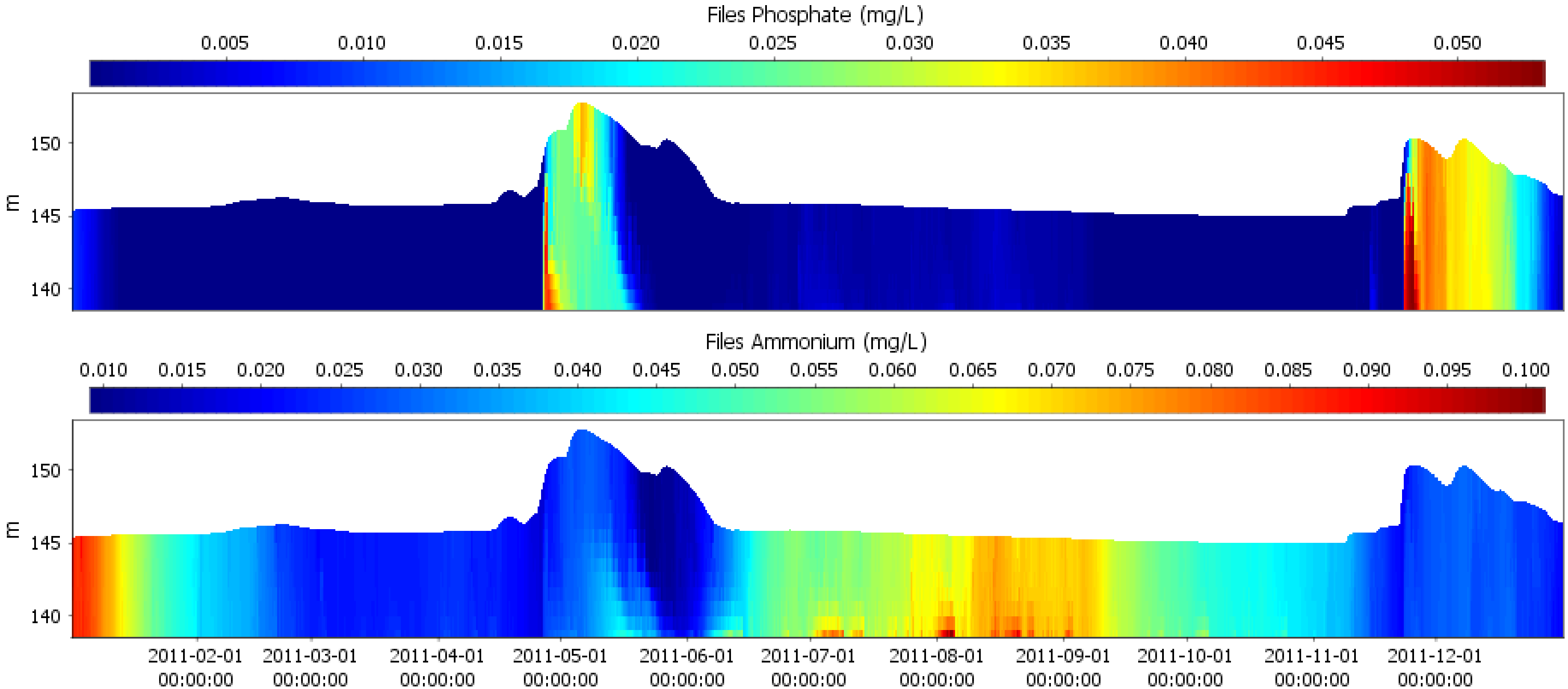
Model simulation years 2011 – 2015

Calibration years: 2011, 2013, 2015

Validation years: 2012, 2014

Parameter (units)	Current RMSE	Target RMSE
Surface Temperature (°C)	2.1	1.6
Bottom Temperature (°C)	1.9	2.7
Total Phosphorus (mg/L)	0.104	0.11
Soluble Reactive P (mg/L)	0.083	0.03
Total Nitrogen (mg/L)	0.71	0.49
Nitrate (mg/L)	0.74	--
Ammonium (mg/L)	0.24	0.20
Chlorophyll-a (µg/L)	4.1	14.2
Dissolved Oxygen (mg/L)	1.5	1.6

Low internal loading by inaccurate stratification duration

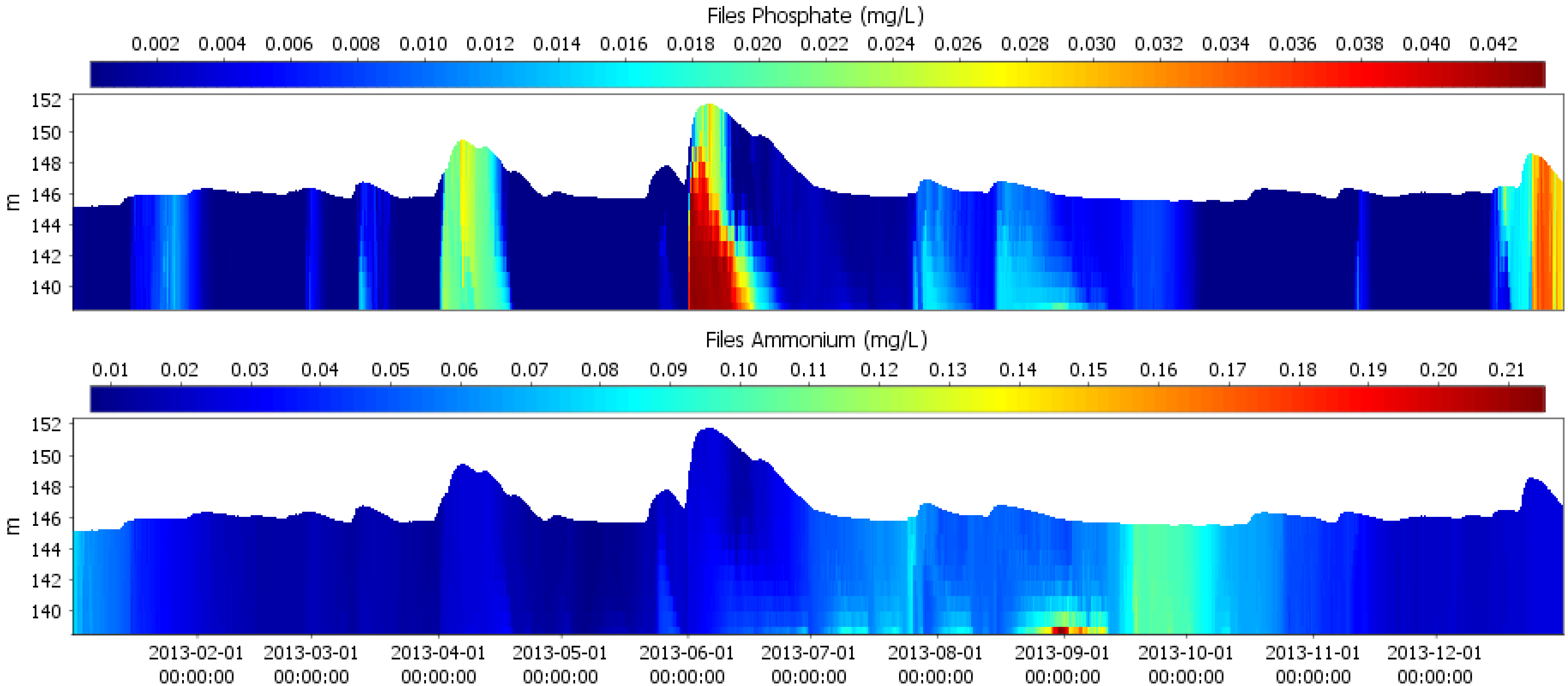


UNIVERSITY OF ARKANSAS
DALE BUMPERS COLLEGE
OF AGRICULTURAL, FOOD & LIFE SCIENCES

bioxdesign

DIVISION OF AGRICULTURE
RESEARCH & EXTENSION
University of Arkansas System

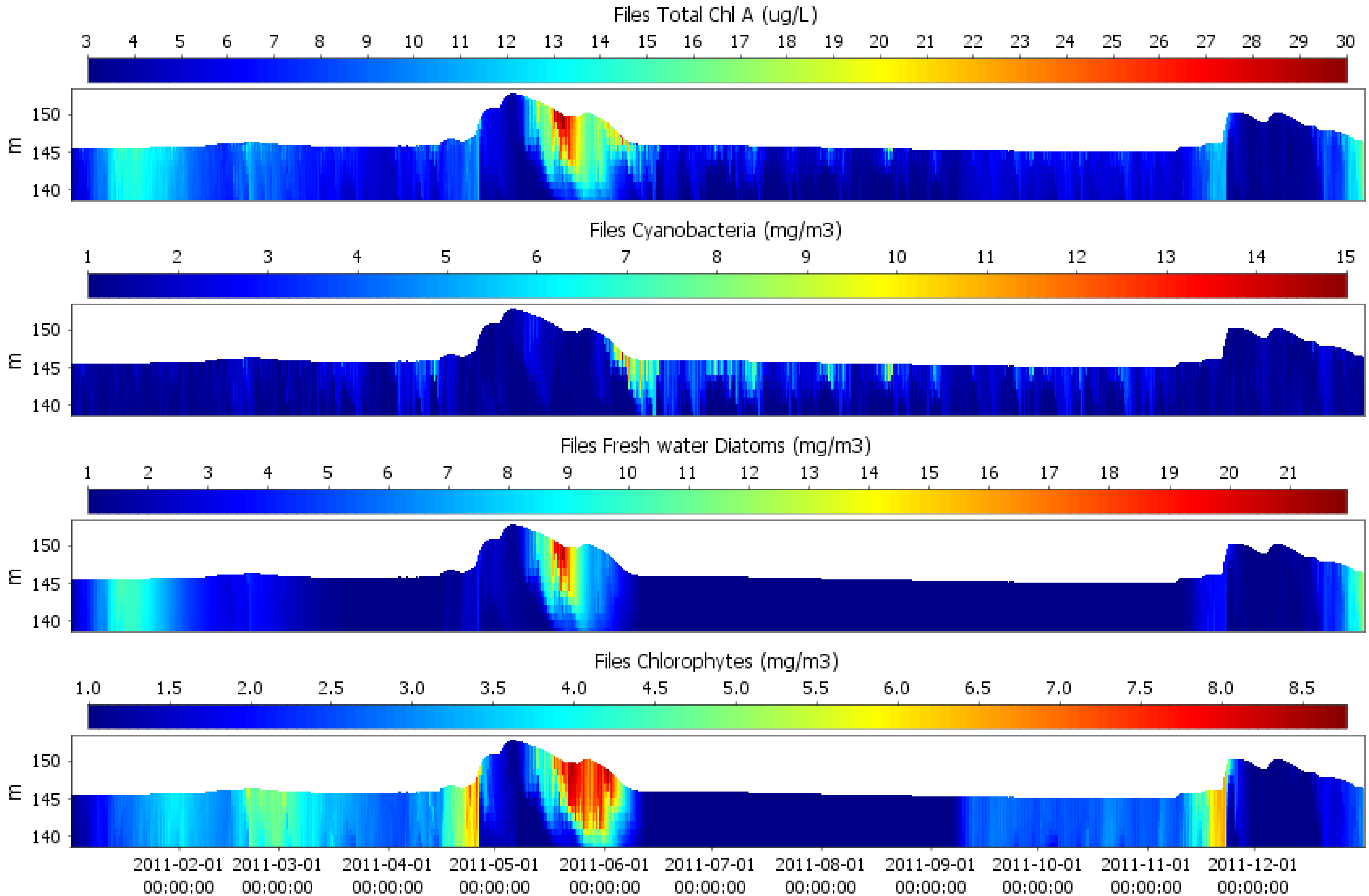
Low internal loading by inaccurate stratification duration



UNIVERSITY OF ARKANSAS
DALE BUMPERS COLLEGE
OF AGRICULTURAL, FOOD & LIFE SCIENCES

bioxdesign

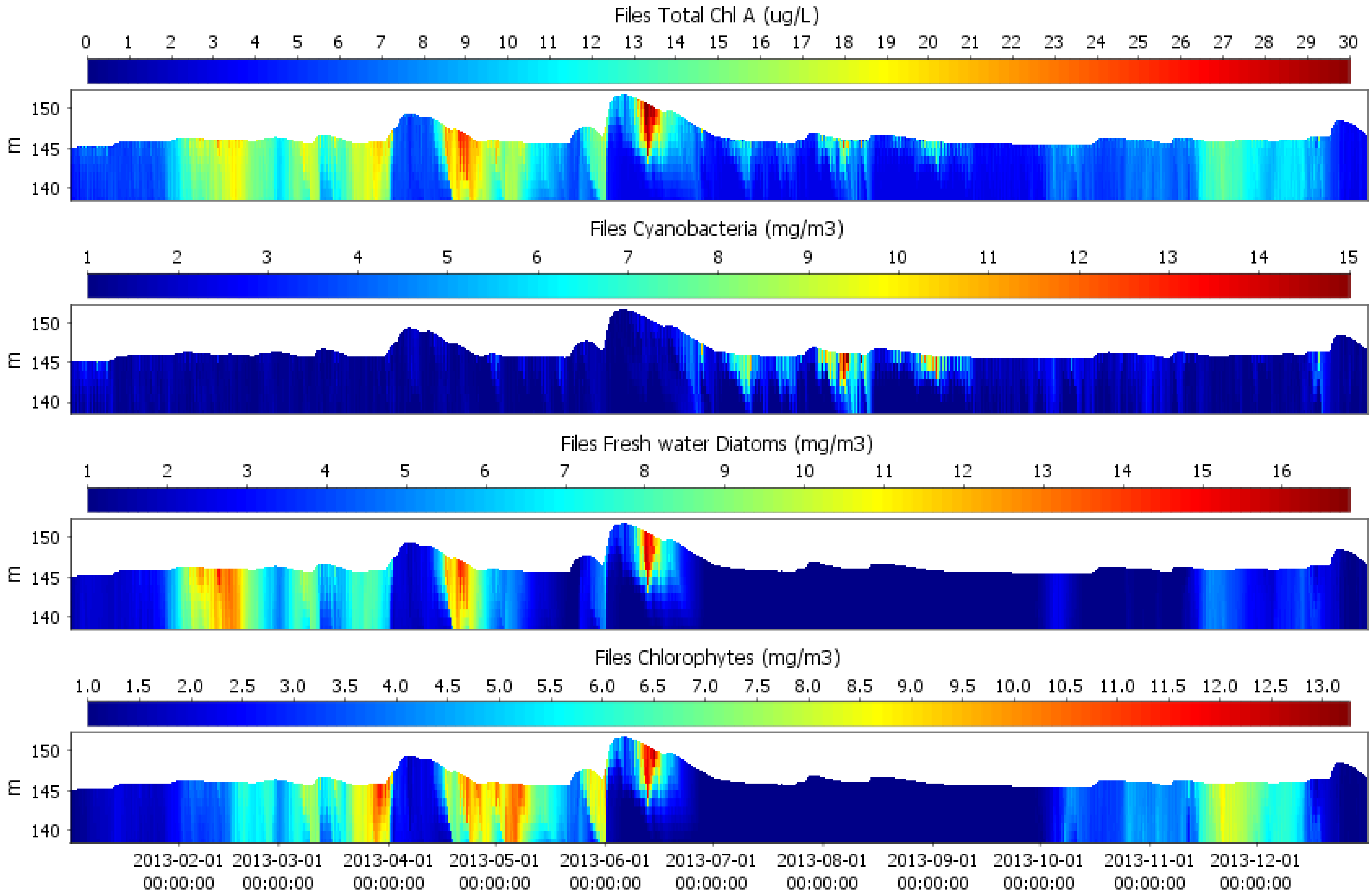
DIVISION OF AGRICULTURE
RESEARCH & EXTENSION
University of Arkansas System



UNIVERSITY OF ARKANSAS
DALE BUMPERS COLLEGE
OF AGRICULTURAL, FOOD & LIFE SCIENCES

bioxdesign

DIVISION OF AGRICULTURE
RESEARCH & EXTENSION
University of Arkansas System



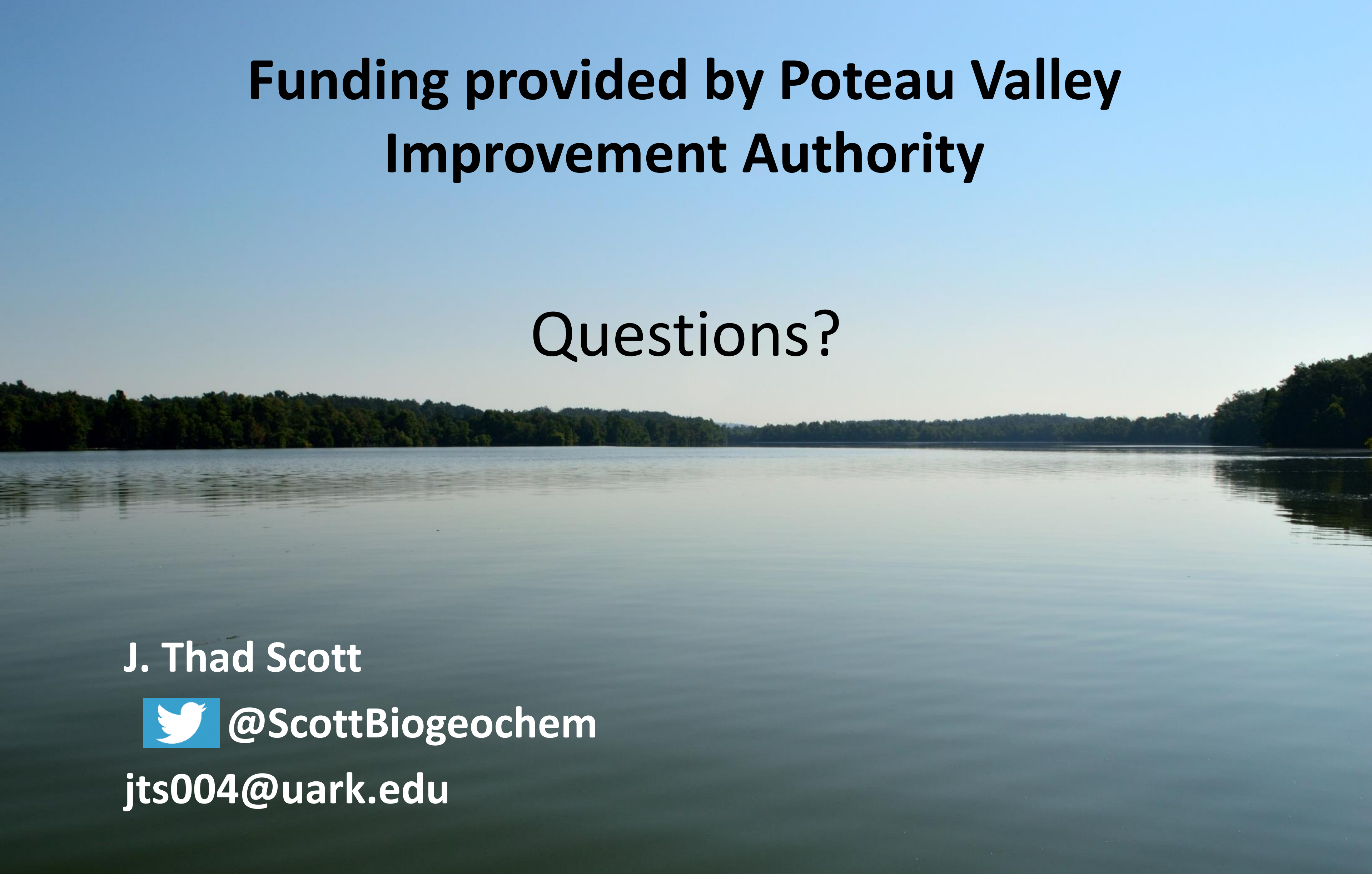
UNIVERSITY OF ARKANSAS
DALE BUMPERS COLLEGE
OF AGRICULTURAL, FOOD & LIFE SCIENCES

bioxdesign

DIVISION OF AGRICULTURE
RESEARCH & EXTENSION
University of Arkansas System

Project Next Steps:

- Complete calibration
- Simulate systematic load reductions on water quality with calibrated model
- Derive specific load reduction estimates needed to achieve water quality targets for Lake Wister
- Simulate the effect of lake management options (alum; wind breaks)
- Final modeling report in November 2016



Funding provided by Poteau Valley Improvement Authority

Questions?

J. Thad Scott

@ScottBiogeochem

jts004@uark.edu

UNIVERSITY OF ARKANSAS
DALE BUMPERS COLLEGE OF AGRICULTURAL, FOOD & LIFE SCIENCES

bioxdesign

DIVISION OF AGRICULTURE
RESEARCH & EXTENSION
University of Arkansas System