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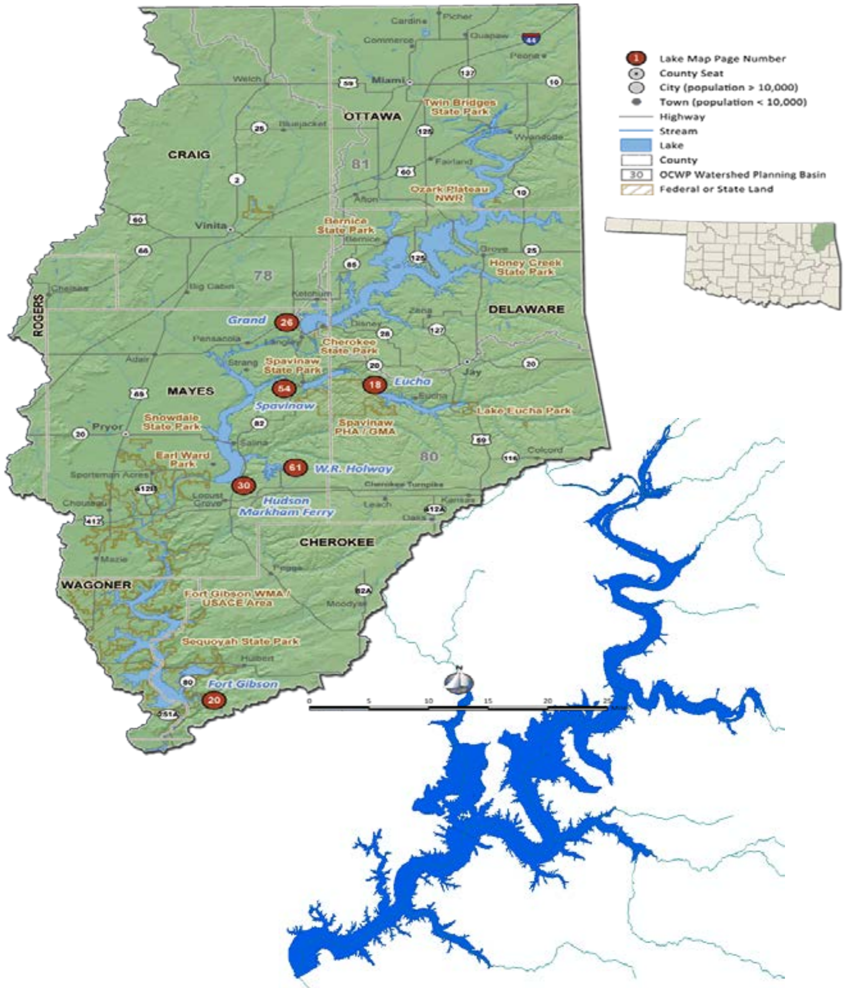
A Three-layer Steady-state Vertical Dissolved Oxygen Model In Grand Lake

Outline

- Introduction
- Methods
- Results
- Summary Discussion
- Conclusion
- Recommendations

Grand Lake



- Grand Lake
  - Stretches through Delaware, Ottawa, and Mayes Counties in NE Oklahoma
  - Pensacola dam in 1940
  - Surface area 18ha
  - Mean depth 11.06m
  - Maximum depth 40.54m
  - 1,672,000 acre-feet
  - 10,298 square miles
  - Land use is primarily agricultural
  - Grand River Dam Authority Monitors the Water Quality
  - Experiencing Harmful Algal Blooms (HAB).

GRDA Monitoring sites

Grand Lake

Introduction

- In aquatic ecosystems, nitrogen and phosphorus act as fertilizers resulting in eutrophication and increase in the concentration of organic matter (Hoagland and Scatasta 2006).

- Eutrophication increases noxious, aquatic plant growth and harmful algal blooms that results in the production of toxins that pose a threat to humans, pets, and livestock health (Bricker *et al*. 2007).

- Eutrophication can lead to hypoxia (low DO concentration) resulting in fish kills and a decrease in biodiversity (Diaz and Rosenberg 2008) .

- Algal blooms in US coastal water cost $82 million annually with major impacts on public health, while nutrient pollution in freshwater has an estimated cost of $2.2 billion annually (Dodds et al. 2009).

- Grand Lake experienced a significant algal bloom on July 4th, 2011 causing the Grand Lake Dam Authority to shut down swimming in the lake.

Grand Lake Trophic Status

Trophic Status Index (TSI) – trophic status is an indicator of the quantities of nutrients in a water body

TSI for Grand Lake in 2013

Name of zones	Low & High Ranges of TSI_s	Survey dates	Average TSI for Grand Lake	Trophic state of Grand Lake	Chl (µg/L)	SD (m)	TP (µg/L)
Riverine	57-77	7/17/2013	65	Hypereutrophic	14.93	0.88	0.16
Transition	51-67	✓	58	Eutrophic	8.80	1.21	0.08
Lacustrine	51-67	✓	57	Eutrophic	8.08	1.40	0.08
Dam	50-67	✓	58	Eutrophic	7.82	1.18	0.08

TSI for Grand Lake in 2015

Name of zones	Low & High Ranges of TSI_s	Survey dates	Average TSI for Grand Lake	Trophic state of Grand Lake	Chl (µg/L)	SD (m)	TP (µg/L)
Riverine	61-77	8/11/2015	67	Hypereutrophic	22.62	0.75	0.15
Transition	57-78	6/16/2015	67	Hypereutrophic	14.87	0.57	0.17
Lacustrine	54-62	7/29/2015	57	Eutrophic	24.58	1.42	0.03
Dam	51-60	7/29/2015	55	Eutrophic	16.32	1.28	0.02

(Green, et al., 2015).

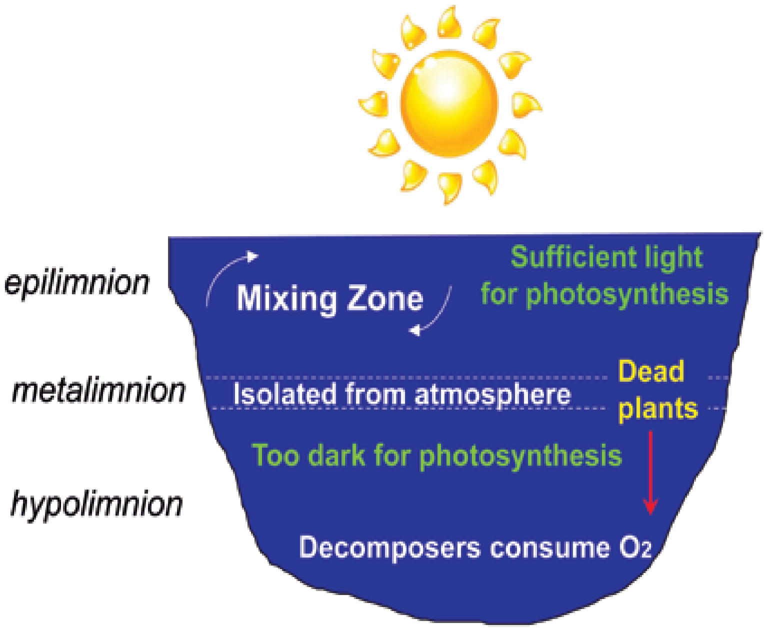
Grand Lake Water Quality Status 303(d) List

Years	Causes of Impairment	Lake portion
2010	Lead, DO	Lower Lake
	DO, Lead, and Turbidity	Middle Lake
	Lead, Turbidity	Upper Lake
2012	Lead, DO	Lower Lake
	Lead, Turbidity	Middle Lake
	Lead, Turbidity	Upper Lake
2014	Lead, DO	Lower Lake
	Lead	Middle Lake
	Lead, Turbidity	Upper Lake

(Integrated water quality assessment', ODEQ, 2015),

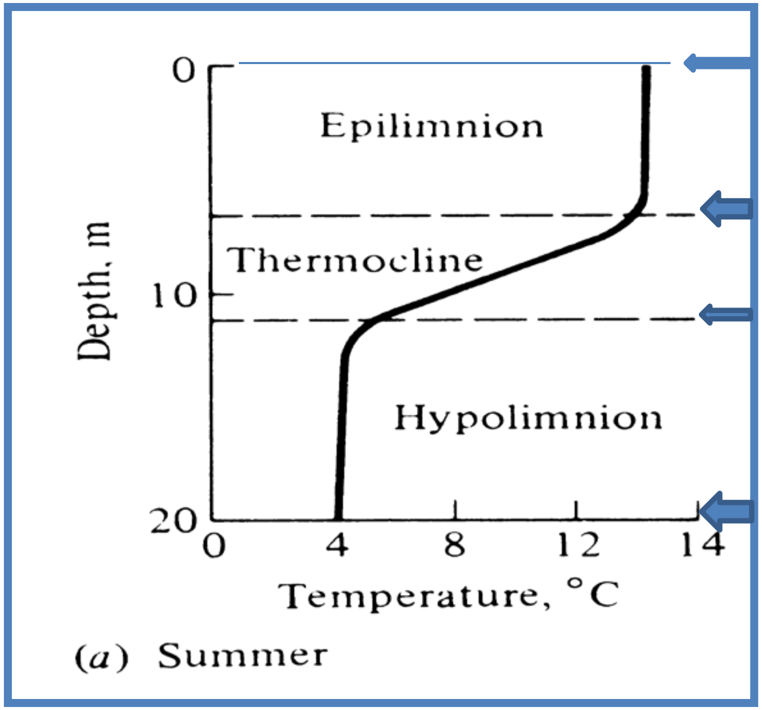
Summer Stratification- Water Temperature

- Summer stratification



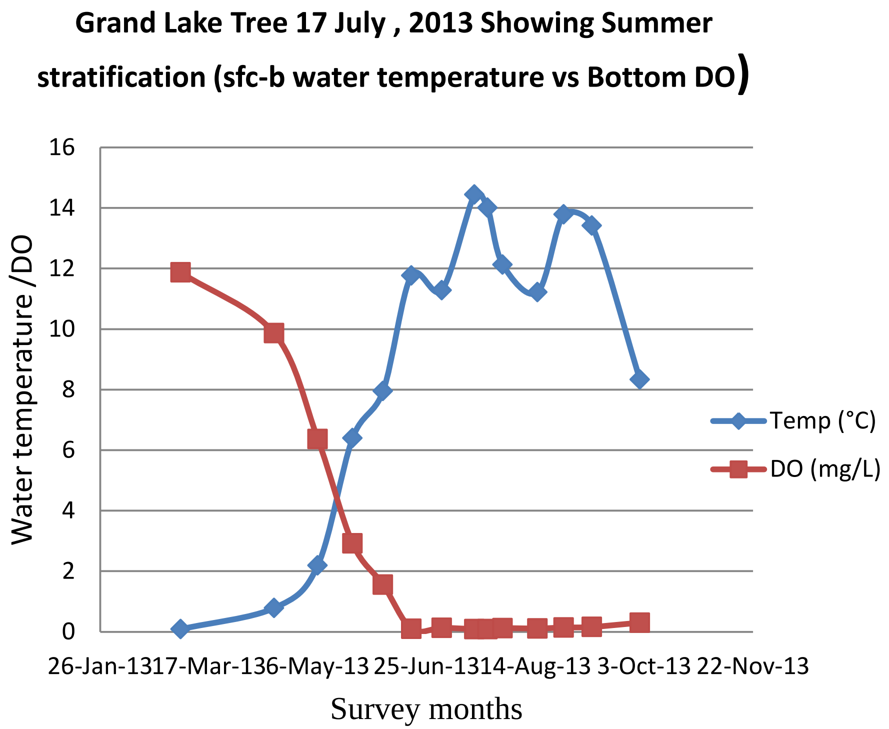
Jones, B. (2011).

- Water temperature , 3-layer

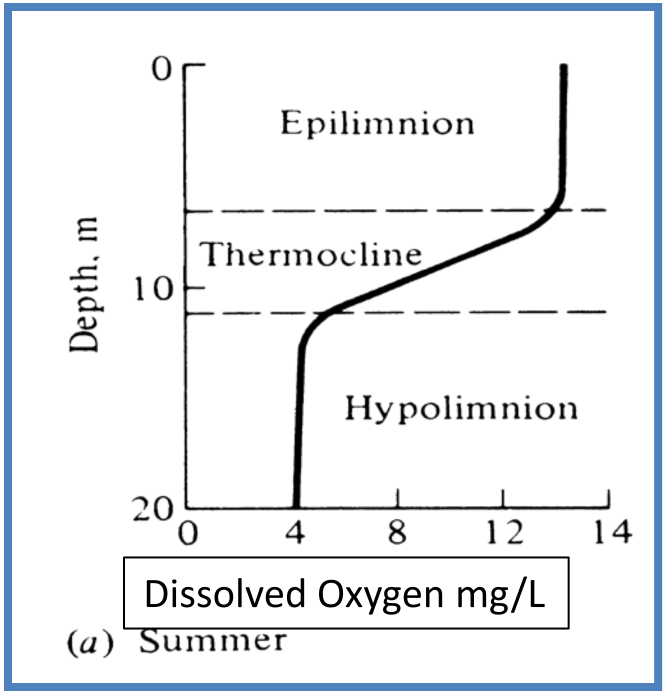


Summer Stratification-Dissolved Oxygen

Summer stratification



Dissolved Oxygen



Research Objectives

- Develop a 3-layer steady-state vertical dissolved oxygen model
- Use physical and water quality data from Grand Lake with kinetic processes and coefficients to estimate model input rates for oxygen production and oxygen consumption
- Use model input rates and kinetic processes to determine the relative effect of source terms, oxygen demand terms and sediment oxygen demand (SOD) on bottom water hypoxia under summer-stratified conditions in Grand Lake.

Description of the model used

- VERTDO3 is a steady-state, one-dimensional analytical model that describes the effect of stratification and biological-chemical processes on the vertical distribution of dissolved oxygen in lakes and reservoirs.

- The model assumes steady-state conditions with negligible horizontal gradients of dissolved oxygen in the water body.

- The dominant vertical gradient in the water column is represented with 3-layers defined as the epiliminion, metalimnnion and hypolimnion.

- The model was designed by HydroQual (1986) as a simplified approach to provide insight into the key physical, chemical and biological factors that influence the occurrence of anoxia and hypoxia below the thermocline.

Sources and Losses of Dissolved Oxygen

Sources of Oxygen

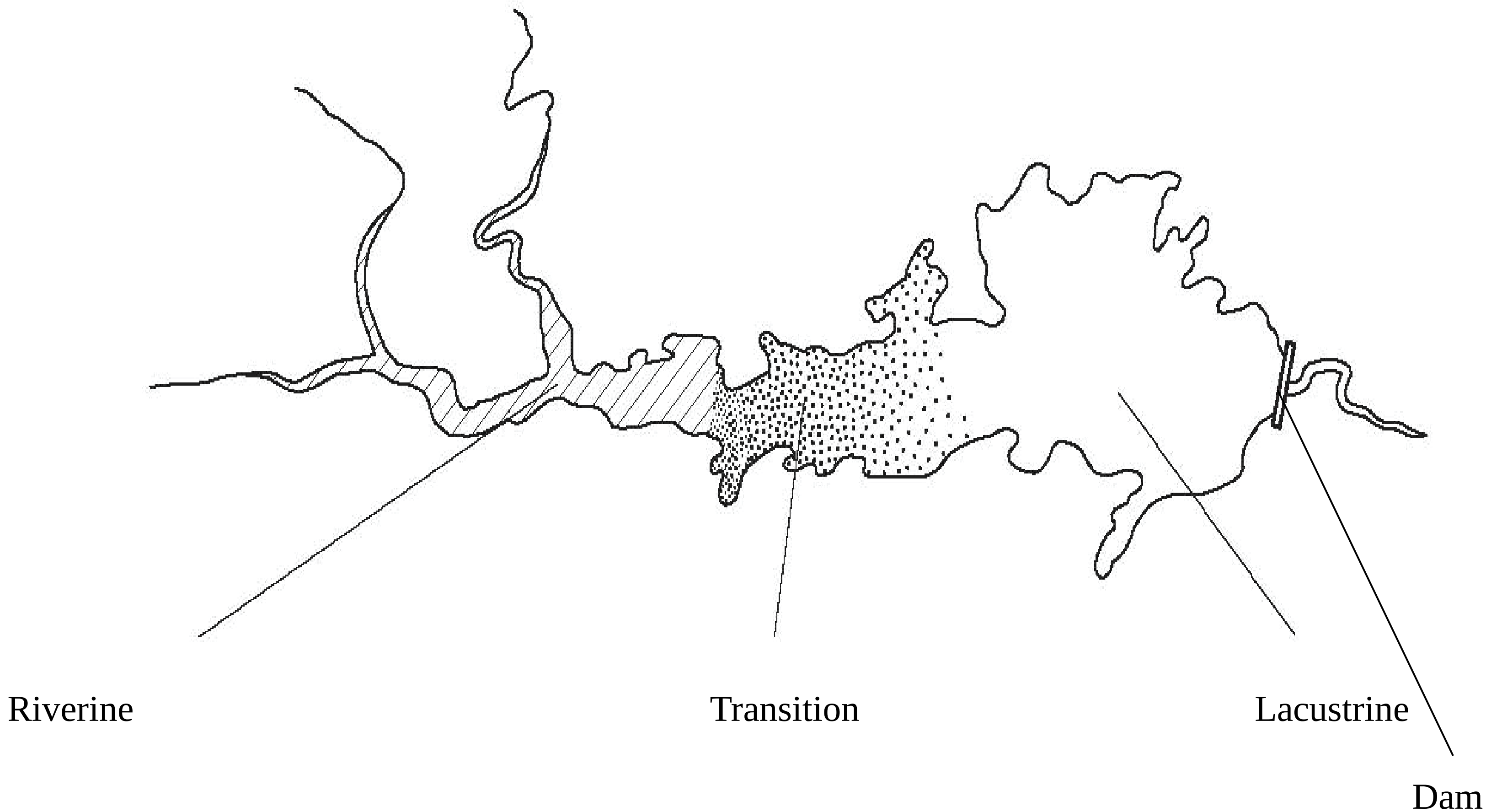
- Atmospheric reaeration
- Phytoplankton production

Losses of Oxygen

- Sediment oxygen demand
- Phytoplankton respiration
- Organic matter decomposition
- Nitrification

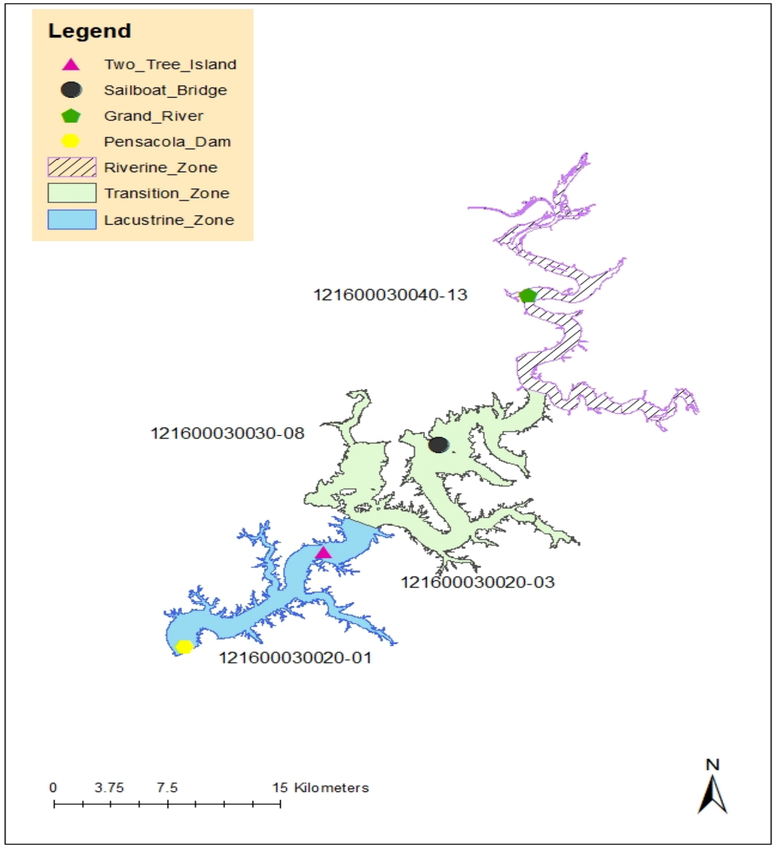
Lake data + Kinetic processes → Input to the model

Characteristic Zones in a Reservoir



Data Sources

- Grand River Dam Authority (GRDA)
- 1986-2015
- Summer 2013 and 2015
- 4 stations in lake
- Representative location of riverine, transition, lacustrine, and dam

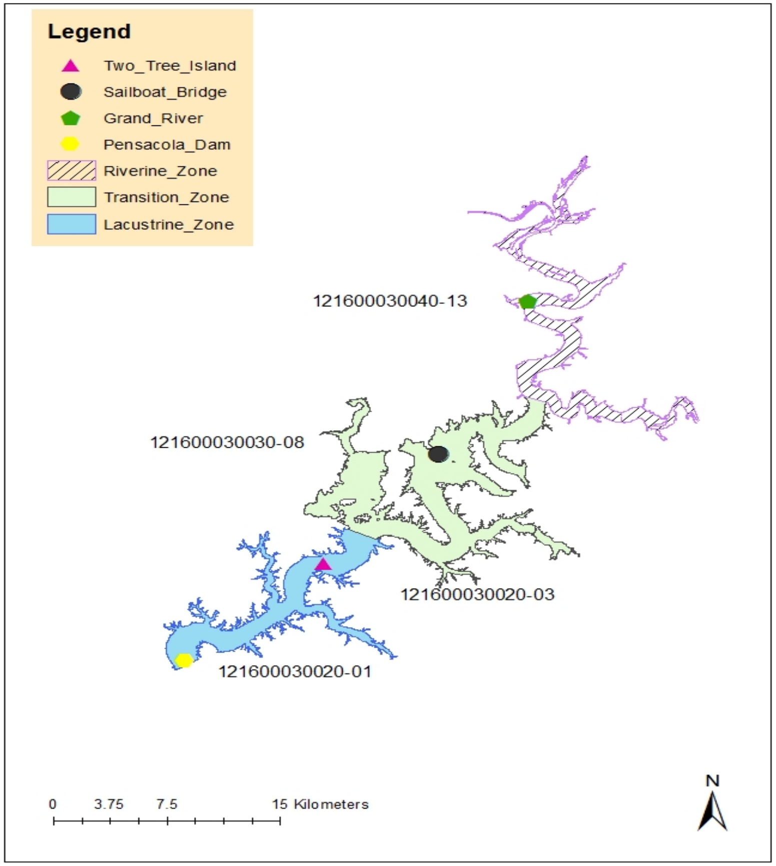


Lake Data

- Physical
  - Water temperature
  - Station depths
  - Secchi depth
  - Solar radiation
  - Wind speed

- Water Chemistry

  - Ortho-phosphate
  - Nitrite-N
  - Chlorophyll-a
  - Dissolved oxygen
  - Ammonia-N
  - Total nitrogen
  - Total phosphorus
  - Total organic carbon



Kinetic Coefficients

Kinetic Coefficient	Units	Tree-2013 and 2015	P-Dam-2013,and 2015
Max Phytoplankton growth rate	1/day	3 -3.5	4.1- 6
Nitrogen half saturation constant, Kn	µgN/L	1.3 10	1
Phosphorus half saturation constant	µgP/L	2	1
Light saturation for phytoplankton	Ly/day	140-150	147
Carbon: Chlorophyll	µgC/µgChl	47-65	25-47
Photoperiod for sample day	Fraction 24hr	0.5- 0.6	0.6
Phytoplankton respiration rate Kr (20ºC)	1/day	0.025 -0.05	0.025
Decomposition OrgC respiration rate Kd (20ºC)	1/day	0.0125	0.025
Nitrification rate Kn(20ºC)	1/day	0.07-0.075	0.07-0.09
Labile fraction TOC	fraction	0.4	0.4-0.7
Dissolved fraction of DOC	fraction	O.9	0.9
Carbon: Nitrogen ratio	gC/gN	7.2	7.2
Nitrogen: Phosphorus ratio	gN/gP	5.56	5.56
Sediment Oxygen Demand	gO2/m^2-day	1.00	1.50-1.90
Vertical mixing E_1	Cm^2/sec	3.00	3.00
Vertical mixing E_2	Cm^2/sec	0.40-0.45	0.36-0.45
Vertical mixing E_3	Cm^2/sec	6.900	6.90
Air-water oxygen transfer,KL	m/day	1.75	1.75

Oxygen Consumption Terms

-Nitrification of ammonia

$$R\ (NH_4) = [NH_4]\ K_n\ (20)\ Ø^{(T-20)} \left(\frac{Oxygen}{Nitrogen}\right)$$

- Organic Carbon

$$R\ (\text{Labile TOC}) = [\text{Detrital\_Labile\_TOC}] * K_d\ (20)\ Ø^{(T-20)} * \frac{Oxygen}{Carbon}$$

- Phytoplankton respiration

$$R\ (\text{phytoplankton}) = [Chl]\ K_r\ (20)\ Ø^{(T-20)*} \left(\frac{Carbon}{Chl}\ \frac{Oxygen}{Carbon}\right)$$

Oxygen Production

- General equation used to estimate oxygen production in the photic zone:

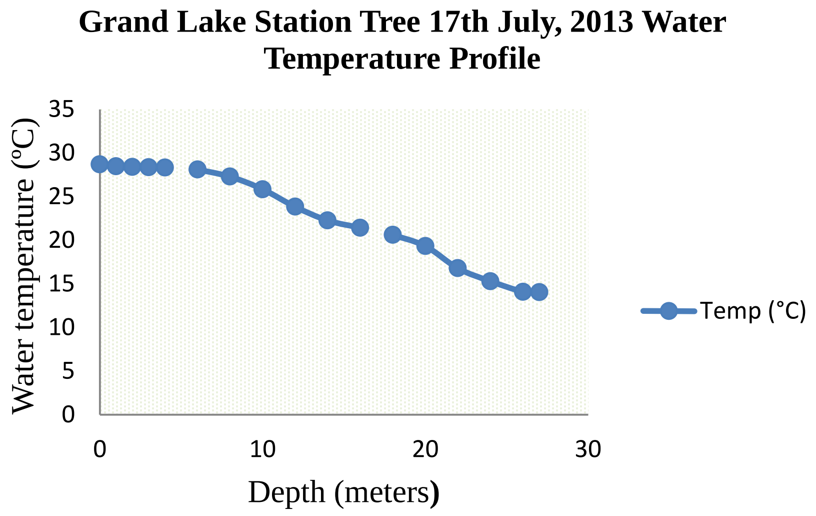
$$- \text{Pa} = \text{Chl}\,[\text{Kg}\,(\text{T, N, P, I})]\,\frac{Carbon}{Chl}\,\frac{Oxygen}{Carbon}\,\frac{1mgC}{1000\mu gC}$$

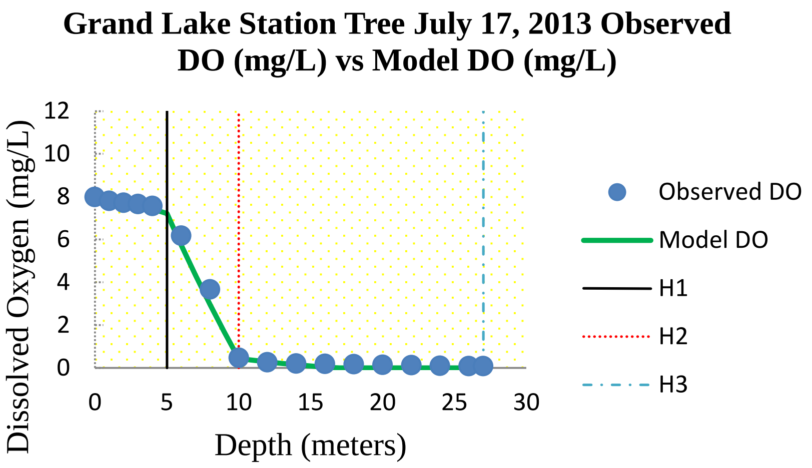
- Phytoplankton growth rate is dependent on water temperature, nutrient limitation, and light limitation

Summary of Model Input Data

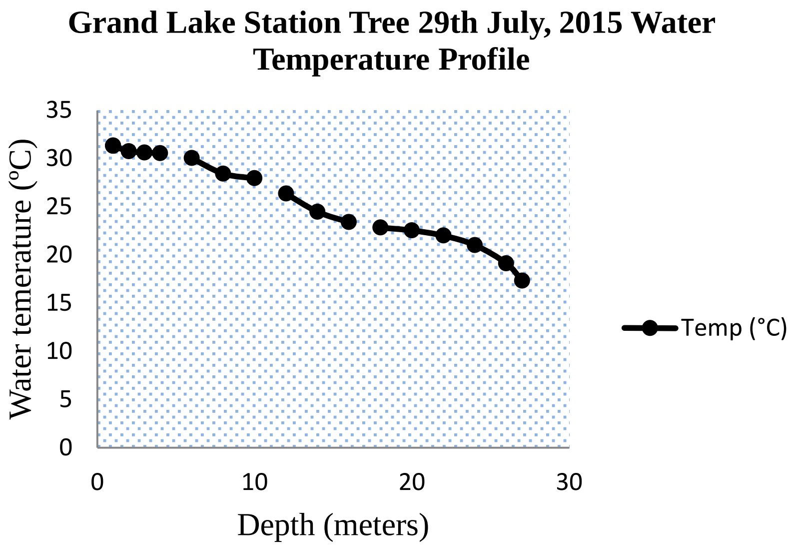
Model input parameters	Units	Range, Tree and P-Dam
KL, air-water transfer	(m/day)	1.75
Cs, DO saturation	(mg/L)	7.2-7.5
Pa, oxygen production	(mg/L-day)	1.2- 2.8
R, oxygen respiration	(mg/L-day)	0.1-0.3
Vertical mixing E1	cm^2/sec	3.0
Vertical mixing E2	cm^2/sec	0.36-0.45
Vertical mixing E3	cm^2/sec	6.900
SOD	gO2/m^2-day)	1.00- 1.90
R1,R2, and R3	(mg/L-day)	0.06-0.17
H1,H2,and H3		

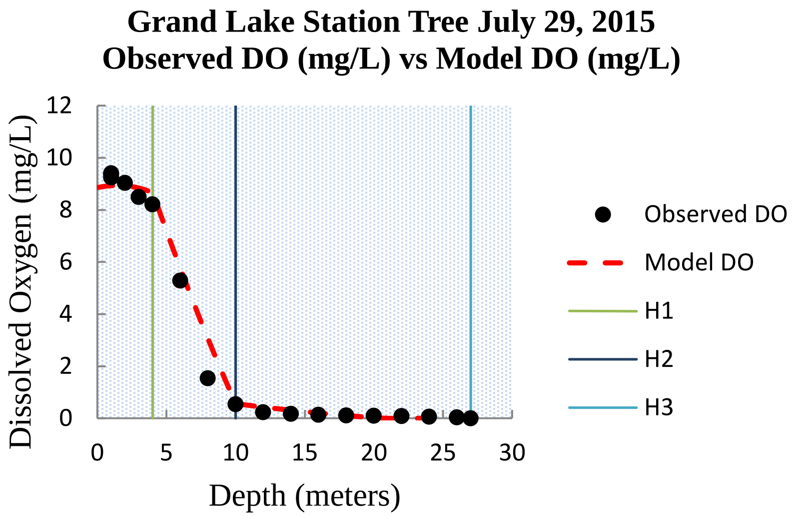
Tree, 17 July 2013



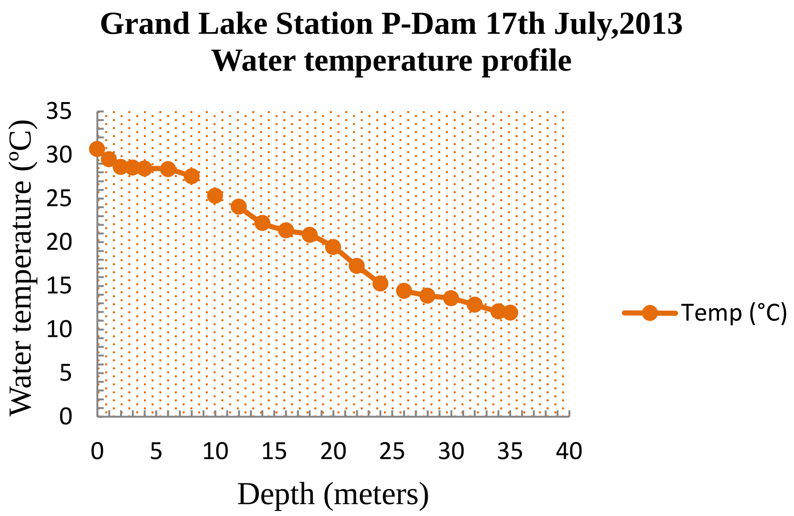


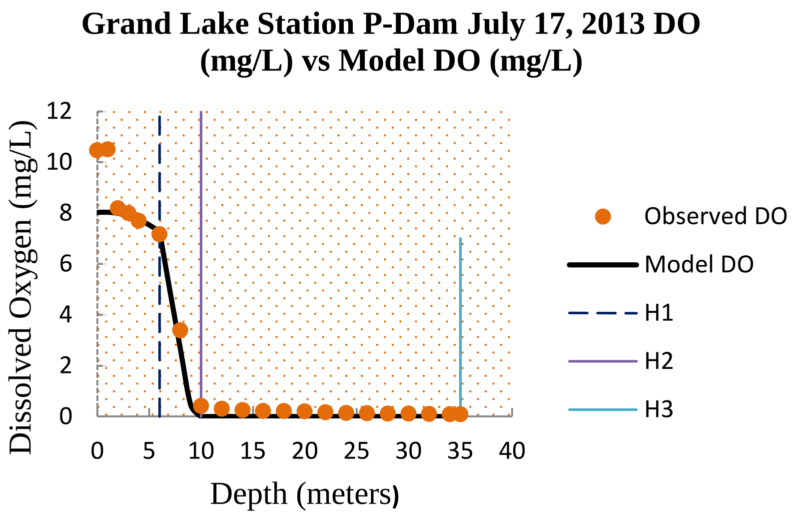
Tree, 29 July 2015



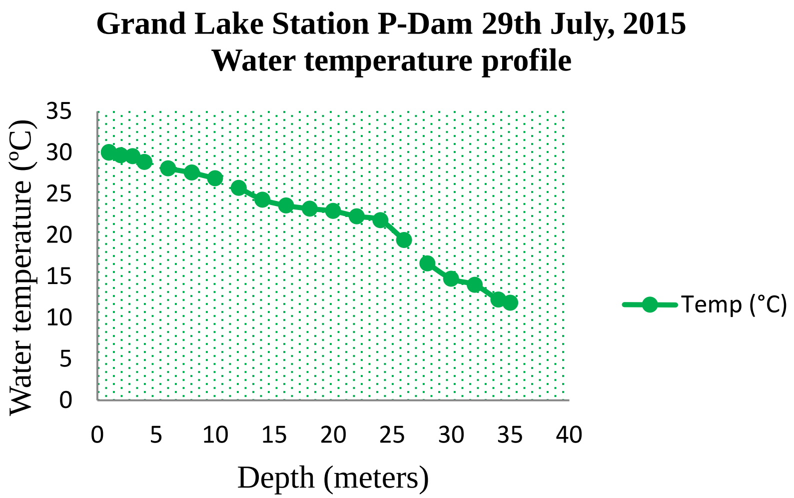


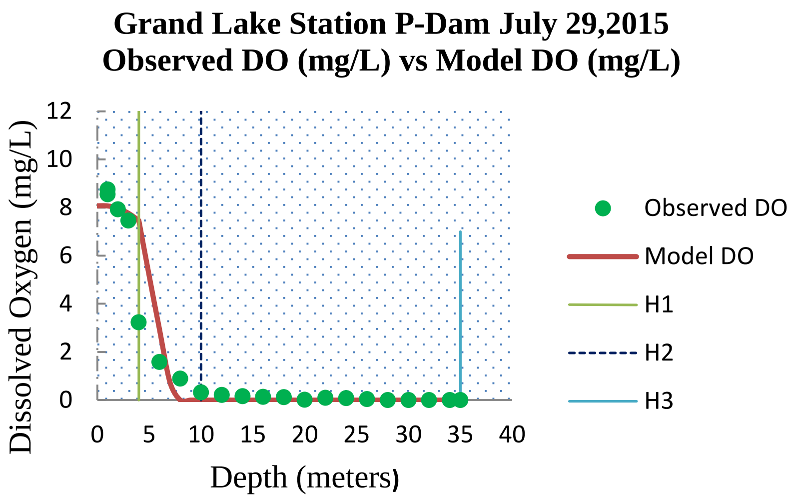
P-Dam, 17 July 2013





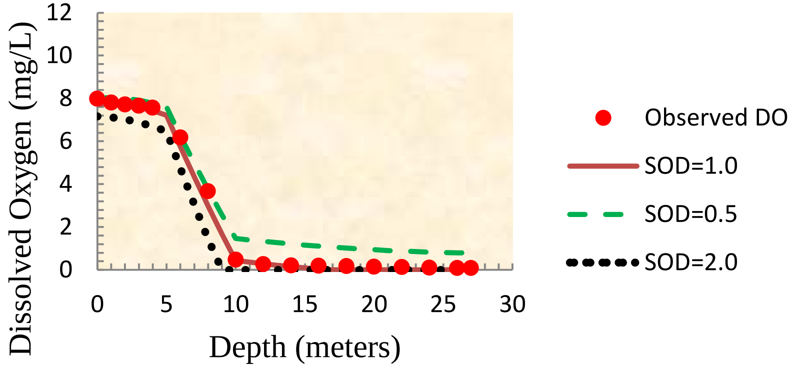
P-Dam, 29 July 2015



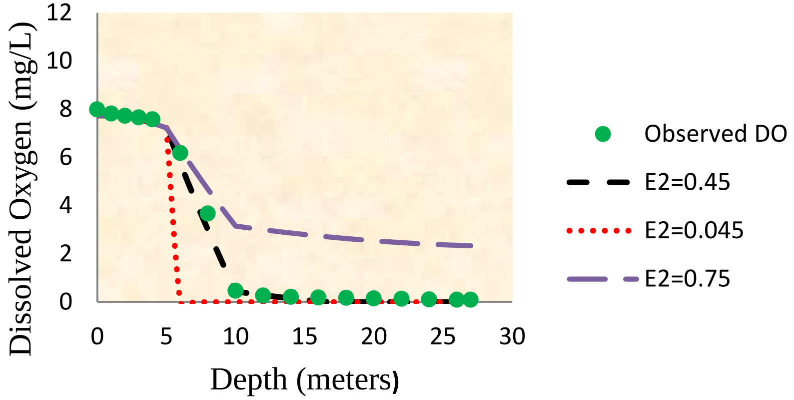


Sensitivity Analysis

Grand Lake Station Tree July 17, 2013 SOD (gO_2/m^2-day) Sensitivity



Grand Lake Station Tree 17 July ,2013 Vertical Mixing (E_2) Sensitivity



Comparison of Results
Grand Lake and Reservoirs in the Ozark Highlands

QW parameters	Unites	Grand Lake	Ozark Highlands (25 lakes)
Chlorophyll	µg/L	7.8-24	1-23
Total Nitrogen	mg N/L	0.19-1.25	0.1-0.59
Total phosphorus	µg/L	1-80	6-38
Secchi depth	meters	0.57-1.42	0.6-3.7
DO respiration	**mg/L-day**	**0.08-0.6**	**(<0.1-0.96)**

Summary of Kinetic processes

Kinetic processes	Units $mgO_2/L\text{-}day$	Tree 2013 and 2015	P-Dam 2013 and 2015
Gross production (pa)	$mgO_2/L\text{-}day$	1.1-2.1	1.5-2.7
Net production	$mgO_2/L\text{-}day$	1.0- 2.0	1.4-2.7
Phytoplankton respiration	%	26.6%- 27%	28.4%- 34.2%
Organic carbon decomposition	%	15.1%- 23%	29.3%- 40.9%
Nitrification	%	33%-44.7%	17.6%-25. %
SOD	%	13.4%-16.2%	7.4%-16.5%

Discussion

- The 3-layer steady-state vertical DO model was able to show good agreement with observed oxygen profile in most cases.
- The P-Dam (July17, 2013) was an exception due to superstation of 140%, and high light limitation at the surface, the model was not able to match upper 0-2m depth to the observed DO.
- The range of respiration rates for Grand Lake estimated by the model is consistent with range of respiration rates measured in Ozark Highlands lakes.
- The water column respiration terms are larger contribution to oxygen depletion than sediment oxygen demand.

Conclusions

- The model did a good job of matching observed DO profiles, except for supersaturated conditions.
- High light limitation at the surface layer, phytoplankton growth rate, and phosphorus were the most critical factors for oxygen production within the epiliminion layer and the least critical factor was nitrogen.
- For the sink term, nitrification was the most critical factor for oxygen demand in 2013, while SOD was the least critical factor for oxygen demand.
- For 2015, the most critical factor to oxygen demand in the hypolimnion was organic matter decomposition, while the least critical factor was SOD.

Recommendations

- Based on the findings, it is recommended that GRDA should start collecting observed water chemistry data in each layer of the lake from surface to bottom at all the 13 stations in Grand Lake.
- It is recommended that GRDA monitoring team should expand monitoring effort to collect benthic flux data for ammonia-N, Phosphate-P, and sediment oxygen demand at key sites in each zone of the reservoir during stratification period (starting June to late September)
- Finally, collecting water chemistry data throughout the water column at all stations and benthic flux data for nutrients and SOD would help to support future analyses including characterization of the effect of benthic flux of nitrogen and phosphorus and SOD in the hypolimnion layer.

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OCLWA

Oklahoma Clean Lakes & Watersheds Association

26th Annual Conference

Value of Informed Water Quality Management

Questions?