

How Changes in Nitrogen Loading to the Neuse River Estuary have Affected Algal Biomass



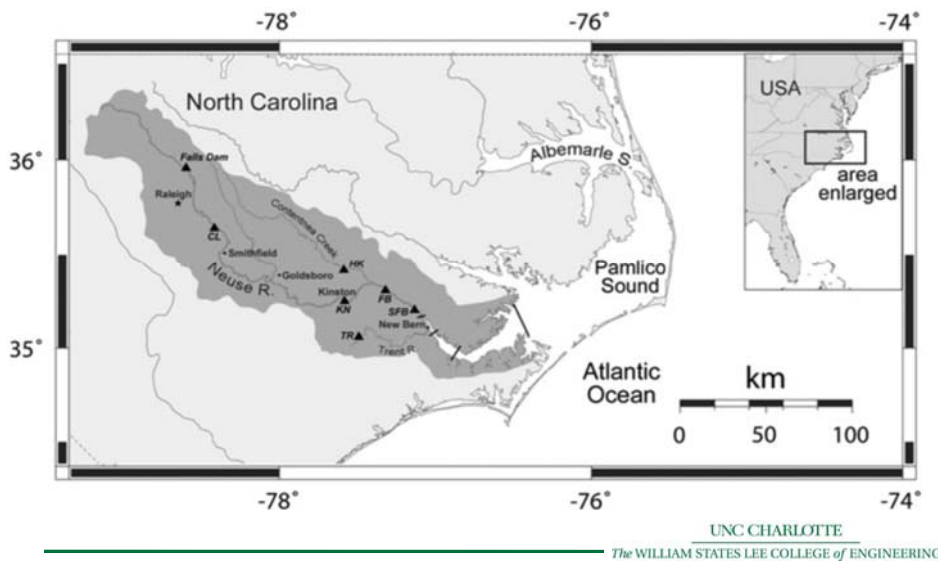
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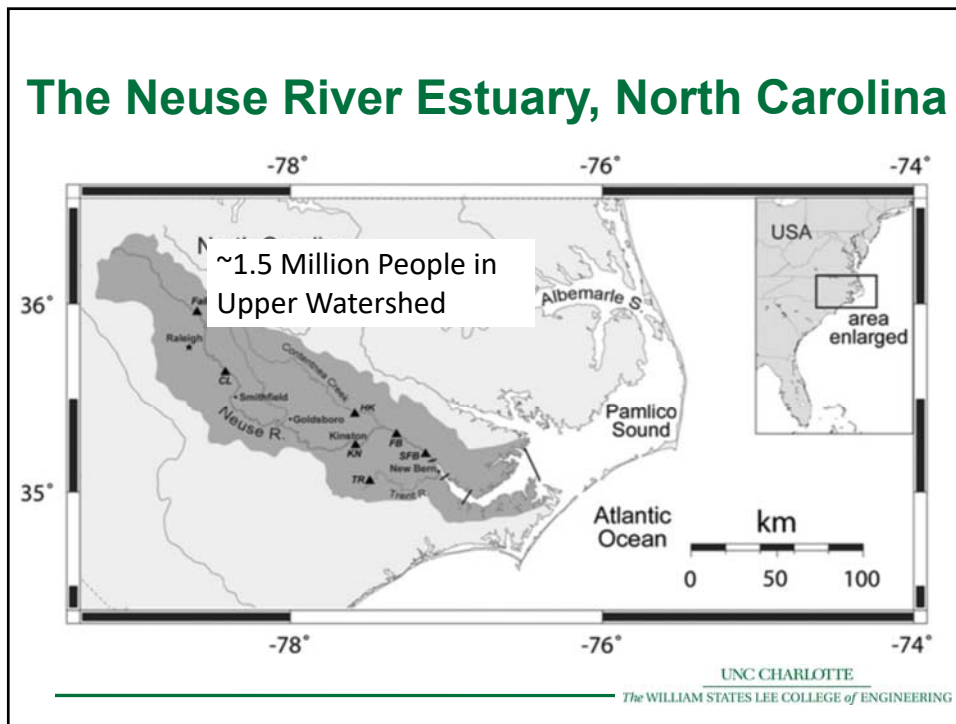
March 16, 2017

James Bowen – Civil & Environmental Engr. Dept.

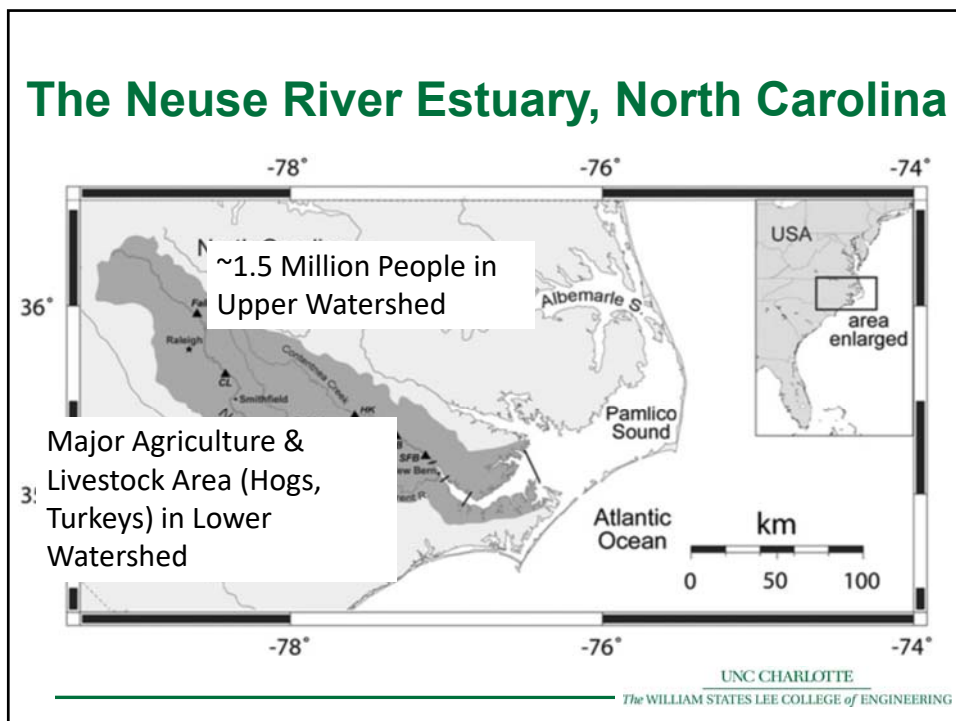
The Neuse River Estuary, North Carolina



The Neuse River Estuary, North Carolina



The Neuse River Estuary, North Carolina



Neuse River Estuary (NRE) water quality problems are not new

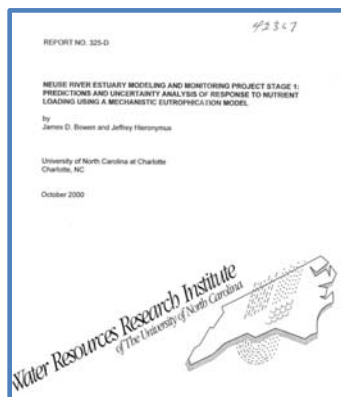
1. Algal Blooms – regular Chl-a water quality criteria (>40 ug/L) exceedences since the 1980's
2. More frequent blooms in lower estuary in the 2000's
3. Multiple major fish kills in late 90's
4. Intermittent, but widespread bottom water anoxia during Spring, Summer, early Fall



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Water Quality Modeling of Neuse River Estuary also not a new story



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Water Quality Modeling of Neuse River Estuary also not a new story

CALIBRATION AND VERIFICATION OF A TWO-DIMENSIONAL, LATERALLY AVERAGED MECHANISTIC MODEL OF THE NEUSE RIVER ESTUARY

Jeffrey Hieronymus and James D. Bowen

Department of Civil Engineering
William States Lee College of Engineering
University of North Carolina at Charlotte
Charlotte, NC 28223

REPORT
NEUSE RIVER
PREDICTIVE
LOADING
by
James D.
University
Charlotte
October 2

The research on which this report is based was supported by funds provided by the North Carolina General Assembly through the North Carolina Department of Environment and Natural Resources.

Contents of this publication do not necessarily reflect the views and policies of the WRRRI, nor does mention of trade names or commercial products constitute their endorsement by the WRRRI or the State of North Carolina.

This report fulfills the requirements for a project completion report of the Water Resources Research Institute of The University of North Carolina. The authors are solely responsible for the content and completeness of the report.

WRRRI Project No. 50262
July 2004

Water Res

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Water Quality Modeling of Neuse River Estuary also not a new story

UNC-WRRRI-343-C

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UNC-WRRP-343-C

CALIBRATION AVERAGED

CALIBRATION AVERAGED

Model Predicted Water Quality Response to Reductions in Inorganic and Organic Nitrogen Loading

James D. Bowen¹ and Jeffrey W. Hieronymus²

Abstract

As part of a total maximum daily load analysis of North Carolina's Neuse River Estuary, eutrophication modeling was conducted using a modified version of an existing two-dimensional, laterally-averaged model (CE-QUAL-W2). The model simulated conditions in the estuary for a 43-month period that included two episodes of extraordinarily high nutrient and freshwater loading. Phytoplankton blooms with chlorophyll-a concentrations in excess of 40 µg/l were seen in three of the four years simulated, while bottom water anoxia was seen intermittently in each of the four summers.

The calibrated model was used to predict the water quality improvement in the estuary associated with a variety of nitrogen load reductions varying from 5% to 30%. For each scenario, an assumption was made as to how much of the reduction would come from dissolved inorganic, dissolved organic, and particulate organic nitrogen. Water quality improvement was quantified by comparing the predicted chlorophyll-a concentrations for the nutrient reduction scenarios to a case without nutrient reduction. Additional cases were run to investigate the extent to which changes in sediment quality, occurring over several years might produce an additional improvement in water quality by reducing sediment oxygen demand and benthically mediated nutrient recycling.

As expected, reduced nitrogen loading produced lower water-column nitrogen concentrations and lower chlorophyll-a concentrations. The magnitude of change in chlorophyll-a concentration was surprisingly small, however, as compared to the magnitude of load reduction. The magnitude of change in chlorophyll-a concentration differed according to the apportionment of nitrogen load reduction. Chlorophyll concentrations were most sensitive to inorganic nitrogen reduction and least sensitive to organic nitrogen load reductions. Including sediment denitrification

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Estuarine and Coastal Modeling (2001)

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Water Quality Modeling of Neuse River Estuary also not a new story

UNC-WRRP-343-C

CALIBRATION AVERAGED

CALIBRATION AVERAGED

A CE-QUAL-W2 Model of Neuse Estuary for Total Maximum Daily Load Development

James D. Bowen, A.M.ASCE,¹ and Jeffrey W. Hieronymus²

Abstract

In support of a total maximum daily load (TMDL) analysis, hydrodynamic and water quality conditions in the Neuse River Estuary were simulated for a 43 month period beginning in June 1999 using the two-dimensional, laterally averaged model CE-QUAL-W2. Several modifications to the model were made for this application including the further development of the existing sediment deposition submodel and an empirically derived light extinction production. The simulation period included two extreme nitrogen loading events and three summers with chlorophyll-a concentrations that exceeded the water quality standard of 40 µg/L. A multidimensional, laterally based procedure was used to calibrate the model to observed chlorophyll-a concentrations. The model was then used to predict changes in chlorophyll-a concentrations and water quality standard violations in estuary regions for a variety of total nitrogen load reductions. The model predicted that a load reduction of approximately 7% was needed to lower the frequency of water quality standard violations below 10%. The process-based modeling approach was found to be a valuable tool for a TMDL analysis, with certain limitations related to its relatively high-data needs and its inability to fully address prediction uncertainty.

DOI: 10.1061/(ASCE)1073-9696(2001)10:4(246)

CE Database subject headings: Estuaries; Water quality; North Carolina; Dissolved oxygen; Models.

Introduction

Like other Eastern United States estuaries, North Carolina's Neuse River Estuary is plagued with high chlorophyll-a and low dissolved oxygen concentrations. In the Neuse, water conditions are not new, as they have been reported repeatedly for more than 30 years (e.g., Hobbie and Smith 1975; Paul et al. 1987). Because of the number of measured surface water chlorophyll-a concentrations above the state water quality standard of 40 µg/L, portions of the Neuse River Estuary have been designated as having impaired water quality. For this reason the state of North Carolina has undertaken a total maximum daily load (TMDL) analysis of the watershed to determine the water quality management actions needed to eliminate the water quality impairment.

Previous water quality investigations in the Neuse River Estuary have included both water quality modeling and monitoring efforts. The Neuse River Estuary Modeling and Monitoring (NREME) Project has been underway since 1997 to develop a water quality model of the estuary and to collect the data necessary to support model development and to improve understanding of complex dynamics in the system. The Modeling project has produced an extensive database of monitoring data from the water column and the underlying sediments of the Neuse Estuary.

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Note. Discussion open until December 1, 2001. Separate discussions must be submitted for individual papers. To extend the closing date by one month, a written request must be filed with the ASCE Managing Editor. The manuscript for this paper was submitted for review and possible publication on July 1, 2001; approved on March 6, 2001. This paper is part of the *Journal of Water Resources Planning and Management*, Vol. 127, No. 4, July 1, 2001. ©ASCE, ISSN 1073-9696/2001/4-246-254/\$18.00.

Estuarine and Coastal Modeling (2001)

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Water Quality Modeling of Neuse River Estuary also not a new story

A CE-QUAL-W2 Model of Neuse Estuary for Total Maximum Daily Load Development
 James D. Bowen, A.M.ASCE,¹ and Jeffrey W. Heronimus²

Water Research
 Volume 47, Issue 15, 1 October 2013, Pages 5783–5793

Mechanistic and statistical models of total *Vibrio* abundance in the Neuse River Estuary
 Brett Froelich^a, James Bowen^b, Raul Gonzalez^c, Alexandra Snedeker^d, Rachel Noble^e

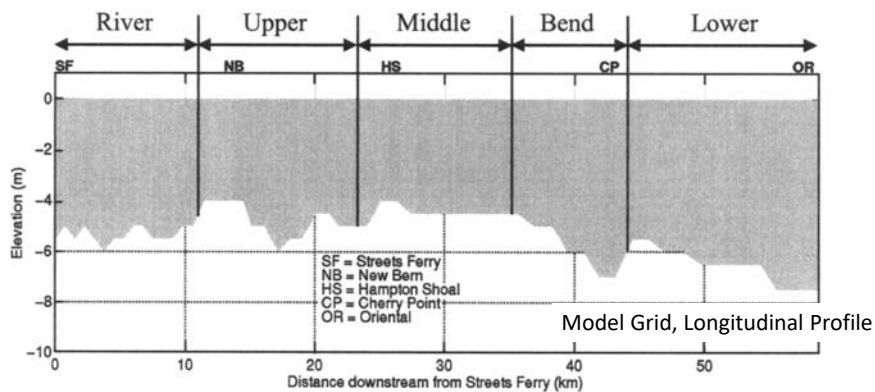
Highlights

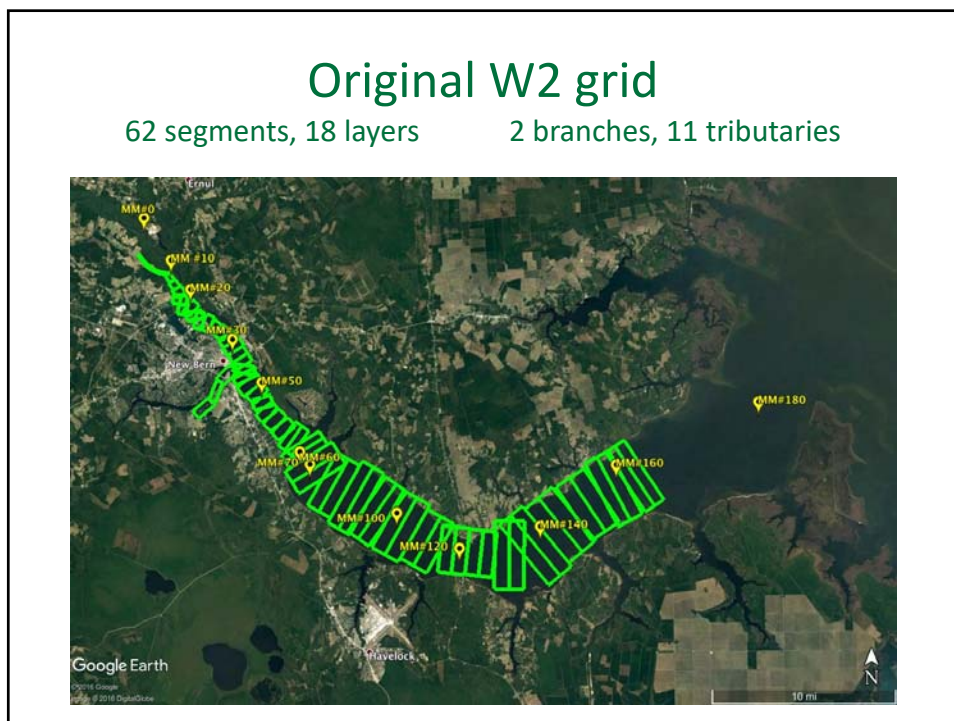
- Presented a new statistical model for *Vibrio* abundance in the Neuse River Estuary.
- Generated a five-parameter mechanistic model of *Vibrio* abundance.
- Longest study-period of *Vibrio* in the Neuse River Estuary.
- Incorporates data from extreme events such as storms, floods, and droughts.

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Neuse Estuary Eutrophication Model (NEEM)

- Two- dimensional laterally averaged model
- Application of CE-QUAL-W2 (61 segments, 20 layers)

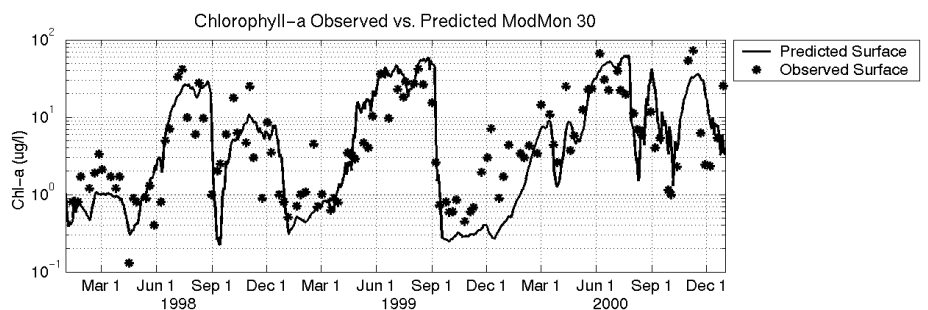




CE-QUAL-W2 Water Quality State Variables

<div style="border: 1px solid black; padding: 5px; margin-bottom: 10px; text-align: center;"><i>Physical Properties</i></div> <p>1. Temperature 2. Salinity 3. Suspended Solids</p> <div style="border: 1px solid black; padding: 5px; margin-bottom: 10px; text-align: center;"><i>Phytoplankton</i></div> <p>4. Diatoms & Dinoflagg's 5. Chloros & Cryptos 6. Blue-Green Algae</p> <div style="border: 1px solid black; padding: 5px; margin-bottom: 10px; text-align: center;"><i>Organic Matter</i></div> <p>7. LPOM 8. RDOM 9. RPOM 10. Part Silica 11. LDOM</p>	<div style="border: 1px solid black; padding: 5px; margin-bottom: 10px; text-align: center;"><i>Nutrients</i></div> <p>12. NH₃ 13. NO₂+ NO₃ 14. Dissolved Silica 15. Ortho Phosphate</p> <div style="border: 1px solid black; padding: 5px; margin-bottom: 10px; text-align: center;"><i>Oxidants/Reductants</i></div> <p>17. Dissolved Oxygen</p> <div style="border: 1px solid black; padding: 5px; margin-bottom: 10px; text-align: center;"><i>Sediment Organic Matter</i></div> <p>18. Labile SOM 19. Refr. SOM</p>
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Old NEEM vs. New NEEM: Chlorophyll predictions, mid-estuary 1998- 2000



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NEEM Development: Added a Sediment Diagenesis Submodel

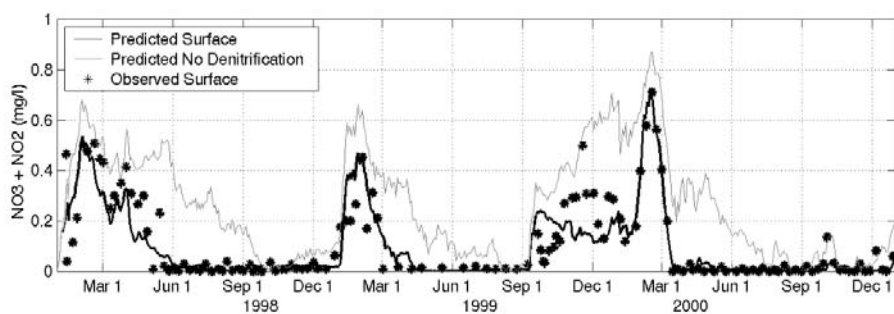


Figure 9. Predicted (bold line), predicted with denitrification turned off (gray line), and observed (symbols) nitrite + nitrate in the near-surface waters at MODMON station 120 from January 1998 to December 2000.



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NEEM Development: Added a light model too

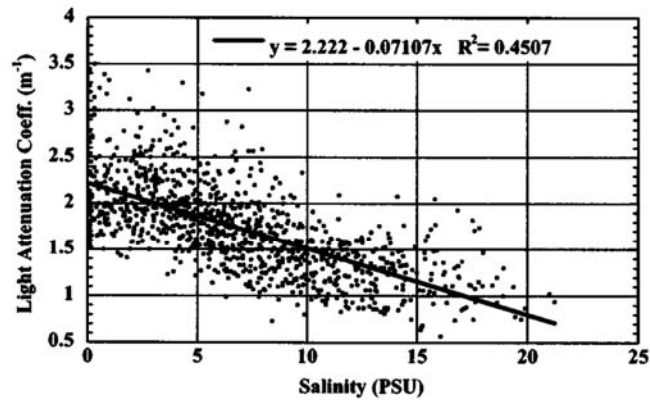
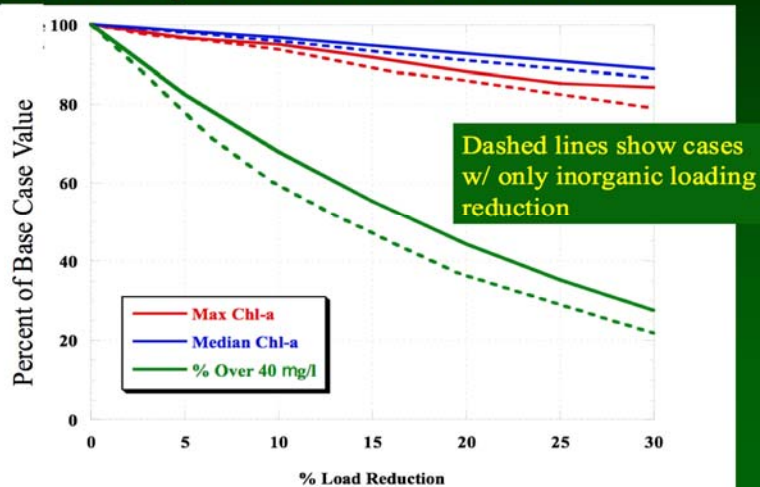


Fig. 4. Measured light attenuation coefficients versus observed salinities in Neuse River Estuary

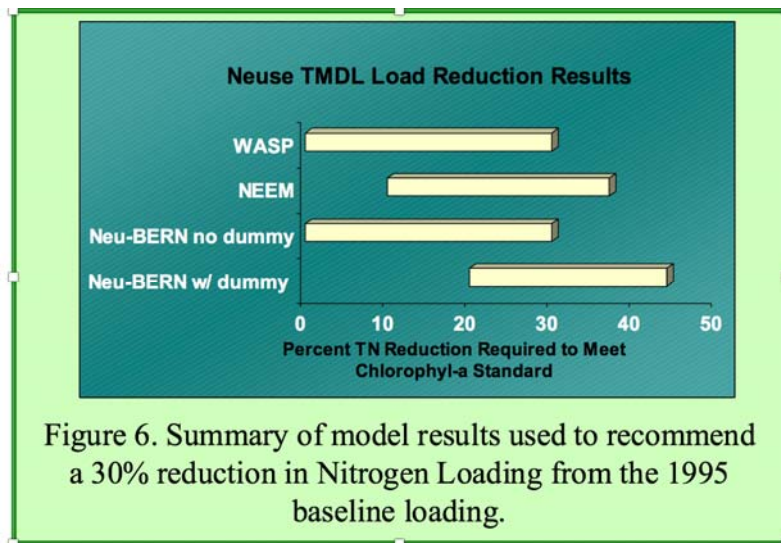
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TMDL Basis - Nitrogen Load Reductions Scenarios

Sensitivity to Load Reduction



Multiple Models Used as Basis for TMDL



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NRE Water Quality Conditions Improved – For a While

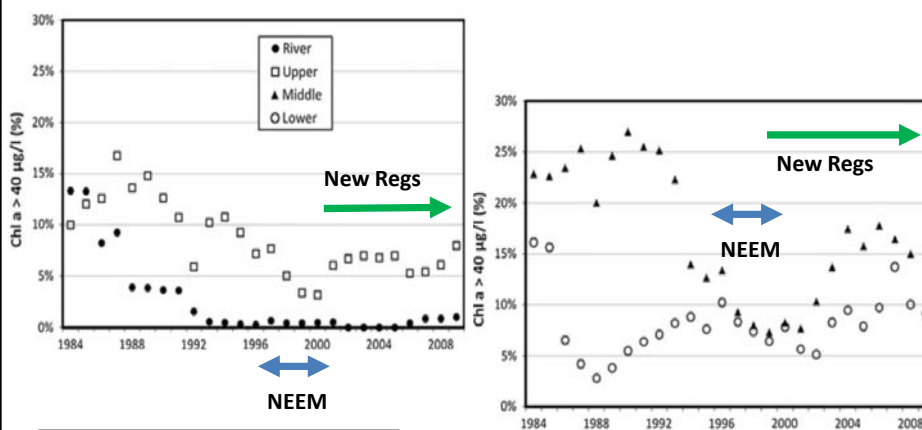
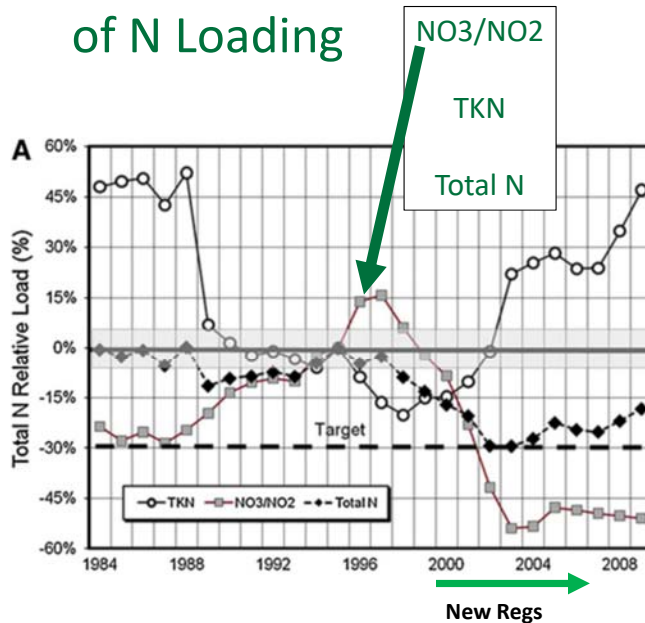


Fig. 9 Cumulative frequency of Chl a greater than 40 µg/l standard by 5-year assessment period and zone along NR Estuary. Values are plotted in year 5 of each period

NRE Trends – Changes in Form & Location of N Loading

Upper Neuse Watershed (Neuse R. @ Clayton)

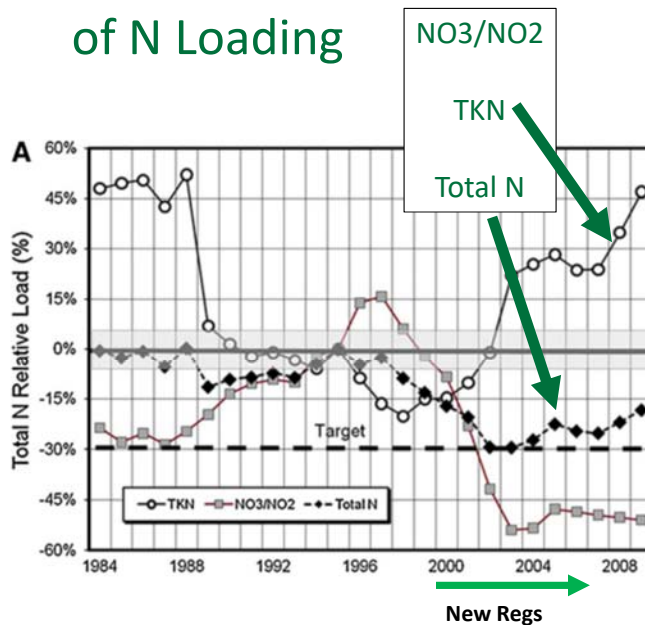
Figure from Lebo et al., 2012, Environmental Management



NRE Trends – Changes in Form & Location of N Loading

Upper Neuse Watershed (Neuse R. @ Clayton)

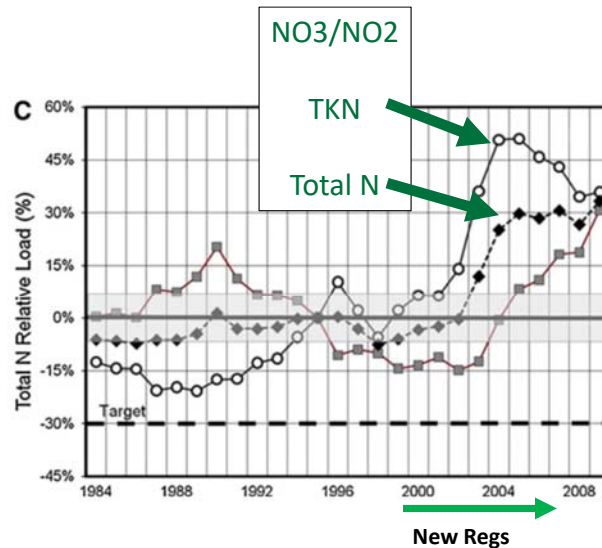
Figure from Lebo et al., 2012, Environmental Management



Nutrient Load Reductions Not Fully Met and Varies by N Form & Location

Estuary
Branch
(Trent River)

Figure from Lebo et al., 2012, Environmental Management



Now Working on an Updated Neuse Estuary Eutrophication Model

- Additional Branches and Lower Estuary Segments
- Model Period: June 1997 – May 2009 (13 yrs!)
- Two Key Questions
 1. How Well Does Updated Model Simulate Water Quality Dynamics?
 2. What are the Consequences of Recent Changes in Nitrogen Load Quantity and Quality?



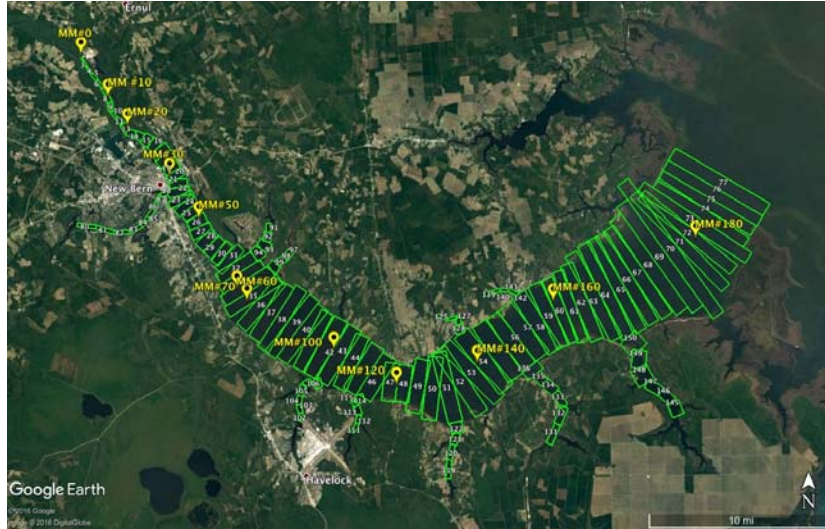
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New W2 grid

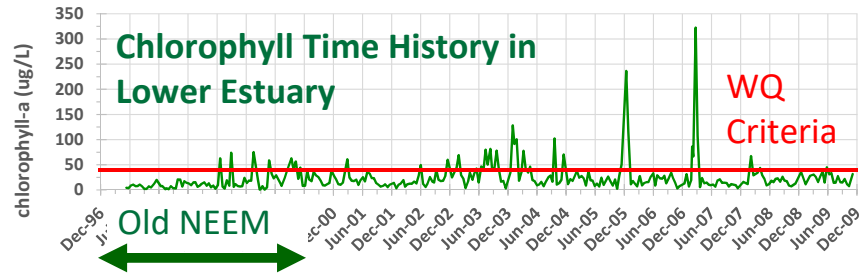
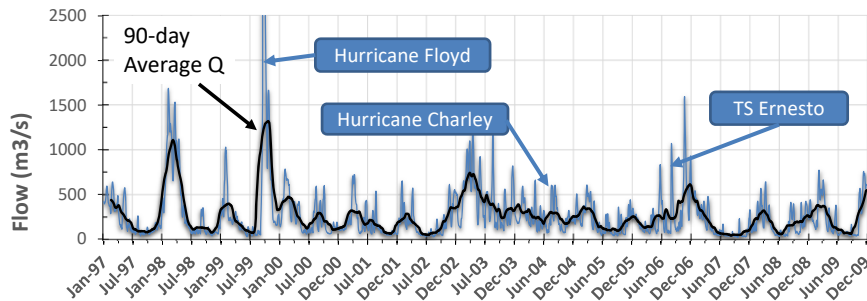
129 segments, 18 layers

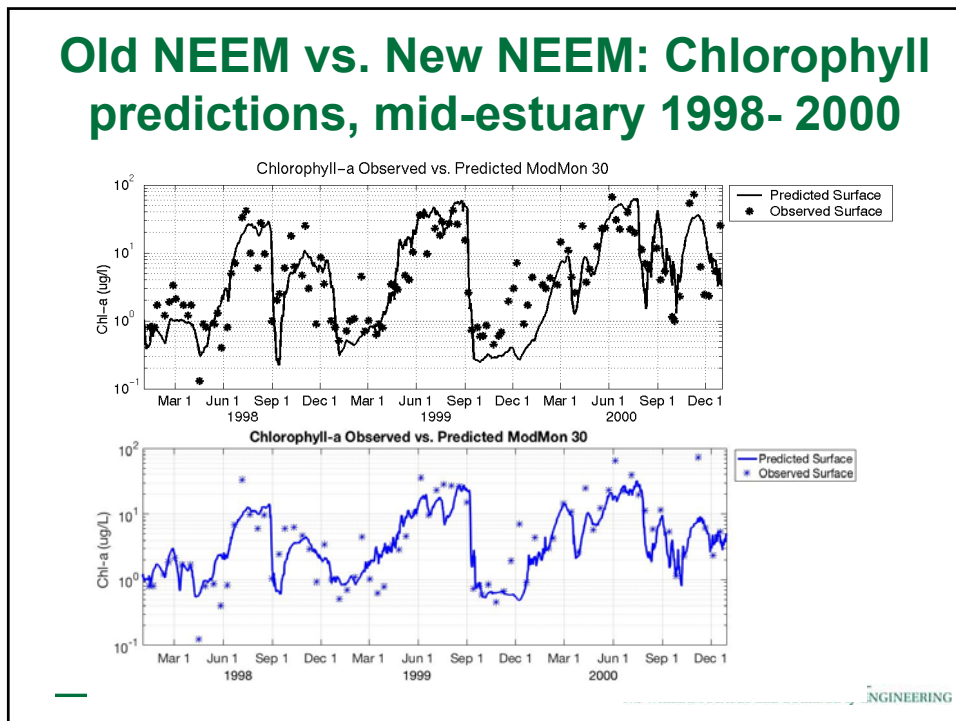
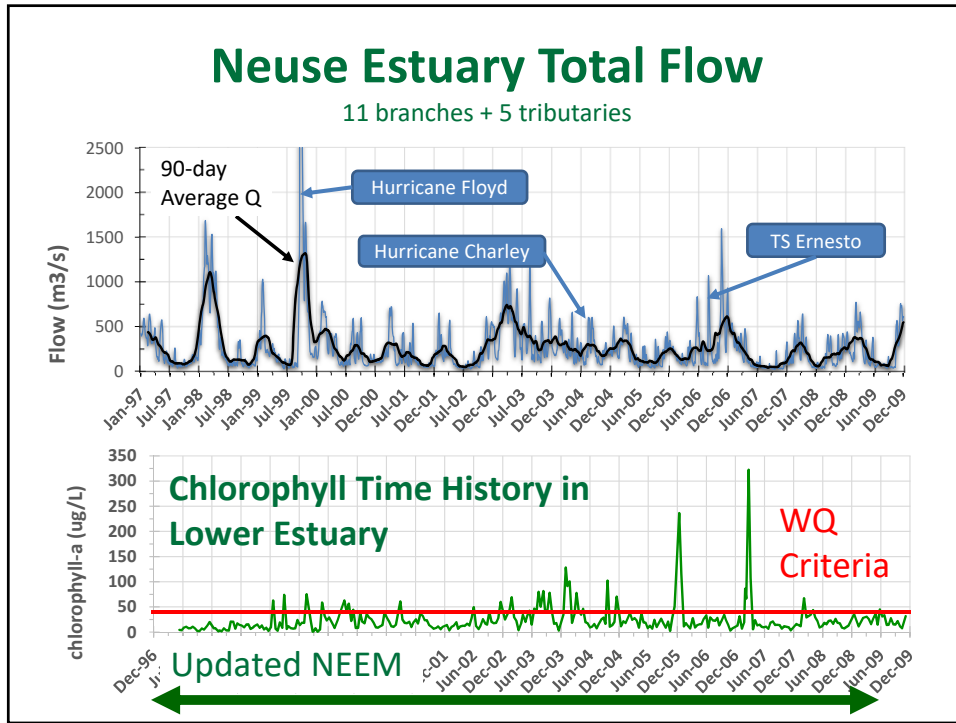
11 branches, 5 tributaries



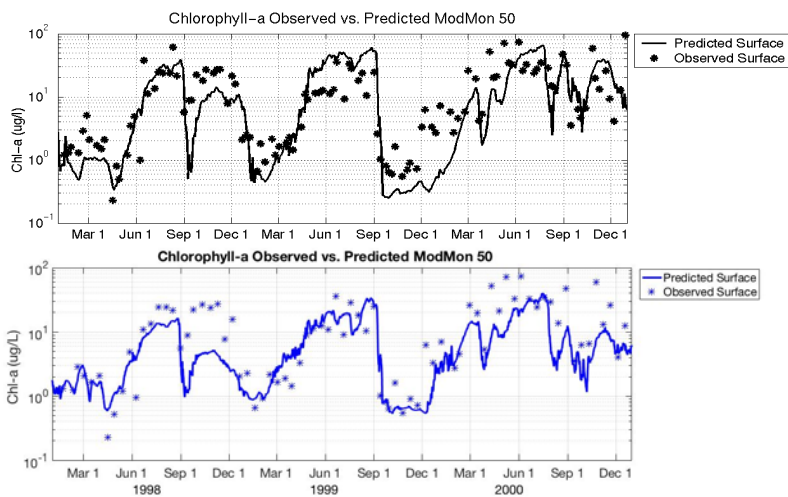
Neuse Estuary Total Flow

11 branches + 5 tributaries



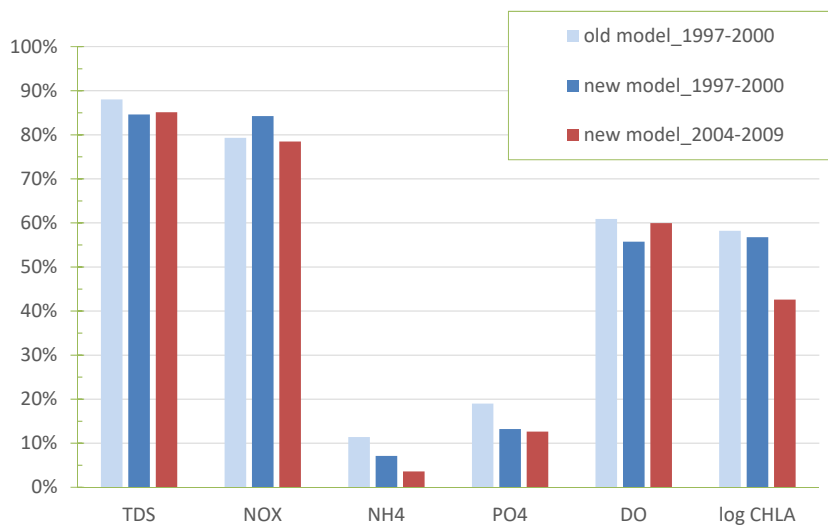


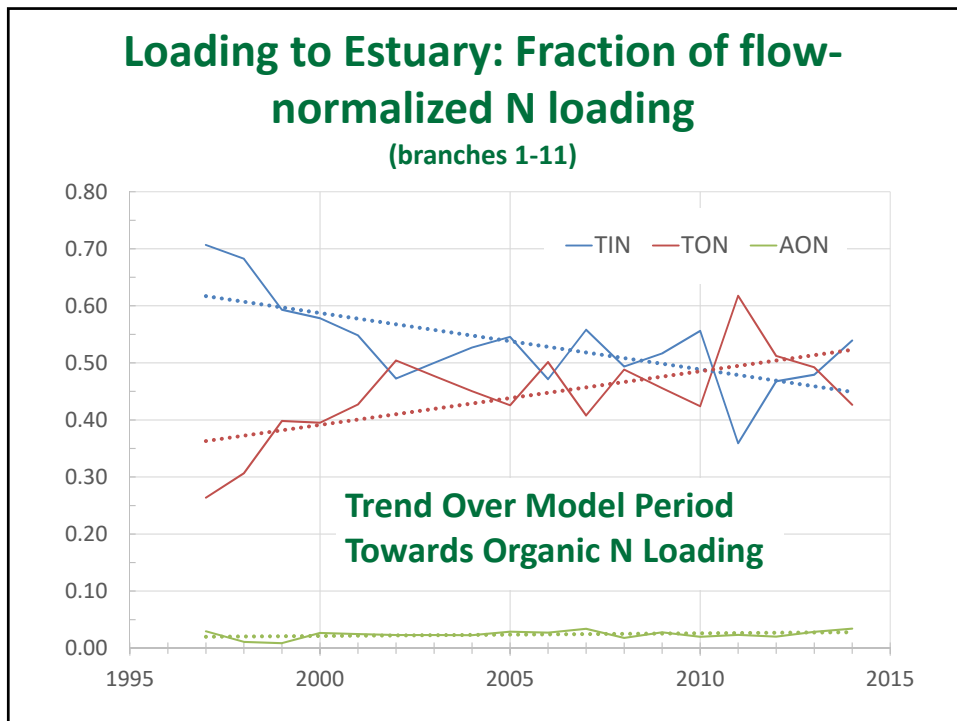
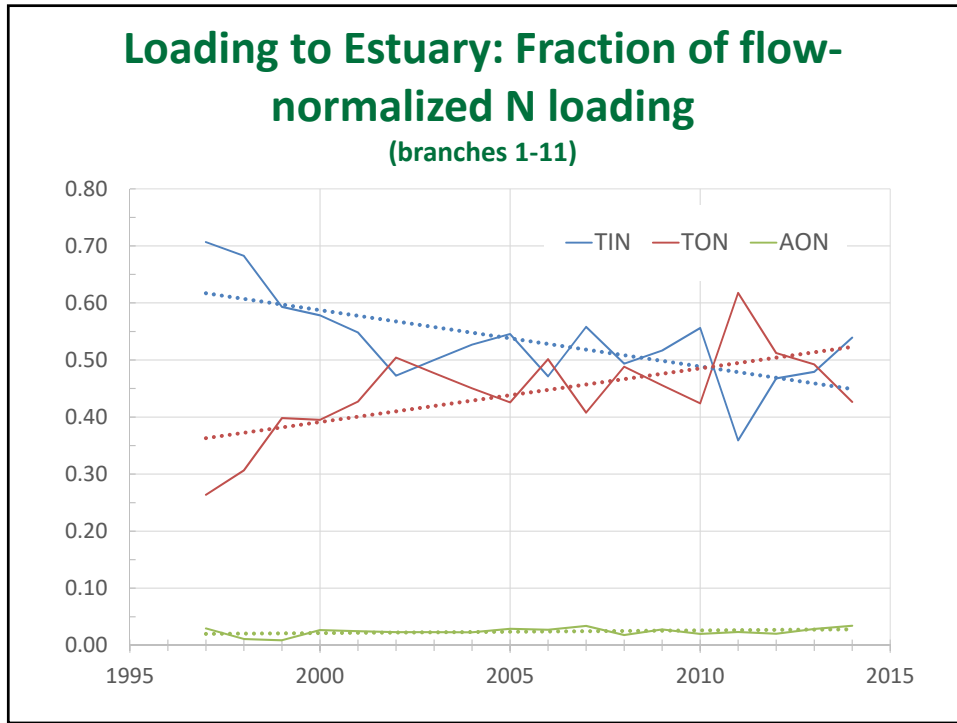
Old NEEM vs. New NEEM: Chlorophyll predictions, mid-estuary 1998- 2000



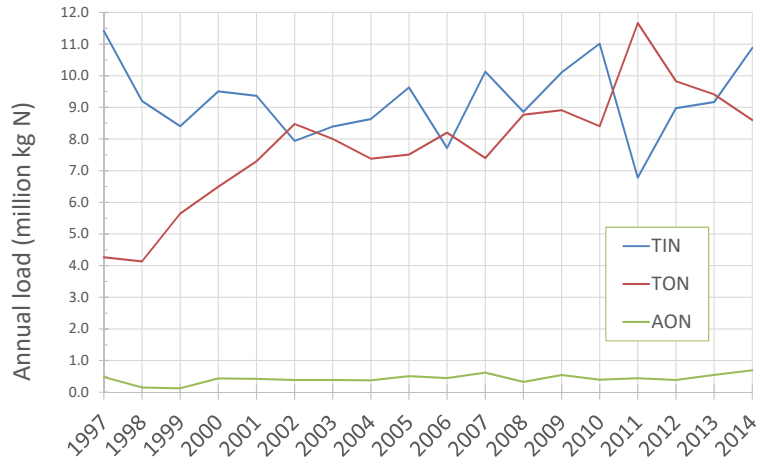
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Correlation between predicted and observed values

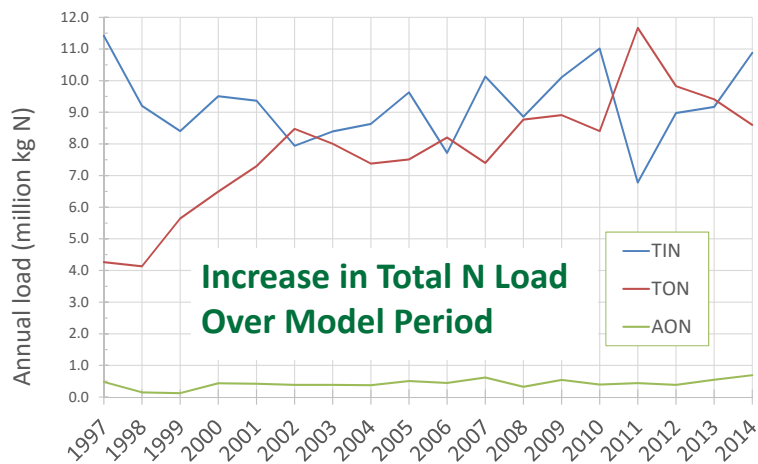




Loading to Estuary: Annual flow-normalized N load (branches 1-11)



Loading to Estuary: Annual flow-normalized N load (branches 1-11)



Latest Results

- Working to Update Sediment Model to Support Scenario Testing (i.e. system sensitivity to load reduction)
- Need to Examine Chlorophyll Frequency Distributions (model vs. predicted)
- Sensitivity to N load reduction much lower in 2004-2009 model runs
 - lack of sediment model?
 - shift to organic N load?
 - Change in spatial-temporal N loading pattern?



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Thank You

Questions?



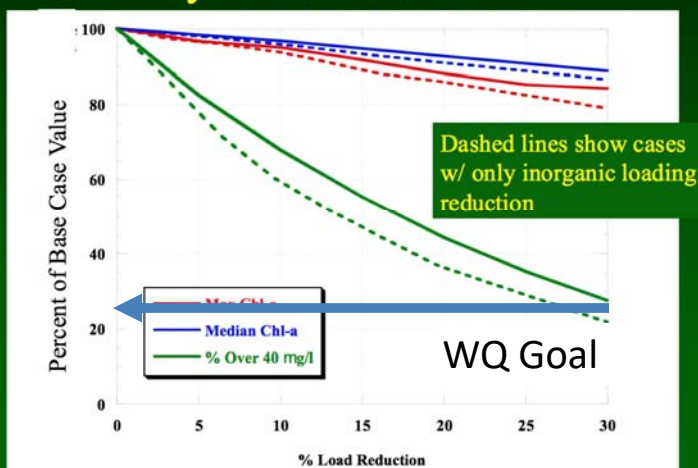
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The Updated Neuse Estuary Eutrophication Model – What to Expect?

ECM 7
Slide

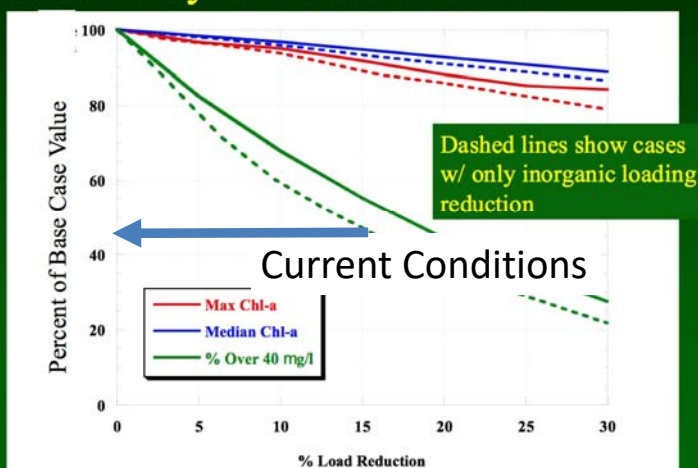
Sensitivity to Load Reduction



The Updated Neuse Estuary Eutrophication Model – What to Expect?

ECM 7
Slide

Sensitivity to Load Reduction



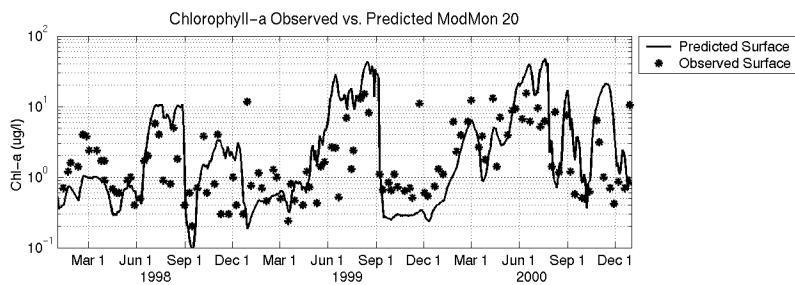
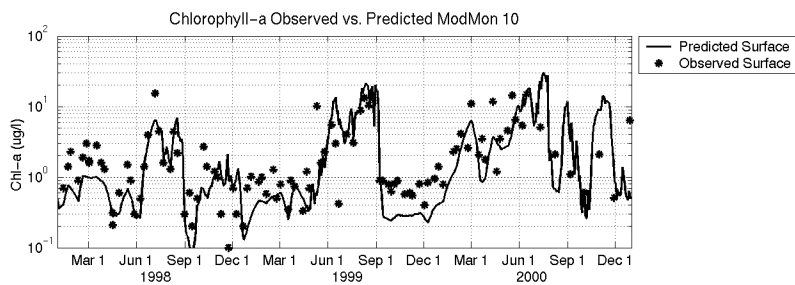
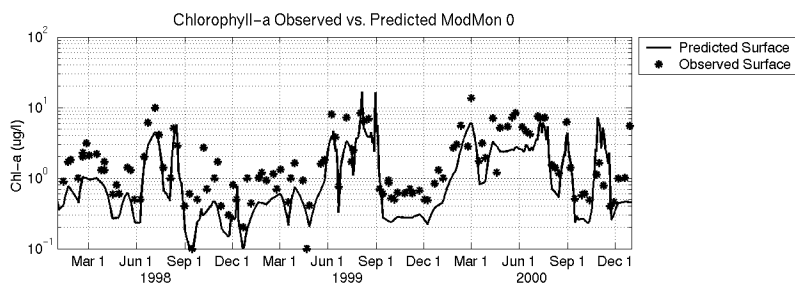
Summary & Future Work

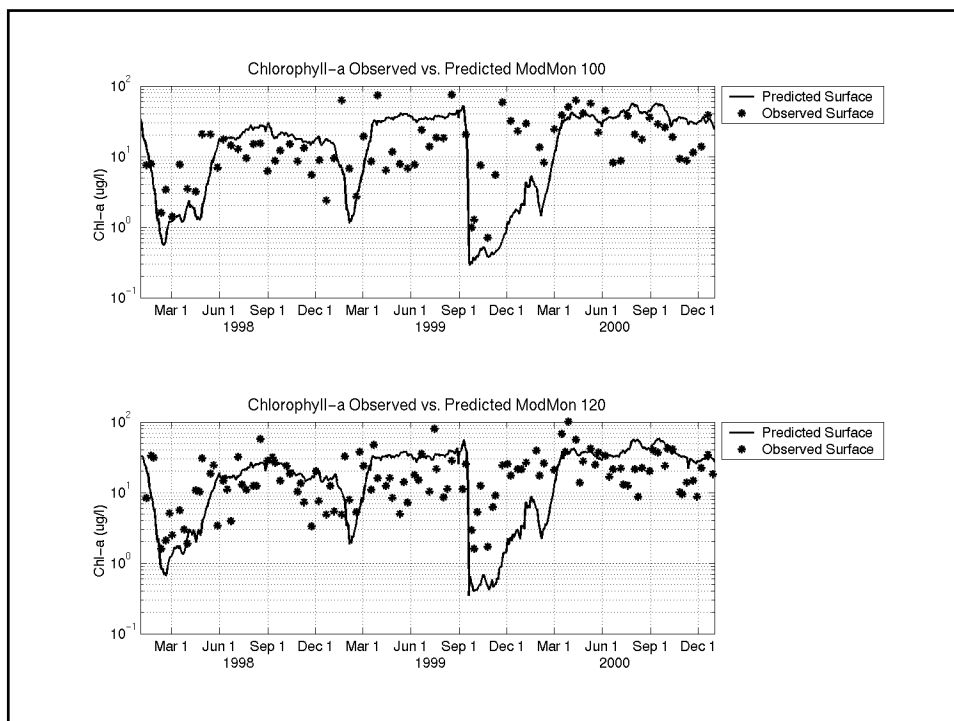
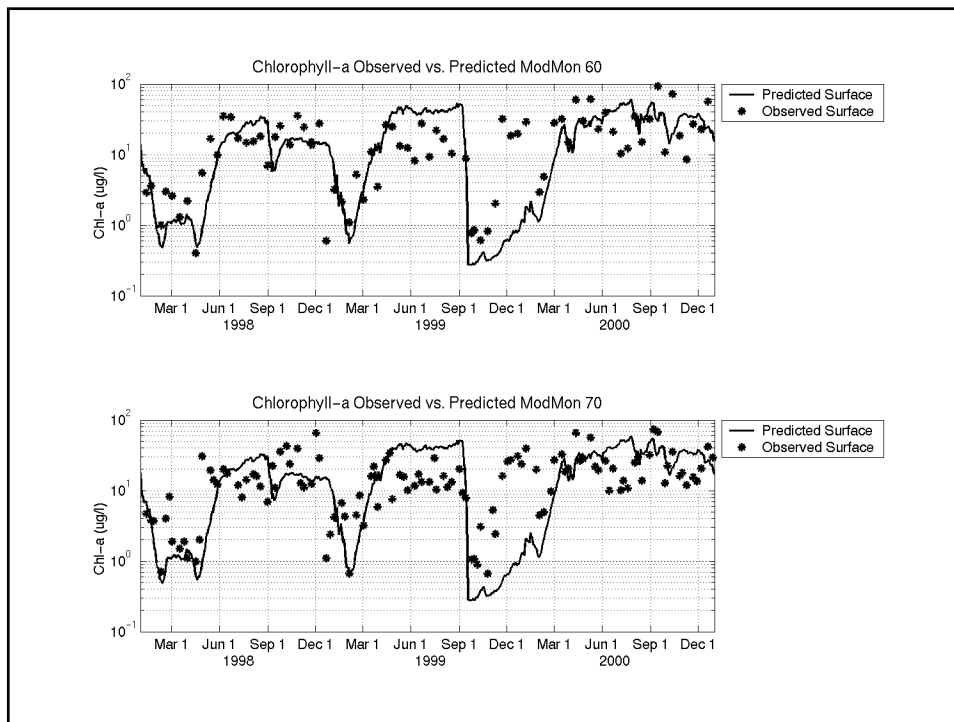
- Updated NRE Model Available by end of 2016
- Greatly expanded simulation time (1997 – 2009)
- Used to examine relative sensitivity to inorganic vs. organic N load
- Model may need additional development of sediment sub-model
- Expected use by NC environmental regulators

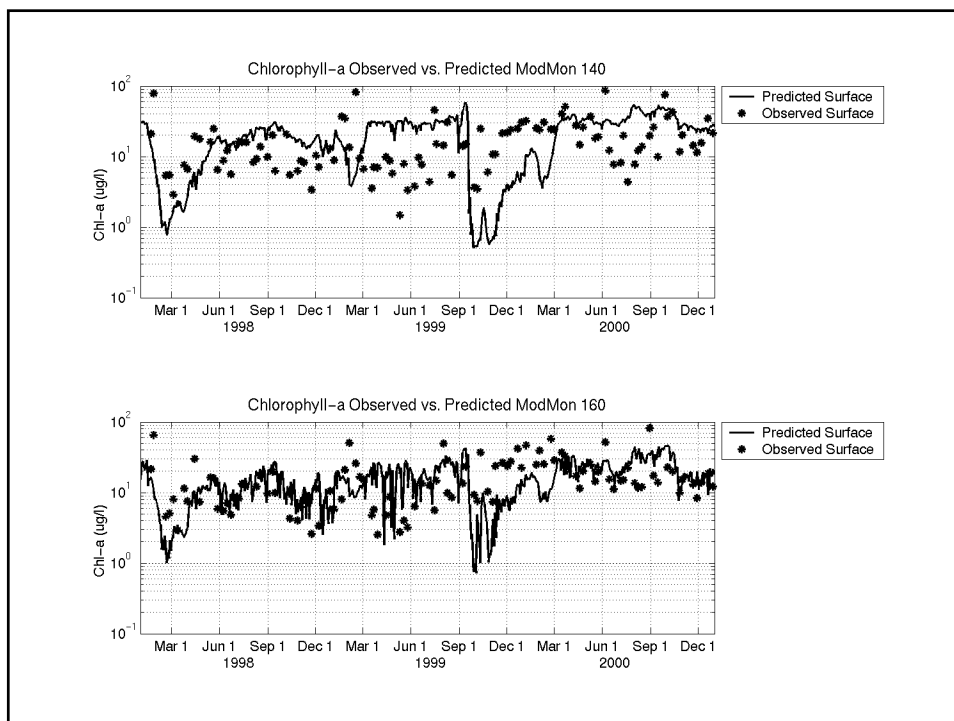
Thank You

Questions?

Chlorophyll-a





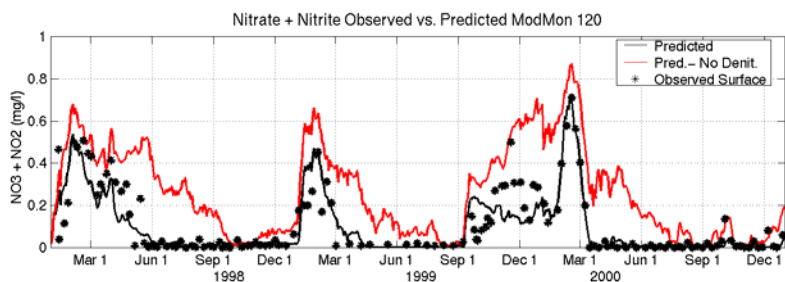
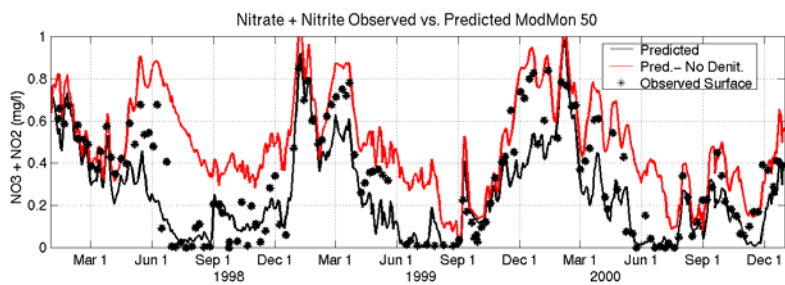


Fit Statistics Summary, '98-'99 Simulations, Entire Estuary

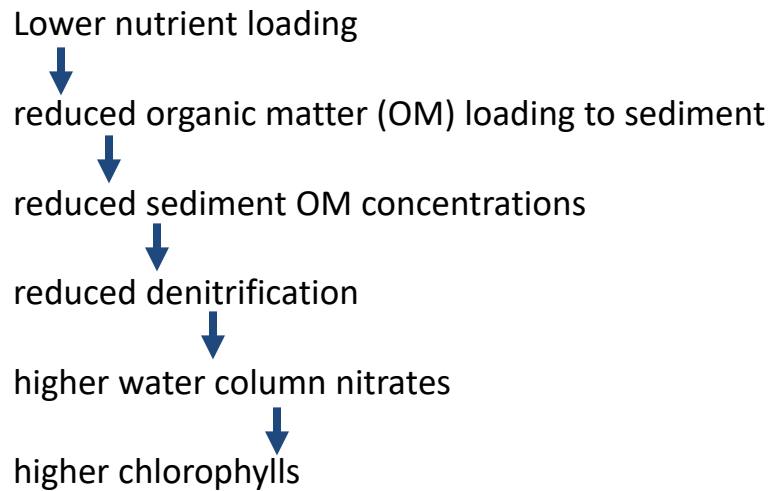
Constituent	# obs	6/97 - 12/99						
		Predictions vs. Observations - All Stations						
		ME	%	MAE	%	RMSE	%	R ²
Salinity (PSU or g/l)	13564	-1.04	-17%	1.46	24%	2.2082	37%	88.0%
Phosphate (mg/l)	1628	0.01	19%	0.02	48%	0.0319	78%	19.0%
Ammonia (mg/l)	1975	-0.01	-13%	0.04	69%	0.0697	122%	11.4%
Nitrate+Nitrite (mg/l)	1807	-0.03	-9%	0.09	29%	0.1405	46%	79.3%
DO (mg/l)	14127	0.12	2%	1.19	16%	1.7629	24%	60.9%

Chl-a, by Station & Region, '98 - '00

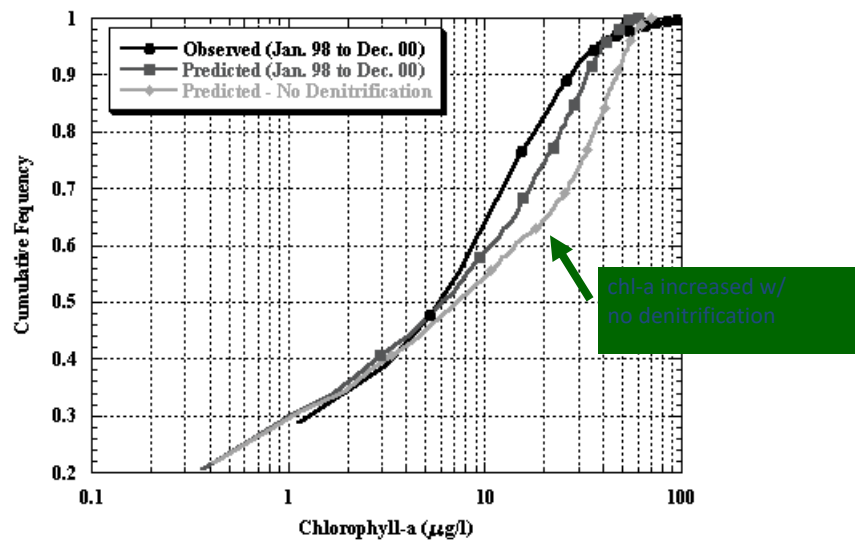
Section	Station	1/98 - 12/00			
		# obs	Log10(Chla ug/l)		
			ME	RMSE	R ²
River	0	192	-0.5931	0.9616	62.2%
	10	162	-0.2065	1.047	43.0%
	20	193	0.1932	1.3144	33.0%
Upper	30	195	-0.0648	1.0821	60.8%
	50	195	-0.2769	1.0963	61.1%
Middle	60	154	-0.218	1.1779	48.2%
	70	194	-0.1701	1.2153	41.1%
Bend	100	154	-0.0865	1.1501	32.8%
	120	193	-0.1733	1.0895	24.7%
Lower	140	175	-0.0751	1.1467	6.9%
	160	171	-0.2093	0.9777	17.5%
River		548	-0.1978	1.1231	41.6%
Upper		390	-0.1709	1.0892	61.0%
Middle		348	-0.1913	1.1989	44.4%
Bend		347	-0.1348	1.1168	28.8%
Lower		346	-0.1414	1.0885	11.3%
Total		1980	-0.1708	1.1195	58.2%



Sediment Denitrification Causes Negative Feedback w/ Chl-a

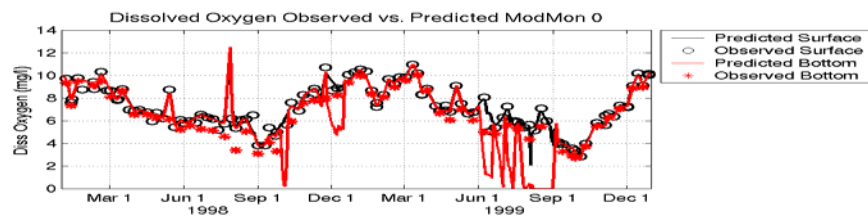


Effect of no denitrification on chl-a

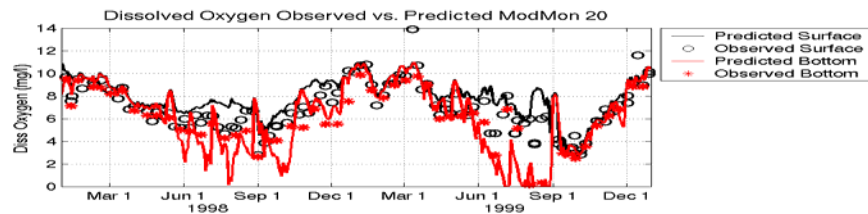
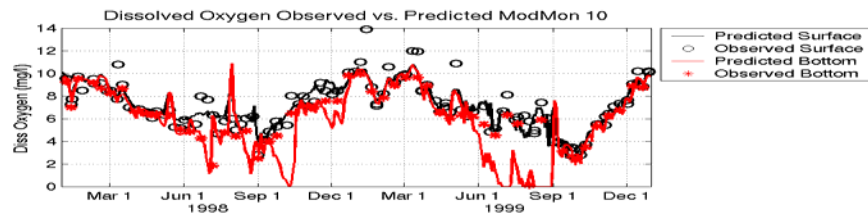


Dissolved Oxygen

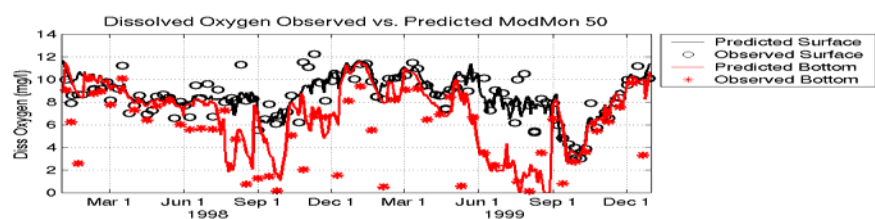
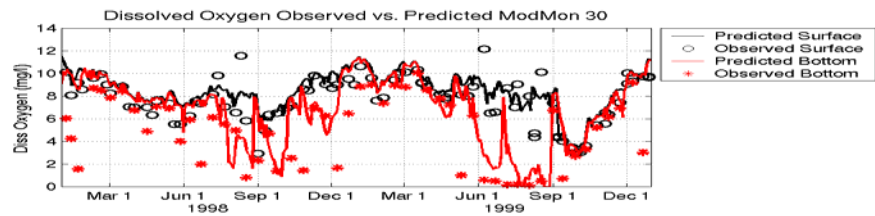
River



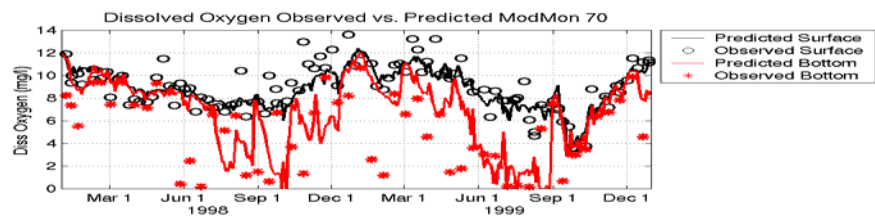
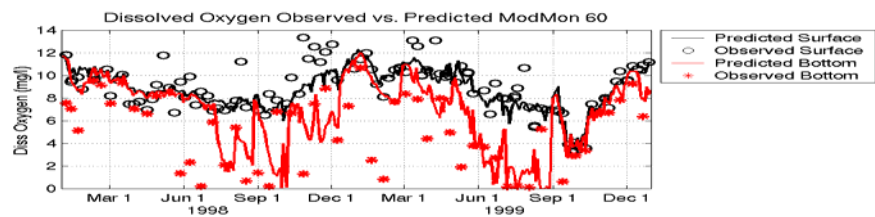
River



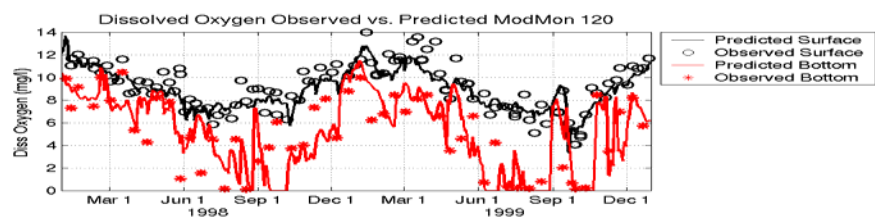
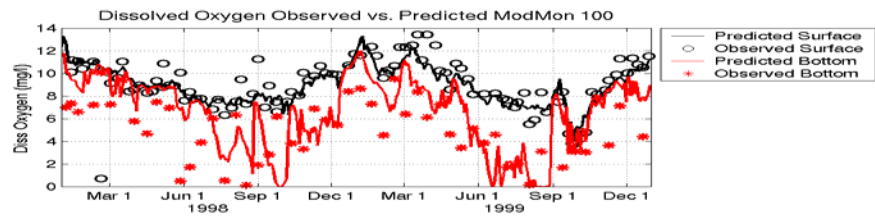
Upper Estuary



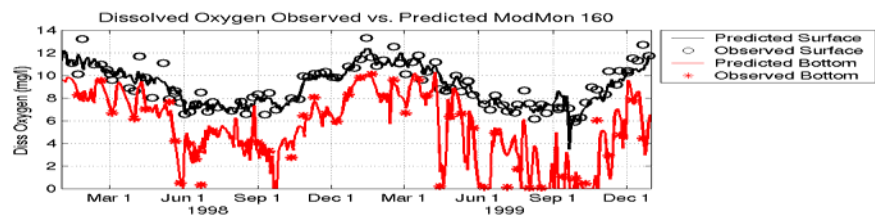
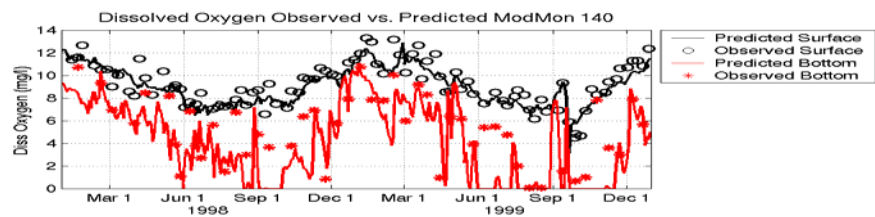
Middle Estuary



Bend of Estuary

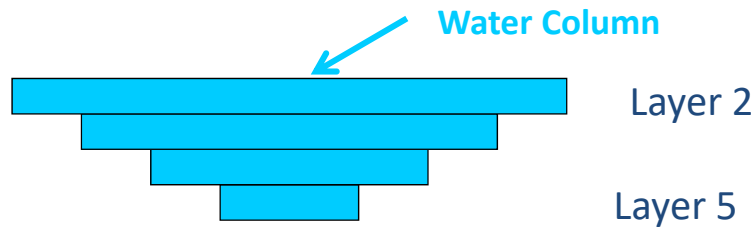


Lower Estuary



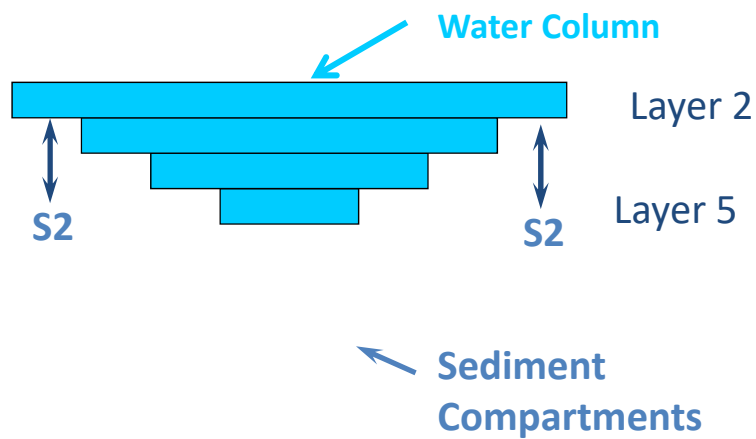
Each Segment divided into Layers

6 - 18 layers vertically (top 3 = 1 m, bottom 15 = 0.5 m)
 Layers may have varying widths



Each Segment divided into Layers

6 - 18 layers vertically (top 3 = 1 m, bottom 15 = .5 m)
 Layers may have varying widths
 Layered sediment compartments too

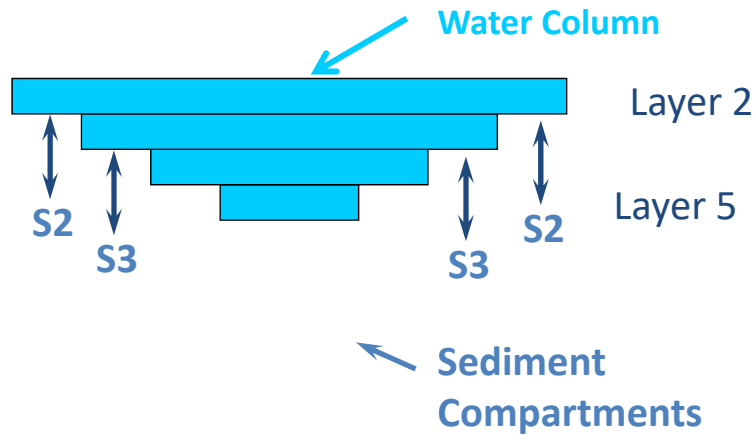


Each Segment divided into Layers

6 - 18 layers vertically (top 3 = 1 m, bottom 15 = .5 m)

Layers may have varying widths

Layered sediment compartments too

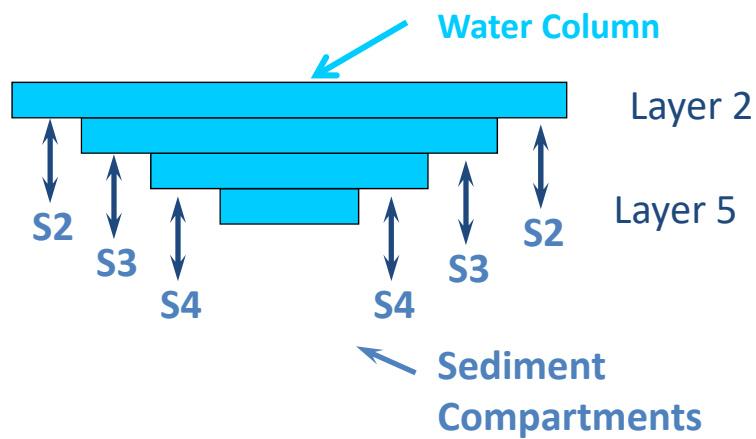


Each Segment divided into Layers

6 - 18 layers vertically (top 3 = 1 m, bottom 15 = .5 m)

Layers may have varying widths

Layered sediment compartments too

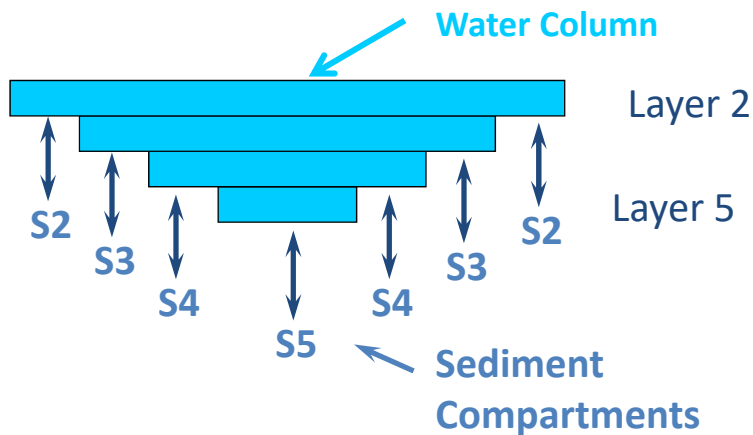


Each Segment divided into Layers

6 - 18 layers vertically (top 3 = 1 m, bottom 15 = .5 m)

Layers may have varying widths

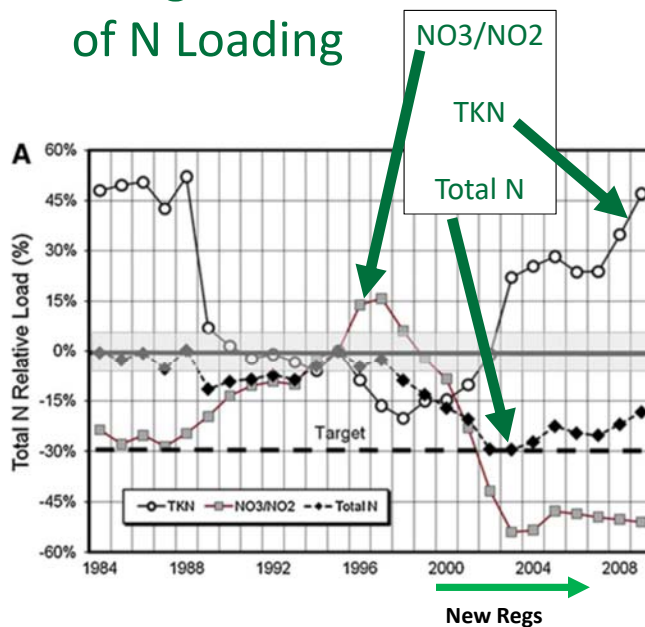
Layered sediment compartments too



NRE Trends – Changes in Form & Location of N Loading

Upper Neuse Watershed (Neuse R. @ Clayton)

Figure from Lebo et al., 2012, Environmental Management



Nutrient Load Reductions Not Fully Met and Varies by N Form & Location

Lower Neuse
Watershed
(Contentnea
Creek)

Figure from Lebo et
al., 2012,
Environmental
Management

