Satellite Remote Sensing of Chlorophyll a in Support of Nutrient Management in the Neuse and Tar-Pamlico River estuaries

Darryl J. Keith, Research Oceanographer

EPA/ORD/NHEERL/Atlantic Ecology Division

Monitor Track
Berne Room
11:30am – noon

Albemarle-Pamlico Ecosystem Symposium
Embarking on a New Voyage

Introduction

- The North Carolina Environmental Management Commission (EMC) has adopted as a water quality standard that chlorophyll *a* concentration should not exceed 40 µg/L in sounds, estuaries and other slow-moving waters.

- Exceedances require the development of a Total Maximum Daily Limit (TMDL) for nutrients in that water body.

- Chlorophyll *a* was chosen as the endpoint to manage total nitrogen concentrations in the Phase I TMDL for the Neuse River

- TMDL compliance would be achieved if Chl *a* exceedances occurred in fewer than 10% of the samples collected in a specified area and time

(aka “10/40 criterion” or “Neuse Rules”)

Questions

- What is the relationship between chlorophyll *a* and total nitrogen (TN) in east coast estuaries and the Neuse River estuary in particular?
- Can the amount of estuarine acres impaired by chlorophyll *a* be determined using the high spatial capability of MERIS derived data?
- Can TMDL compliance and chlorophyll exceedances in the Neuse and Tar-Pamlico River estuaries be assessed at daily and annual time scales from MERIS imagery?
- Which summary statistic of chlorophyll *a* concentrations (sample mean, median, and 90^{th} percentile values) is the most useful for determining TMDL violations and to support environmental compliance monitoring?

Methods

- Conducted linear regression analysis of TN concentrations and Chl *a* values from Mid-Atlantic (including the Neuse River estuary) and New England estuaries.

  **Datasets were collected by the USEPA Mid Atlantic Integrated Assessment (MAIA-1998) and National Coastal Assessment (NCA) Programs (2000 - 2004) as well as the Lower Neuse Basin Association (LNBA-1995 and 1998)*

- Used the MERIS Chl *a* product derived from atmospherically-corrected, full resolution (300 X 300 m pixel size) images (n= 206) of the Neuse and Tar-Pamlico River estuaries to determine the number of pixels exceeding 40 µg/L from January 2006 to December 2009.

  ** MERIS images were acquired from the European Space Agency (ESA) by Ross Lunetta of the EPA National Exposure Research Laboratory (NERL) Landscape Characterization Branch (LCB) in 2009 to create the Albemarle-Pamlico Basin Change Detection Viewer website (http://maps6.epa.gov/aptw/viewer.htm).*

Methods

- Used Type I linear regression to develop a semi-empirical model to predict Chl *a* concentrations (Chl $a_{ambient}$) calibrated for the Neuse and Tar-Pamlico River estuaries from MERIS chlorophyll values using *in situ* Chl *a* data from FerryMon and the NCDENR Ambient Monitoring System (AMS).

* The accuracy of the correction algorithm was assessed by calculating the goodness-of-fit (R^2) of measured vs. predicted values

*Error was assessed from Root Mean Square Error (RMSE) of the corrected Chl *a* concentrations from:

$$RMSE\ (\mu g/L)=\sqrt{((\sum(Chl\ a_{measured})-Chl\ a_{predicted})^2)/(N-1)}$$

where N = number of samples

Methods

- Daily compliance of the 10/40 criterion for the Neuse and Tar-Pamlico estuaries was evaluated by summing the number of pixels with chl *a* concentrations ≥40 ug/L and dividing by the total number of pixels in an image to get a percentage.
- The percentage was then used to determine if violations of the 10/40 criterion had occurred on a daily image.

Did fewer than 10% of the samples collected in an estuary in a day exceed 40 ug/L?

- Annual compliance was evaluated by aggregating all pixels that violated the 10/40 criterion for a given year and dividing by the total number of pixels for all MERIS images during that period.
- The percentage of pixels >40 ug/L was used to determine TMDL status for the year

Did fewer than 10% of the samples collected in an estuary in a year exceed 40 ug/L?

Methods

- The arithmetic mean, median (50th percentile), and 90th percentile concentrations of Chl $a_{ambient}$ for each image were calculated using statistical routines found in the Data Analysis tool package of EXCEL 2007 and plotted against time.

What is ocean/estuary color?

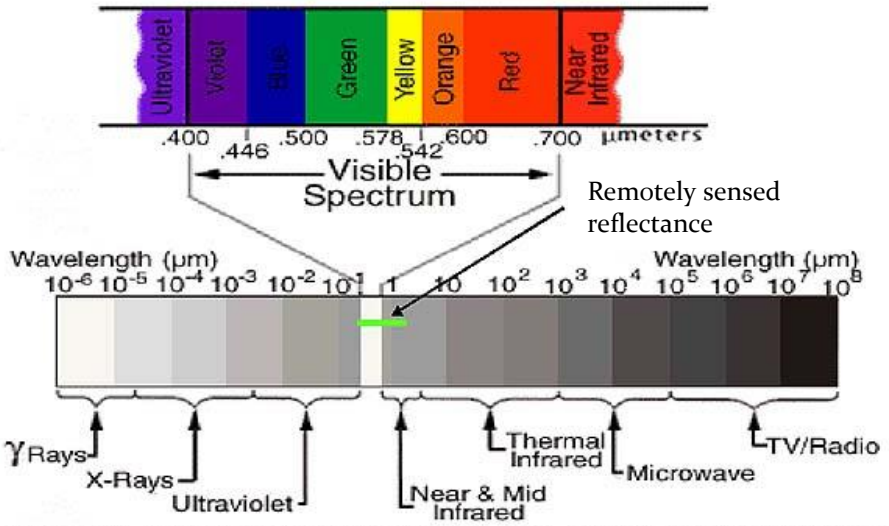


Figure 1. Electromagnetic spectrum and region of reflected light remote sensing.

Definition of Remotely Sensed Reflectance (R_{rs})

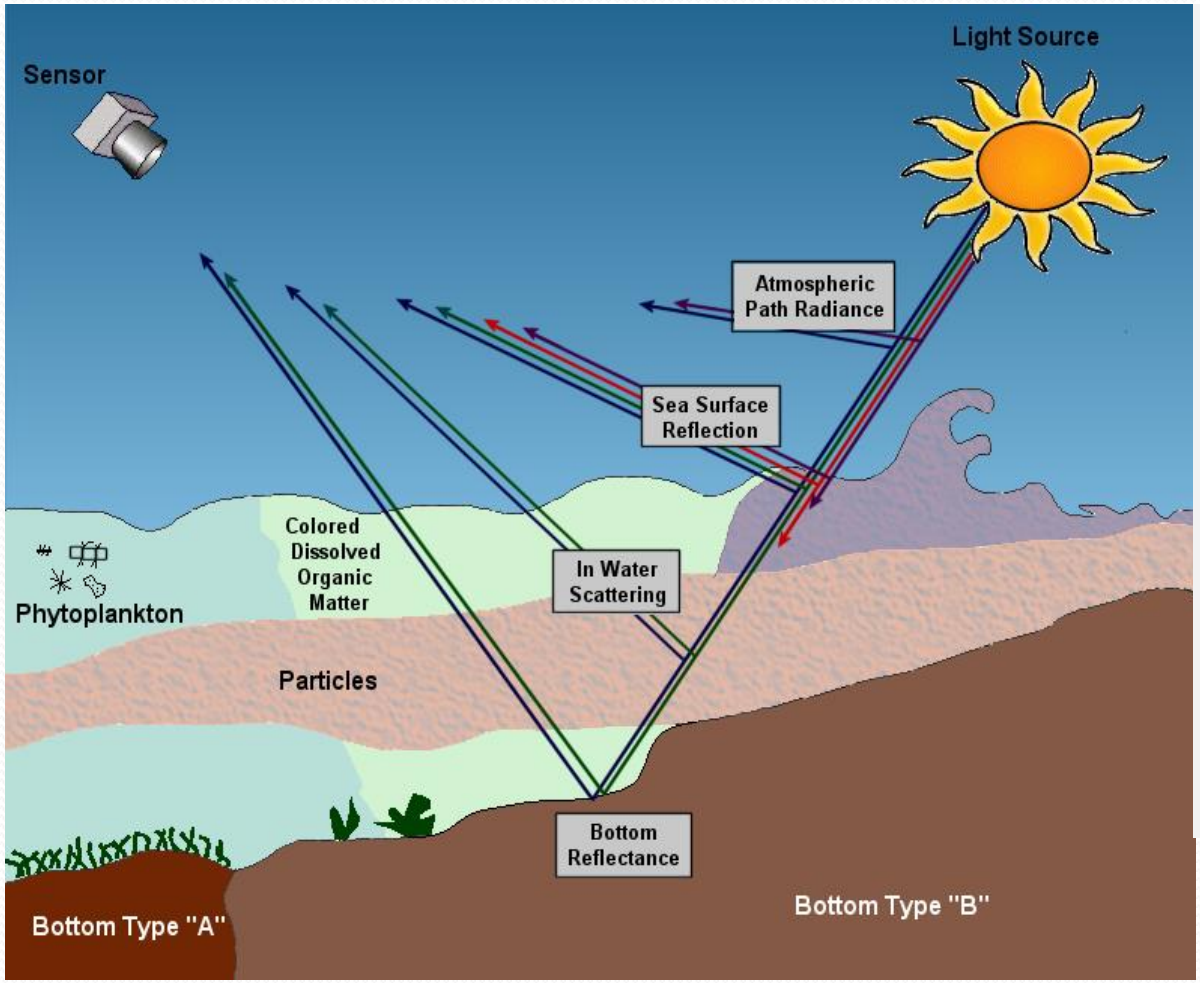
$$R_{rs}(0^+,\lambda) = L_w(0^+,\lambda)/\ E_s(0^+,\lambda)$$

R_{rs} = remotely sensed reflectance (1/sr)

L_w (λ) = water leaving radiance measured above the air/water interface (W m^{-2} sr^{-1}),

E_s (λ) = downwelling irradiance measured above the air/water interface (W m^{-2} sr^{-1})

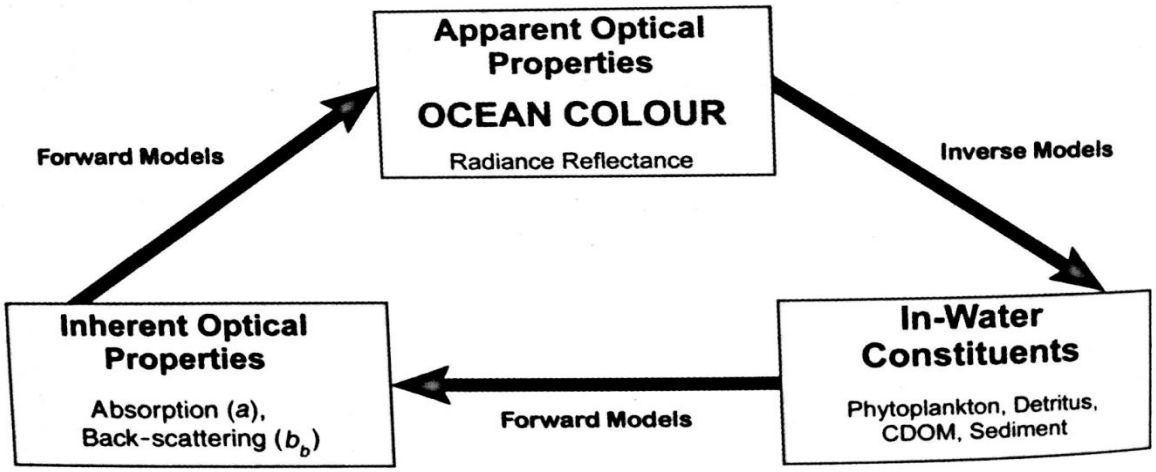
Optical components and pathways of radiance and reflectance in coastal waters



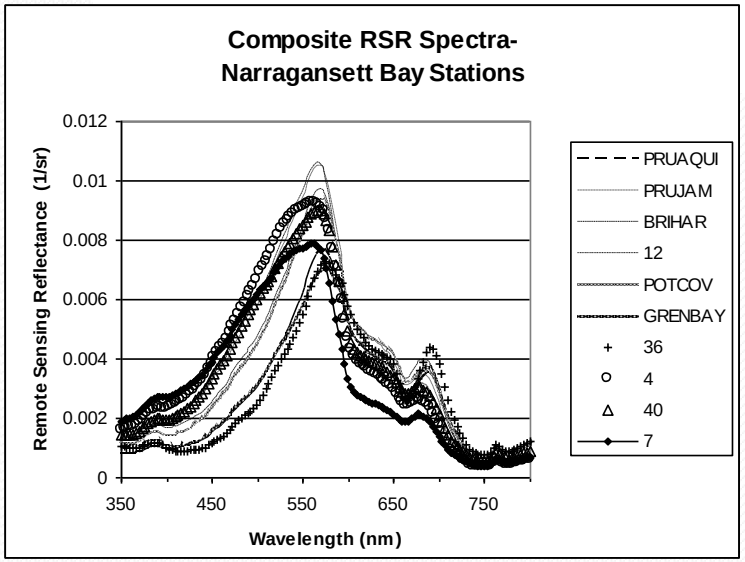
Multiple light paths

- ***Scattering due to:***
  - atmosphere
  - aerosols
  - water surface
  - suspended particles
  - bottom
- ***Absorption due to:***
  - atmosphere
  - aerosols
  - suspended particles
  - dissolved matter

Interrelationship between optical properties and in-water constituents



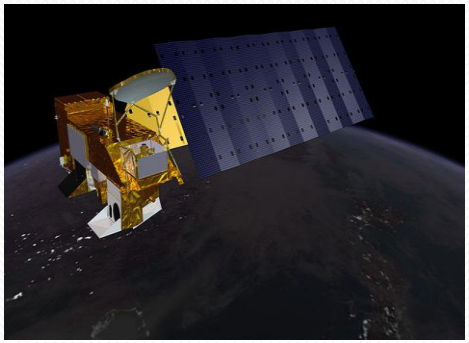
For example:



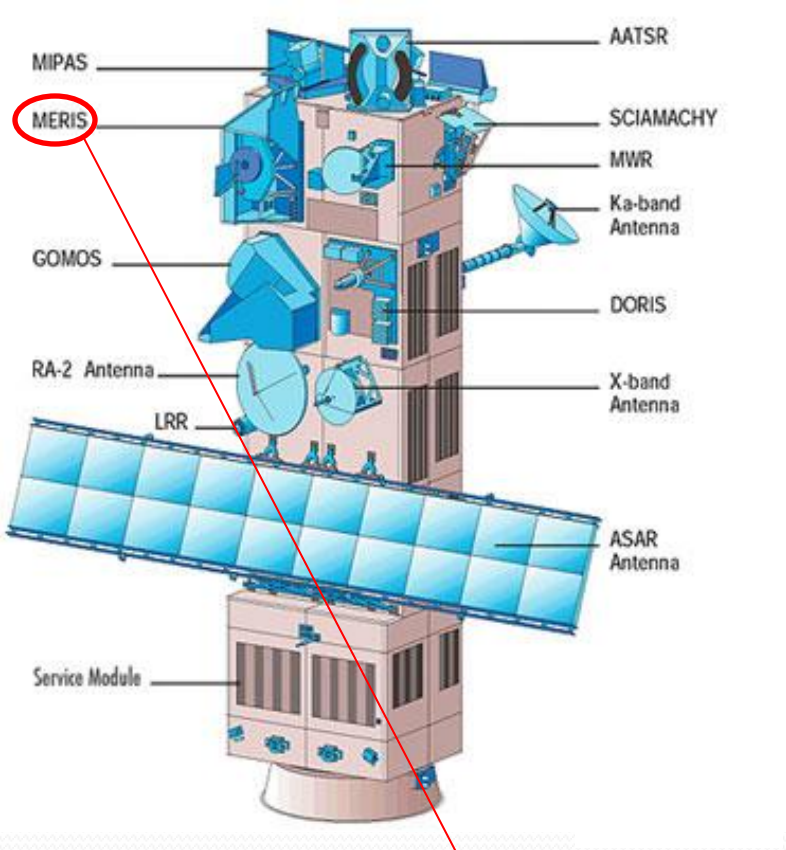
Empirical models

- *[Chl a]*
- *[TSS]*
- *CDOM*
- *salinity*

Space-based Coastal Ocean Color Sensors

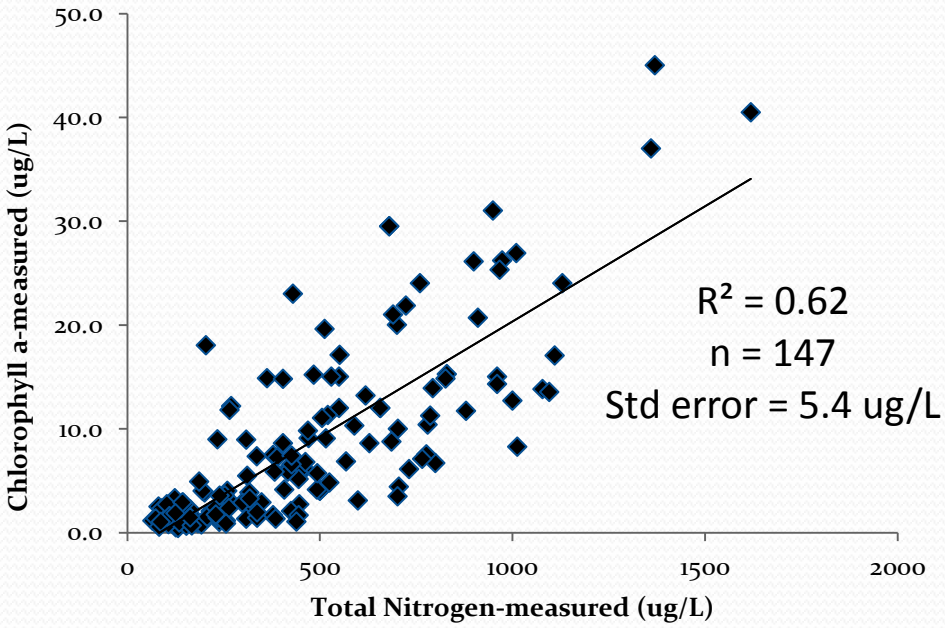
SENSOR (spatial resolution)		PLATFORM	AGENCY	Data Distribution Policy	Data Access	Cost to User
HICO 100 m		International Space Station (Sept 2009 –present)	NASA ISS Program	Products distributed online from HICO/OSU web site	Investigator Proposal Required	No cost
MERIS 300/1000 m		ENVISAT (Jan 2002-Apr 2012)	European Space Agency	Free online access of reduced resolution datasets through 'My Earthnet' website Access restrained data sets by submitting a 'My Earthnet' project proposal	Registration required Investigator Proposal required	No cost No cost
MODIS-Aqua 250/500/1000 m		Aqua (EOS-PM1) (May 2002 – present)	NASA	Ocean color products along with metadata are online at the Ocean Color Data Processing System at Goddard Space Flight Center	Registration required to access online browser	No cost

ESA ENVISAT platform



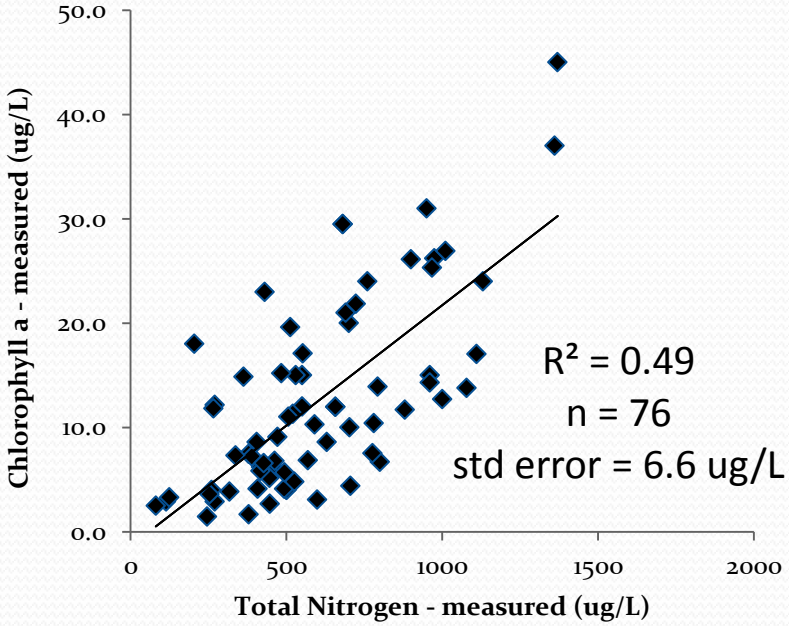
MERIS = Medium Resolution Imaging Spectrometer

Relationship between chlorophyll and total nitrogen in estuarine waters



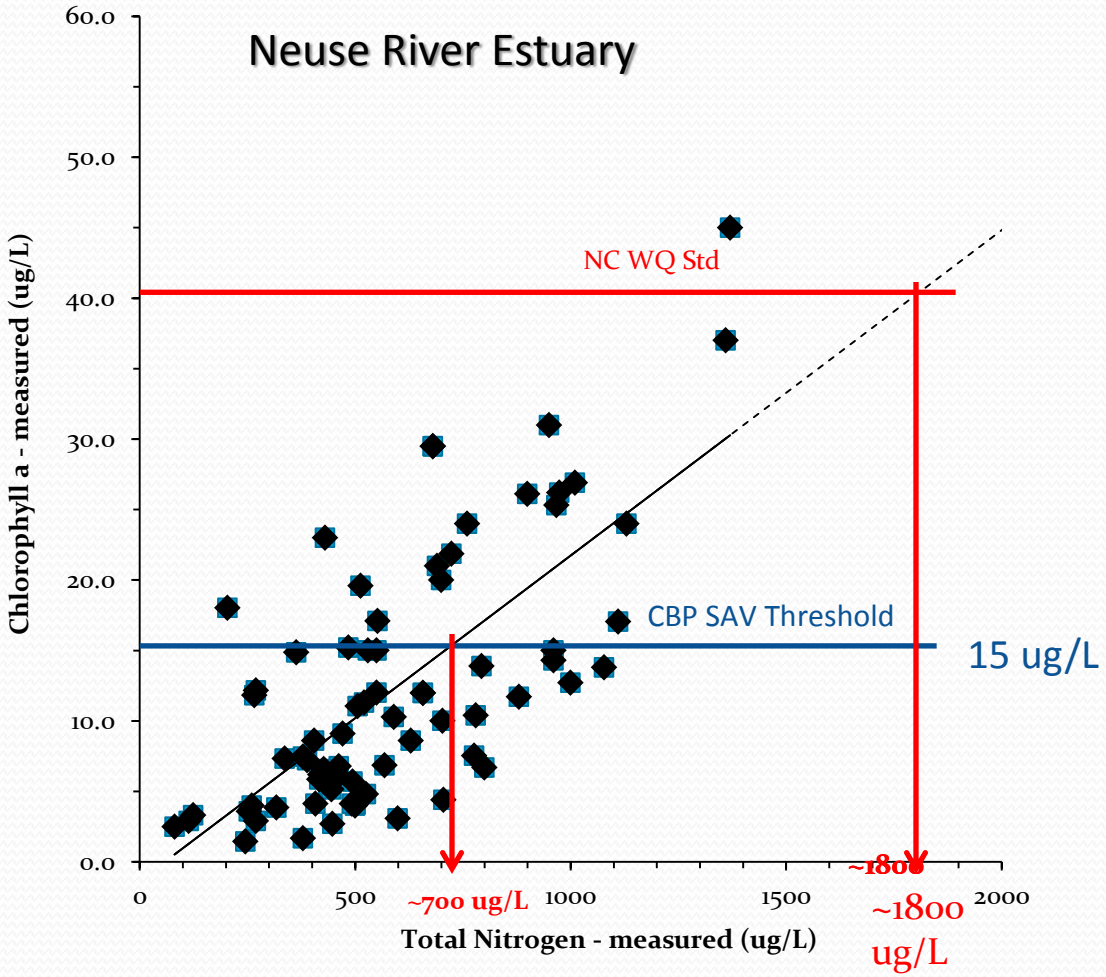
East Coast estuaries
(including Neuse River estuary)

Neuse River Estuary only



**Datasets were collected by the USEPA Mid Atlantic Integrated Assessment (MAIA-1998) and National Coastal Assessment (NCA) Programs (2000 -2004) as well as the Lower Neuse Basin Association (LNBA-1995 and 1998)*

Comparison of Water Quality Thresholds using NC Water Quality and Chesapeake Bay Program Submerged Aquatic Vegetation Standards

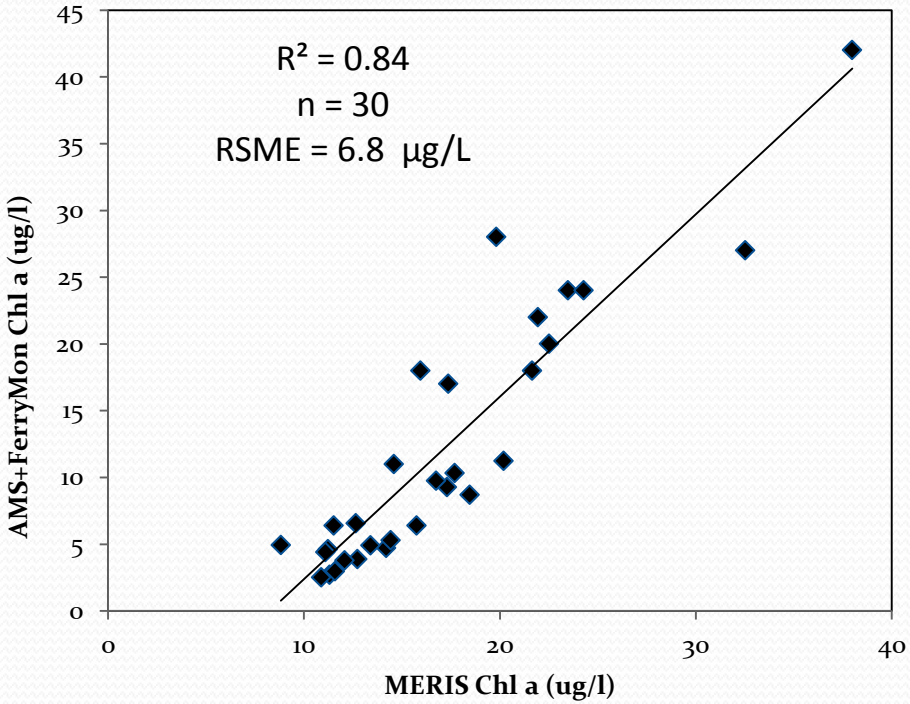


Calibrating MERIS derived chlorophyll values to the Neuse River Estuary

- FerryMon monitoring program from crossings (n = 19) during 2006 – 2009 of the Neuse River Bend and Lower Neuse River Estuary segments (Cedar Island/Orcacoke, Cherry Branch/Minnesott) and in Pamlico Sound (Swan Quarter/Orcacoke)

- NC DWQ Ambient Monitoring System (AMS) Chl *a* data collected along the Lower Neuse River Estuary segment (n= 11) from 2008-2009.

- The *in situ* data were collected at dates and times concurrent with MERIS overflights.

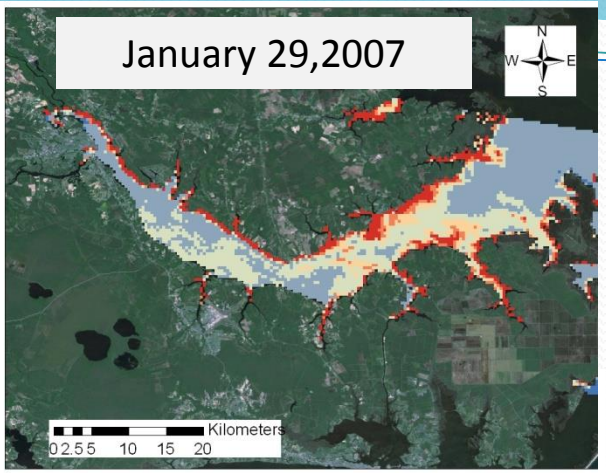


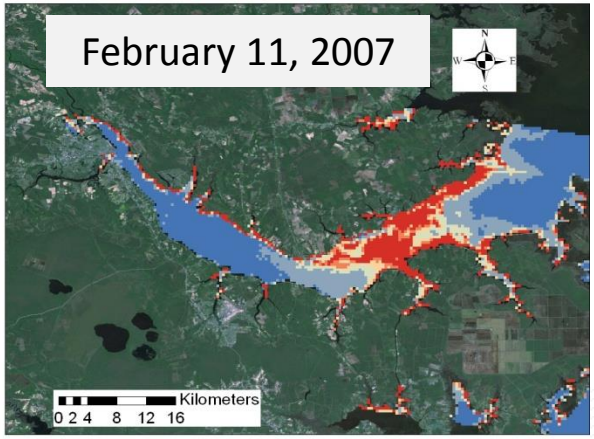
Chl *a* $_{ambient}$ = 1.3671 * (MERIS Chl *a* - 11.283)

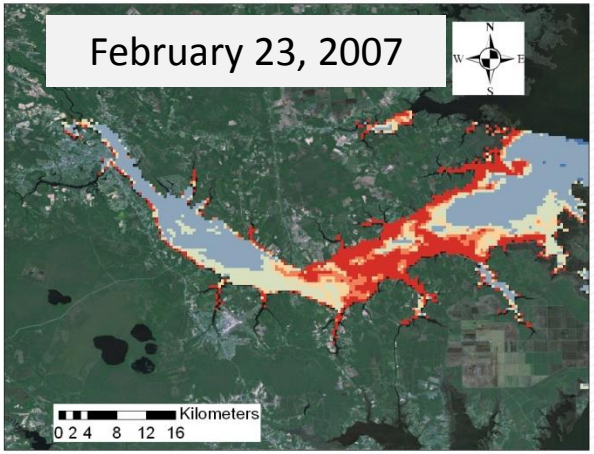
NCDENR

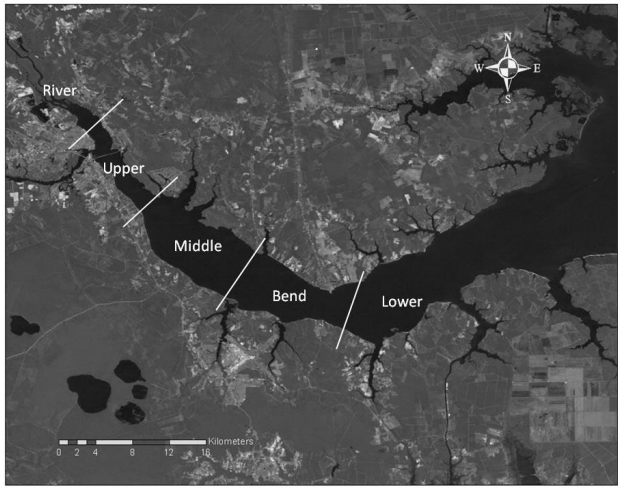
FerryMon

Time Series of a TMDL Violation - Neuse River Estuary: Winter -Spring 2007



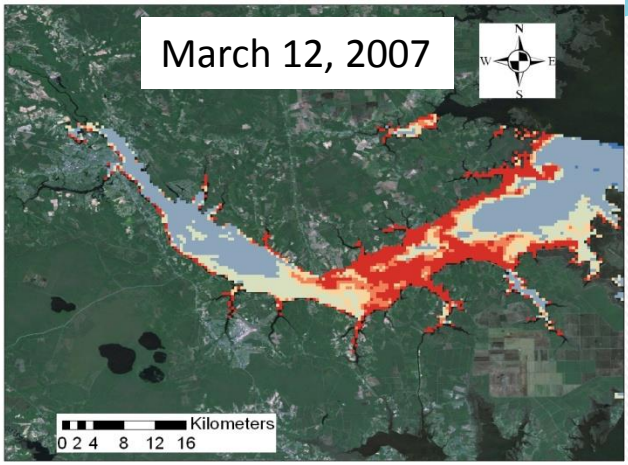


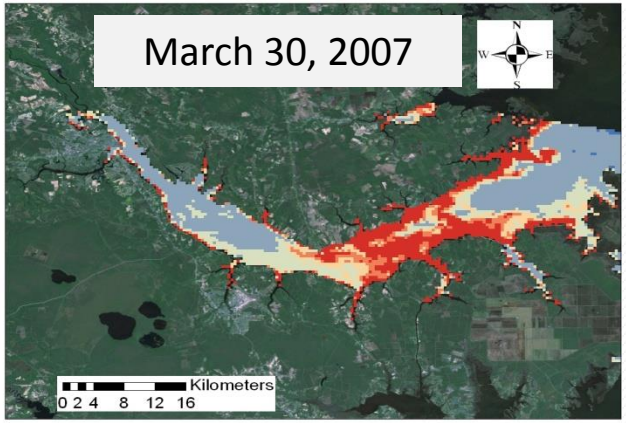


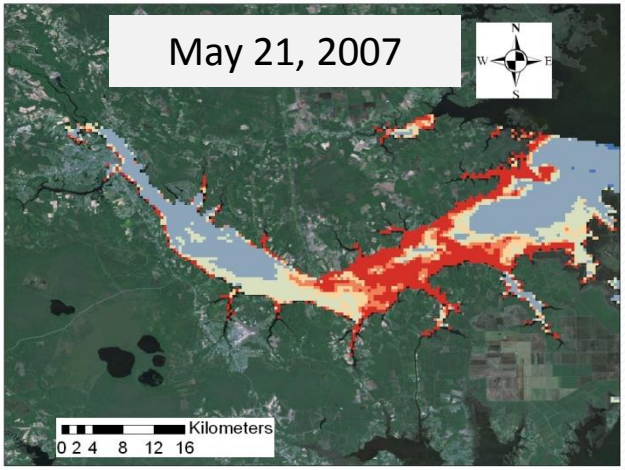


Chlorophyll a Concentration (ug/L)

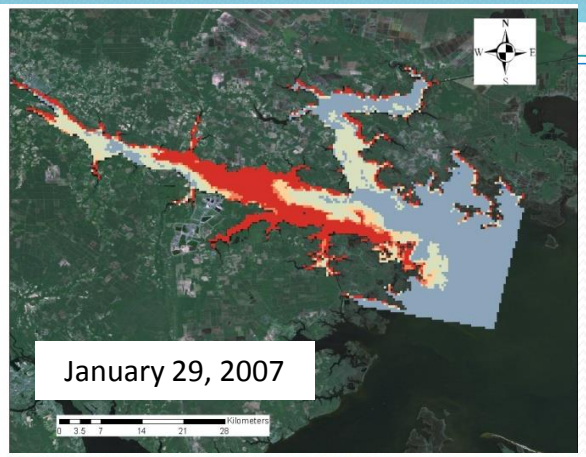
- < 10
- 10.1 - 20
- 20.1 - 30
- 30.1 - 40
- 40.1 - 50
- 50.1 - > 60

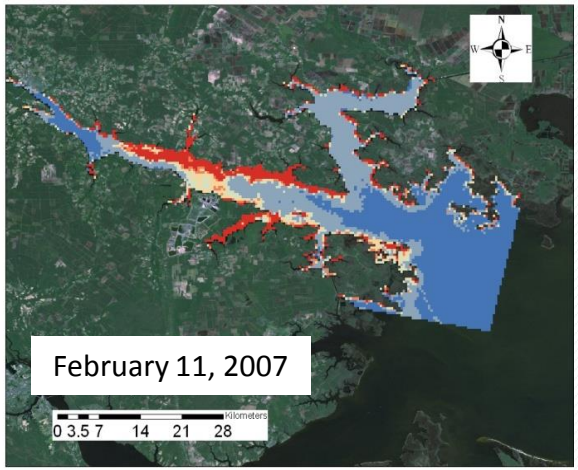


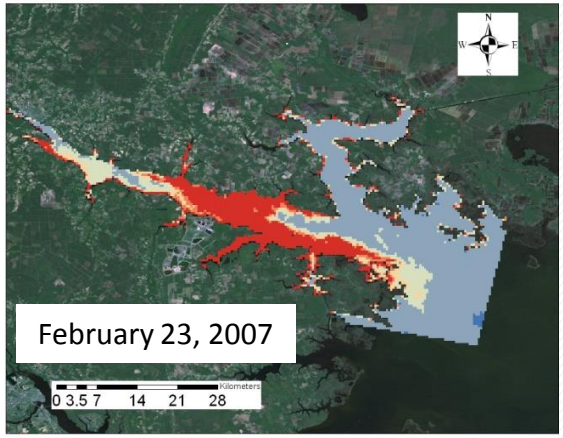


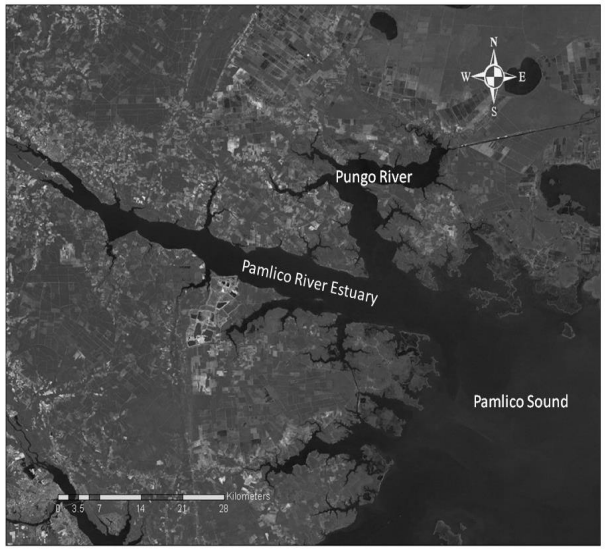


Time Series of a TMDL Violation Tar-Pamlico River Estuary: Winter – Spring 2007



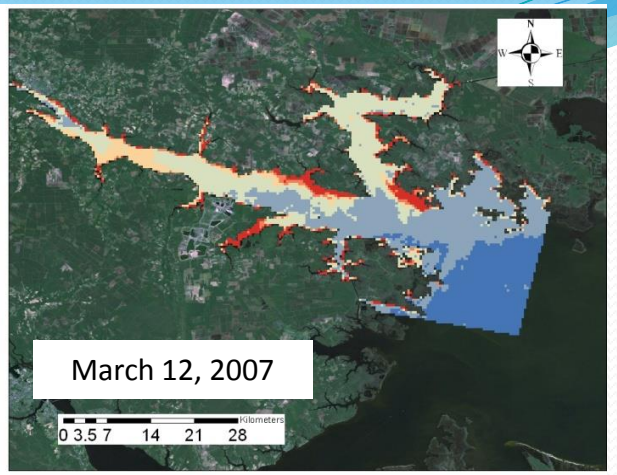


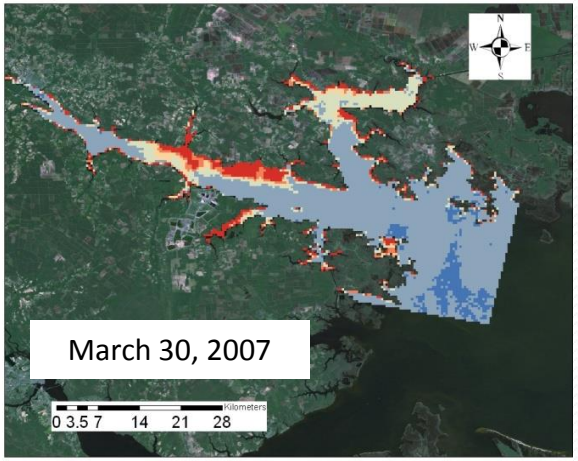


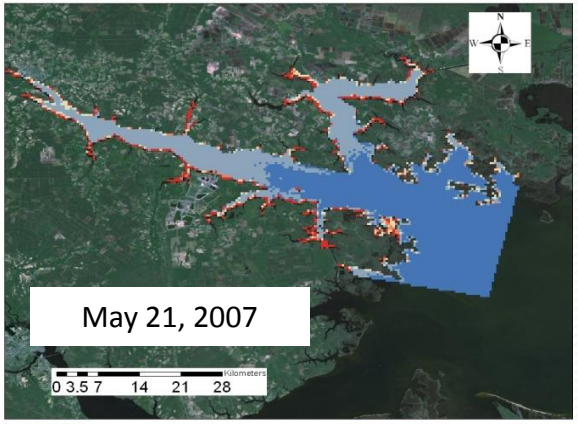


Chlorophyll a Concentration (ug/L)

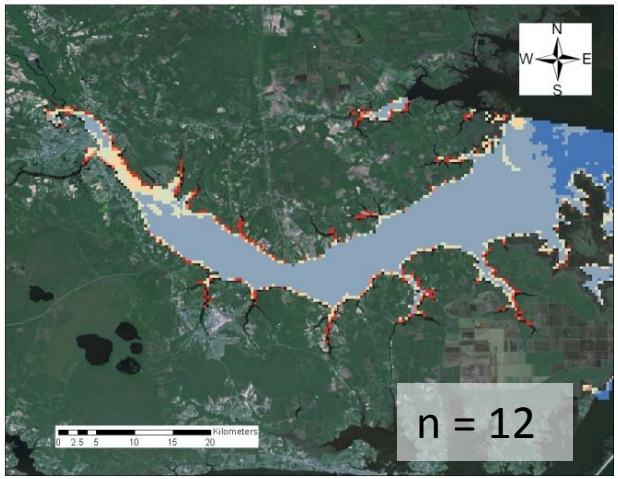
- < 10
- 10.1 - 20
- 20.1 - 30
- 30.1 - 40
- 40.1 - 50
- 50.1 - > 60



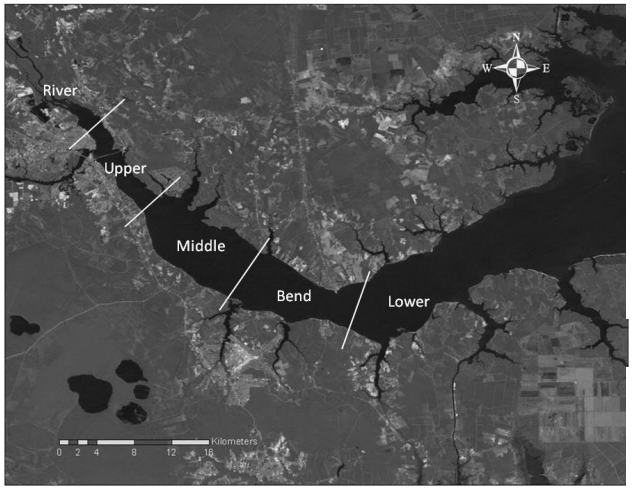


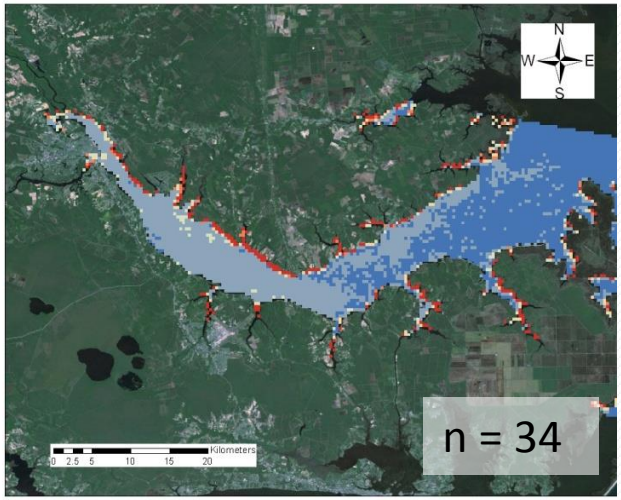


MERIS Chl a concentrations composited on an annual basis along the Neuse River Estuary

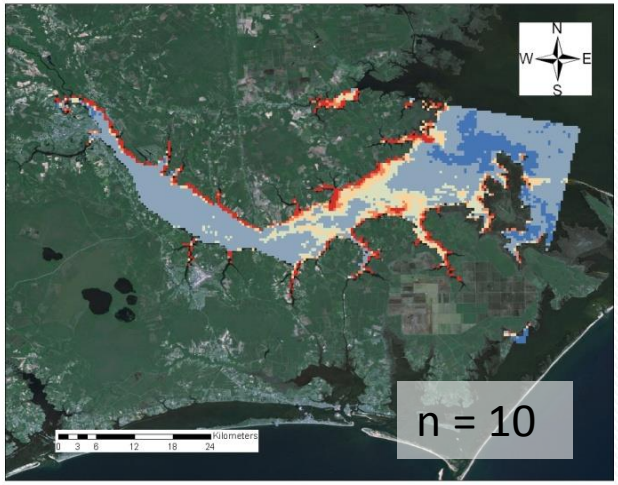


2006





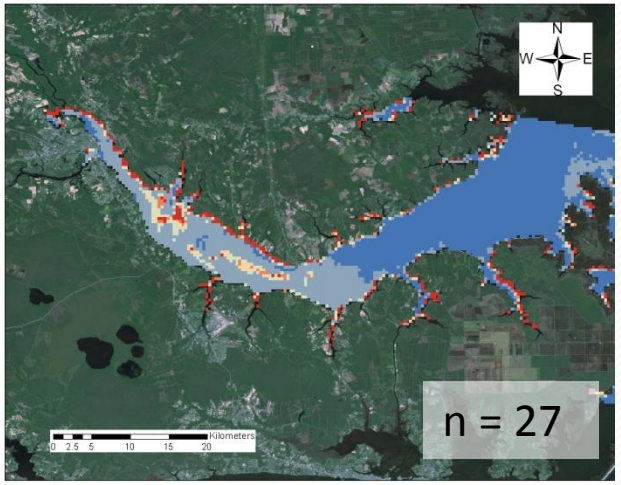
2008



2007

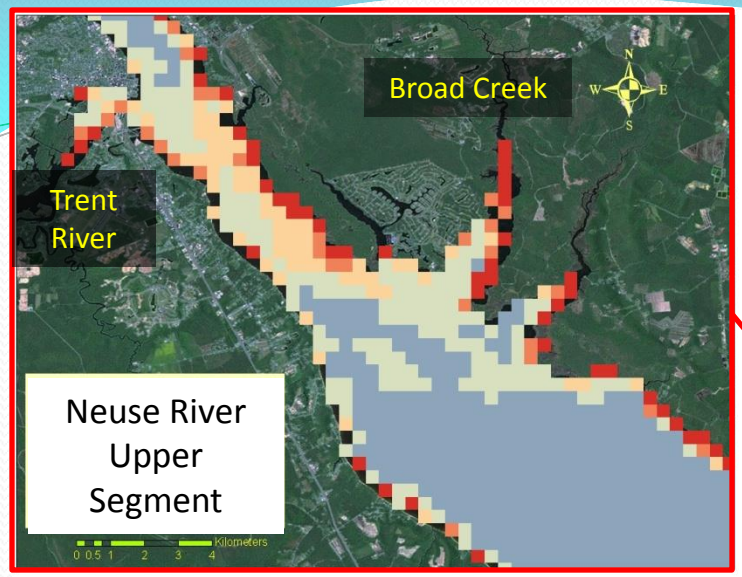
Chlorophyll a Concentration (ug/L)

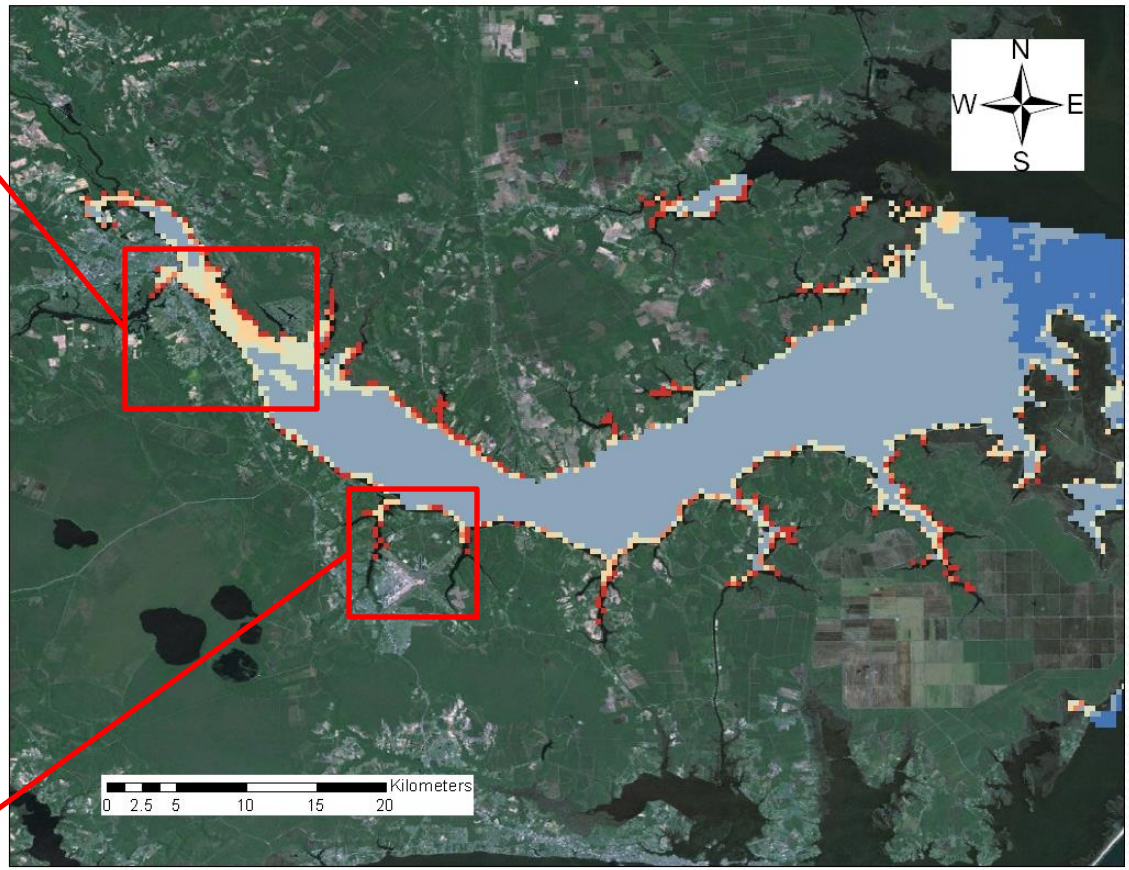
- < 10
- 10.1 - 20
- 20.1 - 30
- 30.1 - 40
- 40.1 - 50
- 50.1 - > 60

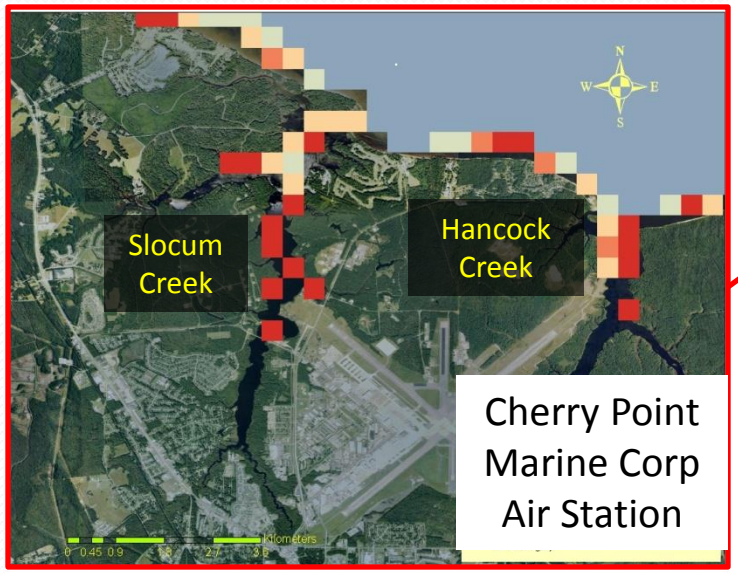


2009

Neuse River
2006 Composite Image



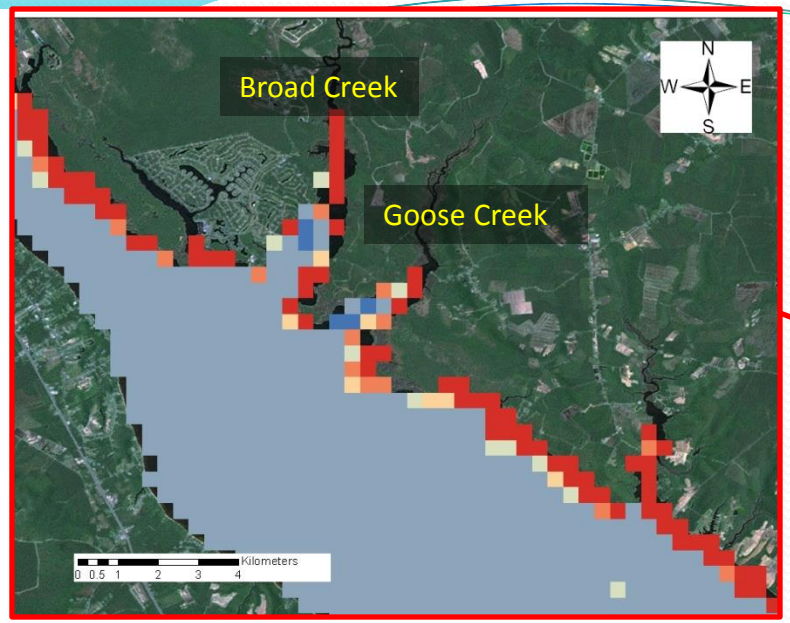


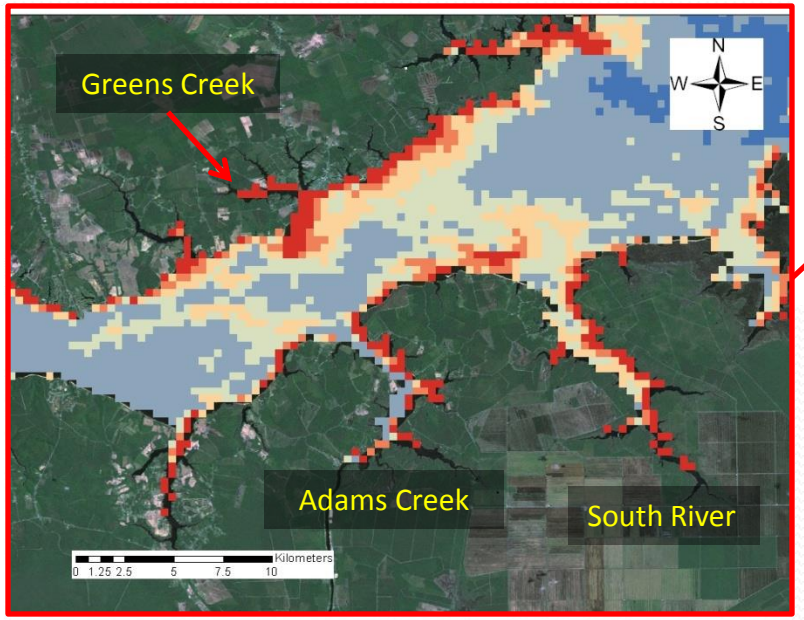


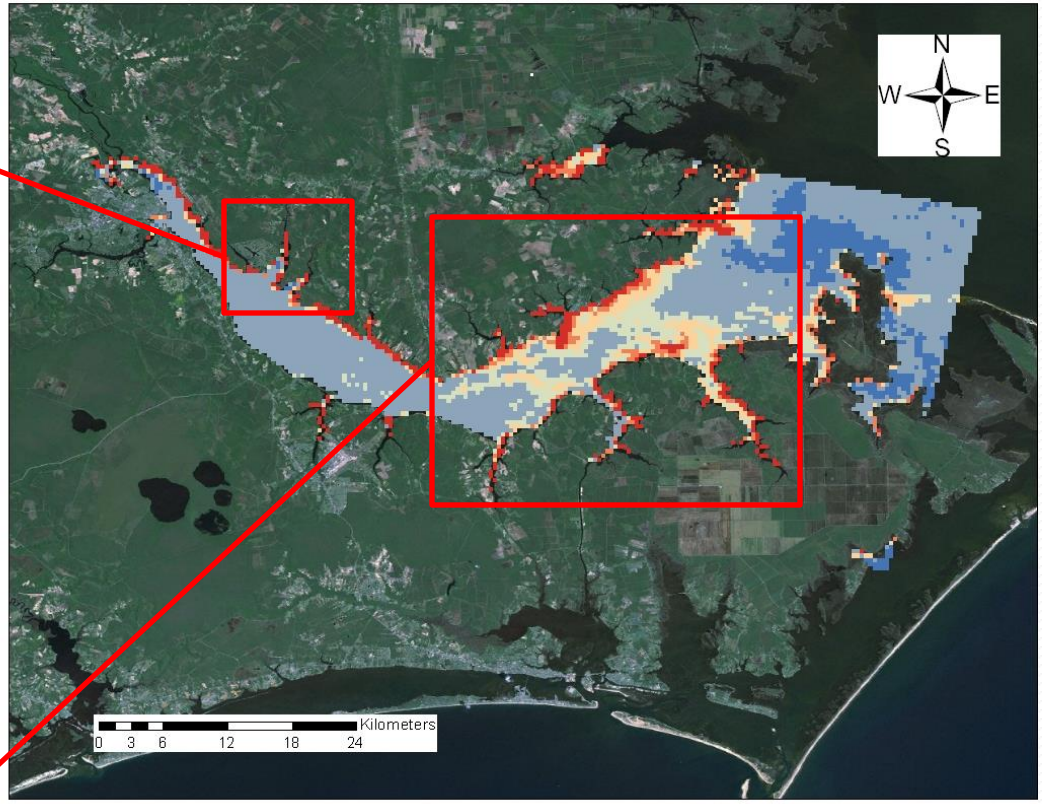
Chlorophyll a Concentration (ug/L)

- 6.9 - 10
- 10.1 - 20
- 20.1 - 30
- 30.1 - 40
- 40.1 - 50
- 50.1 - > 60

Neuse River
2007 Chl *a* composite image



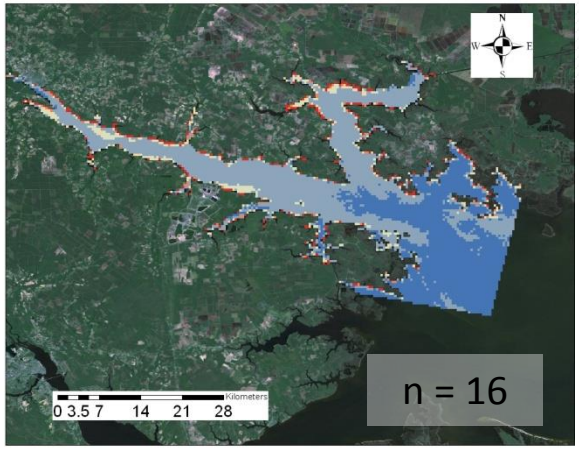




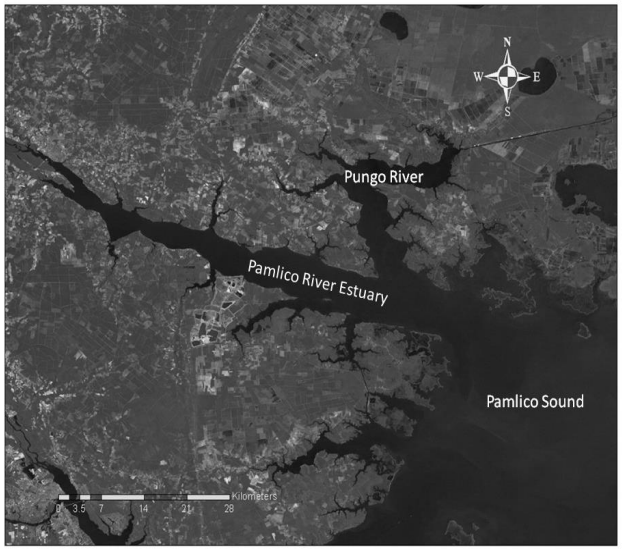
Chlorophyll a Concentration (ug/L)

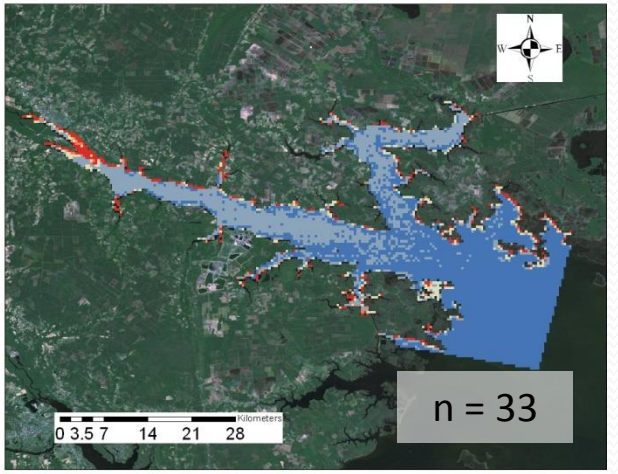
- 4.8 - 10
- 10.1 - 20
- 20.1 - 30
- 30.1 - 40
- 40.1 - 50
- 50.1 - > 60

MERIS Chl a concentrations composited on an annual basis along the Tar-Pamlico River Estuary

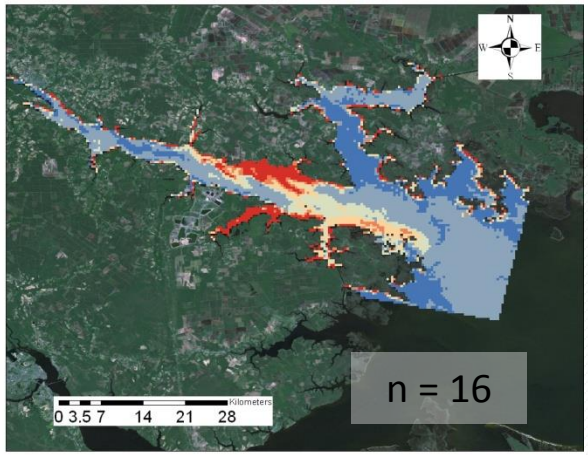


2006





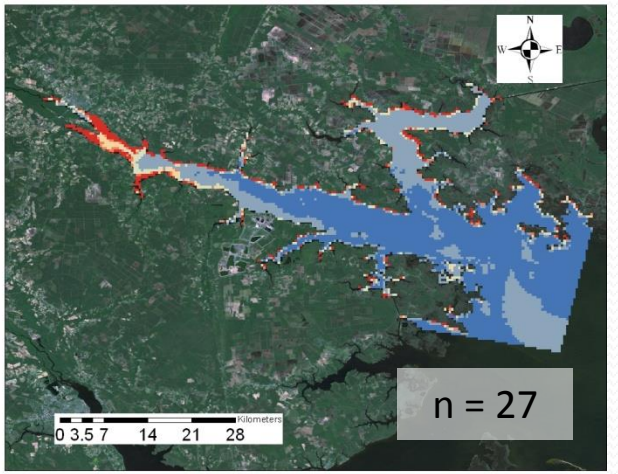
2008



2007

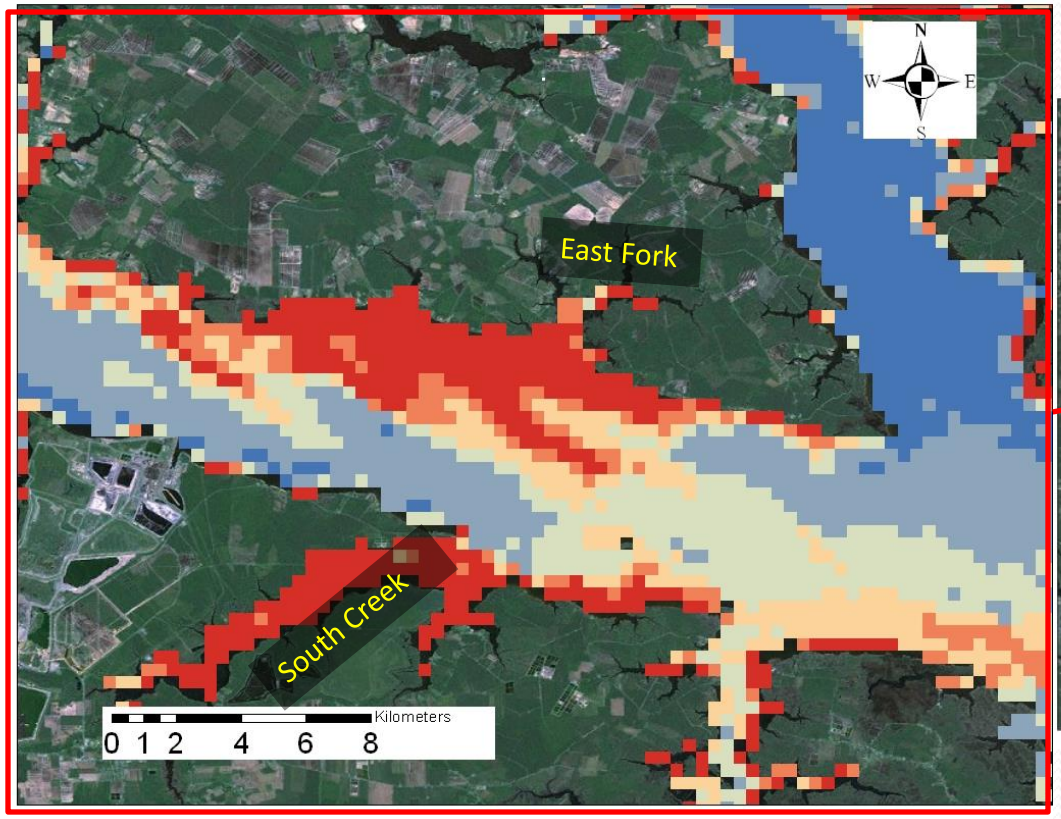
Chlorophyll a Concentration (ug/L)

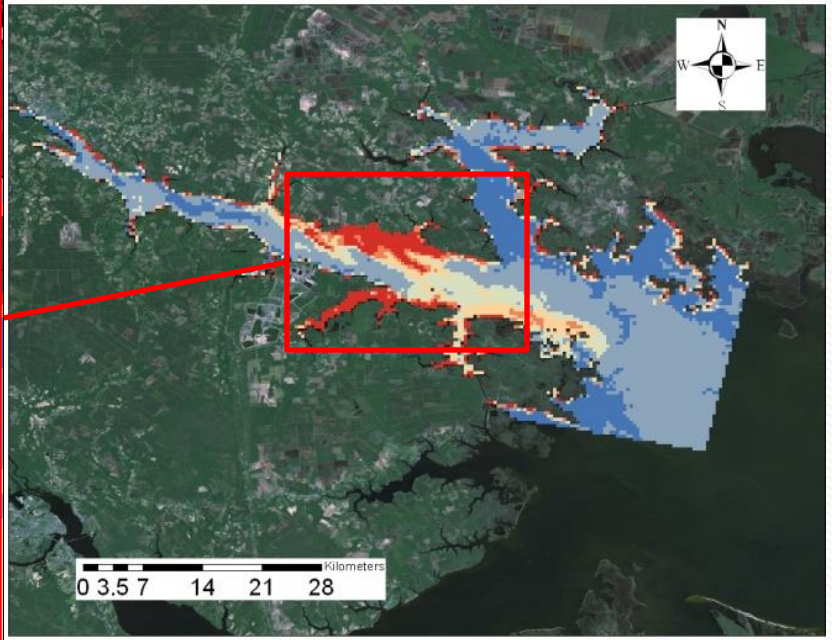
- < 10
- 10.1 - 20
- 20.1 - 30
- 30.1 - 40
- 40.1 - 50
- 50.1 - > 60



2009

Tar-Pamlico River
2007 Chl *a* composite image

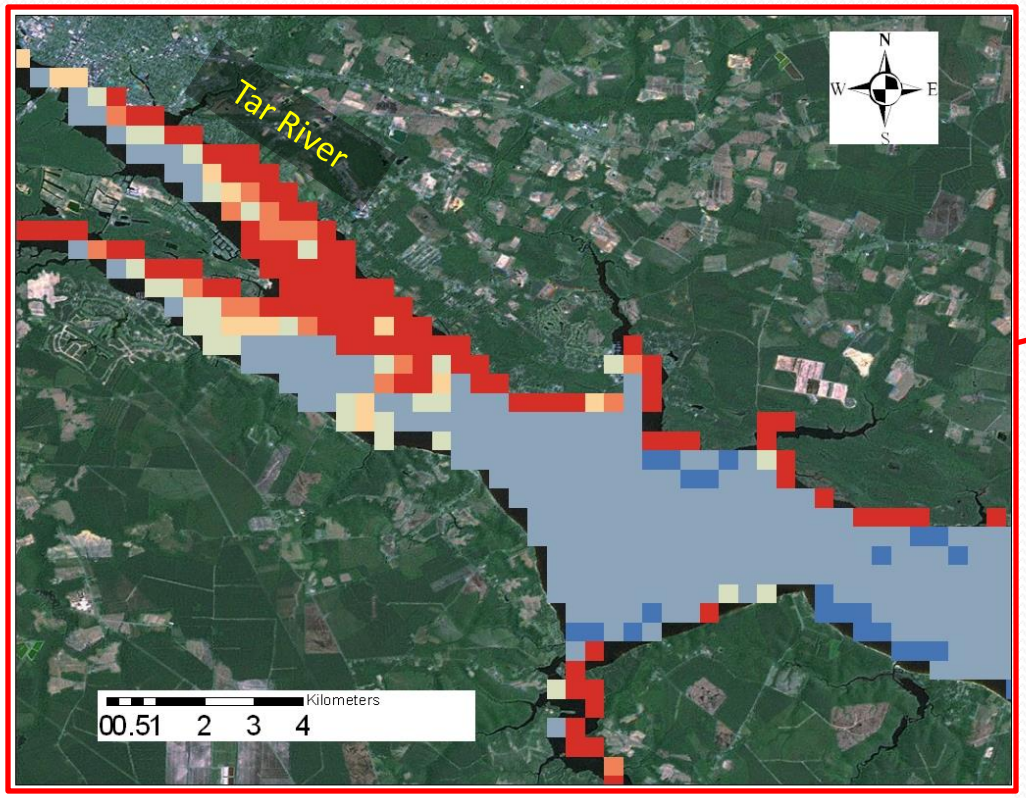


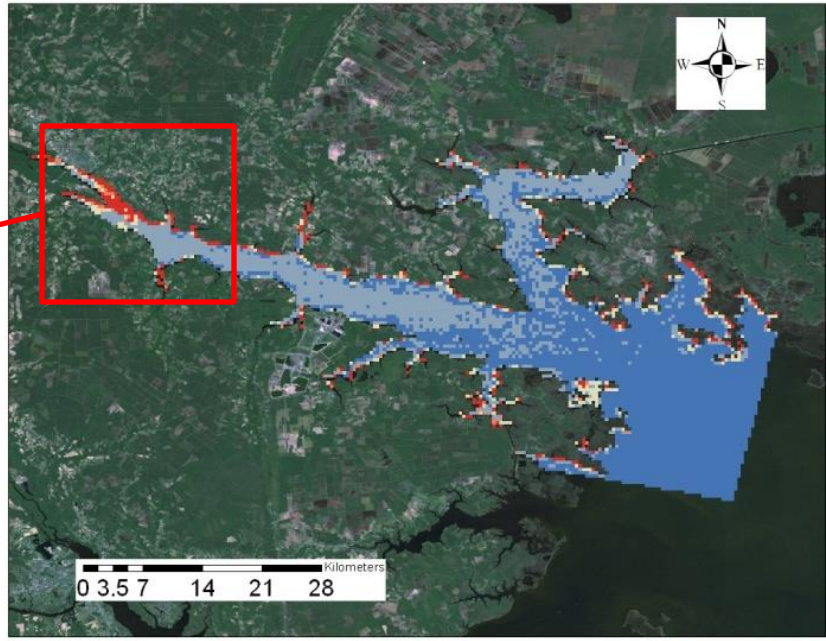


Chlorophyll a Concentration (ug/L)

- < 10
- 10.1 - 20
- 20.1 - 30
- 30.1 - 40
- 40.1 - 50
- 50.1 - > 60

Tar-Pamlico
2008 Chl *a* composite image





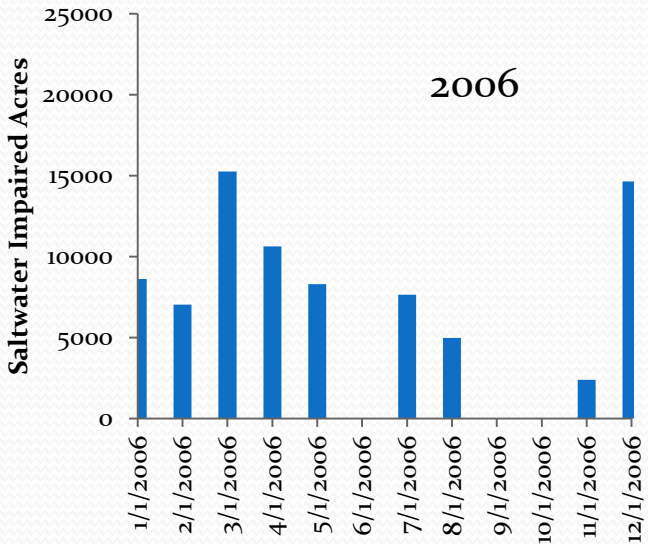
Chlorophyll a Concentration (ug/L)

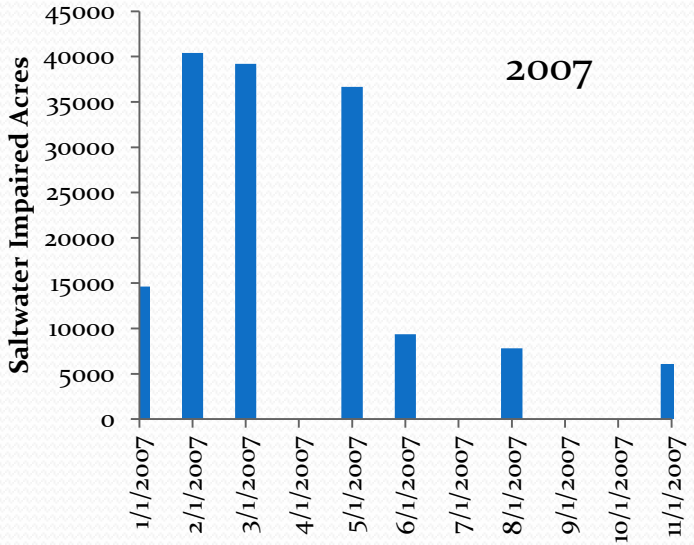
- < 10
- 10.1 - 20
- 20.1 - 30
- 30.1 - 40
- 40.1 - 50
- 50.1 - > 60

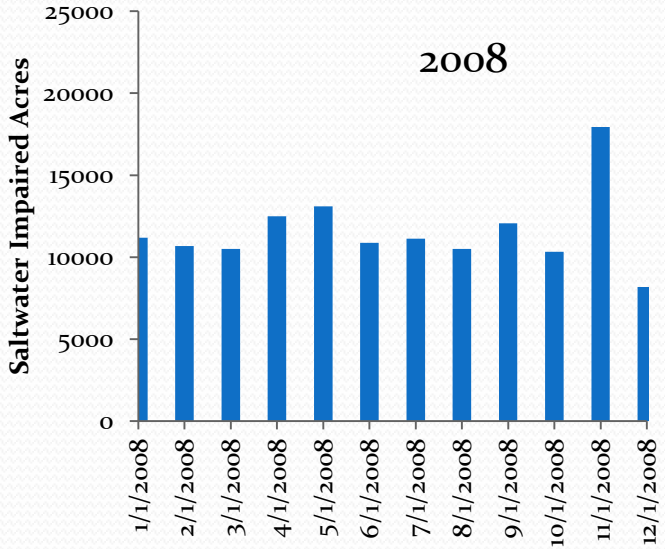
Assessment of the quantity of impaired acres during TMDL violations

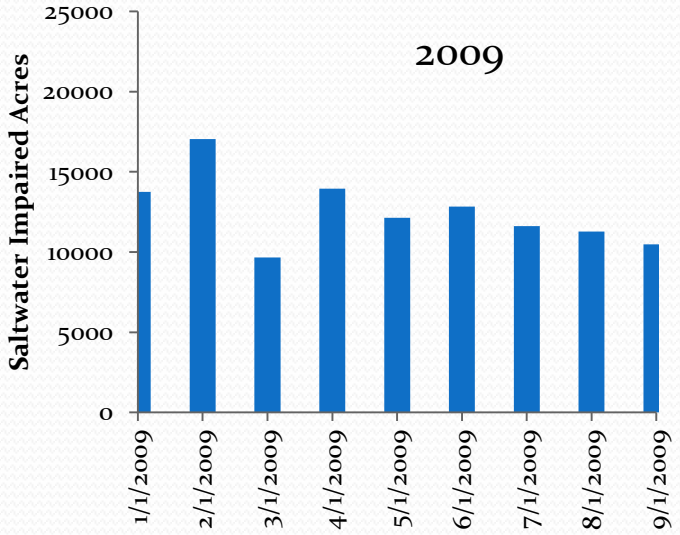
Date	Neuse River Estuary		Tar-Pamlico Estuary	
	Percentage of pixels that violate the 10/40 criterion	Impaired Acres	Percentage of pixels that violate the 10/40 criterion	Impaired Acres
3/4/2006	**10.3**	**13,034**	**<10**	**-**
1/26/2007	**12.5**	**11,647**	**22.3**	**35,682**
1/29/2007	**16.5**	**21,090**	**28.1**	**44,878**
2/11/2007	**19.7**	**27,436**	**15.4**	**24,662**
2/23/2007	**27.1**	**34,504**	**26.3**	**41,990**
2/24/2007	**22.9**	**29,184**	**21.7**	**34,732**
3/12/2007	**15.0**	**19,095**	**10.9**	**17,461**
3/18/2007	**27.6**	**33,478**	**27.9**	**44,574**
3/30/2007	**24.6**	**31,312**	**13.2**	**21,166**
1/1/2009	**9.2**	**11,742**	**12.2**	**19,532**
2/5/2009	**10.9**	**13,927**	**10.9**	**17,385**
2/15/2009	**11.4**	**14,554**	**11.1**	**17,708**
4/23/2009	**<10**	**-**	**10.2**	**16,378**
6/10/2009	**<10**	**-**	**10.1**	**16,112**
Total		**261,003**		**352,260**
Average		**21,750**		**27,097**

Neuse River Estuary Impaired Acres derived from MERIS Chlorophyll

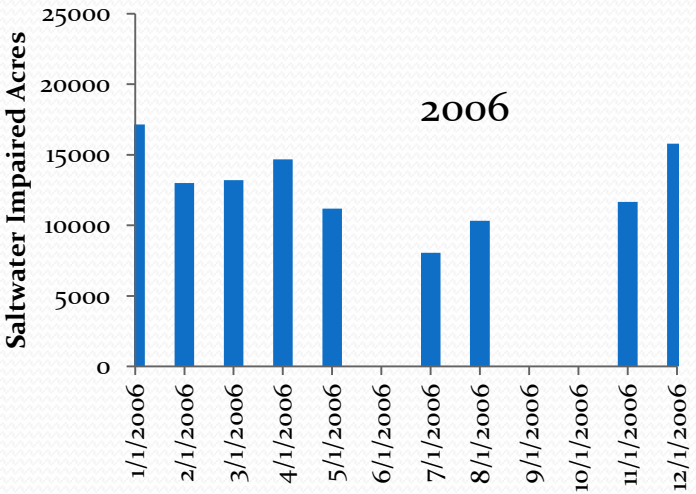


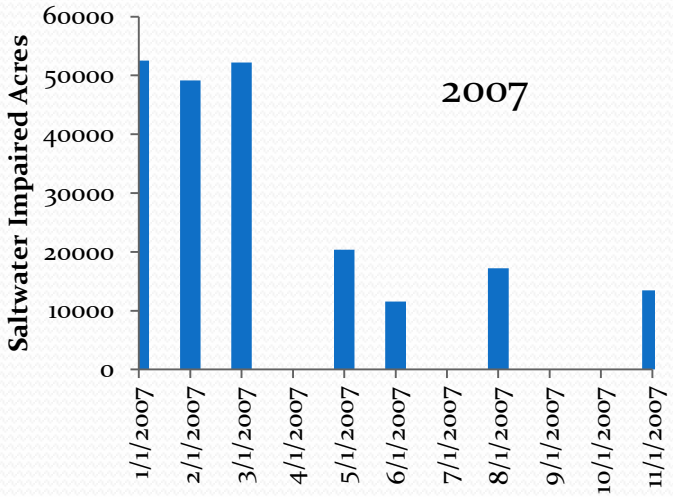


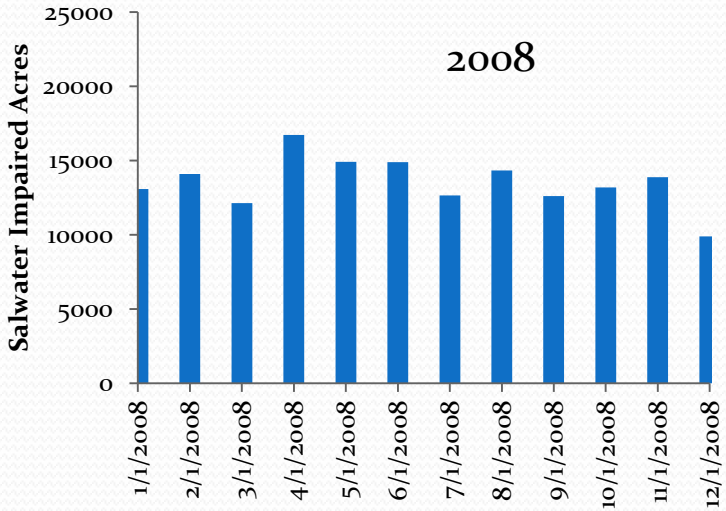


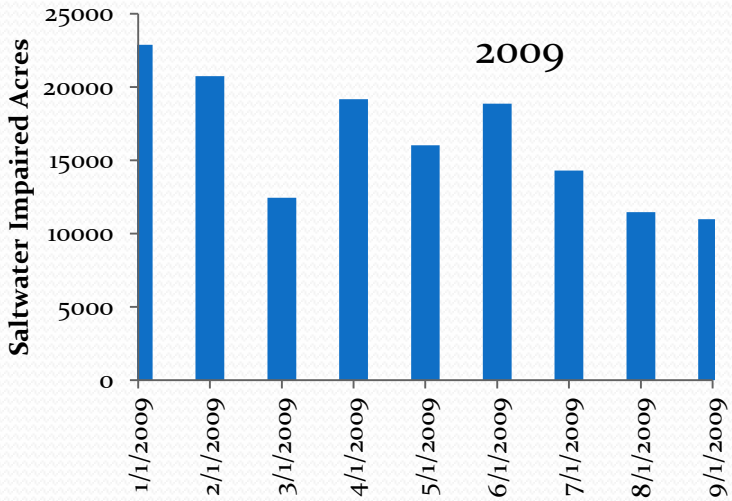


Tar-Pamlico River Estuary Impaired Acres derived from MERIS Chlorophyll

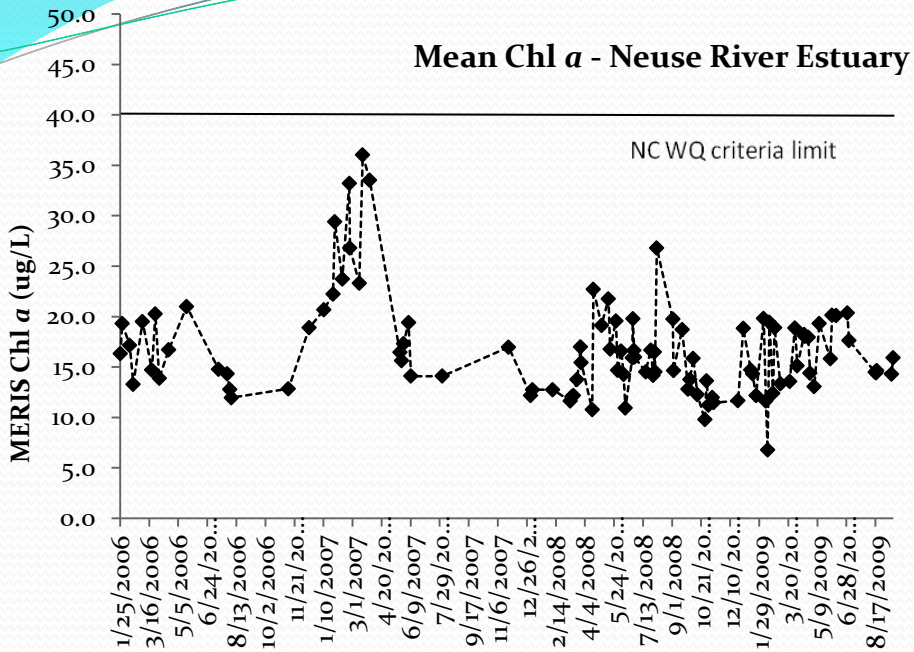


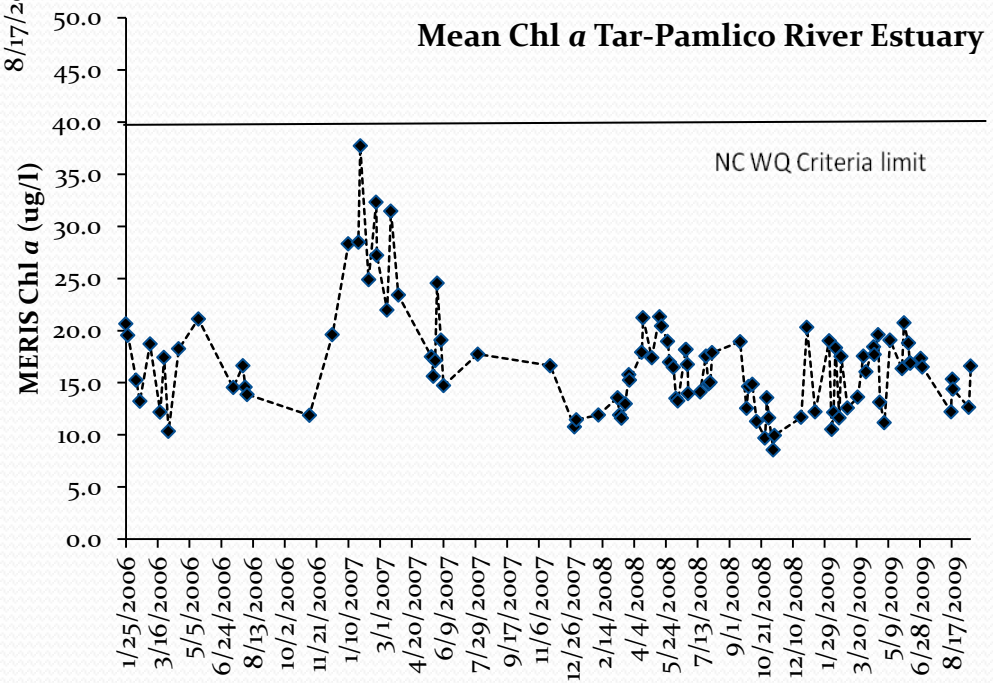




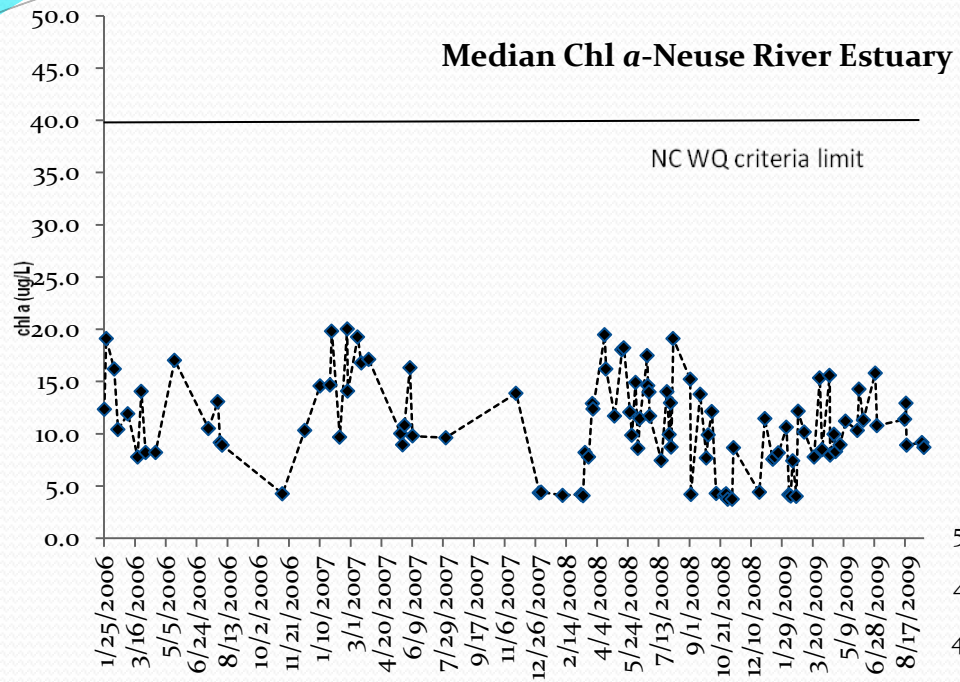


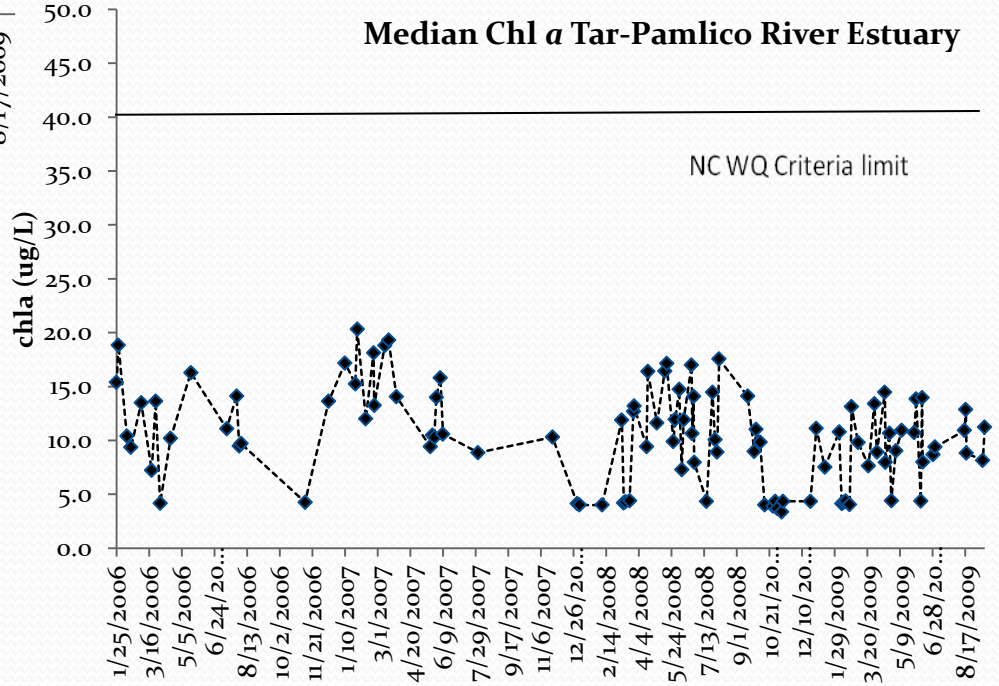
Mean chlorophyll *a* estimates: 2006 – 2009

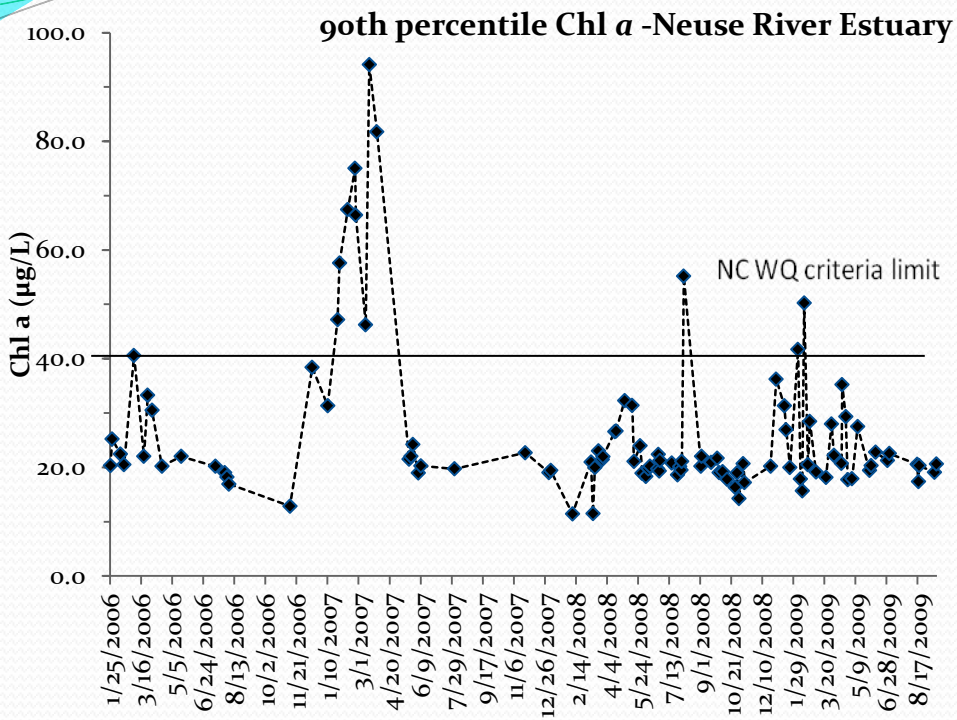




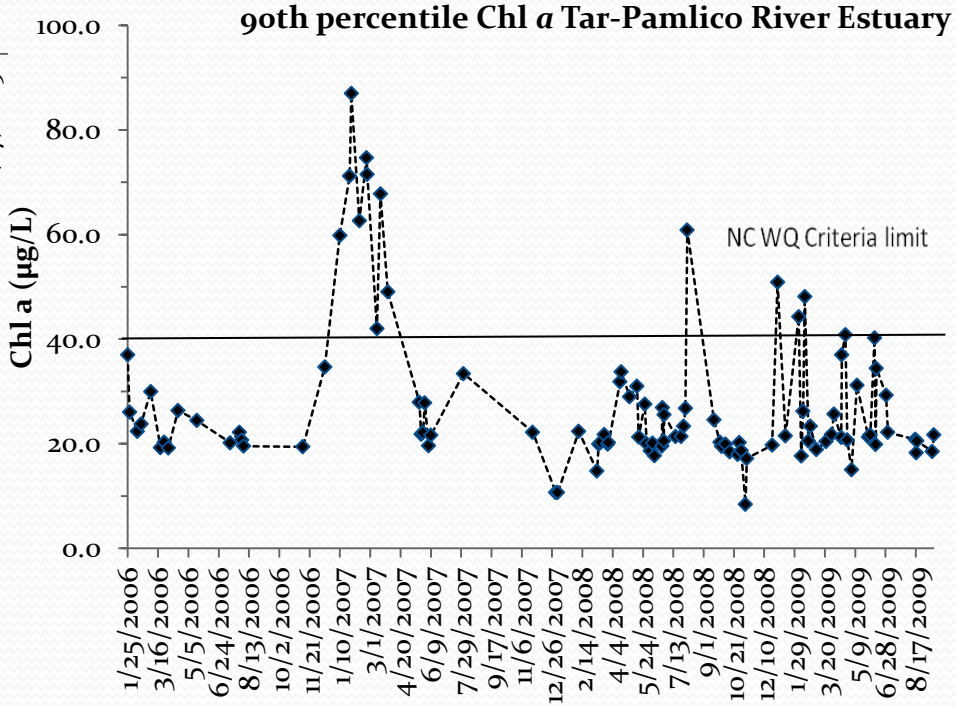
Median chlorophyll *a* estimates: 2006 – 2009



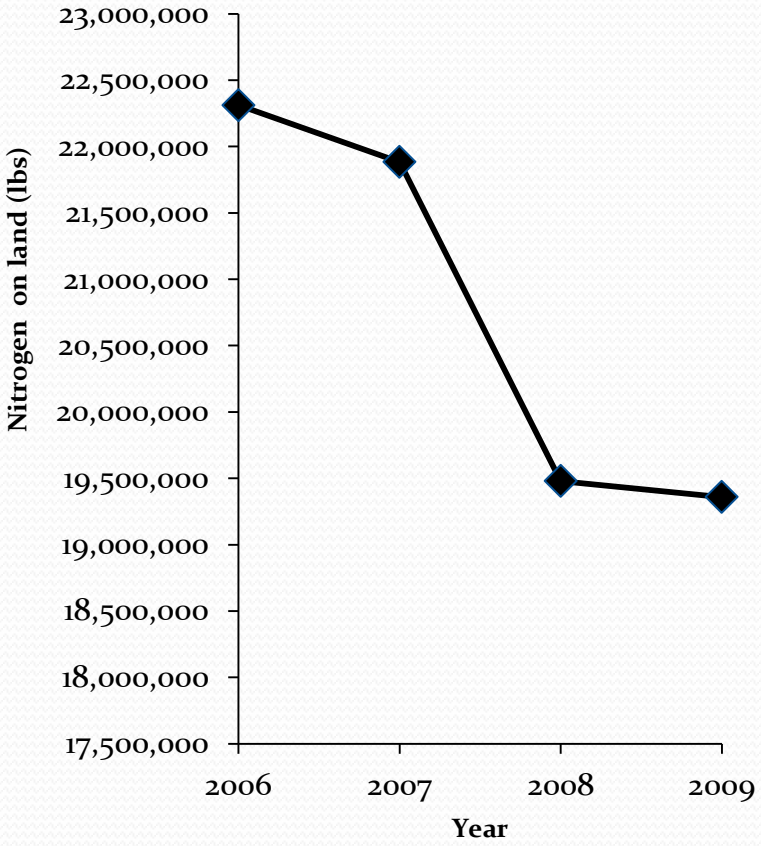


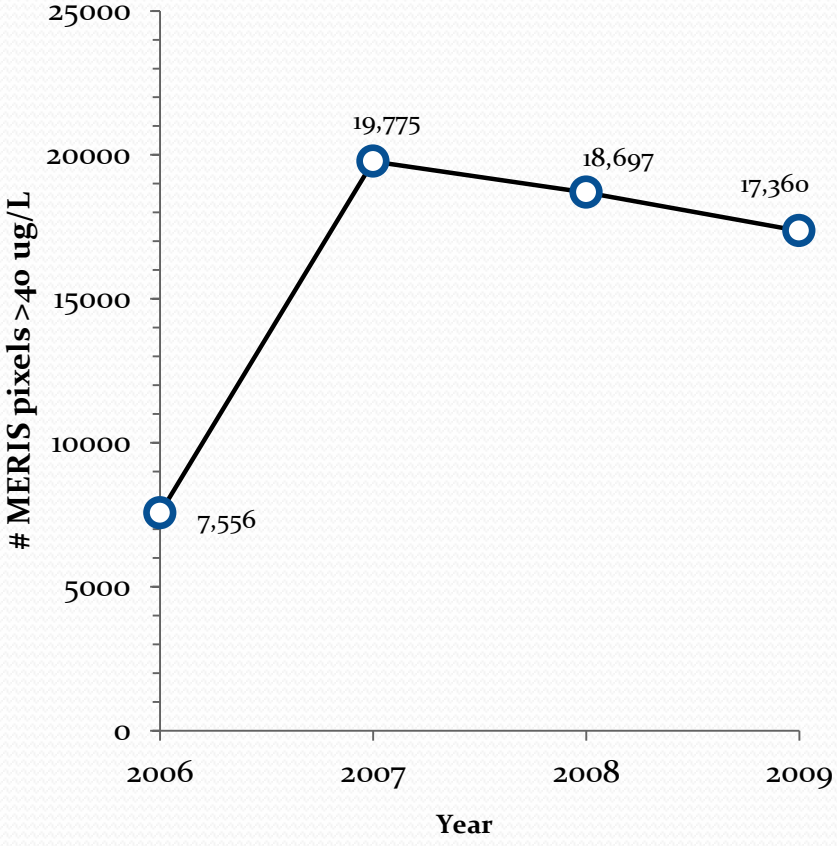


90th percentile chlorophyll *a* estimates: 2006 – 2009



NC Water Quality Violations in relation nitrogen reduction on land: Tar-Pamlico River Estuary





* Data source: Annual Report on the Tar-Pamlico Agricultural Rule - A Report to the NC Environmental Management Commission from the Tar-Pamlico Basin Oversight Committee, Crop Years 2006, 2007, 2008 and 2009

Conclusions

- MERIS data can be successfully used for compliance monitoring at the temporal and spatial scales needed for assessing water quality for the Neuse and Tar-Pamlico River estuaries.
- The high resolution capability of MERIS data can provide data needed to assess the quantity of estuarine acres degraded by excess chlorophyll in estuarine waters.
- 90th percentile values of MERIS Chl *a* provide the most useful statistical value for compliance assessment and detection of TMDL exceedances.

Acknowlegements

- Ross Lunetta (USEPA/NERL)
- Diane Reid (NCDENR)
- Kathy Stecker (NCDENR)
- Research conducted under EPA ORD Safe and Sustainable Waters Research Program
- MERIS data provided by the European Space Agency