Use of SPARROW and ASSETS to Assess Nitrogen Loading and Eutrophication in the Neuse Estuary

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Background

- Risk Exposure and Assessment for the Secondary National Ambient Air Quality Standards (NAAQS) for NOx and SOx requires ecological impacts assessment
- Aquatic Nutrient Enrichment case study, one of four case studies to look at impacts of NOx and SOx atmospheric deposition
- Neuse case study site chosen due to data richness and availability

Study Methods

- Needed to incorporate atmospheric deposition effects over watershed in ecological assessment of receiving water bodies
- Must use methods that will allow for extrapolation or application to the entire U.S.
- Evaluation of impacts needed in terms of ecosystem services for valuation where possible
- Ultimate choice in methods:
  - SPARROW watershed model
  - ASSETS eutrophication assessment of estuary

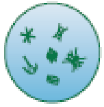
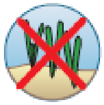
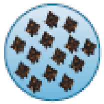
SPARROW

- SPAtially Referenced Regression On Watershed attributes (SPARROW)
- Empirically relates nitrogen source loads within each defined watershed catchment to instream nitrogen loads; includes attributes for loss processes instream and in land to water delivery
- Model created through calibration to annual averaged monitored instream loads throughout the watershed
- Various sources can be considered in model creation depending on the watershed

ASSETS

- NOAA's National Estuarine Eutrophication Assessment (NEEA) examined more than 140 estuaries along the coasts of the conterminous United States
  - Assessment of Estuarine Trophic Status eutrophication index (ASSETS EI)
  - Categorical assessment of eutrophication within an estuary
  - Pressure-State-Response framework
- Uses combination of three indices to result in final EI
  - Overall Human Influence (nitrogen loading and susceptibility)
  - Overall Eutrophic Condition (OEC; quality measurements)
  - Determined Future Influence (expected changes to nitrogen loading)

Overall Eutrophic Condition Index

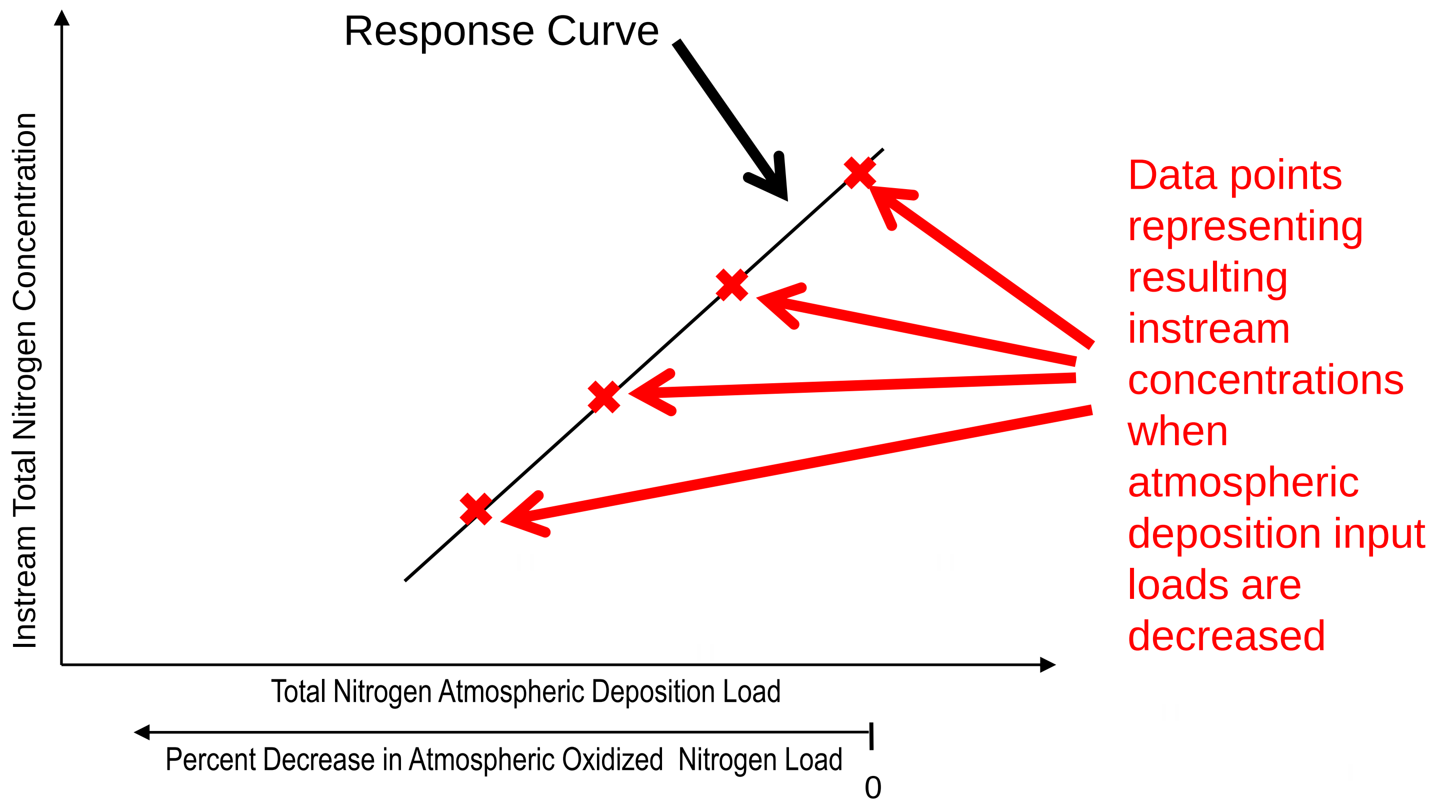
Symptom	Parameters	Expression: Low	Expression: Moderate	Expression: High
Chlorophyll *a* (phytoplankton)  Typical high concentration ($\mu g\ L^{-1}$) in an annual cycle determined as the 90[th] percentile value.	*Spatial coverage:* High >50% Moderate 25–50% Low 10–25% Very low 0–10% *Frequency:* Episodic Periodic Persistent *Concentration:* High >20 $\mu g\ L^{-1}$ Medium 5–20 $\mu g\ L^{-1}$ Low 0–5 $\mu g\ L^{-1}$	*Low symptom expression:* *Conc. / Coverage / Frequency* low / any / any medium / mod. - v. low / episodic high / low - v. low / episodic	*Moderate symptom expression:* *Conc. / Coverage / Frequency* medium / high / episodic medium / moderate / periodic high / low - v. low / periodic high / moderate / episodic	*High symptom expression:* *Conc. / Coverage / Frequency* medium / high / periodic high / mod. - high / periodic high / high / episodic
Macroalgae  Causes a detrimental impact on any natural resource.	*Frequency of problem:* Episodic (occasional/random) Periodic (seasonal, annual, predictable) Persistent (always/continuous)	No macroalgal bloom problems have been observed.	Episodic macroalgal bloom problems have been observed.	Periodic or persistent macroalgal bloom problems have been observed.
Dissolved oxygen  Typical low concentration (determined as the 10[th] percentile value) in an annual cycle.	*Spatial coverage:* High >50% Moderate 25–50% Low 10–25% Very low 0–10% *Frequency:* Episodic Periodic Persistent *State:* Anoxia 0 mg L^{-1} Hypoxia 0–2 mg L^{-1} Biol. stress 2–5 mg L^{-1}	*Low symptom expression:* *State / Coverage / Frequency* anoxia / mod. - low / episodic anoxia / very low / periodic hypoxia / low - v. low / periodic hypoxia / moderate / episodic stress / any / episodic stress / mod. - v. low / periodic	*Moderate symptom expression:* *State / Coverage / Frequency* anoxia / high / episodic anoxia / low / periodic hypoxia / moderate / periodic hypoxia / high / episodic stress / high / periodic	*High symptom expression:* *State / Coverage / Frequency* anoxia / moderate - high / periodic hypoxia / high / periodic
Submerged aquatic vegetation  A change in SAV spatial area observed since 1990.	*Magnitude of change:* High >50% Moderate 25–50% Low 10–25% Very low 0–10%	The magnitude of SAV loss is low to very low.	The magnitude of SAV loss is moderate.	The magnitude of SAV loss is high.
Nuisance/toxic blooms  Causes detrimental impact on any natural resources.	*Duration:* Persistent, seasonal, months, variable, weeks, days, weeks to seasonal, weeks to months, or days to weeks *Frequency:* Episodic, periodic, or persistent	Blooms are either a) short in duration (days) and periodic in frequency; or b) moderate in duration (days to weeks) and episodic in frequency.	Blooms are either a) moderate in duration (days to weeks) and periodic in frequency; or b) long in duration (weeks to months) and episodic in frequency.	Blooms are long in duration (weeks, months, seasonal) and periodic in frequency.

*For further technical documentation of the methods, refer to Bricker et al. 1999 and Bricker et al. 2003.

Two Assessment Methods – What Now?

- Individually, each method addresses an objective of the project
  - SPARROW: determines contribution of atmospheric deposition to total nitrogen load
  - ASSETS EI: characterizes health of estuary
- Need to create a link between the two methods in order to relate atmospheric deposition to estuarine health
  - SPARROW nitrogen load → instream concentration → Overall Human Influence index of ASSETS EI
  - Link illustrated through series of response curves

Linked Modeling Assessment – Relate Deposition to Instream Concentration

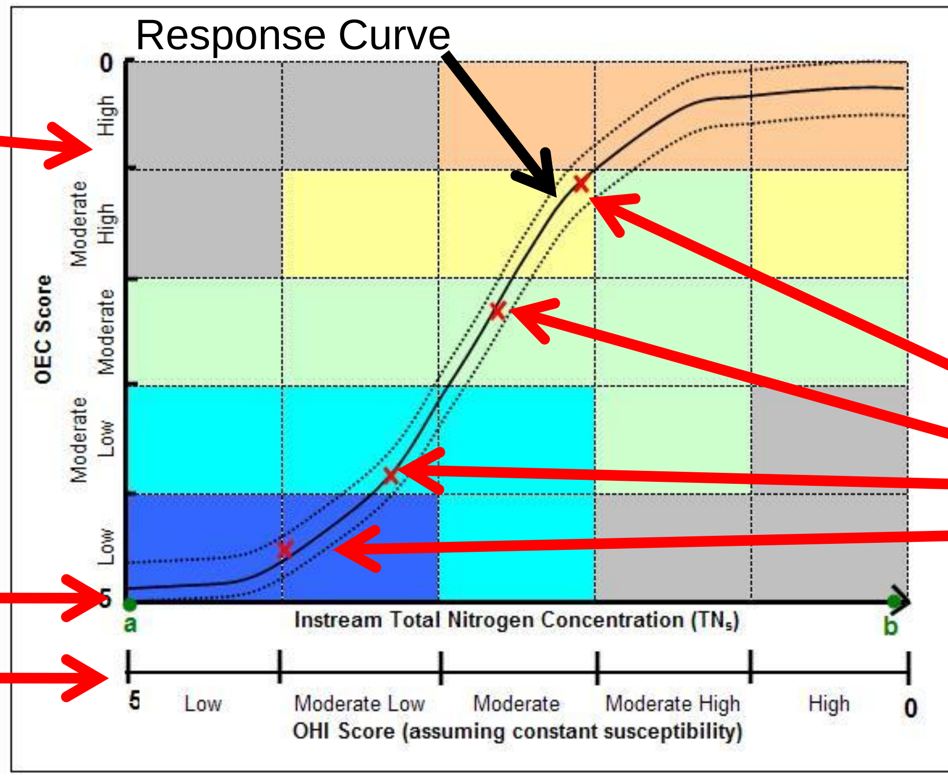


Linked Modeling Assessment – Relate OHI and OEC to ASSETS EI

OEC Index presented by category along y-axis

Instream N concentration from SPARROW along x-axis 1

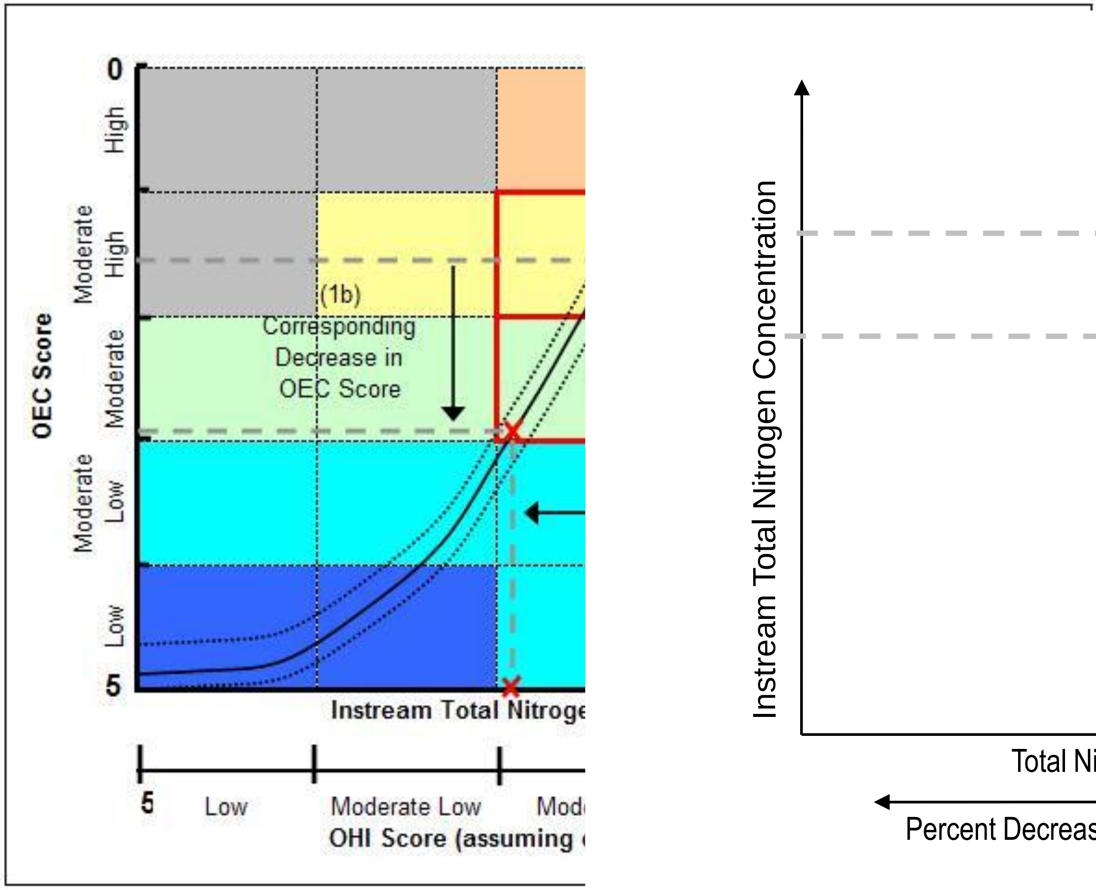
OHI Index along x-axis 2

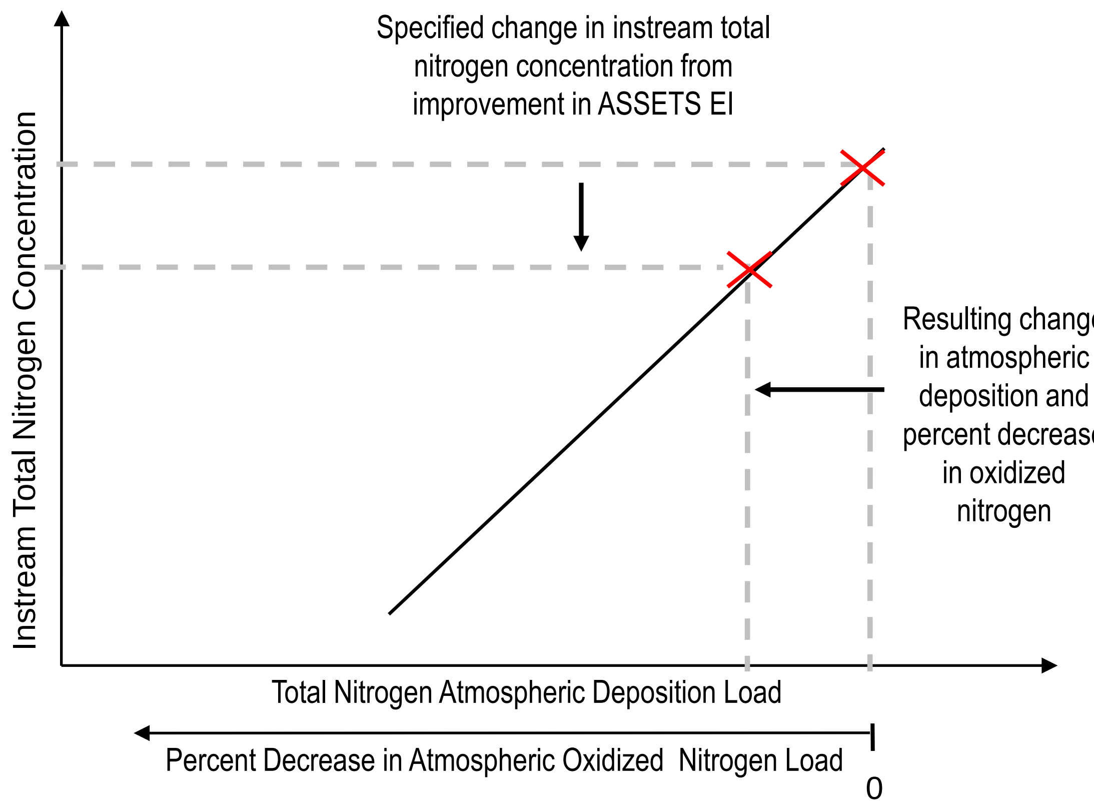


Data points representing calculated OEC and OHI indices from different years through with a logistic curve is fit

- Susceptibility assumed constant (for this example “High”)
- DFO assumed to be constant (for this example “Improve”)
- ASSETS EI results from combination of calculated OEC & OHI and assumed DFO

Back Calculation of Required Deposition Reductions





Data Sources

- SPARROW
  - Southeast Major River Basin SPARROW modeling effort by the USGS (contact: Anne Hoos)
  - Included Cape Fear and Tar-Pamlico basins in model creation in order to increase degrees of freedom within model
  - Atmospheric Dep. inputs provided by the EPA in grid cells
    - Dry deposition had been modeled with CMAQ
    - Wet deposition was compiled from NADP monitoring sites
- ASSETS
  - STORET
  - MODMON (contact: Ben Peierls)
  - State of NC data sources (DENR, DWQ)
  - NEEA Report

Analyses

- Current conditions
  - Base year of 2002 used
  - SPARROW model was calibrated to this data
- Alternative effects
  - For this case study we examined what reductions in deposition levels would be needed to improve the current ASSETS EI from Bad to Poor or Moderate or Good
  - A new SPARROW calibration was not completed for each alternative effects level; rather only deposition inputs were changed and the current conditions SPARROW model was reapplied to the data

Current Conditions Assessment (2002)

Calibrated Model

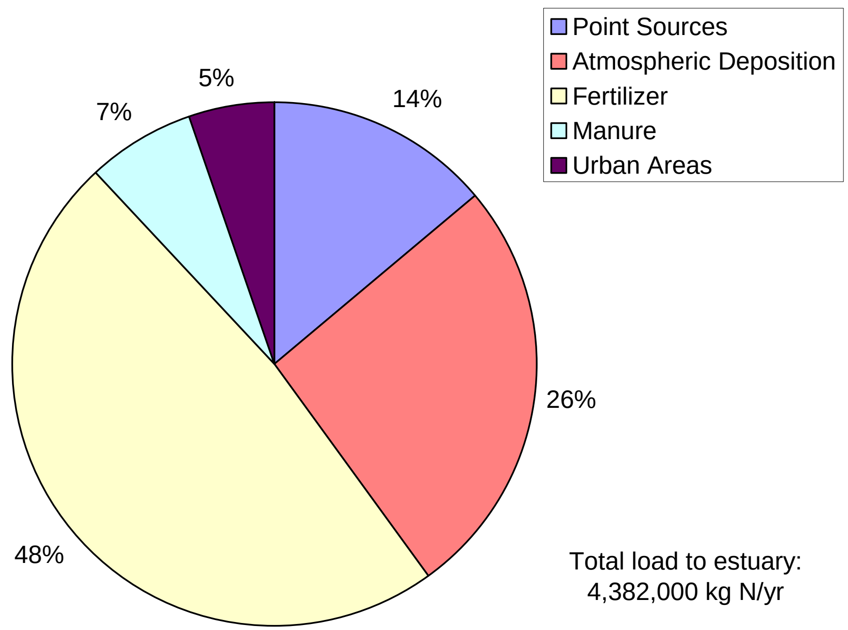
Source Parameters	Parameter Estimate
Point Sources	0.84
Atmospheric Deposition	0.082
Fertilizer	0.13
Manure	0.017
Urban Area	1.6
Decay and Loss Parameters	
Soil Permeability	−0.52
Reach Decay Group 1	0.17
Reach Decay Group 2	0.029
Reservoir Decay	3.4

Model Fit Statistics

Evaluation Criteria	Value
Number of Observations	40
R Squared	0.99
Adjusted R Squared	0.98

SPARROW modeling for 2002 predicts that atmospheric deposition was 26% of the total nitrogen loading (4,380,000 kg N/yr) to the Neuse River's estuary, producing a TN_s of 1.1 mg/L

Relative Contributions of Nitrogen Sources to Neuse Estuary



Total load to estuary:
4,382,000 kg N/yr

Current Conditions Assessment (2002)

Year	Parameter	Zone	Value	Concentration	Spatial Coverage	Frequency	Expression	Score	Primary/ Secondary Scores	OEC Score
2002	Chlorophyll a	Mixing	35	High	High	Persistent	High	0.9945	0.9945	HIGH (1)
	Chlorophyll a	Tidal Fresh	9.0	Medium	Moderate	Periodic	Moderate			
	Macroalgae	ALL	NA	Unknown	Unknown	Unknown	Unknown	NA		
	Dissolved Oxygen	Mixing	1.6	Hypoxia	Moderate	Periodic	Moderate	0.5	1	
	Dissolved Oxygen	Tidal Fresh	2.7	Bio Stress	High	Periodic	Moderate			
	Submerged Aquatic Vegetation	ALL	NA	NA	NA	NA	Unknown	NA		
	Harmful Algal Blooms	ALL	NA	NA	NA	NA	High	1		

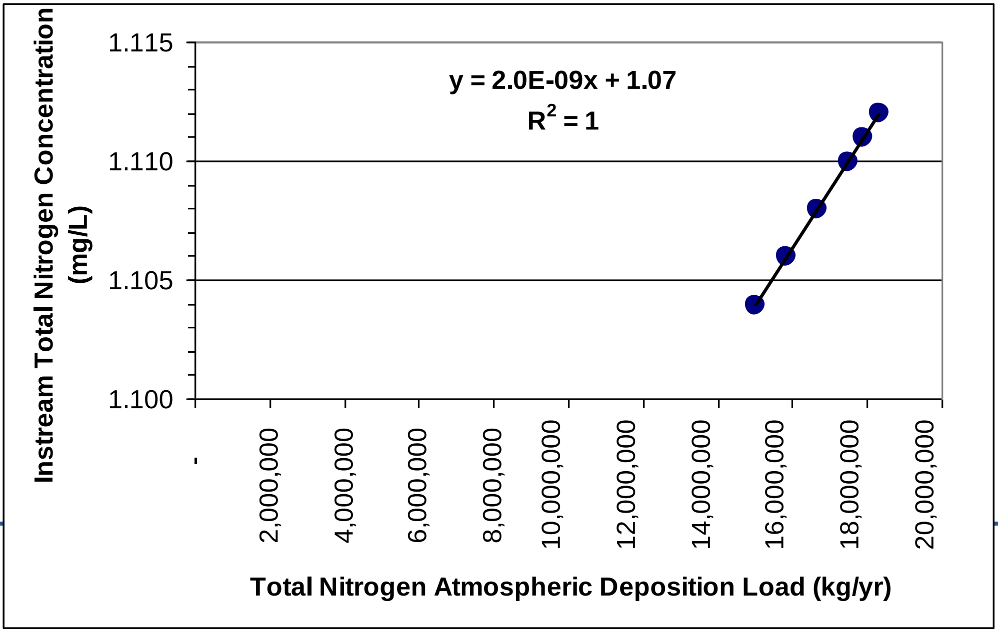
- ASSETS EI of “Bad”
  - OEC of “High”
  - OHI of “High” (“High” Susceptibility and “High” N loading from SPARROW)
  - DFO of “Worsen High”

SPARROW Alternative Effects Analysis

- NOx atmospheric deposition loads were decreased by rates of 5%, 10%, 20%, 30%, and 40% from their original 2002 levels
- Zero percent decrease corresponds to the 2002 current condition analysis
- Remaining SPARROW inputs and calibrated model kept the same
- New nitrogen loads to the estuary calculated for each deposition load
- Rating curve created relating deposition levels to instream nitrogen concentration (from nitrogen load)

SPARROW Alternative Effects Levels

Percent Decrease in Oxidized Nitrogen (NOx)	Total Nitrogen (NOx + NHx) Atmospheric Deposition Load, TN_{atm} (kg/yr)	Decrease in Oxidized Nitrogen (NOx) Atmospheric Deposition Load from Base Case (kg/yr)	Instream Total Nitrogen (NOx + NHx) Load (kg/yr)	Instream Total Nitrogen Concentration, TN_S (mg/L)
0	18,340,000	0	4,382,000	1.112
5	17,920,000	410,000	4,378,000	1.111
10	17,510,000	830,000	4,374,000	1.110
20	16,680,000	1,660,000	4,366,000	1.108
30	15,850,000	2,490,000	4,358,000	1.106
40	15,020,000	3,320,000	4,351,000	1.104

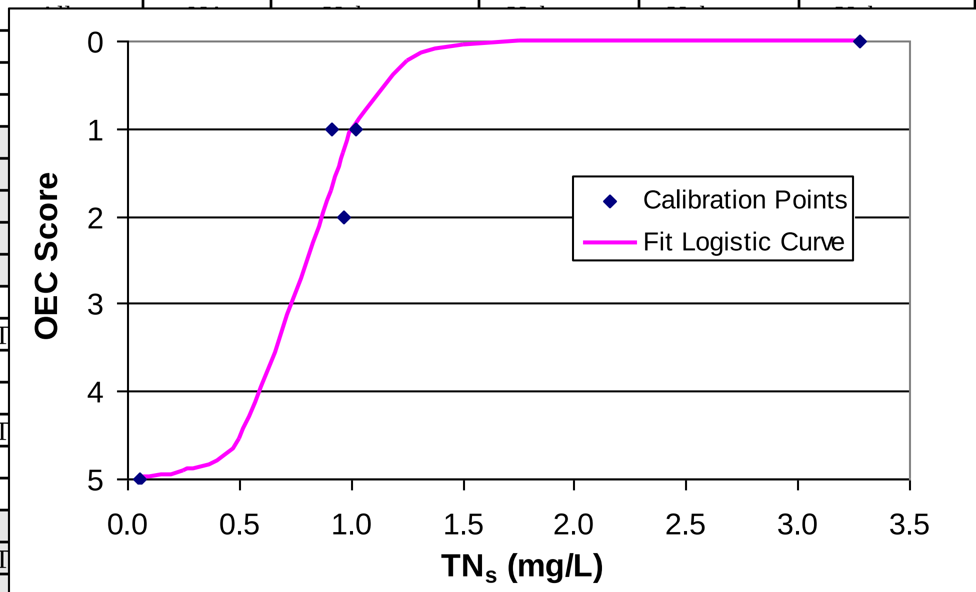


ASSETS Alternative Effects Analysis

- Compile data to determine an OEC score during various years where a corresponding estimate of nitrogen loading (or instream concentration) to the estuary is available
  - Loading is not necessarily derived with the SPARROW model
- Plot graph of OEC versus instream nitrogen concentration as shown previously

ASSETS Alternative Effects Levels

Year	Parameter	Zone	Value	Concentration	Spatial Coverage	Frequency	Expression	Score	Primary/ Secondary Scores	OEC Score
1992	Chlorophyll a	Mixing	28	High	Very Low	Periodic	Moderate	0.5	0.5	High(1)
	Macroalgae							NA		
	Dissolved Oxygen							0.25	1	
	SAV							NA		
	HAB							1		
1993	Chlorophyll a							0.99	0.99	High (1)
	Macroalgae									
	Dissolved Oxygen							0.5	1	
	SAV							NA		
	HAB							1		
2003	Chlorophyll a								1	High (1)
	Chlorophyll a	T						1		
	Macroalgae							NA		
	Dissolved Oxygen								0.99	
	Dissolved Oxygen	T						0.99		
	SAV							NA		
	HAB							0.5		
2007	Chlorophyll a								1	Moderate High (2)
	Chlorophyll a	T						1		
	Macroalgae							NA		
	Dissolved Oxygen	Mixing	2.6	Bio Stress	High	Periodic	Moderate		0.5	
	Dissolved Oxygen	Tidal Fresh	3.1	Bio Stress	High	Periodic	Moderate	0.5		
	SAV	All	NA	NA	NA	NA	Unknown	NA		
	HAB	All	NA	NA	NA	NA	*Low/ Moderate*	0.5		



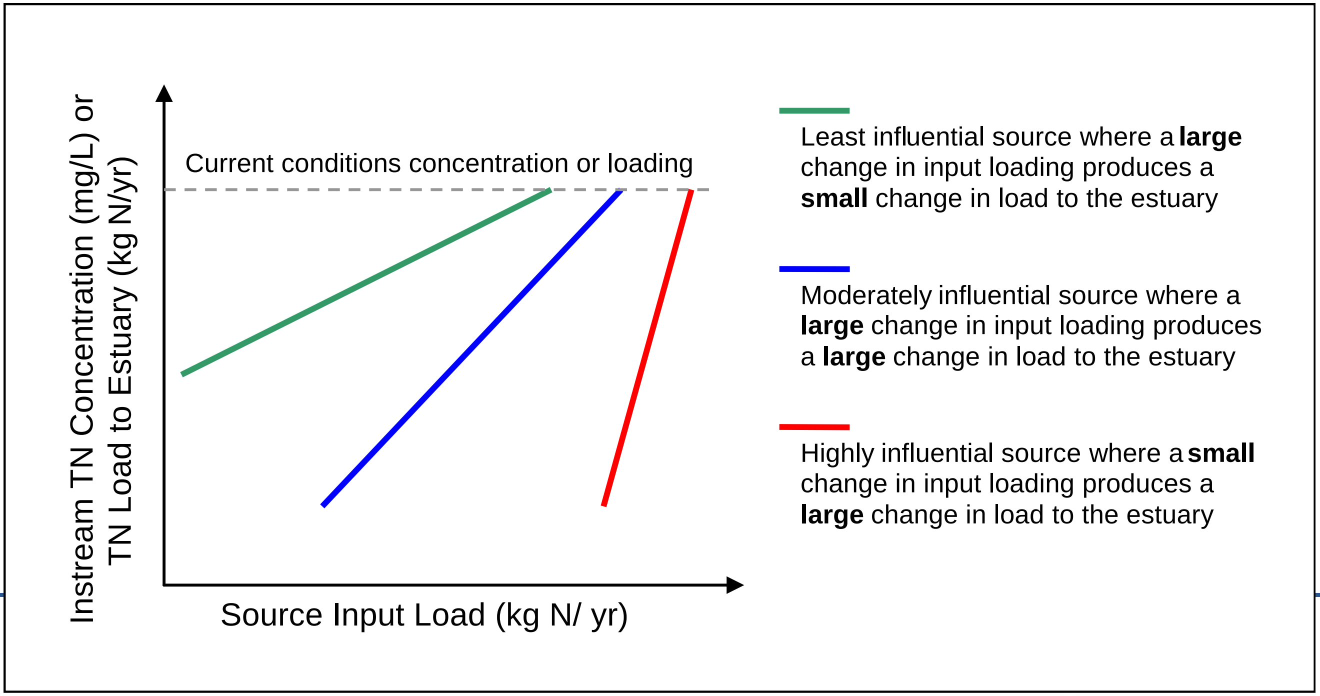
Back Calculation Results

- Current conditions ASSETS EI = 1 (*Bad*)
- Current TN_{atm} = 1.8 x 10^7 kg N/yr
- Analyses to improve the ASSETS EI by 1 or more categories produced infeasible results
  - TN_{atm} would need to be reduce by over 650%
  - Reductions are needed in other sources within the basin to improve OEC/ASSETS EI

Statistic	**TN_{atm} (kg N/yr)**	**% TN_{atm} Decrease**
ASSETS EI = 2 (*Poor*)		
Mean	-1.43×10^8	880
Median	-1.43×10^8	880
5th Percentile	-1.47×10^8	901
95th Percentile	-1.01×10^8	653
ASSETS EI = 3 (*Moderate*)		
No feasible solutions found		
ASSETS EI=4 (*Good*) and ASSETS EI = 5 (*High*)		
All $TN_{atm}{}^{*}_{i} = -5.35 \times 10^8$, i.e. $TN_s{}^{*}_{i} = 0$ mg/L		

Implications of Results

- In Neuse SPARROW model
  - Fertilizer sources act as bottom, red line where small change in input causes a large change in estuarine load
  - Atmospheric deposition acts like top, green line where even large changes in inputs do not greatly affect the estuarine load



Summary

- Screening level, annual assessment completed
- Attempted to determine if reductions in atmospheric nitrogen deposition load would help estuary improve eutrophic conditions
- Created cross-media modeling method through combination of SPARROW watershed modeling and categorical ASSETS eutrophication index measure
- Revealed that other land-based nitrogen sources (e.g. fertilizer application) so dominate instream nitrogen loads that reductions in atmospheric deposition do not greatly affect impacts within the estuary

Thank you. Questions?

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