Flow and Mass Transport in River Basins of the Eastern U.S. : Characteristics, Trends and Implications for Estuarine Health

Overview

* **What are some of the possible impacts of managing flow and nutrient pollution on ecology and water quality, particularly as related to estuaries?**
* **We'll look at why flow and yields are important, what are typical nutrient loads and yields worldwide, on the east coast of the US, and what's typical in North Carolina**
* **How can we achieve sustainable aquatic systems using scientific flow and pollution management?**

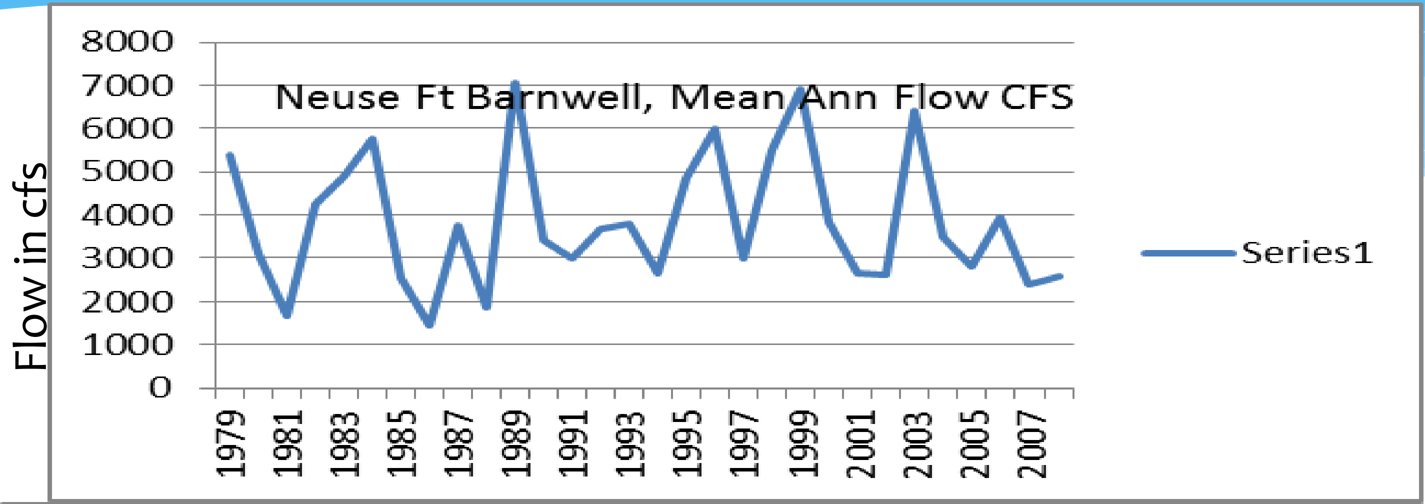
Result of trying to meet human needs while ignoring needs of the ecosystem is often disastrous and results in loss of ecosystem services (from Richter et al., 1997, Freshwater Biology 37 231-249).

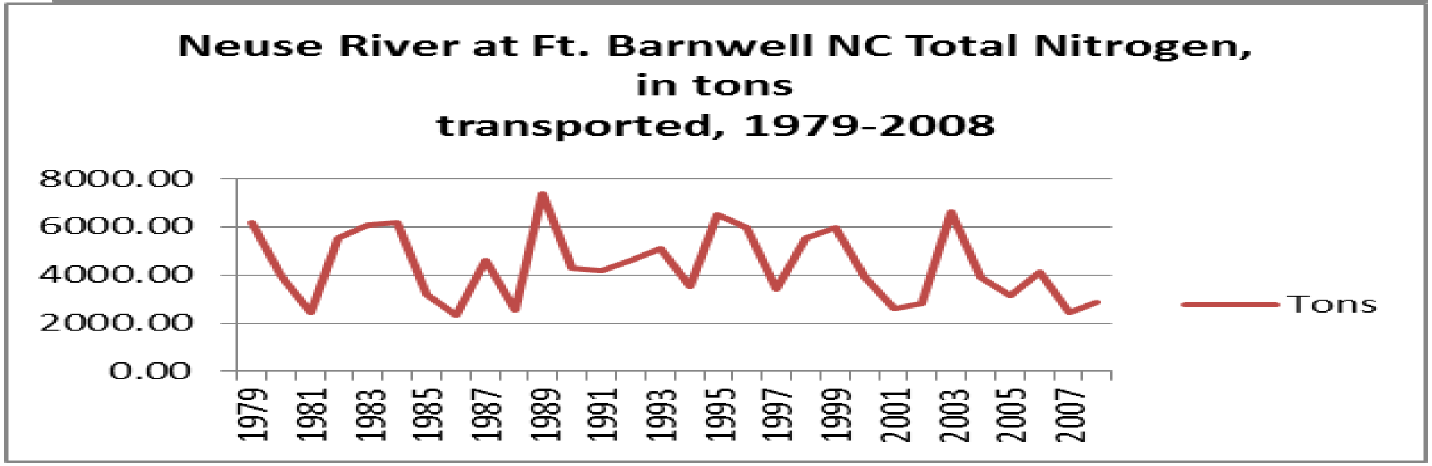
- Three principal causes:
- 1. Alteration of river regimes due to dam operations
- 2. Non-point source pollution- (sediment, bacteria, and **nutrients** are the most important)*
- 3. Invasive species

Flow and mass loads are highly correlated

* Anything that affects flow will affect loading rates—if less flow, then less material transported and vice versa

Flow largely controls transport





Loads and Yields

- **Load** Q (flow volume/unit time) X C (mass/ unit volume) = L (mass/unit time)

  ie. tons / day

  kilograms/ day

- **Yield** mass / unit area/ unit time

  usually tons per square mile per year

  kilograms per square kilometer per year

* usually tons per square mile per

Flow is a major control on the habitat, physical, and chemical aquatic environment characteristics

- Streamflow is the primary mass transport medium and affects major erosion and corrosion processes that occur in a watershed
- The flow of water affects the nature of all aquatic environments:

1. Slow-moving associated with autocthonous systems, highly susceptible to overproduction-includes estuaries in summer-fall when flows are lowest (exception (obviously!-hurricanes), are depositional zones, and can become oxygen depleted (anoxic or hypoxic)from over-production
2. Fast-moving upland streams-highly oxygenated not as susceptible to over-fertilization, primarily allocthonous systems
3. Timing, duration, and frequency are important at all levels of an aquatic ecosystem.

Important Flow metrics (from Richter et. al., 1996 Conservation Biology V. 10 No. 4). Primary analytical components of *Indicators of Hydrologic Alteration*

- **Magnitude-*average monthly conditions characterized –median, mean***
- **Magnitude and duration of annual extreme flow *events-characterize extreme (max and min) water conditions duration 1,3,7,30,90 day cycles***
- **Timing of annual extreme *conditions-identifies occurrence of annual 1-day flow minima and maxima(Julian day).***
- **Frequency and duration of high and low pulses-characterizes periods of year when and how long high (above 75th percentile and low (below 25th percentile) occurs**
- **Rate and frequency of change in *conditions-measure of rises and falls during specified time period***

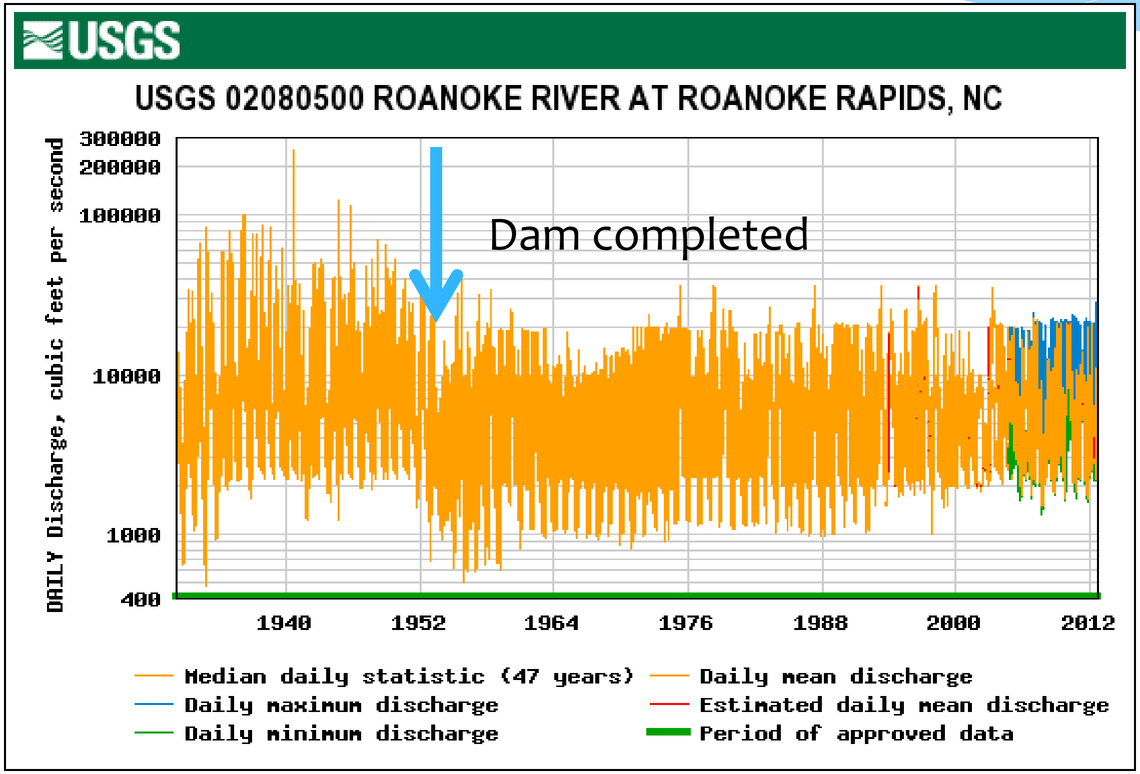
Changes in flow can affect chemistry, biological behavior, habitat and ultimately ecological integrity

All of these flow features are important in determining the types and numbers of organisms in the particular environment

Determination of healthy ecosystems depends on identification and characterization flow characteristics *before* changes are implemented and require comprehensive and well thought out monitoring program.

Impacts should be measured and evaluated according to standard procedures and modified as necessary to achieve healthy river ecosystems (systems that approximate the undisturbed setting as closely as possible)..

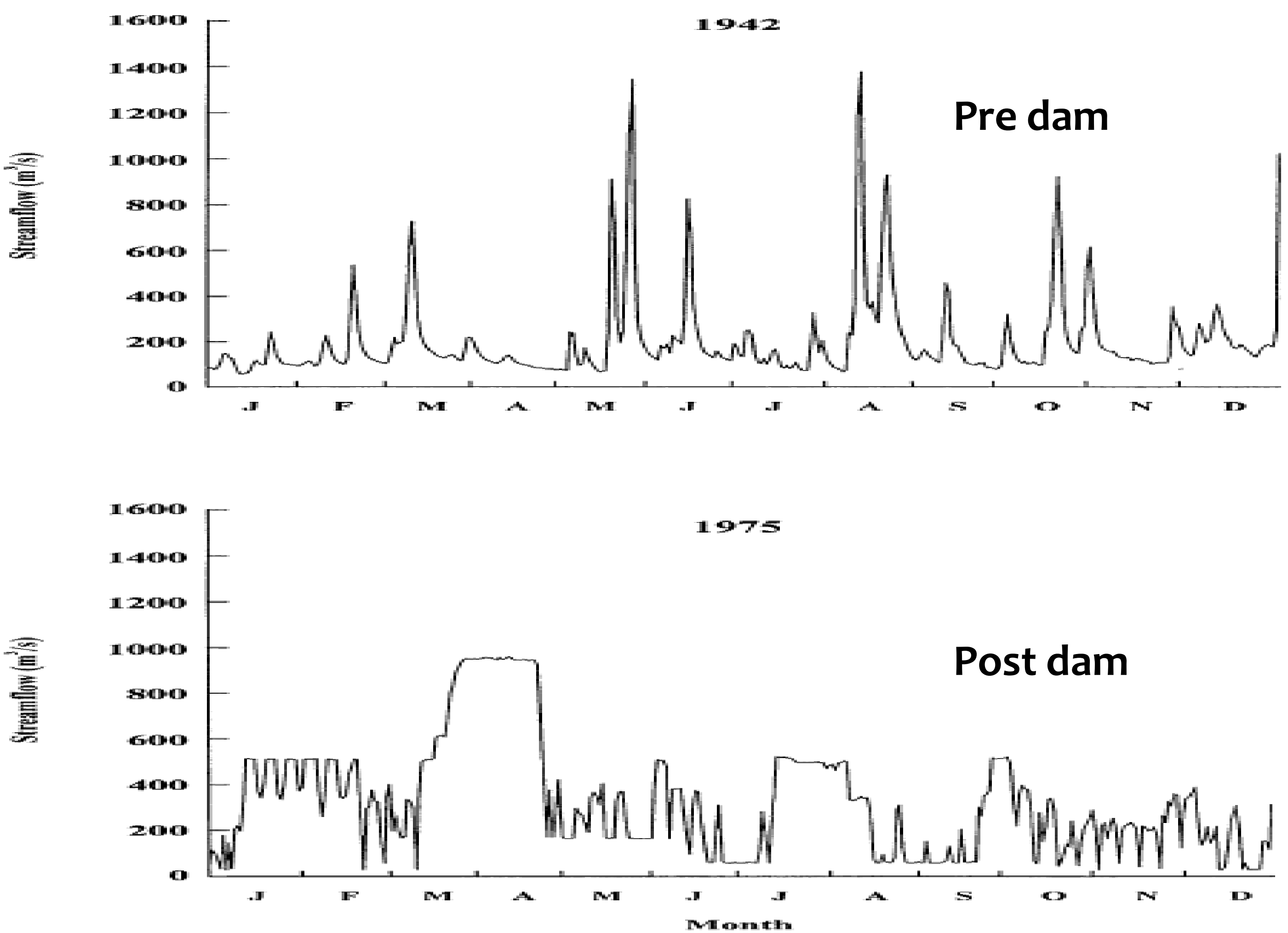
Changes due to management-dam at Roanoke Rapids



	1935-51	1952-1968
Min	1240	501
Q25	4000	2940
Median	6060	5750
Mean	9042.0	6866.8
Q75	9815.0	8600.0
Maximum	254000.0	40100.0
S.D.	11005.4	5284.6
C.V.	121.7139	76.9579

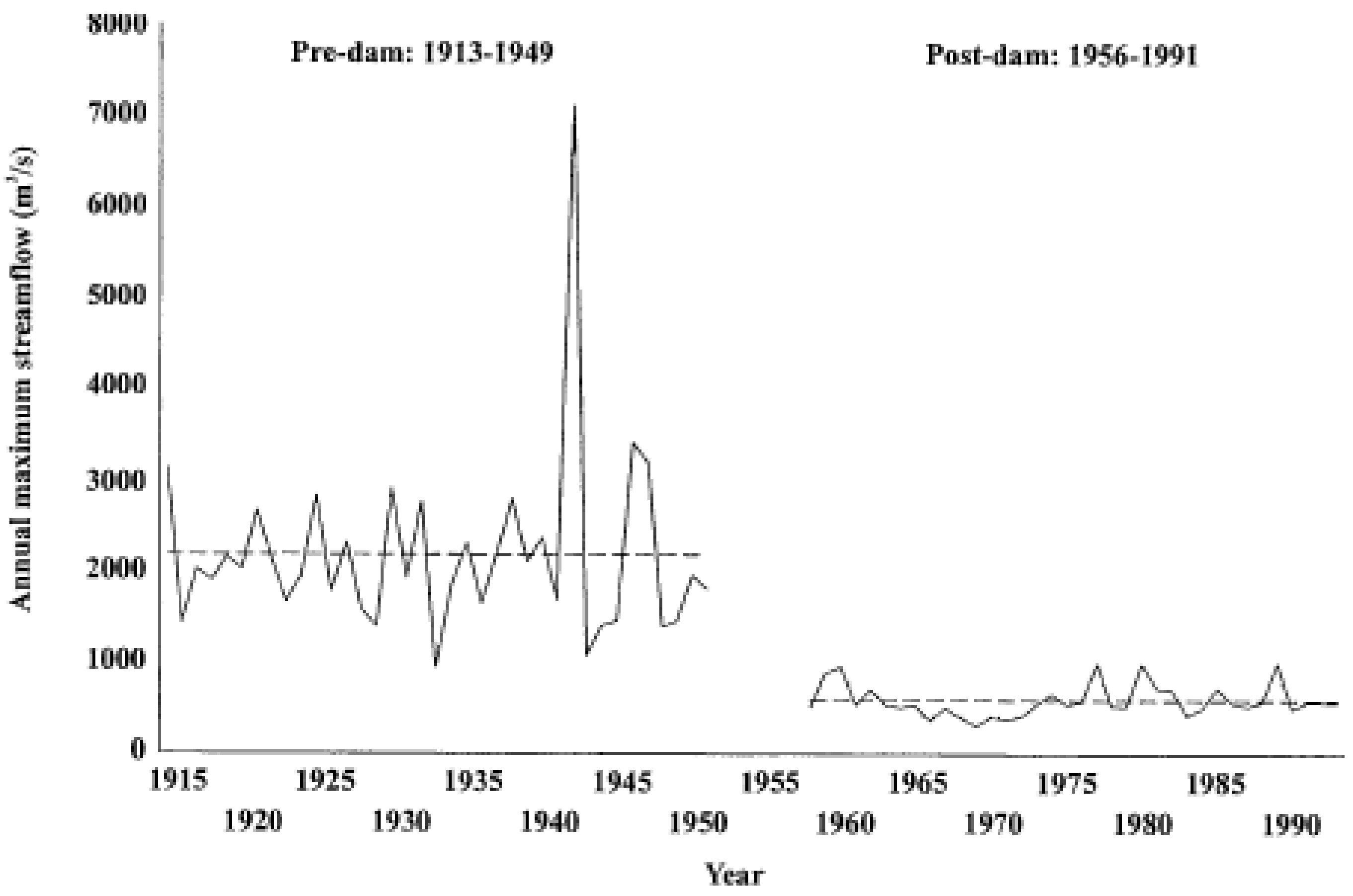
Peaks removed and flow increased at low end- Roanoke at Roanoke River.

Figure from Richter et al., 1996, Conservation Biology, V. 10 No. 4

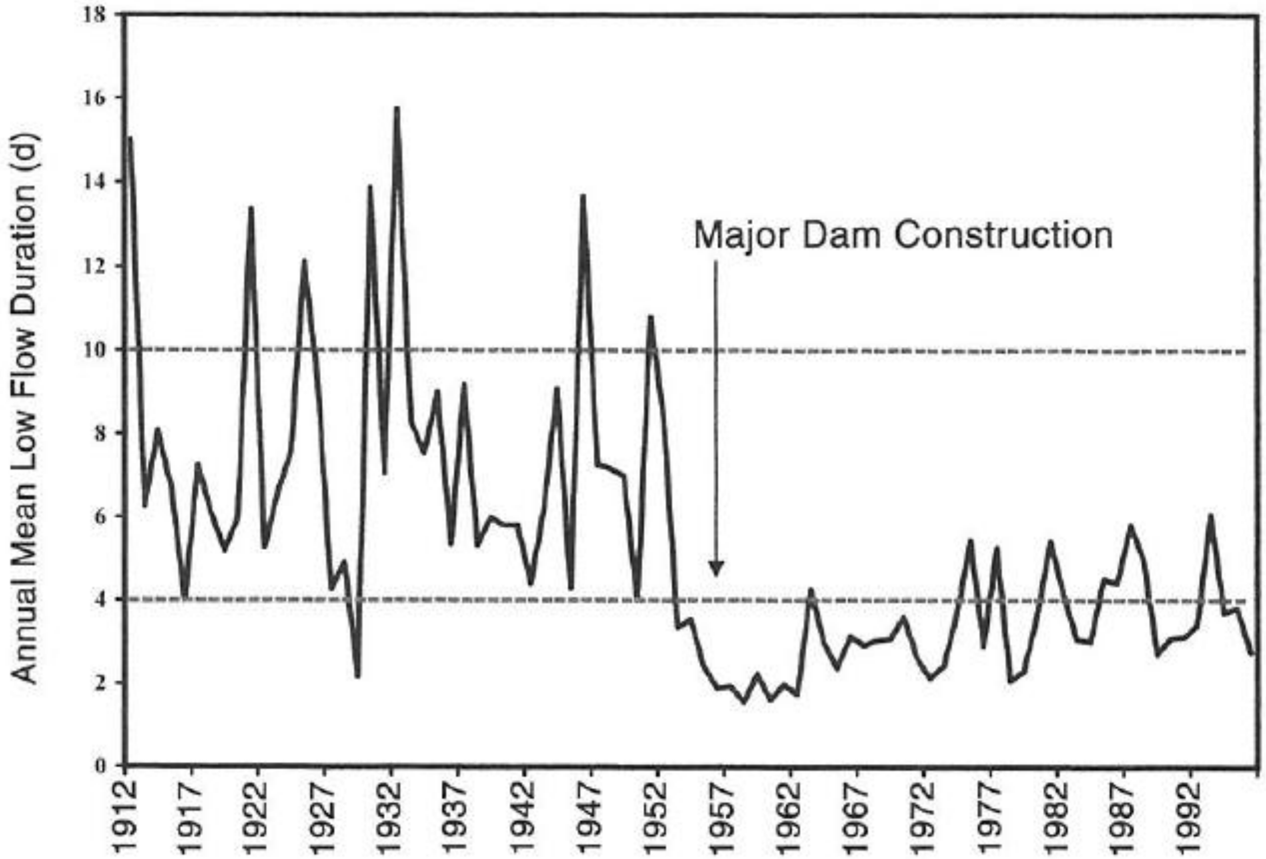


High flows reduced

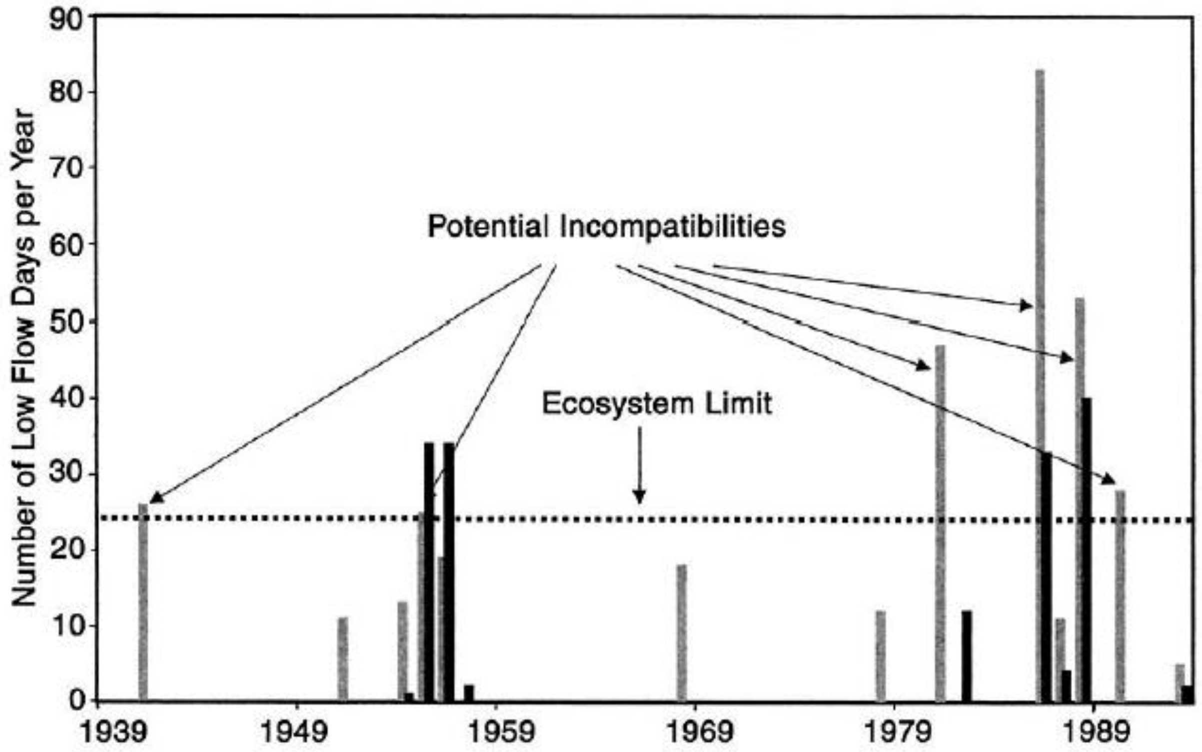
Figure from Richter et al., 1996, Conservation Biology, V. 10 No. 4



Annual Mean Low Flow Duration- number of low flow days reduced



Number of low flow days increased as a result of increased human demand in the ACF



* In the Appalachicola-Flint, a maximum of 24 low flow days/year was determined to be the maximum

From Ecologically Sustainable Water Management: Managing River Flows for Ecological Integrity by Richter, Mathews, Harrison, and Wigginton
Ecol. Applications V.13 No.1 p. 206-224

Ecologically sustainable water management protects the ecological integrity of affected ecosystems while meeting intergenerational human needs for water and sustaining the full array of other products and services provided by natural freshwater ecosystems.

Impact of high flows due to dam releases or to changes in landscape vegetation due to urban and agricultural activities (as they affect runoff characteristics)

* Increased scour and erosion in uplands and increased deposition in lakes an estuaries where velocity drops
* Increase turbidity and sediment transport
* Increased nutrient and contaminant transport
* Increased oxygen from turbulent flow
* Increased freshwater volume
* Extremely high flows due to hurricanes can deposit massive amounts of organic debris which can cause oxygen depletion

Impact of reduced flows due to controlled dam releases, water withdrawals, diversions, drought, groundwater depletion from pumpage

* Reduced loading of sediment and nutrients
* Increased light penetration, decreased turbidity and increased temperature
* Increased number of low flow days
* Advance of salt water upriver from estuary and increase in salinity of the sound and estuary

Objective to Attain Sustainable Rivers

* In river systems with dams, maintain natural flow frequency and duration as closely as possible (match seasonal flow patterns)

When natural variability in river flows is altered too much, marked changes in the physical, chemical, and biological conditions and functions of natural freshwater ecosystems can be expected. When changes to natural flow regimes are excessive, causing a river ecosystem to degrade toward an altered character, the costs are high to both biodiversity and society (Postel and Carpenter 1997, IUCN 2000, WCD 2000) (Fig. 1). The

Process to achieve sustainable rivers

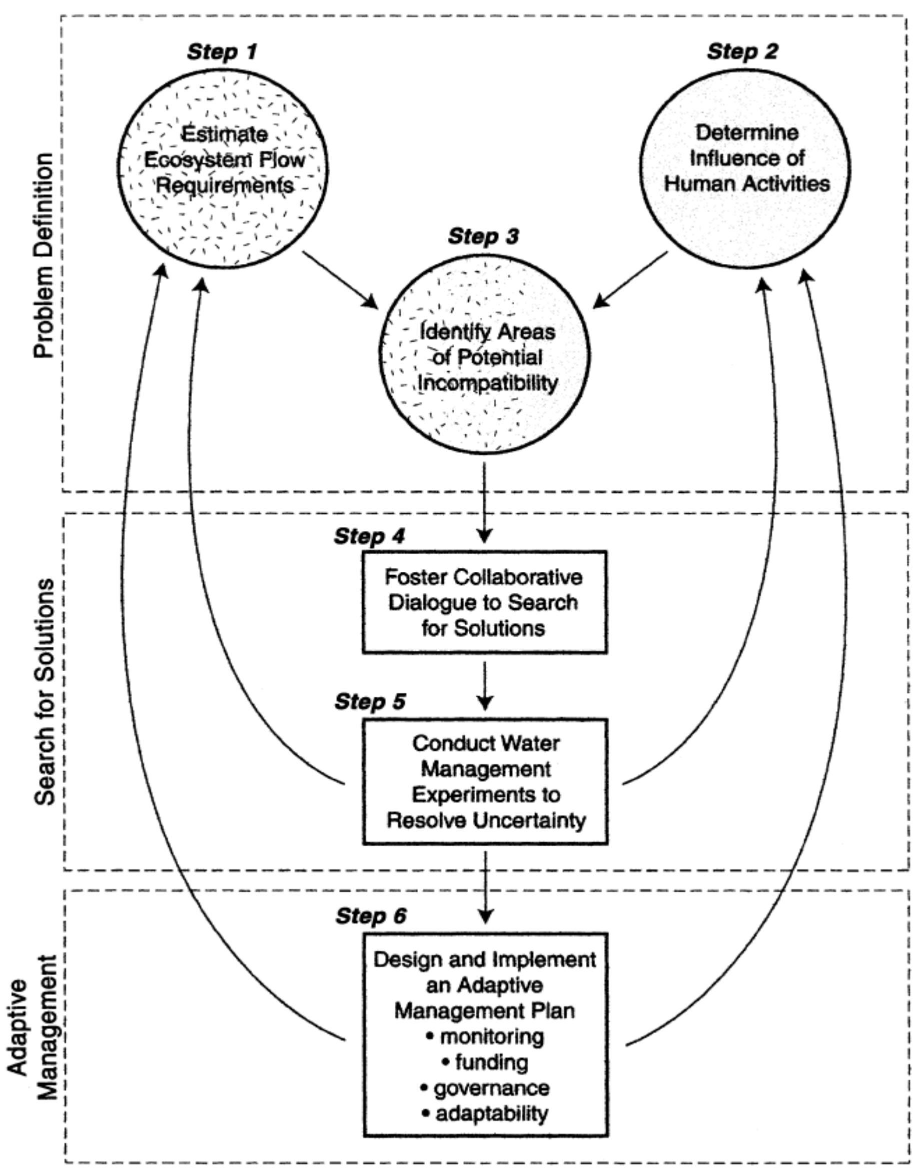


FIG. 2. A framework for ecologically sustainable water management.

Richter et. al.2001

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Loads and Yields useful to characterize nutrient transport processes in different environments and land uses

* Loads are useful primarily as indicators of change through time, but they indicate ALL transport processes taking place at all upstream areas-difficult to tease out specifics
* **Yields are potentially most useful as indicators of change and because they reflect regional environmental process variables, including land use, and are normalized by unit area**
* To eliminate the major effect of the flow variable, it is necessary to divide by flow to show concentration only-best to evaluate changes in point sources of nutrients

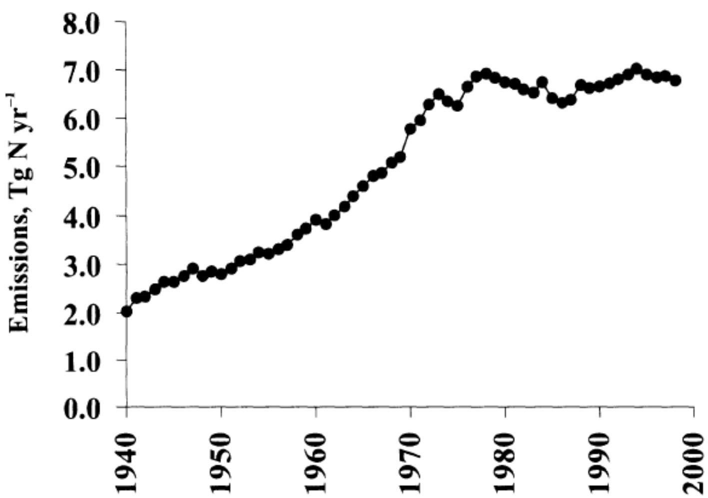
Why is movement of nutrient loads to coastal waters important?

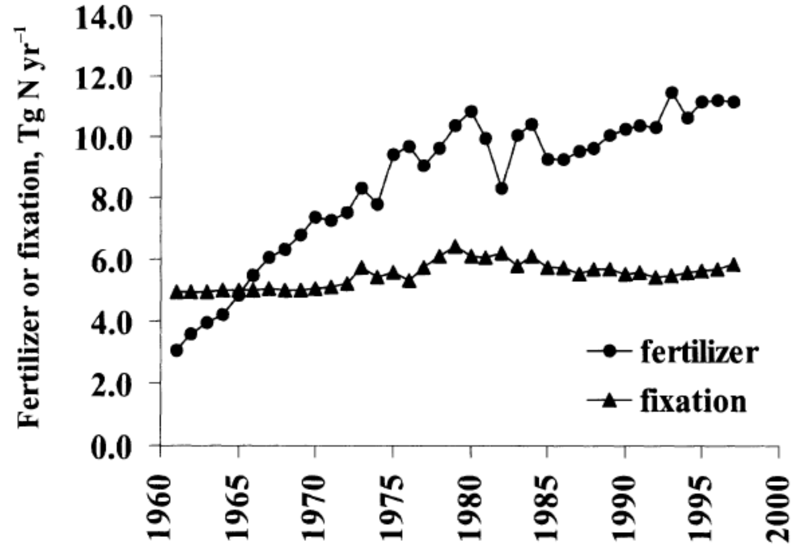
* Excess nutrients can exacerbate eutrophication processes-in freshwater systems, it is usually P that is the limiter; in brackish and marine systems, it is usually N. When both are in excess, light becomes the primary limiting factor
* Results in increase in species that are pollution tolerant and potentially toxic
* Increase in massive amounts of oxygen- depleting algal growths, can cause fish kills through hypoxia
* Increase in nutrient loading has resulted in worldwide increase in dead zones, rare before 1960 (Diaz and Rosenburg, 2008 Science V.321).
* Hydrologic processes important in timing of late summer/fall nuisance growths

Agricultural Changes in Use of Nitrogen and Phosphorus through time

* **Sources of nitrogen and phosphorus have gone up since the turn of the century and particularly since 1960 (Smil 1991; Schlesinger (1997); *Howarth et al. 2002); for NC, Don Stanley (1992) and Stow, Borsuk, and Stanley (2001)***

Figure 1. Atmospheric NO_x emissions in the USA from 1940–2000. Data from US EPA (18).





So….have yields increased since the 1970s?

1. ***Worldwide, loads (and therefore yields) DIN and DIP increased ~3 X between the 1970s and 1990s (Smith et al. 2003)***.

2. **Total N** from about 1 tpsm to **3 tpsm** (NE US) and 2 tpsm (SE US) (Howarth et al. 2000); 2.1 tpsm (calculated from DIN reported in Smith et al. (2003)

3. **Total P** from 0. 07 tpsm to **0.2 tpsm** **(east Coast U.S. calculated from DIP reported in Smith et al. (2003))**

Typical World, SE US, and North Carolina (A-P) N and P Yields in tpsm

Nutrient	Europe and eastern US (late 1990s)	SE US (late 1990s)	A-P (early 1980s-mid90s)
Total Nitrogen	2.1 (using 0.7 tpsm for DIN) (S); 3 (H)	2 (H) 1-2 tpsm (HM)	TN=0.53-1.6 (Hnd)
Total Phosphorus	0.2 (using 0.08 for DIP) (S)	NI (0.2 from Smith)	TP=0.03-0.21(Hnd)

H=Howarth et al., 1996 Biogeochemistry 35 75-139
S= Smith et al., 2003, Bioscience 53 No. 3, 235-245
Hnd=Harned et al., 1995 USGS WRI 95-191
HM=Hoos/McMahon 2009 Hydrologic Processes DOI: 10.1002/hyp.7323

In order to maintain ecosystem integrity, nutrient loading must be controlled

- While huge improvements have been made in controlling point source discharges, the same can't be said for non-point sources.
- Excess nitrogen is still moving into U.S. estuaries which will require more active controls by the states to maintain healthy coastal ecosystems.

Vollenweider (1975,1976)

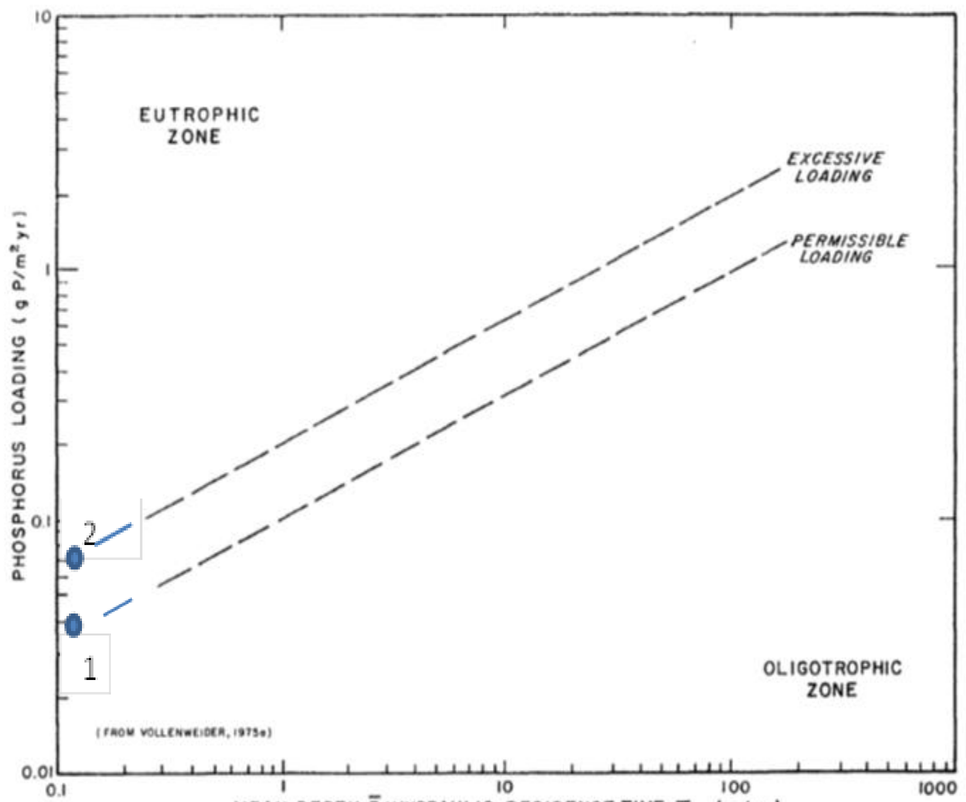


Figure 7. Initial Vollenweider Total Phosphorus Loading and Mean Depth/Hydraulic Residence Time Relationship.

Maximum P loading to a shallow
slow lake/estuary is about **0.1 tpsm making the nitrogen maximum about 1 tpsm.**

Fast moving streams can sustain higher nutrient loading without exhibiting eutrophication

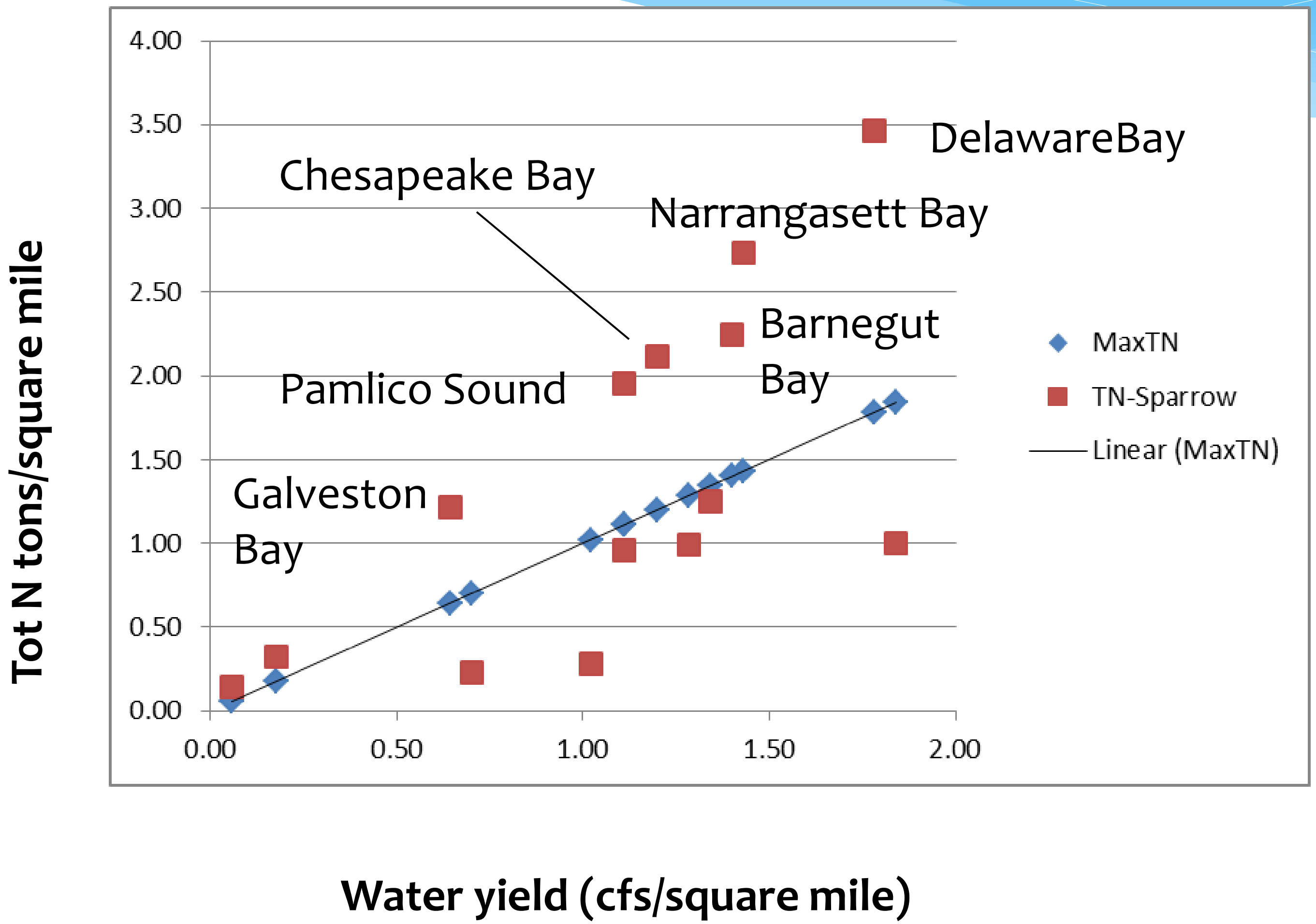
Lakes and estuaries are highly susceptible to nutrient pollution.

Selected estuaries Included in study of 42 estuaries in the Eastern U.S. From Nitrogen Loading in Coastal Water Bodies. Valigura et. al., 2001.AGU. Data from Alexander, USGS SPARROW MODEL.

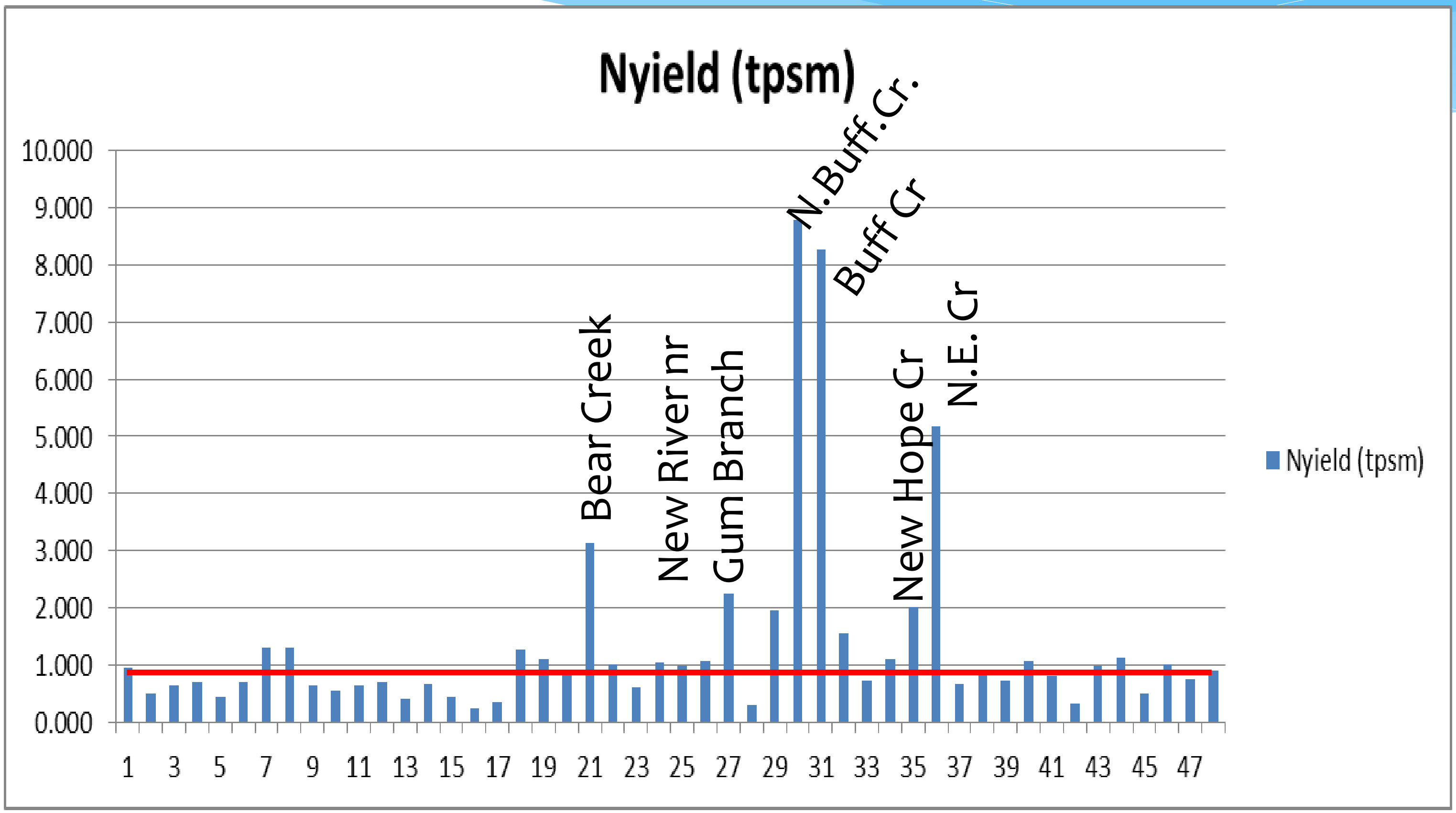
ESTUARY		AREA	cfs/sqmi	MaxTN	TN-Sparrow
Casco Bay		32	1.84	1.84	1.00
Great Bay		2590	1.28	1.28	0.99
Narrangassett		4662	1.43	1.43	2.73
Barnegat Bay		878	1.40	1.40	2.25
Delaware Bay		34965	1.78	1.78	3.46
Cheseapeake Bay		56980	1.20	1.20	2.12
Pamlico		11600	1.11	1.11	1.95
Charleston Harbor		40922	1.02	1.02	0.28
Indian River		4926	0.70	0.70	0.23
Charlotte Harbor		8547	1.11	1.11	0.96
Tampa Bay		5895	1.34	1.34	1.25
Galveston Bay		60597	0.64	0.64	1.22
Matagorda Bay		90672	0.18	0.18	0.32
Corpus Christi Bay		44841	0.06	0.06	0.15

Total N Loads to Coastal Estuaries

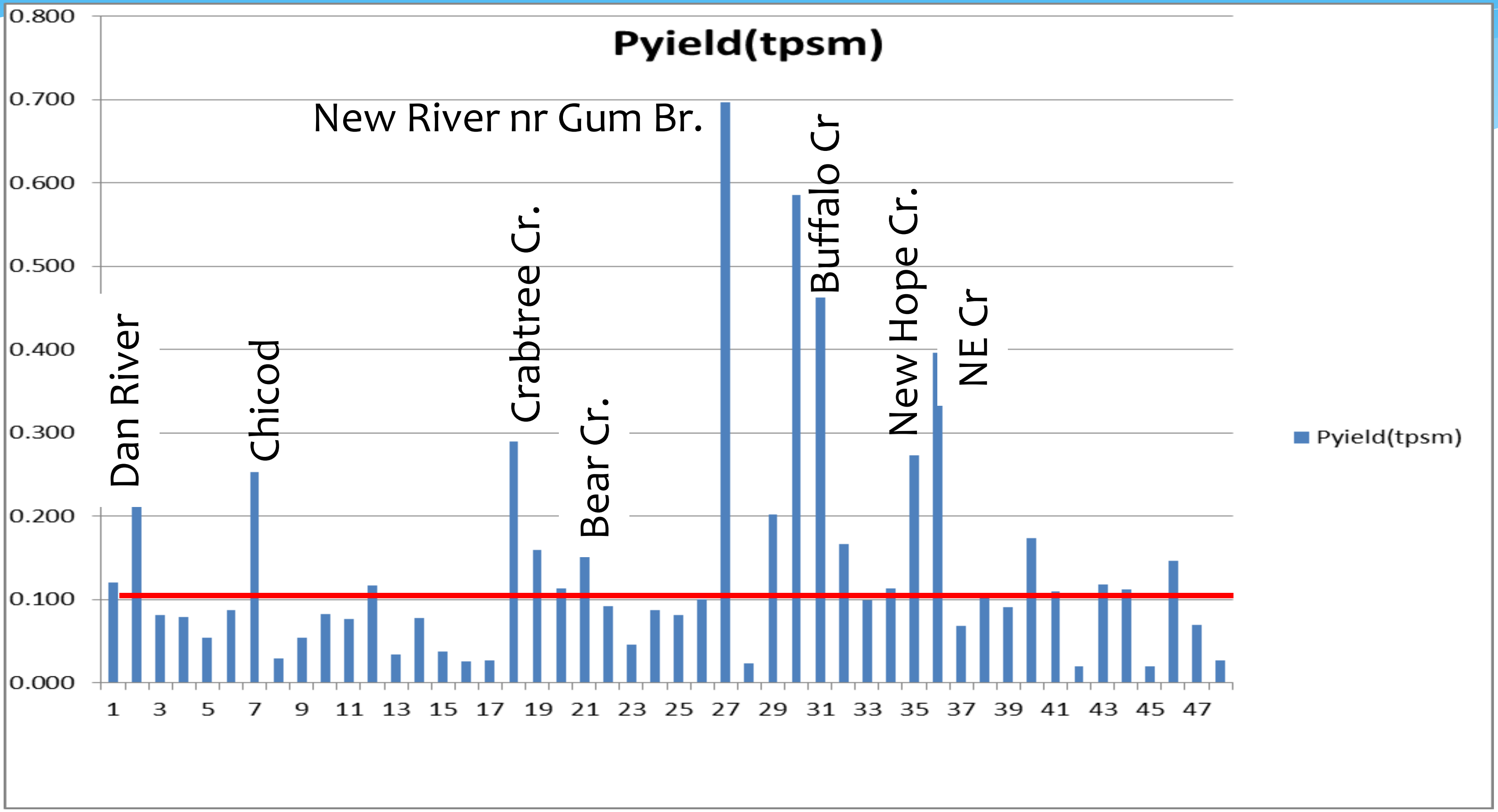
Data from 1976-1992 . Line shows Tot N=1 tpsm.



How does North Carolina Do? Tot N.
Data from USGS and NCDENR DWQ 1997-2008



Tot-P



Pyield(tpsm)
0.800
0.700
0.600
0.500
0.400
0.300
0.200
0.100
0.000
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37 39 41 43 45 47
New River nr Gum Br.
Dan River
Chicod
Crabtree Cr.
Bear Cr.
Buffalo Cr
New Hope Cr.
NE Cr
Pyield(tpsm)

Conclusions

* **Attaining sustainable aquatic ecosystems will require identifying natural flow *and mass loading features of each system,* attempt to duplicate them as closely as possible while trying to resolve conflicts between people's needs and specific ecosystem needs.**
* **The scientific basis for determining sustainable flow and mass load management is available-the data are there and more earnest efforts should be made to use it. Populations are increasing in these basins and limits need to be defined.**