Buzzards Bay Project

Empirical relationships between nitrogen loading and ecosystem response in Buzzards Bay embayments: Is there transferability for TMDLs elsewhere?

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National Estuary Program

May 5, 2004
2:30-3:00

Additional Information at
www.BuzzardsBay.org

"A TMDL specifies the maximum amount of a pollutant that a waterbody can receive <u>and still meet water quality standards</u>, and allocates pollutant loadings among point and nonpoint pollutant sources." **US EPA**

Talk Outline

Brief historical overview of our original approach

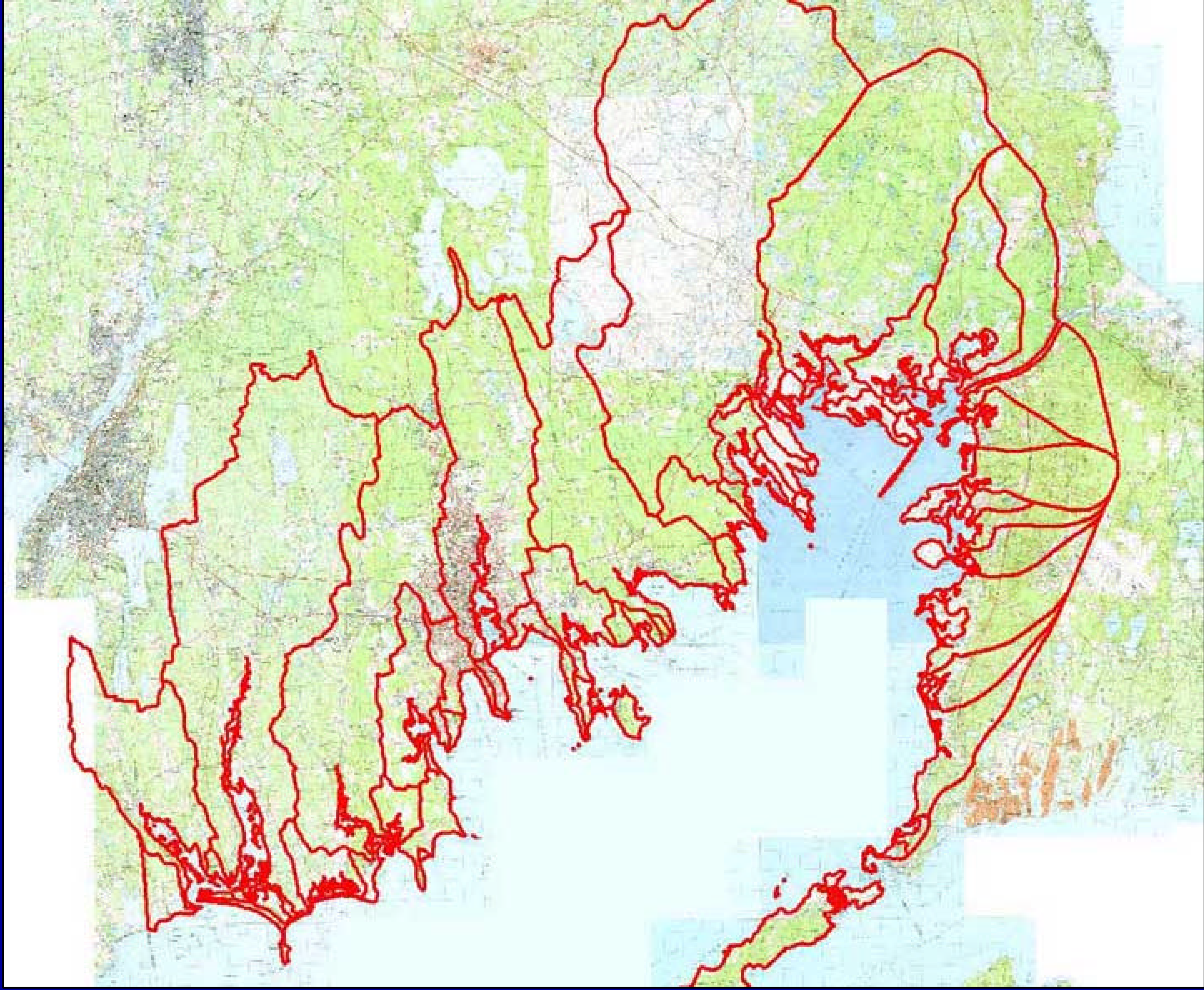
Philosophy on TMDLs (science versus management)

Describe the new ongoing effort of the Massachusetts Estuary Program to establish Nitrogen TMDLS

Discuss the log-normal ecosystem response to nitrogen loading and the high temporal variability in ecosystem response

Introduce the concept of a 10 second TMDL

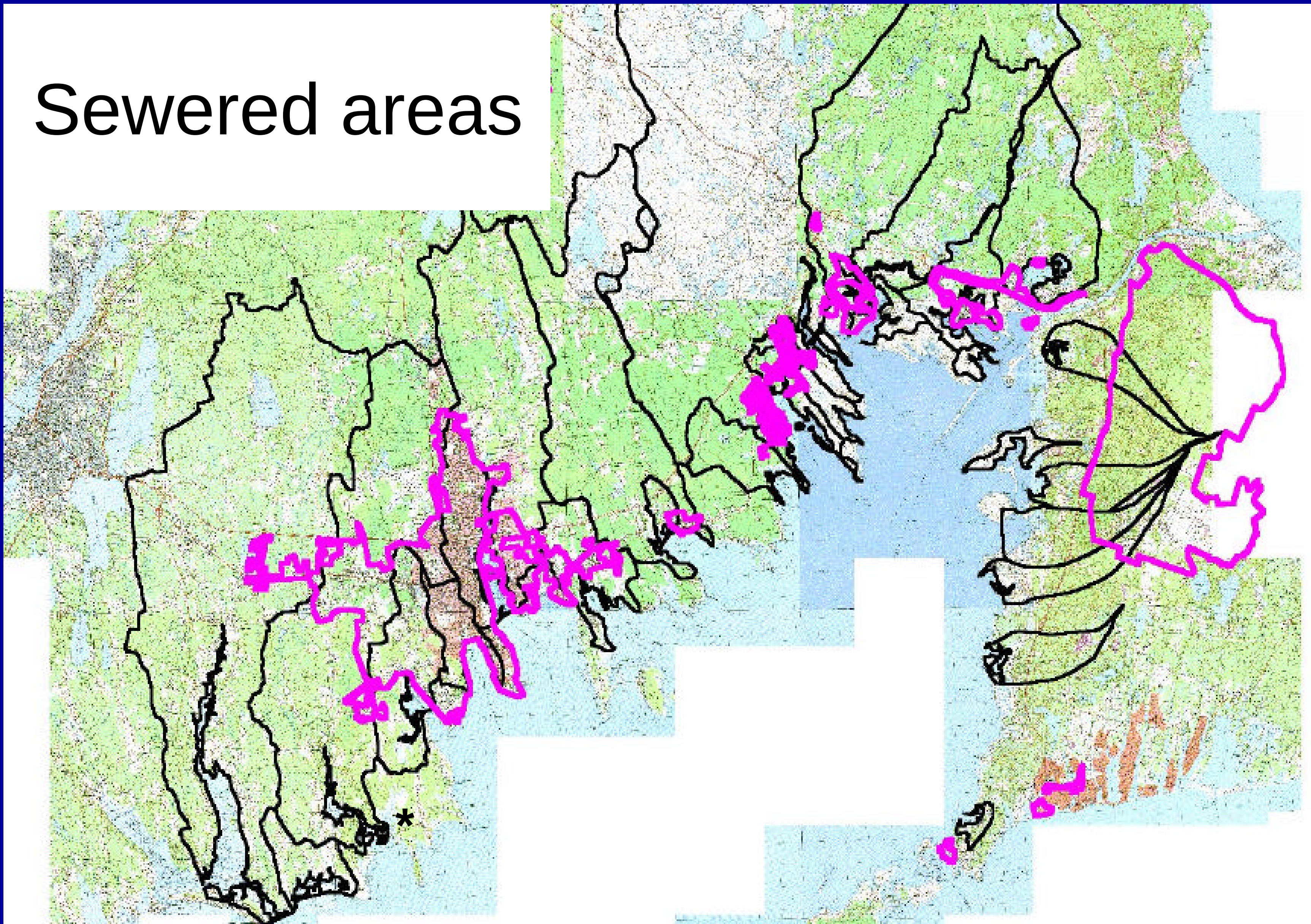
The Problem & Motivation.



Buzzards Bay, a National Estuary Program established in 1985, has dozens of coastal embayments, many of which are threatened or impacted by anthropogenic nitrogen loading. Previous studies focused on bay-wide conditions. Most embayments threatened by cumulative impacts of NPS pollution. Management Plan developed in 1991.

24 of 28 embayments had no large point sources of nitrogen.

Sewered areas



Buzzards Bay Project Nitrogen Management Strategy

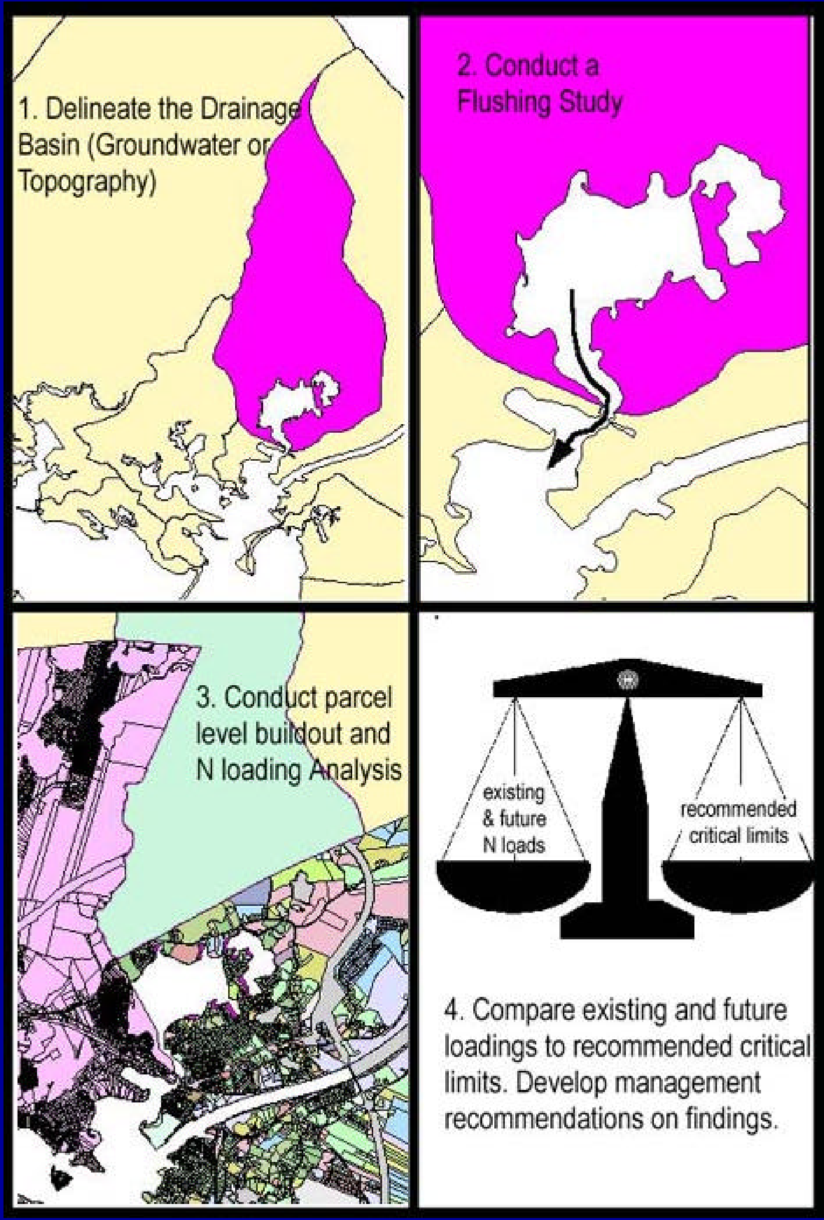
-Novel "TMAL" strategy adopted in 1991. Limits based on empirical relationships between loading and ecosystem response.

-Mass Loading standard, not water quality standards

- parcel level evaluation recommended

- new embayment specific models needed where large $ decisions involved

-Proposed loading standards incorporated:
o flushing (Vollenweider term)
o volume
o bathymetry
o water quality classifications (SA, SB, ORW, etc.)



1991 proposed Nitrogen Management Strategy

-For impacted bays, do historical assessment to find loading target
-For bays with large $ decisions (like STF designs), do a bay-specific loading model
-For other bays, used tiered approach below

Original approach:

Embayment type	SB Waters[b]	SA Waters[b]	Outstanding Resource Waters[b]
Shallow[c]			
-flushing: ≤4. 5 days	350 mg m^{-3} Vr^{-1}	200 mg m^{-3} Vr^{-1}	100 mg m^{-3} Vr^{-1}
-flushing: >4. 5 days	30 g m^{-2} yr^{-1}	15 g m^{-2} y^{r-1}	5 g m^{-2} yr^{-1}
Deep			
-lesser of	500 mg m^{-3} Vr^{-1} or 45 g m^{-2} y^{r-1}	260 mg m^{-3} Vr^{-1} or 20 g m^{-2} y^{r-1}	130 mg m^{-3} Vr^{-1} or 10 g m^{-2} yr

Volumetric limit • volume at half tide (in m^3) • $(1+\tau_w^{½})/\tau_w$ ÷ 1,000,000
where τ_w is the hydraulic turnover time in years.

Most Loading Models are structured matrices in spreadsheets

Wareham River	Watershed areas in Hectare			sewered	sewerec	sewered	
Landuse type	whole	lower	upper	whole	lower	upper	N (kg)
Cropland	11.7	1.9	9.8				177
Pasture	10.3	8.3	2.0				99
Forest	8286.9	964.6	7322.3				1015
Non-forested wetland	178.7	105.6	73.0				0
Mining	19.1	1.6	17.6				103
Open land	177.9	56.8	121.1				24
Participatory recreation	163.9	13.3	150.6				3497
Spectator recreation	0.0	0.0	0.0				0
Water based recreation	15.0	12.4	2.5				106
R0: residential multi-family	12.2	12.2	0.0	1.6	1.6	0.0	855
R1: Residential- <¼ acre lots	218.5	146.3	72.1	65.6	64.5	1.1	9239
R2: Residential- <¼-½ acre lots	392.3	199.5	192.8	78.0	78.0	0.0	11413
R3: Residential- <½ acre lots	238.7	98.7	140.1	7.3	7.3	0.0	3829
Salt marsh	120.9	93.5	27.5				0
Commercial	69.9	68.3	1.6	24.6	24.0	0.6	5647
Industrial	51.6	37.4	14.3	14.0	14.0	0.0	951
Urban open	65.4	16.0	49.4				8
Transportation (maj. highways)	113.4	100.7	12.7				1695
Waste disposal	25.1	25.1	0.0				398
Water (ponds, other freshwater)	629.8	74.5	555.2				0
Woody perrenial (bogs, orchards, etc	0.0	0.0	0.0				0
NA	0.0	0.0	0.0				0
Cranberry Bog (part of #21	1161.1	388.0	773.1				17314
Powerlines (part of #6)	142.0	14.5	127.5				17
Saltwater Beach (part of #9)	0.0	0.0	0.0				0
Golf (part of #7)	39.6	0.0	39.6				816
Tidal Salt Marsh (part of #14)	0.0	0.0	0.0				0
Irreg. Flooded Salt Marsh (part of #14	0.0	0.0	0.0				0
Marina (part of #8)	0.0	0.0	0.0				0
New Ocean	0.0	0.0	0.0				0
Urban Public (part of #17)	40.9	20.9	20.0				6
Transportation Facility (part of #18)	5.0	5.0	0.0				78
Heath (part of #17)	0.0	0.0	0.0				0
Cemetaries (part of #17)	14.1	14.1	0.0				418
Orchard (part of #21)	0.0	0.0	0.0				0
Nursery (part of #21)	1.6	1.6	0.0				33
Forested Wetland (part of #3)	0.0	0.0	0.0				0
TOTAL LAND AREA (ha)	11575.3	2405.8	8724.6				
Major road length, km	21.3	20.5	0.8				
All Roads, km	436.4	135.6					
Secondary Road length, km	415.1	115.1	300.0				
Road Area (ha)	367.9	126.5	241.3				2157
Embayment area (ha)	249.00						1918
Total Loading based on landuse, pre adjustments							**59143**
Reported Area occupancy	2.2	2.2	2.2				
Predicted units (existing)	4914	2842	2072	sewered units			
actual units (1990 census)	5091	3550	1541.0	1408	1408	0	
roof+lawn loading from census units		5210	1583	27.7%	39.7%	0.0%	6793
Unit density (per acre)	0.2	0.5	0.1				
Predicted population (existing)	10712	6196	4516				
Actual population (1990 Census)	10030	6230	3800.0	2022	2022	0	
Population w/ seasonal adjustment	11688	7788	3900	2528	2528	0	
septic loading from census pop. data							21394
actual/assumed annualized occupar	2.3	2.2	2.6				
Total Loading based land use, census units, cenus pop, and actual roads							**67971**
Animal units	0.0	0.0	0.0	0.0	0.0		0
Point sources (MGD, ppm)		24867.5	0.0				24867
Other Special:		0.0	0.0				0
Sewering adjustment units		0	0				
upper watershed adjustment (kg)							0
lower watershed adjustment (kg)							0
Final Adjusted Loading, landuse/census based							**92839**

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upper watershed adjustment (kg)							0
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Final Adjusted Loading, landuse/census based							**89009**

Loading Summaries		
	Residential NPS:	31.7%
	Indust.+Comm.+Rds	11.3%
	Cropland:	19.8%
	Farm Animals:	0.0%
	Point Sources:	27.9%
	Forest	1.1%
	Other Sources	8.2%
	Total	100%

ading Summaries		
	Residential NPS:	61.3%
	Indust.+Comm.+Rds	19.2%
	Cropland:	2.3%
	Farm Animals:	0.0%
	Point Sources:	0.0%
	Forest	0.4%
	Other Sources	16.8%
	Total	100%

Note: Management vs. Science Occupancy rates

History and future of practical nitrogen management in Massachusetts

1980s Starting Point: Freshwater Pond and Lake Phosphorus loading studies, GW nitrogen loading studies of Long Island and CCPEDC, coastal studies in RI, and Town of Falmouth water quality standards for Total Nitrogen in coastal waters

We liked the Falmouth loading approach, but reliance existing water quality (no accounting for lag time), inappropriate methods for measuring TN was unacceptable, as well as the piecemeal management approach.

We sought to pull out the WQ element and have management decisions focus exclusively on the easier to manage annual nitrogen loads from new development.

Our limits were initially hard to defend because we had little good embayment water quality (used eelgrass loss and a few good stuies in SE Mass and RI.) We were also hamstrung because there were few good ecosystem response models, and little money to implement more ambitious assessments.

1991 Strategy Weaknesses

(and how they were addressed)

• Inadequate baseline WQ data
(addressed with WQ monitoring program commencing in 1991)

• Inadequate description of conditions expected for given loading
(addressed with WQ monitoring program commencing in 1991, we proposed water quality standards in 1998)

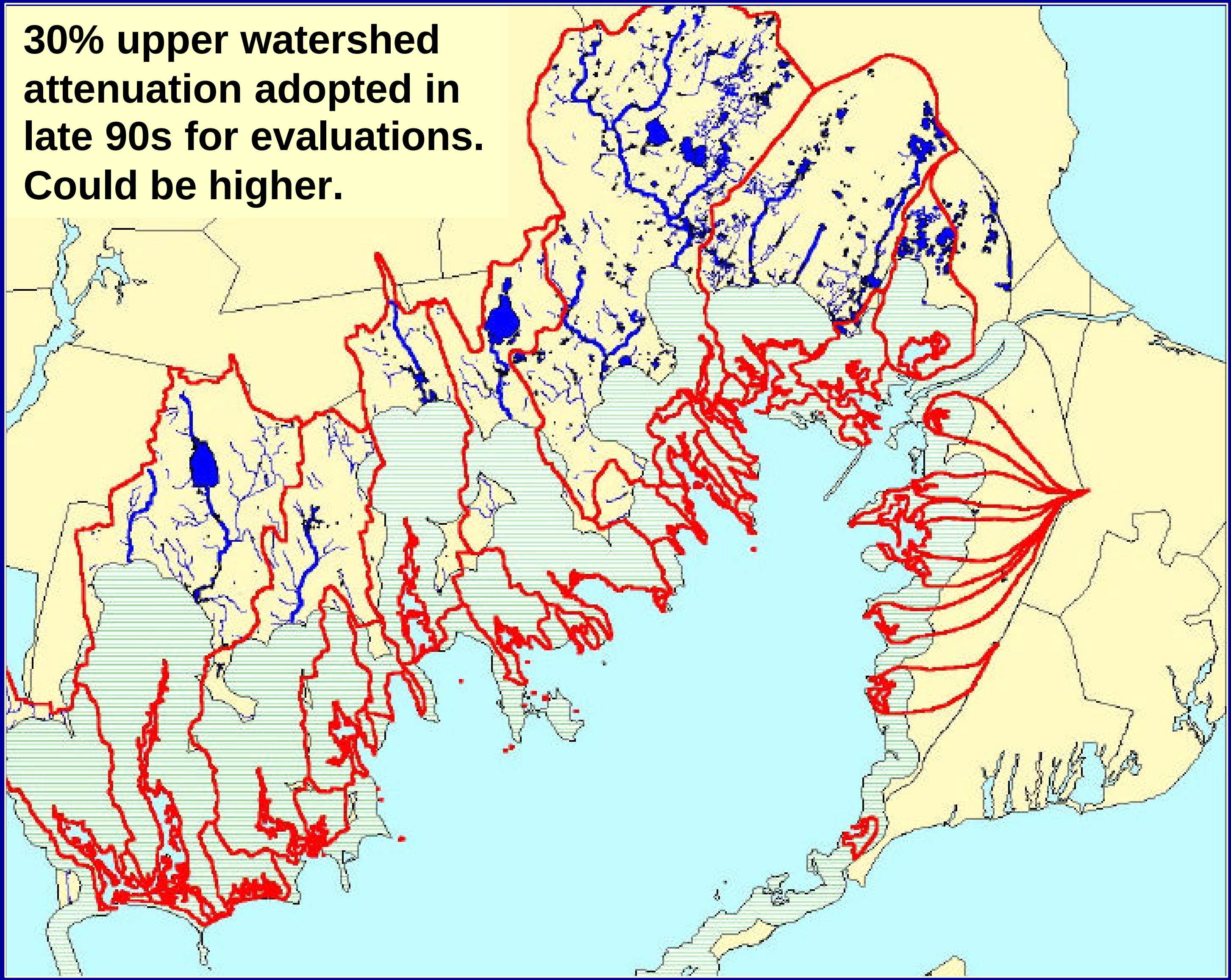
• No attenuation or loss terms for upper watershed or groundwater/wetland losses
(30% loss for upper watershed, unless better documentation)

• No Atmospheric N for Forest or other undeveloped
(adopted 1.5 uM N groundwater background)

• Disagreement with certain loading terms (e.g. Septic systems)
(ok to use different loading models, but don’t use our standards)

•Adequately Protective? (loading limits halved)

BB Sub-basins: Upper and lower watersheds



Our effort is now superceded by MA DEP's "Massachusetts Estuaries Project"

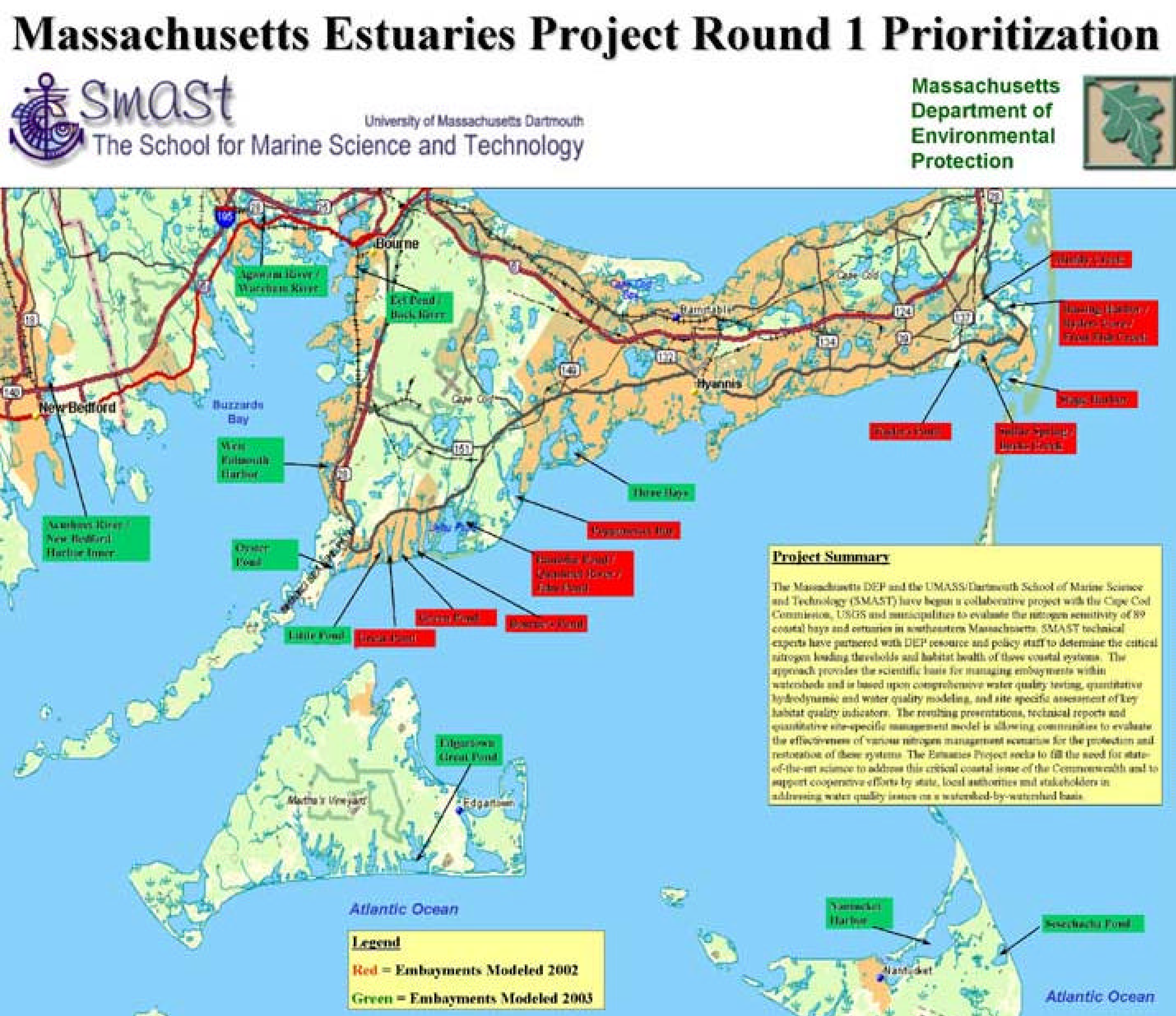
-Started in 2000. Meets our 1991 vision of the way things should be done.

-Study of 89 embayments (Loading -Flushing –Modeling) with recommended TMDLs and evaluation effectiveness of selected management options.

-original projection $13 Million or $158,500 per embayment, more likely around $200,000 or more?

-**Original estimate was 6 years to complete, but may be closer to 10 years and will be largely determined by funding levels. First draft evaluations released in Spring 2004.**

-**Completion of study will identify management options, but regulatory tools for managing cumulative impacts of NPS have changed little in the past 20 years (i.e. zoning and sewering still leading options, innovative waste disposal requirements, non point source management still difficult to manage at state and federal level.)**

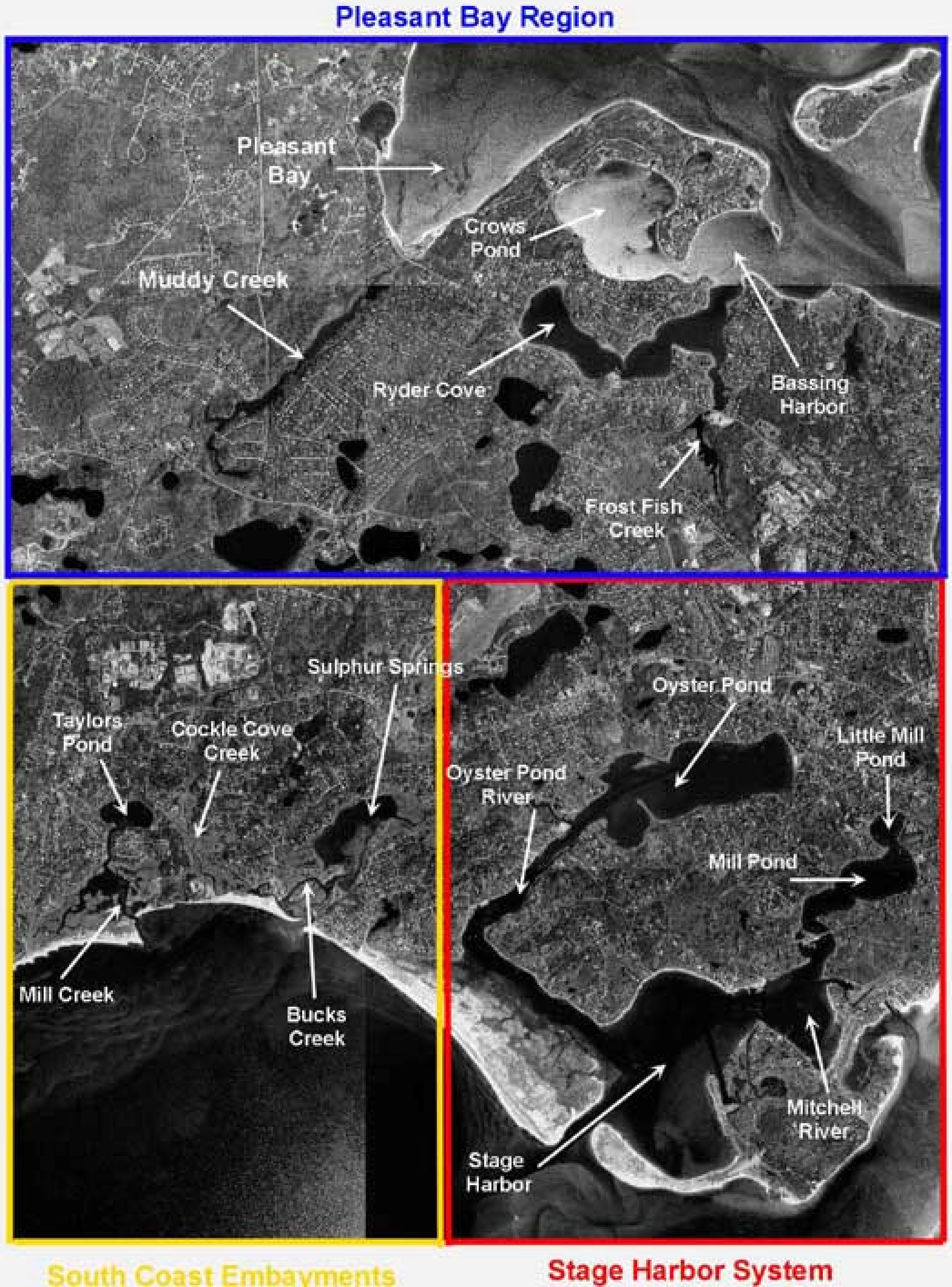


Chatham estuaries draft TMDLs just released

Massachusetts Estuaries Project:

Chatham Report Released

Primary Tool used by Dr. Howes is SMS (surface water modelling system) that links a hydrodynamic model (RMA-2) to a water quality model (RMA4).



Is any part of the BBP 1990s approach transferable to areas where dollars and time are not on your side?

Yes, certain concepts….

The correct management solution for development and implementation N TMDLS for NPS pollution:

1) **Good water quality monitoring data sets for the scale watershed you are trying to manage**

2) **Appropriate Water and Living resource Goals**

3) **Good model for predicting changes in WQ parameters (reductions or increases)**

4) **Implementation will most often focus on wastewater management. TMDLs will require application of mass loading limits (lb/s per acre) for new development using codified loading standards, and remediation strategies for existing development to meet certain targets.**

1998 proposed water quality standards

Table 1. Proposed water quality standards, for various surrogate measures of nitrogen loading, that correspond to the proposed TMALs for nitrogen. Targets are mean summertime concentrations when critical conditions are most likely to occur. Based on best professional judgment.

	(Formerly ORW	SA	SB)	
Parameter	Excellent	Good	Fair	Poor
Eutrophication Index	70	60	50	40
Alternate Eutroph.Index (no 0_2)	65	55	45	30
Total N (ppm)	0.39	0.45	0.54	0.65
Chl a (mg/l)	4.0	6.0	7.0	9.0
Secchi depth (m)	2.0	1.7	1.5	1.3
Eelgrass to core habitat ratio	0.9	0.7	0.5	0.3

Point #1: Establishing TMDLs is more of a management process than a scientific exercise.

- It is really translating science into a regulatory and management standard.

- Reality: Ecosystem response is a continuum, and highly variable in time space, even in one embayment.

- Scientists can define and document a problem. They can predict ecosystem response if you reduce a pollutant load. They can predict pollutant reductions with certain actions. But there is uncertainty in these evaluations.

- EPA TMDLs are numerical limits water quality or habitat criteria and goals. Even if these standards are numeric, are based on value judgments of what is “good” and “bad”, and evaluations beneficial uses. EPA TMDLs are required only for 303(d) list or Category V listed waters.

- Some municipalities (or counties) may want to adopt TMDLs even when a body of water is not listed. Or they don’t want to wait for the state or EPA.

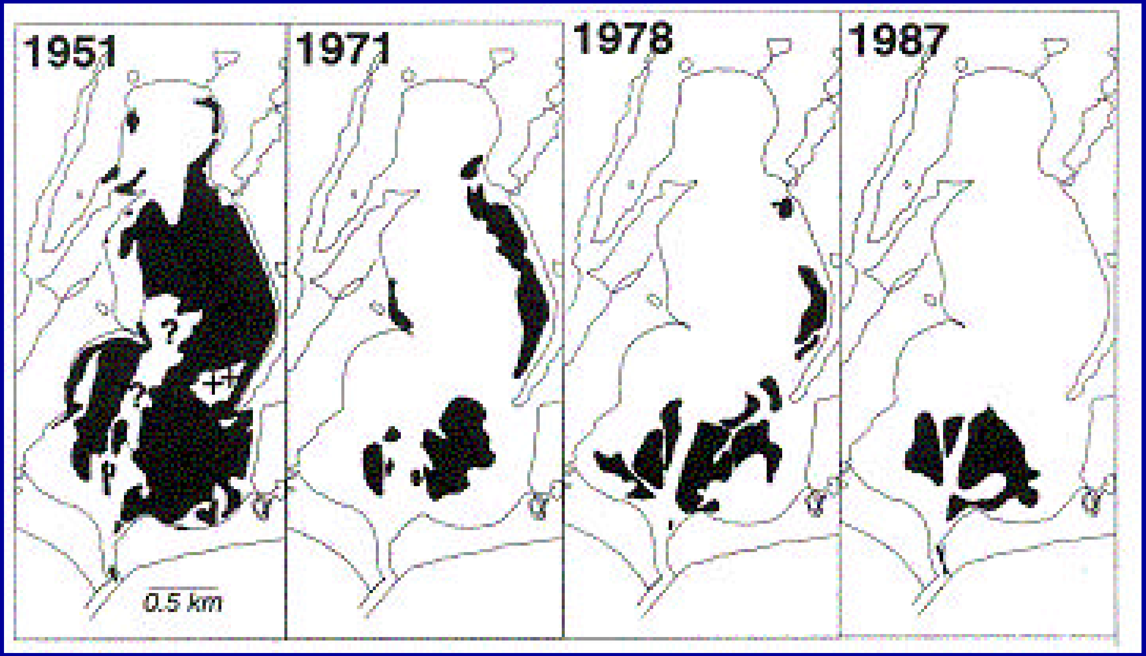
Point #2: The best you can hope for: Management decisions are made, and regulations adopted that are based on the best available scientific information.

Scientific knowledge continually changes, models improve, standards will change, and ideally regulations will change to reflect new scientific data. Management decisions and new development will not wait for you to develop the perfect TMDL model.

Principle 15 of the 1992 Rio Declaration on the Environment: "…lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation". Example: CCC: No Net Increase in nitrogen

Most inappropriately used statement by scientists about management decisions: "But will it stand up in court?" Environmental laws have changed considerably during past 20 years- a case law model, with most decisions overturned because of procedural errors, or lack of objective or consistently applied criteria, design standards, or performance standards.

Example: Waquoit Bay Eelgrass Loss



Near complete loss by the 1990s

Eelgrass critical loading about 1971, with 1450 homes in the watershed.

Management action was stymied because of endless debate on loading models.

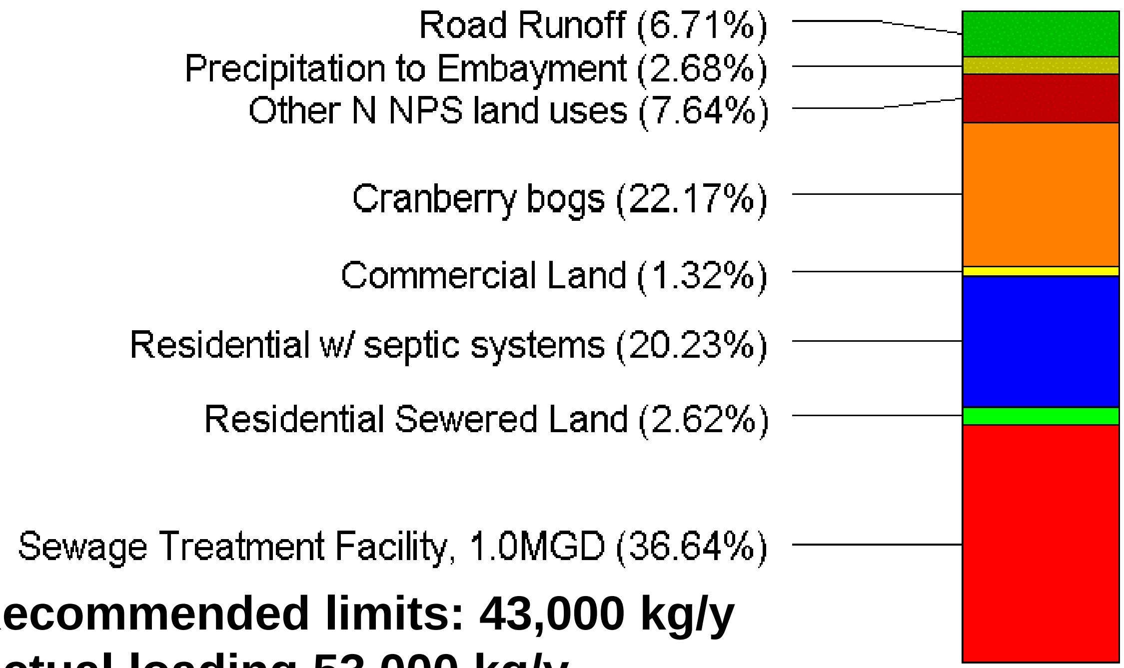
Loading models may differ by factor of 2, but many missed the fact that conclusions and management recommendations were robust if loading models and regulatory calculations are equivalent (with additional margin of safety if desired).

That is, the nitrogen load from the equivalent of 1450 residential units (and associated roads) represented the critical limit for eelgrass habitat in Waquoit Bay.

Example: Wareham STF

discharge conc		kg/y	kg savings
4	ppm	9947	14920
5	ppm	12434	12434
6	ppm	14920	9947
7	ppm	17407	7460
8	ppm	19894	4973
10	ppm	24867	0
12	ppm	29841	
16	ppm	39788	
18	ppm	44761	

N sources in the Wareham River Estuary



Recommended limits: 43,000 kg/y
Actual loading 53,000 kg/y
But new development could add 20,000 to 30,000 kg annually to the estuary

Town accepted 3 ppm TN limit during warm weather and 5 ppm in winter as the new limits. Why? Non-N upgrades =$22 million, N upgrades, an extra $3 million.

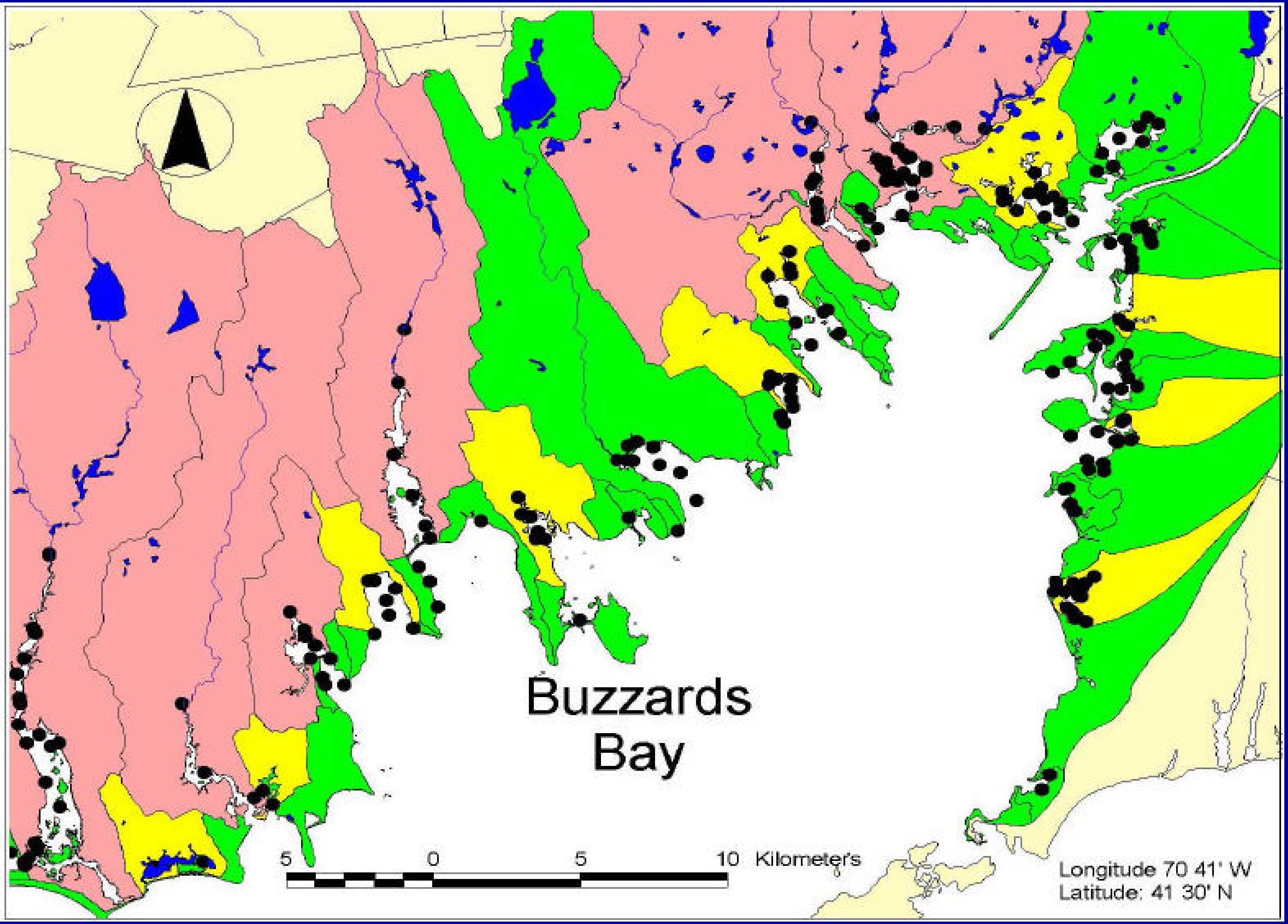
What about new development?

Point #3: TMDL implementation is a management process, not a scientific process.

“We often look to a panel of scientific experts to not just identify the problems, but also the solutions. They may not be the ones to best figure out how to repair the watershed, in fact, they can be downright naive.”

Dr. Sari Sommarstrom, President Watershed Management Council

Empirical relationships: the need for data satisfied with a Citizen Monitoring Program (stations below)



4x summer:

TN

DON

DIN

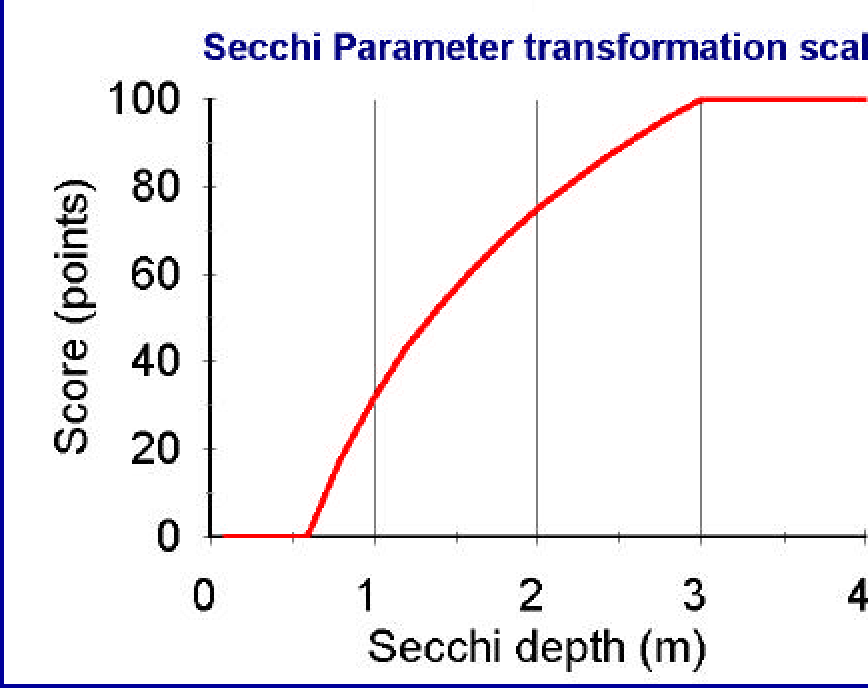
Chl a

Every 5 days

Secchi

Early AM O2

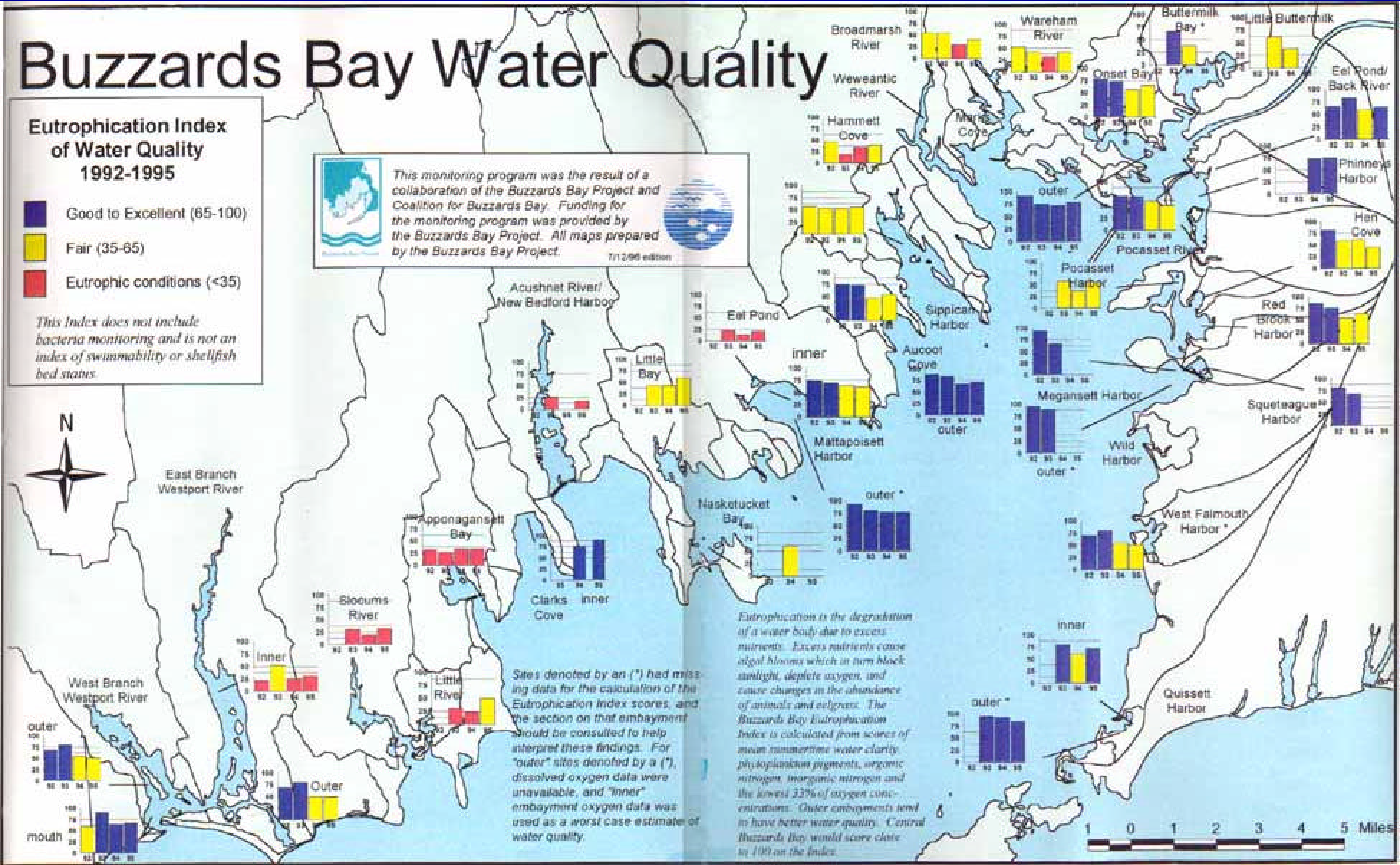
Eutrophication Index



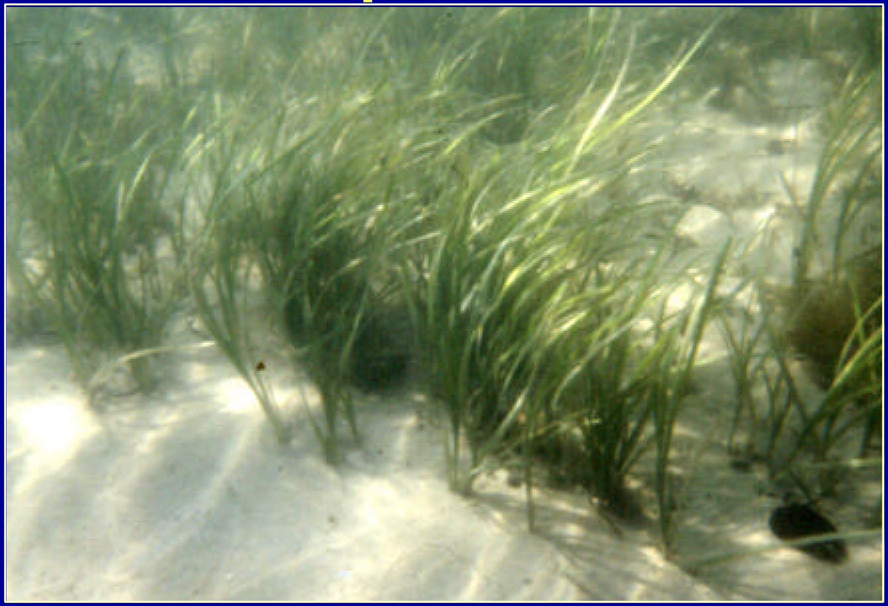
Parameter		0 point value		100 point value	
Oxygen saturation (mean of lowest 33%)		40	%	90	%
Transparency	0.6	m	3.0	m	
Chlorophyll		10.0	:g/l	3.0	:g/l
DIN		10.0	:M	1.0	:M
Organic N		0.60	ppm	0.28	ppm

Score=(ln(value)-ln(0 pt. value))/(ln (100 pt. value)-ln(0 pt. value))

Citizens Monitoring Program 1996 report was very effective in raising awareness, building public support, and initiating municipal actions.



Eelgrass Grows underwater, both in quite water and the open coast, down to 20 feet or more.



Shallow bed
(to 0.5 ft MLW in protected areas)

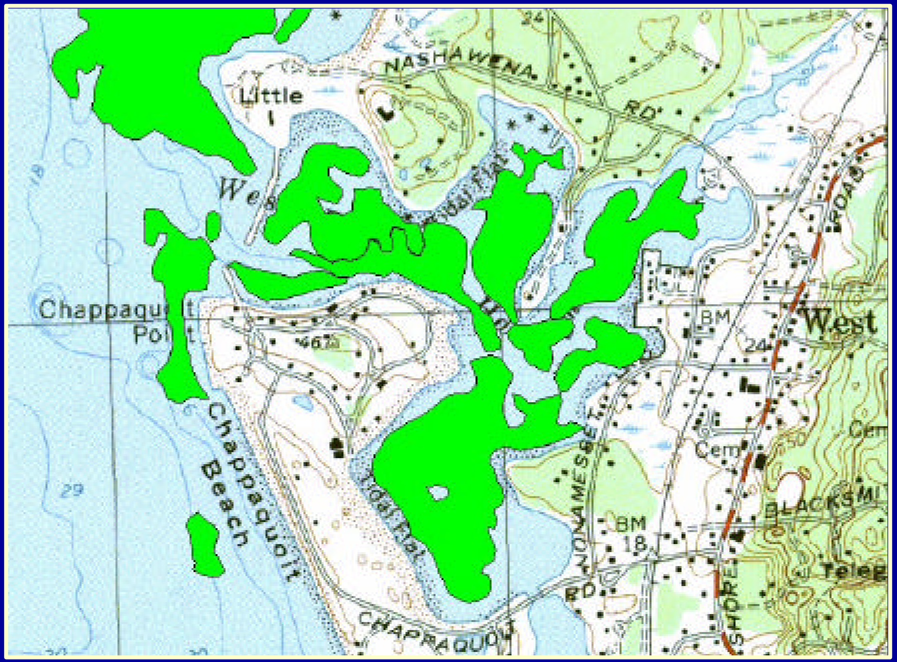
Deep Bed
Often to 22 feet MLW,
rarely to 50 ft+ in clearest waters

Eutrophic Conditions

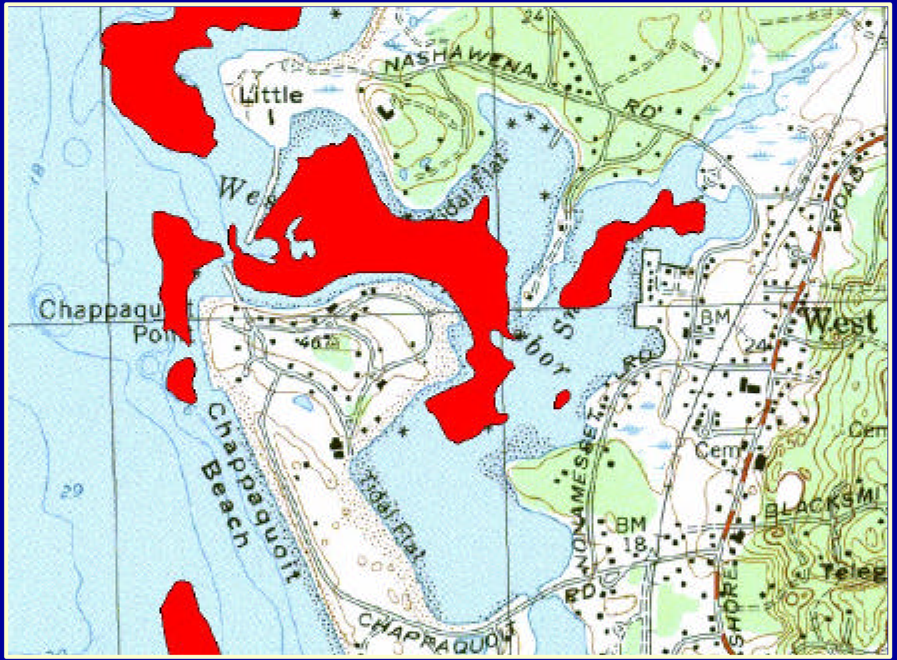
Eelgrass History: Wasting disease loss in the 1930s, recovery by the 1960s and 1970s in most areas. New declines in 1970 to to 1990s i in areas of heavy development

Example:
West Falmouth Harbor

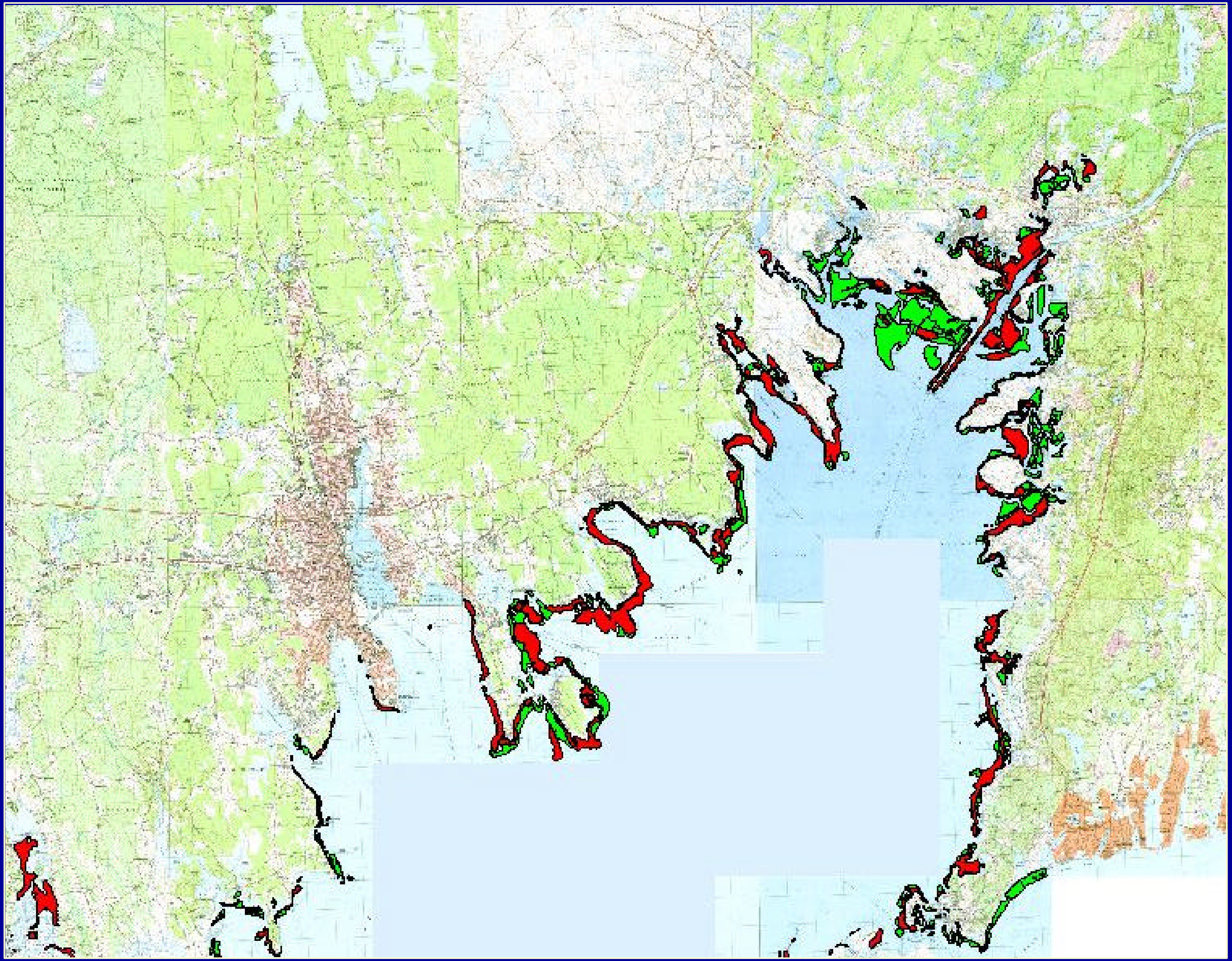
1980s



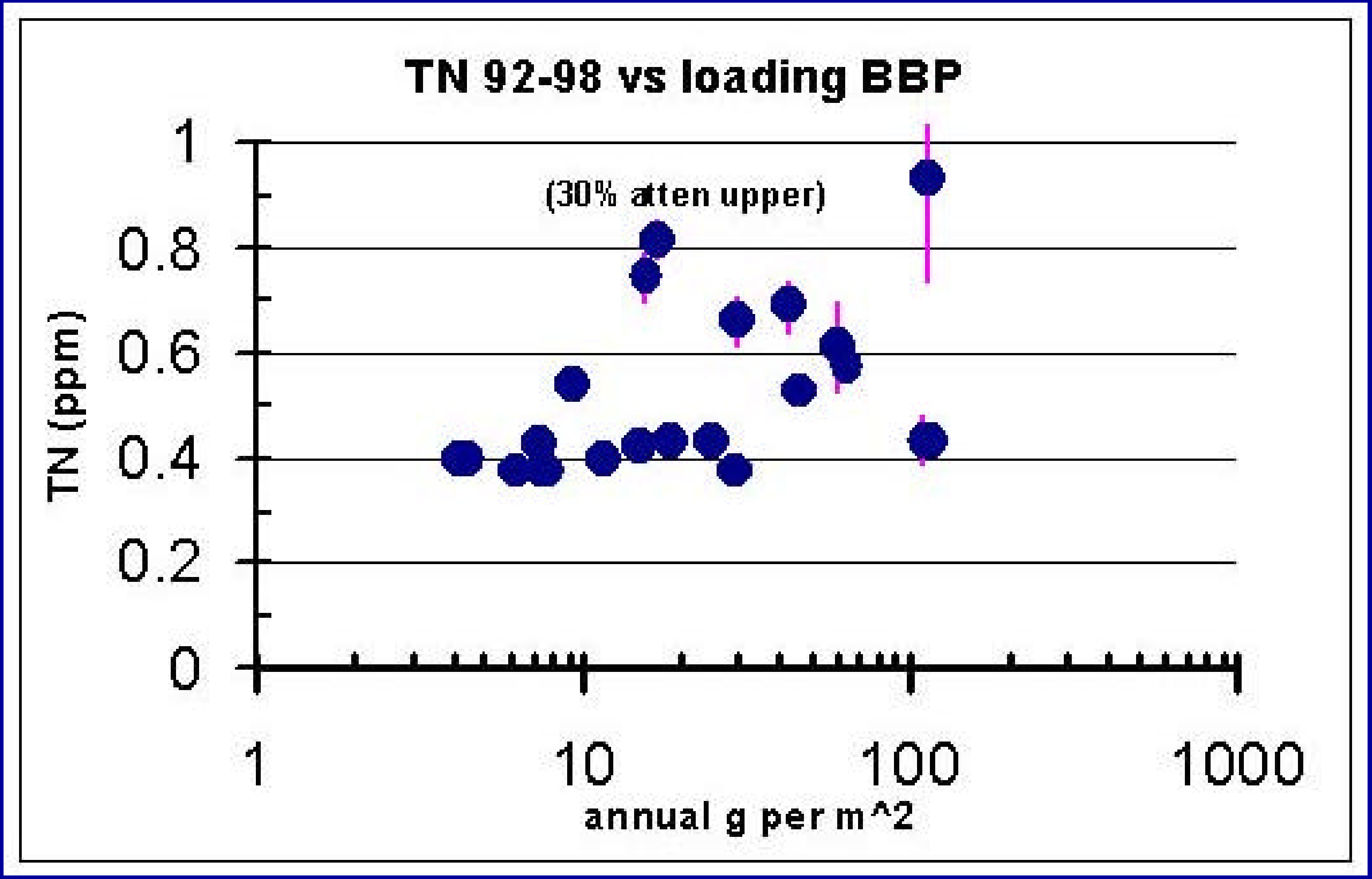
1990s



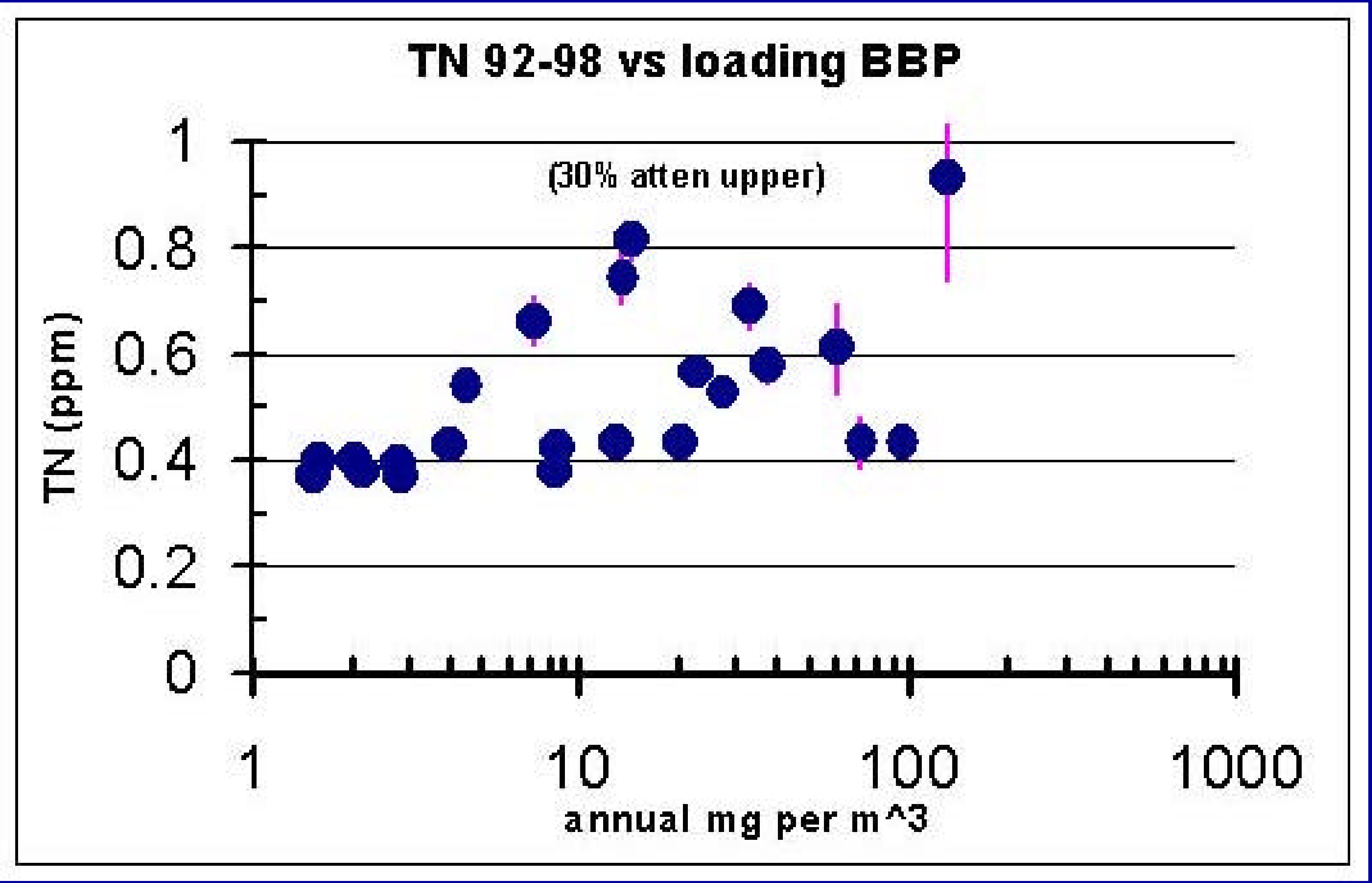
1980s vs 1996 Surveys



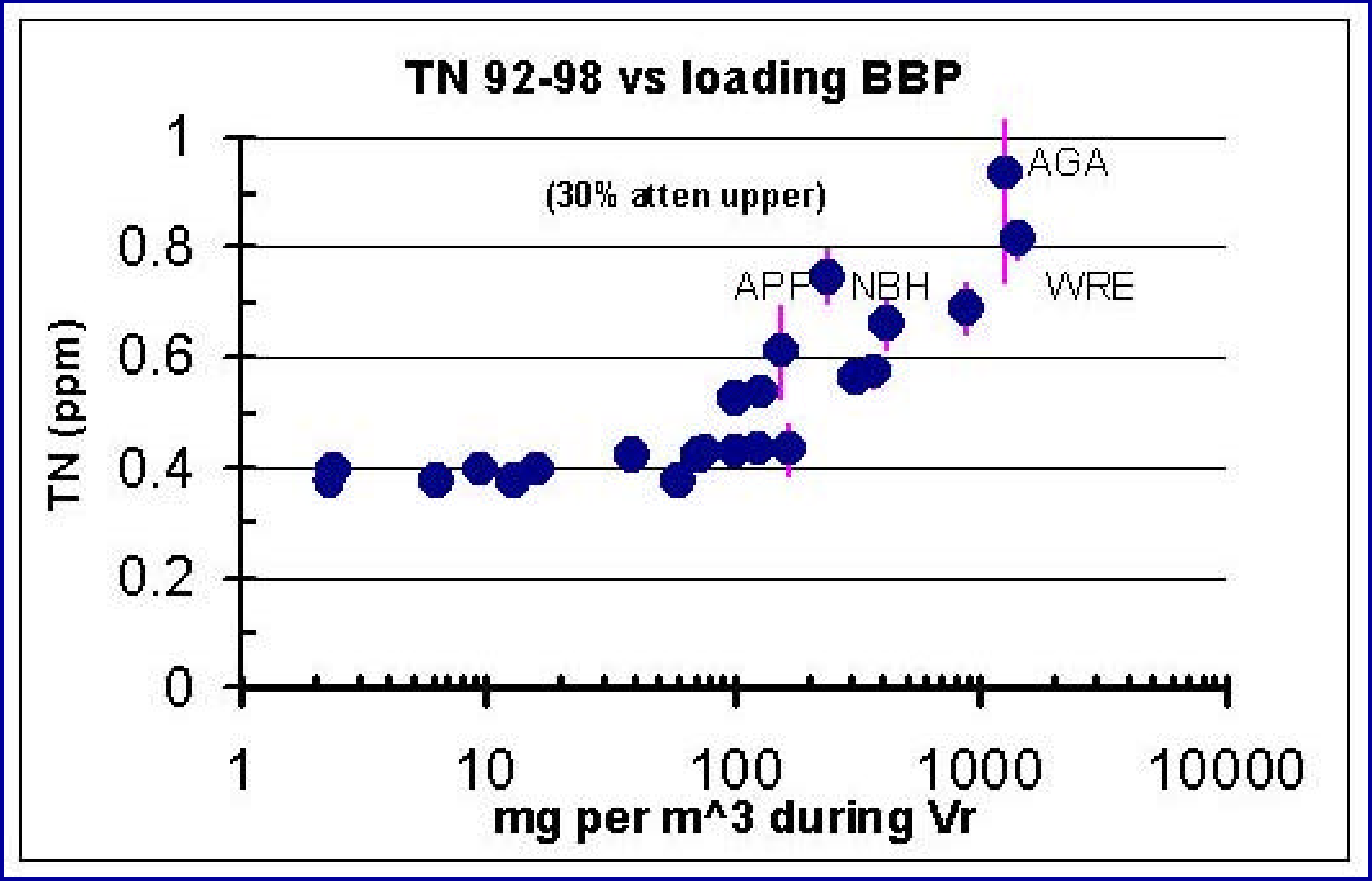
Loading Characterization: per unit area



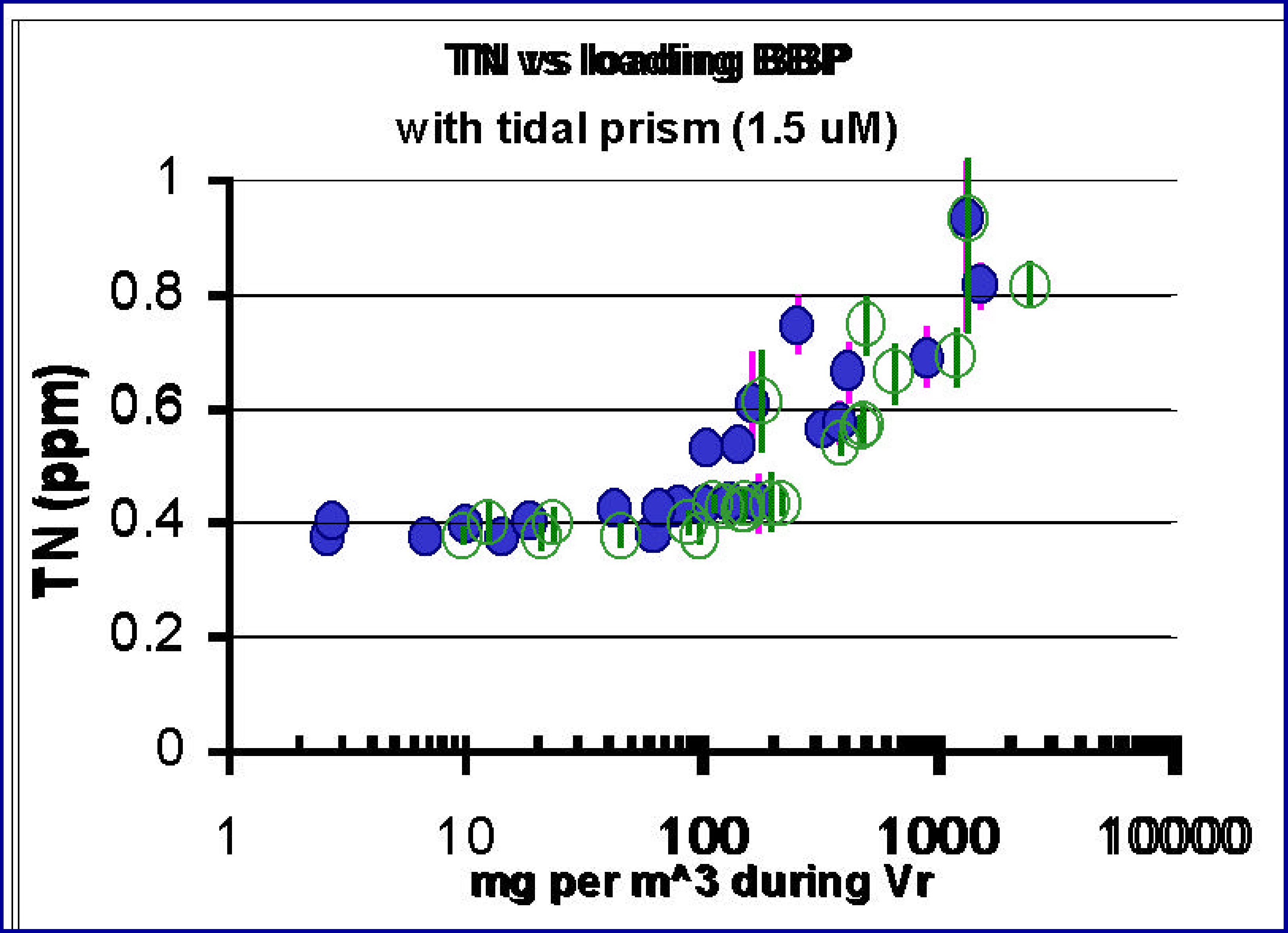
Loading Characterization: per unit volume



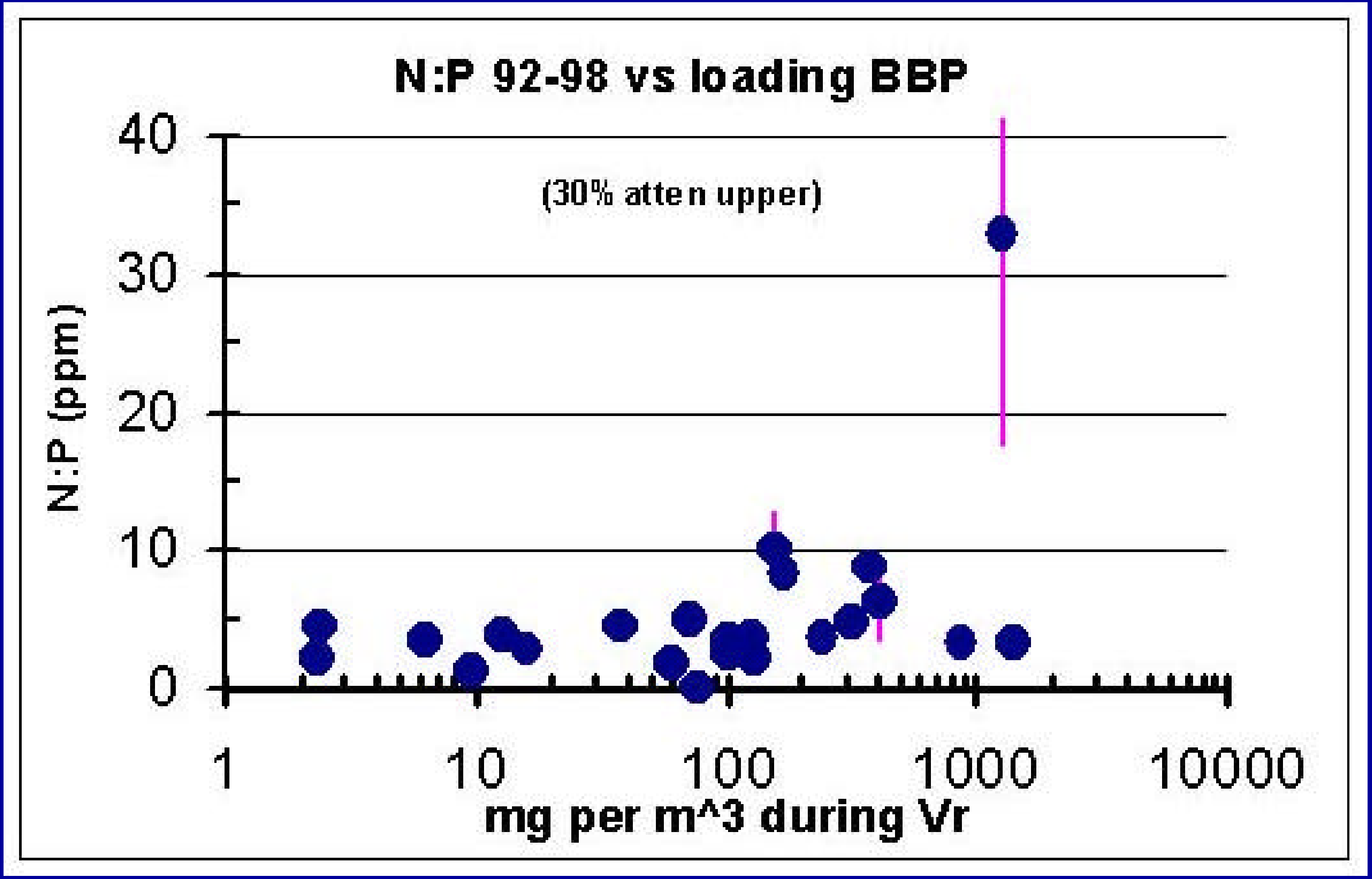
TN versus loading per V- residence



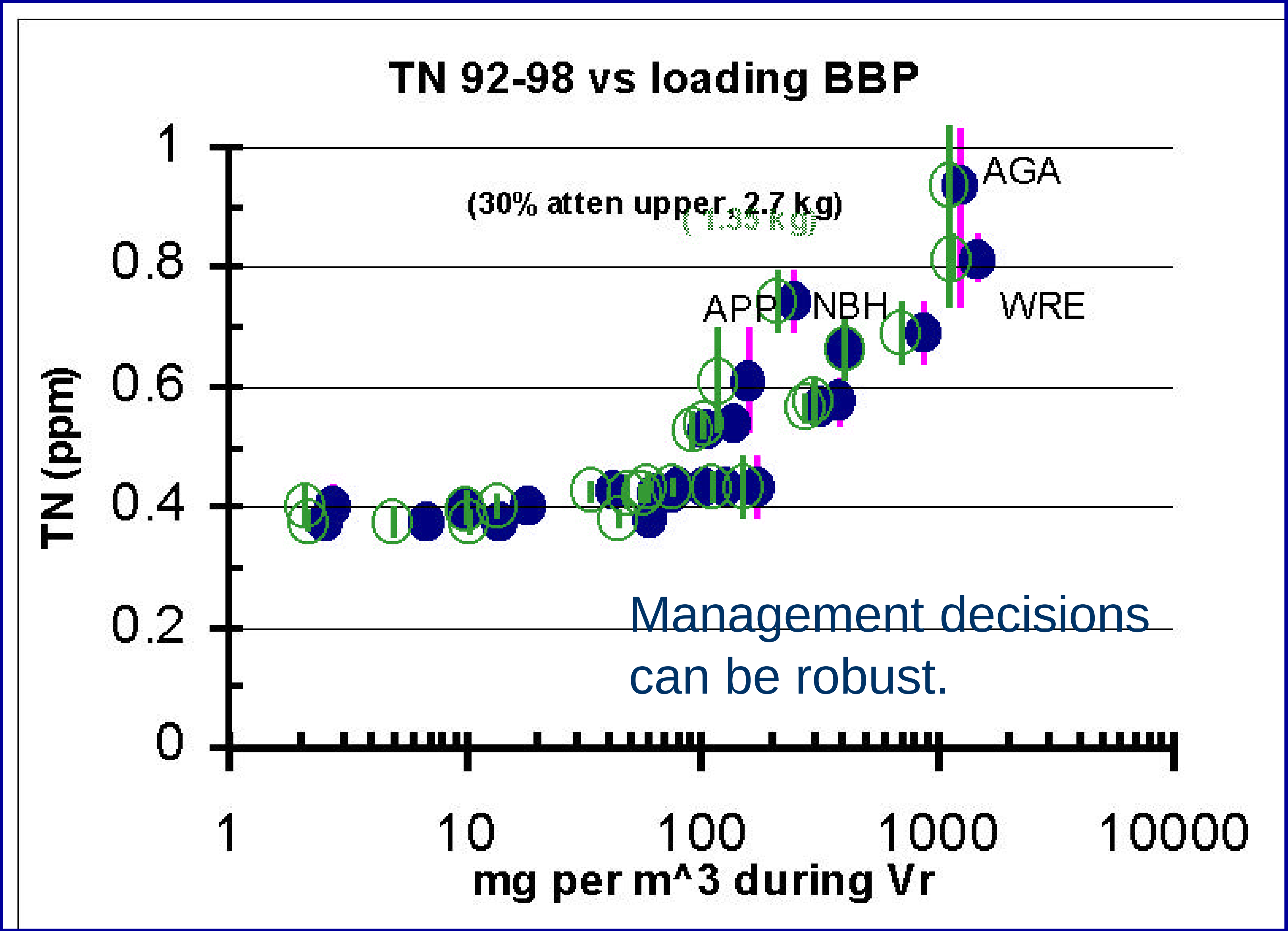
Tidal Prism DIN



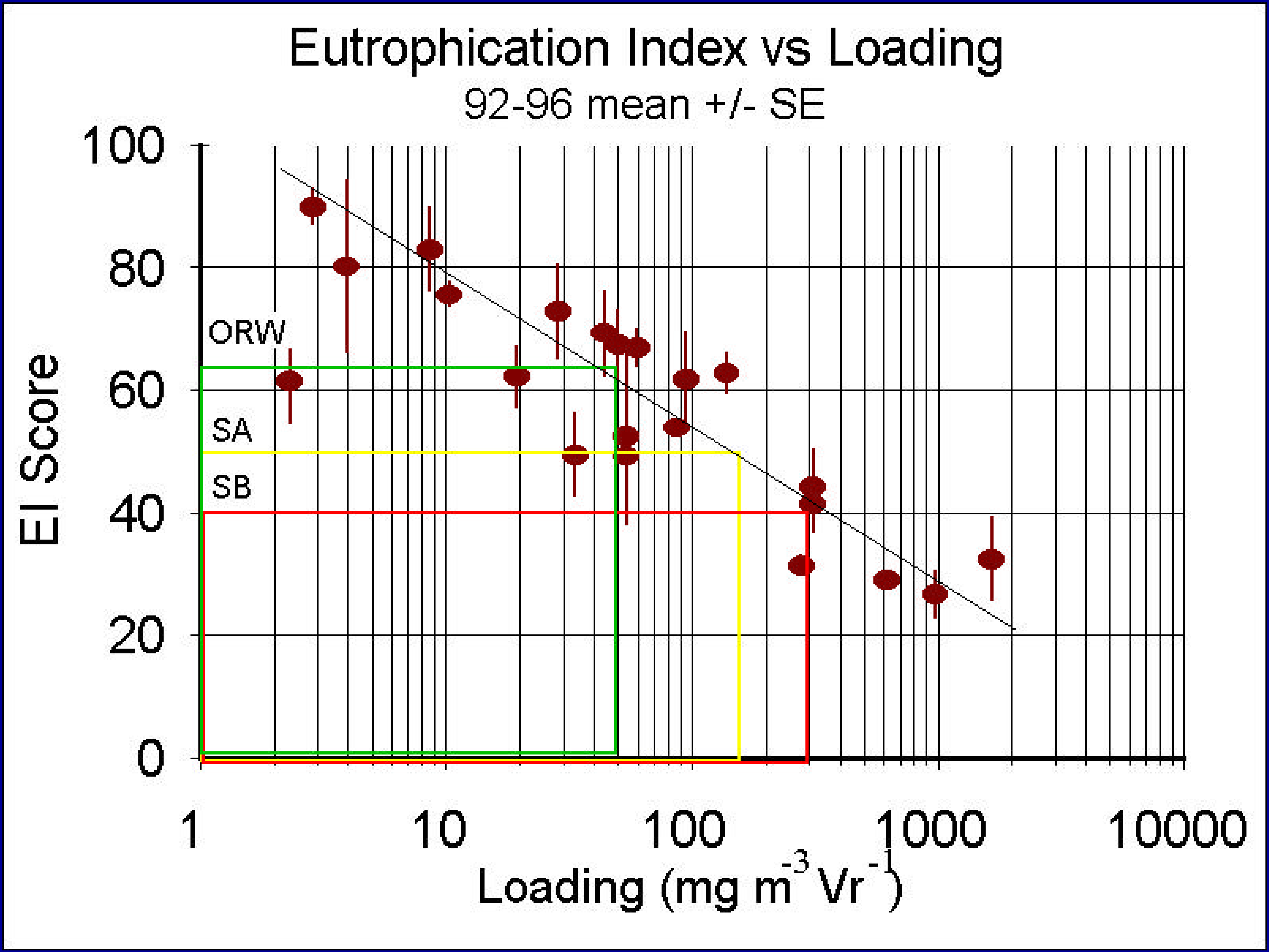
N:P vs. Loading Vr



Septic loading assumptions



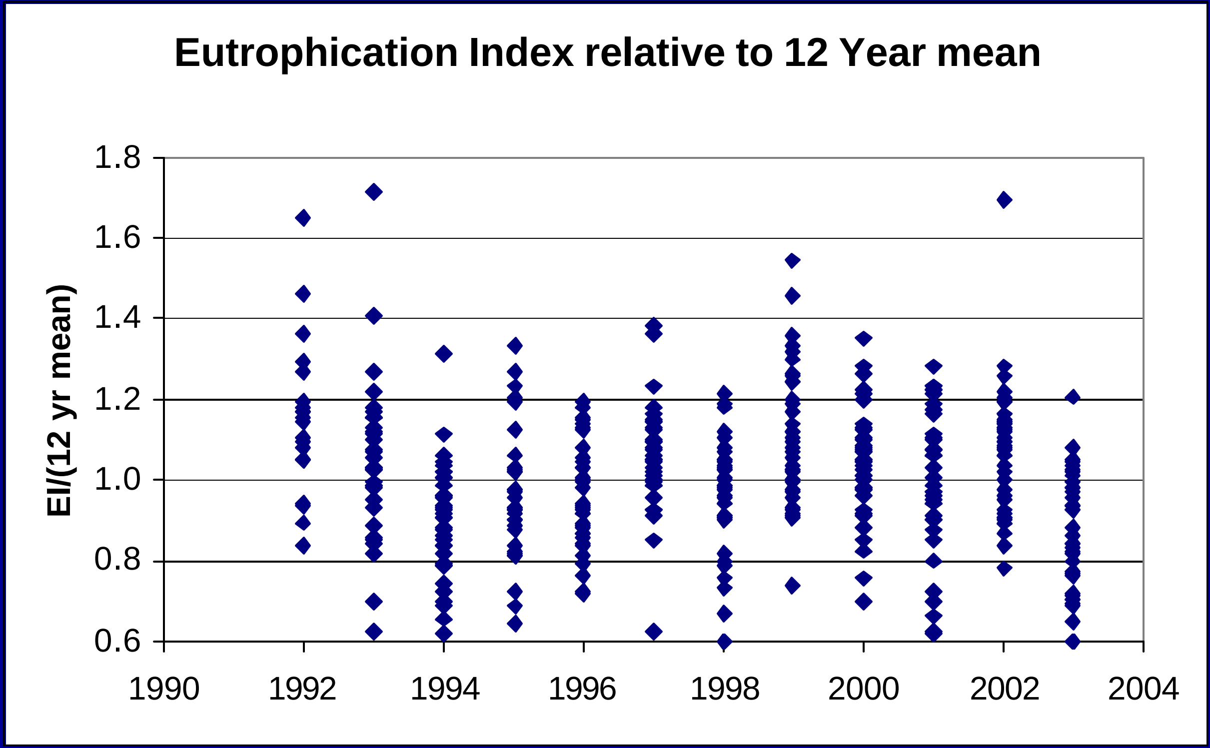
Management decisions can be robust.

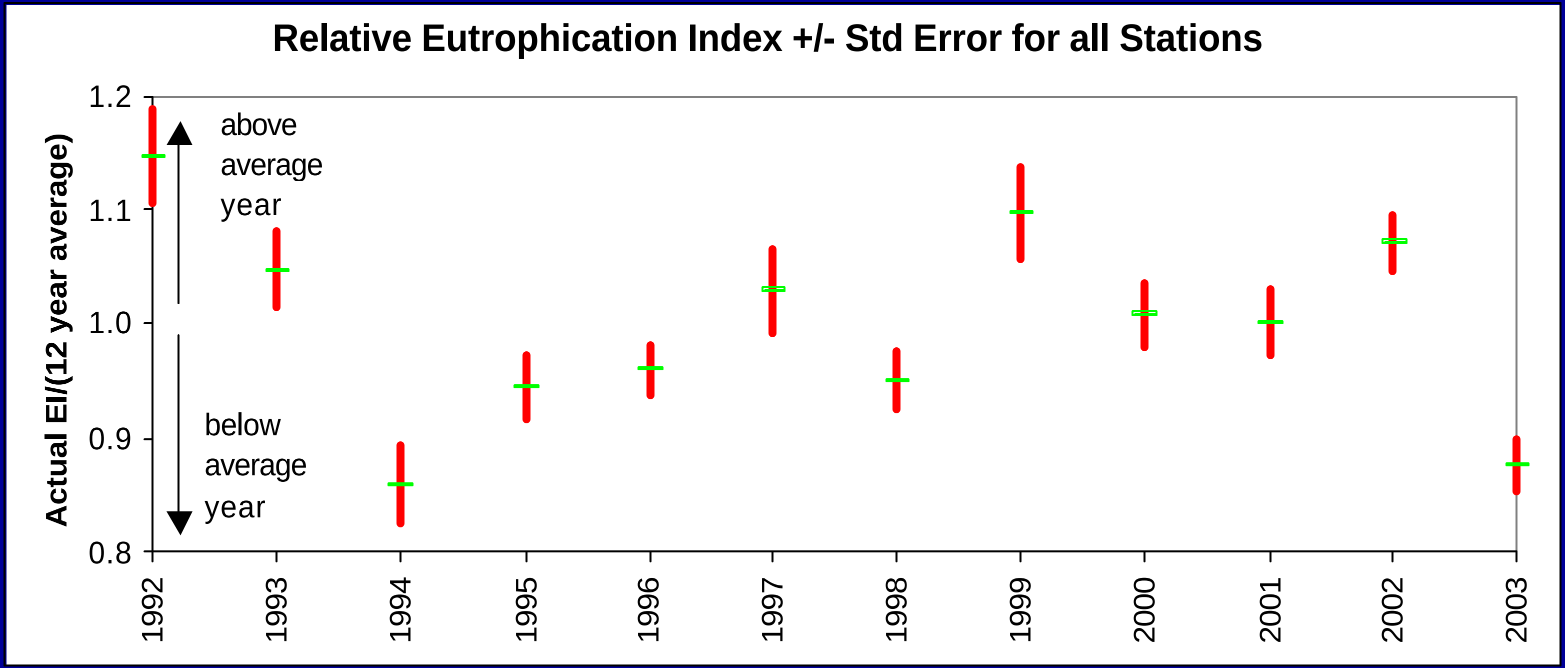


Eutrophication Index vs Loading
92-96 mean +/- SE
100
80
60
40
20
0
EI Score
ORW
SA
SB
1
10
100
1000
10000
Loading (mg m-3 Vr-1)

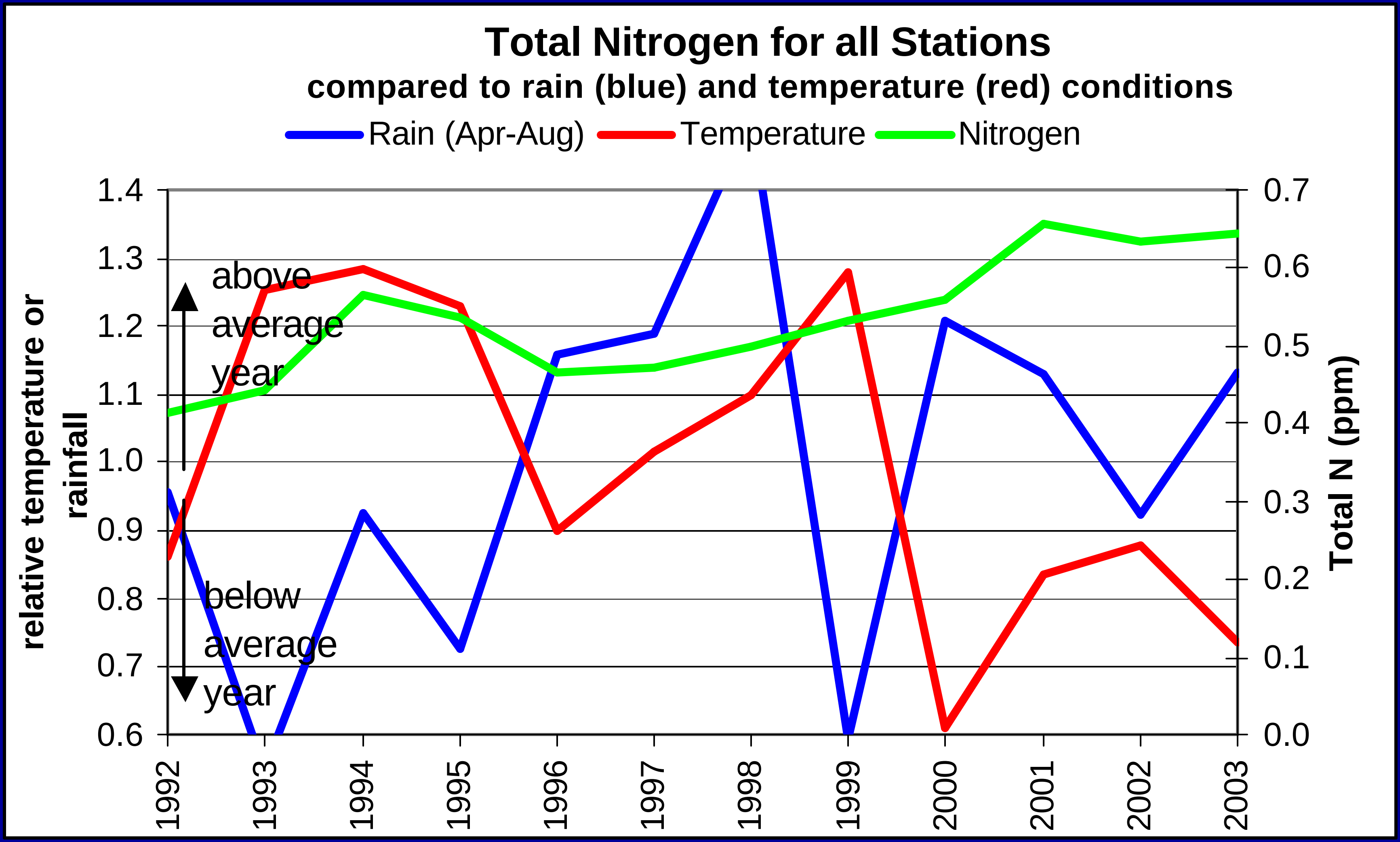
Eutrophication Index variability

Seasonal rainfall, Temperature, conditions around sampling time.

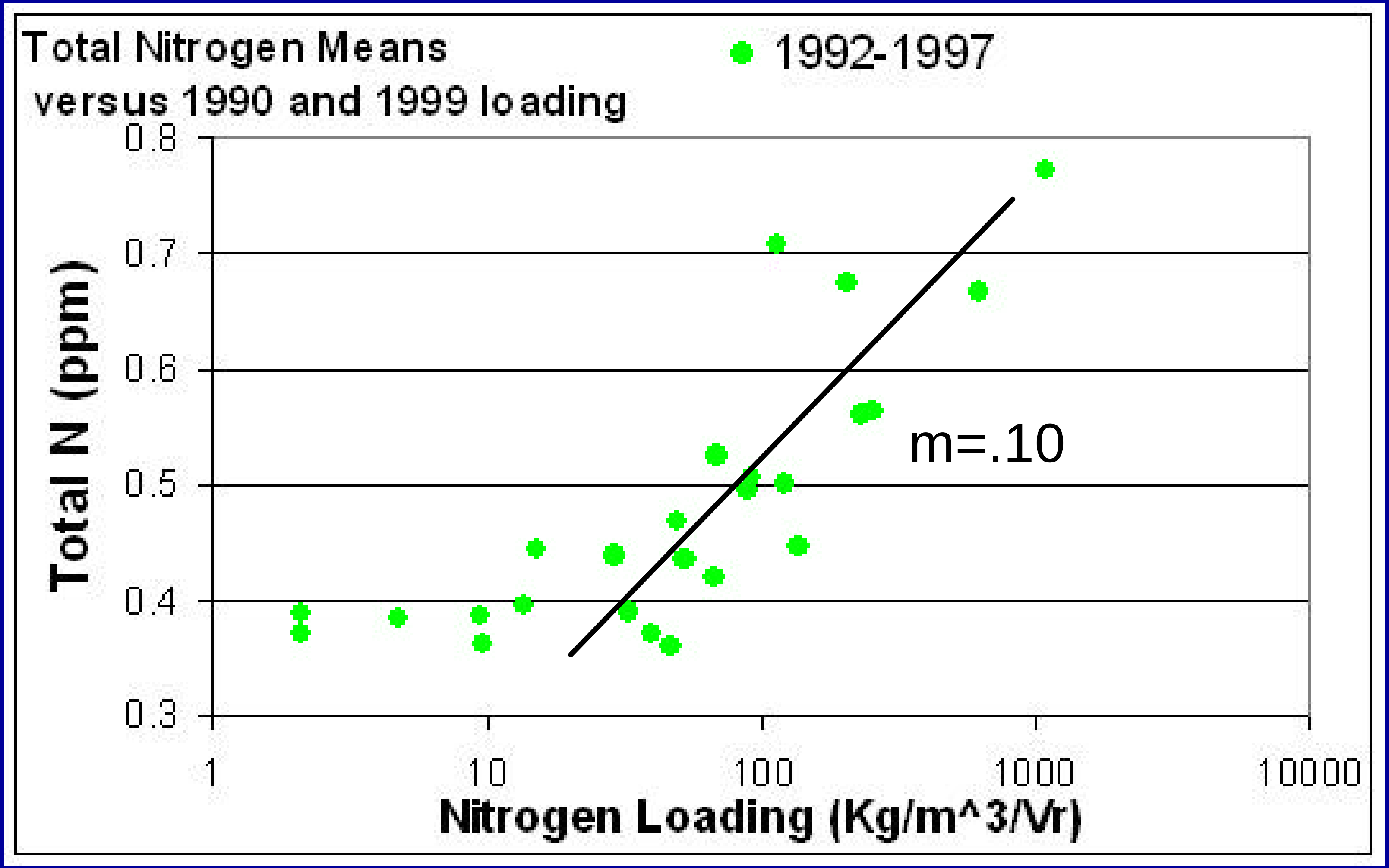




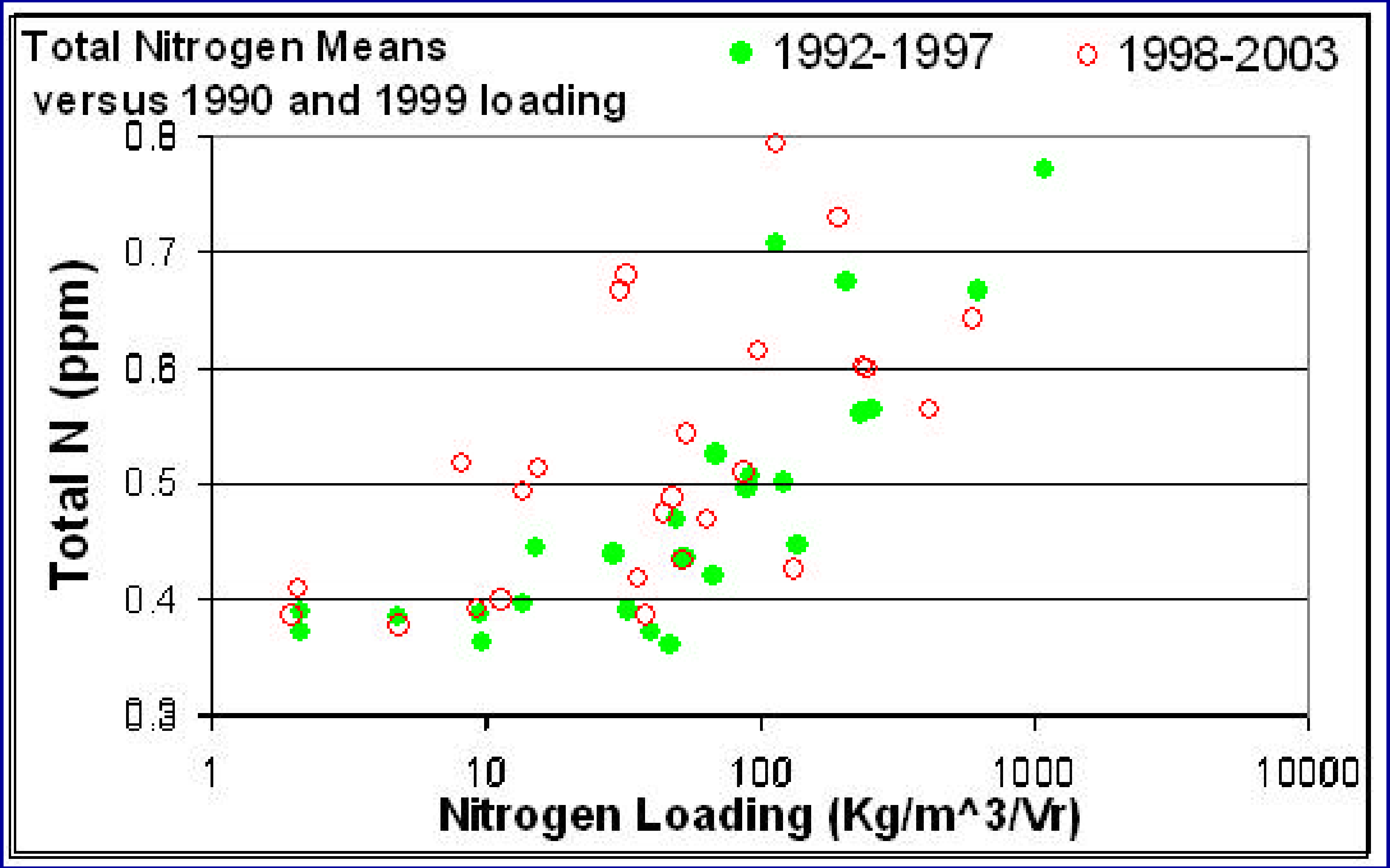
Total Nitrogen variability



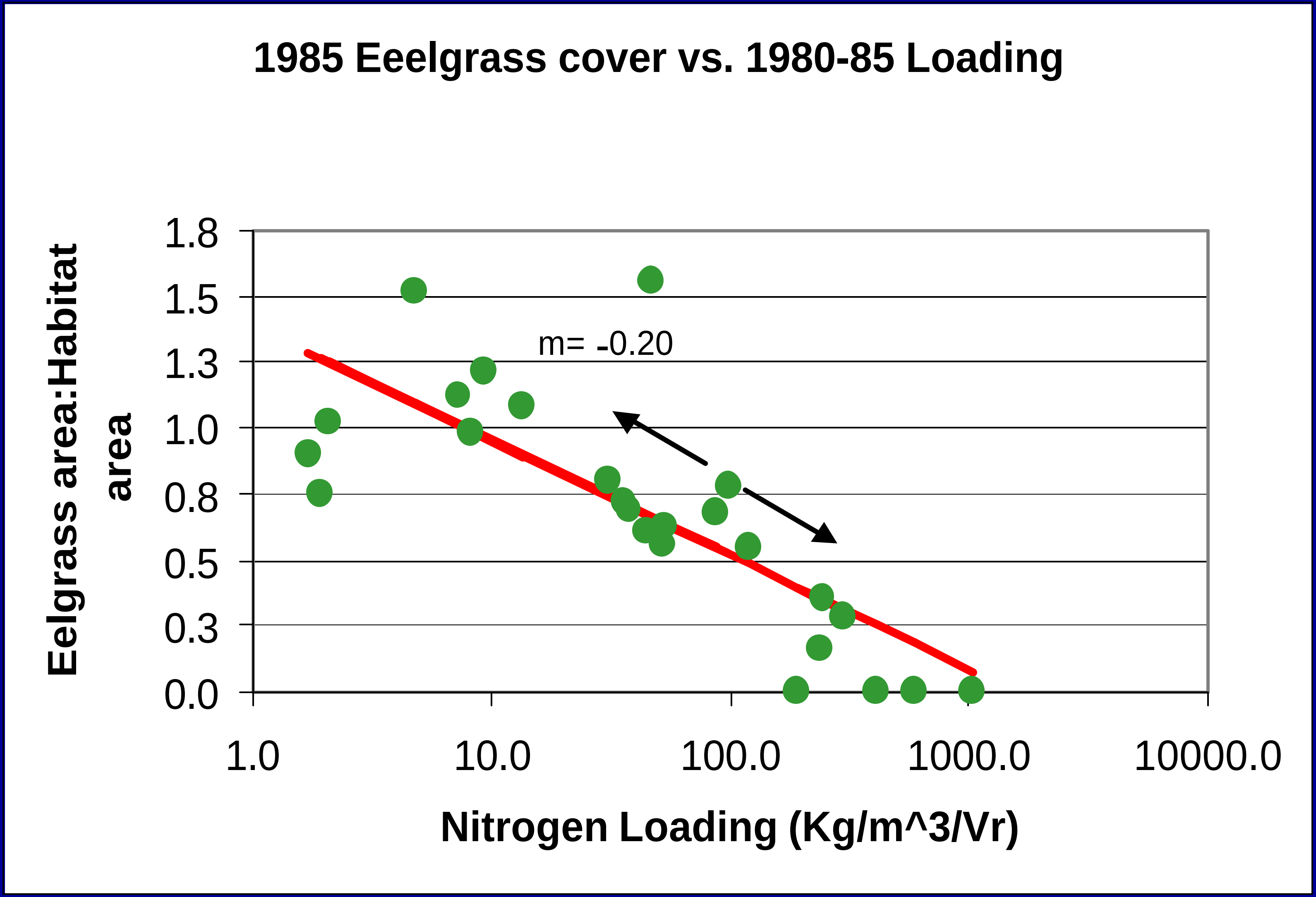
TN during 1992-1997 versus 1998-2003



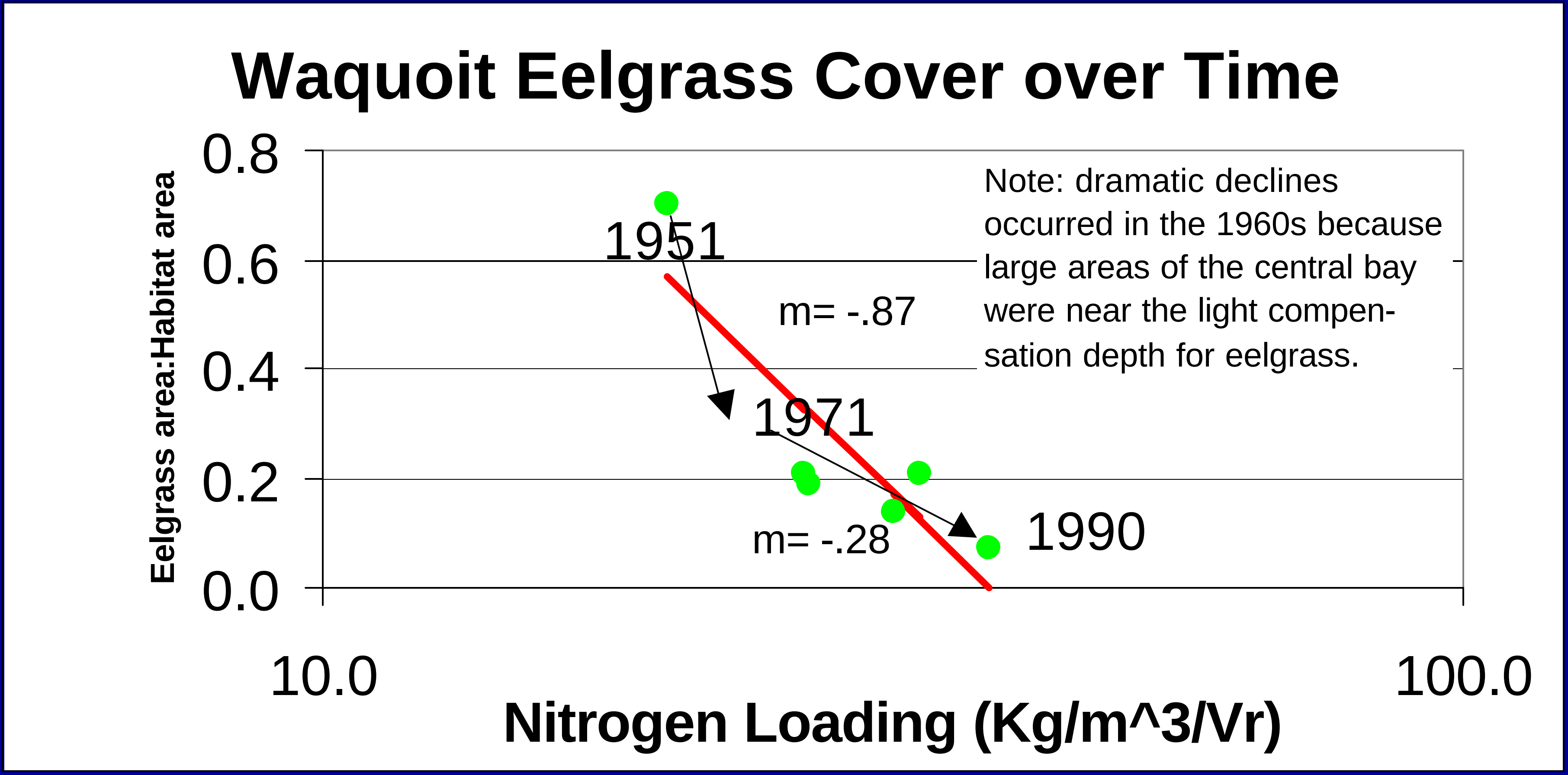
TN during 1992-1997 versus 1998-2003



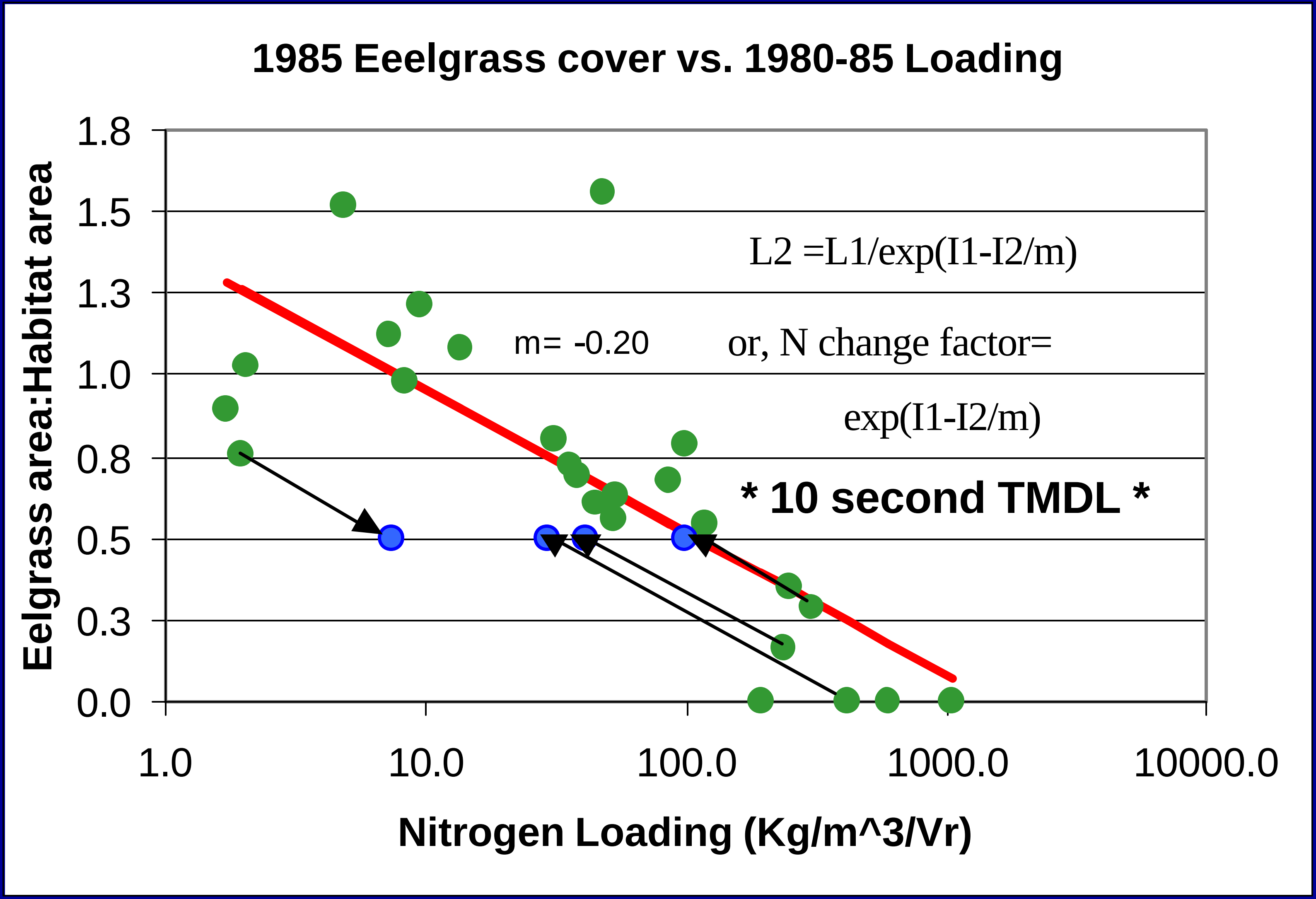
Eelgrass Cover versus Nitrogen Loading



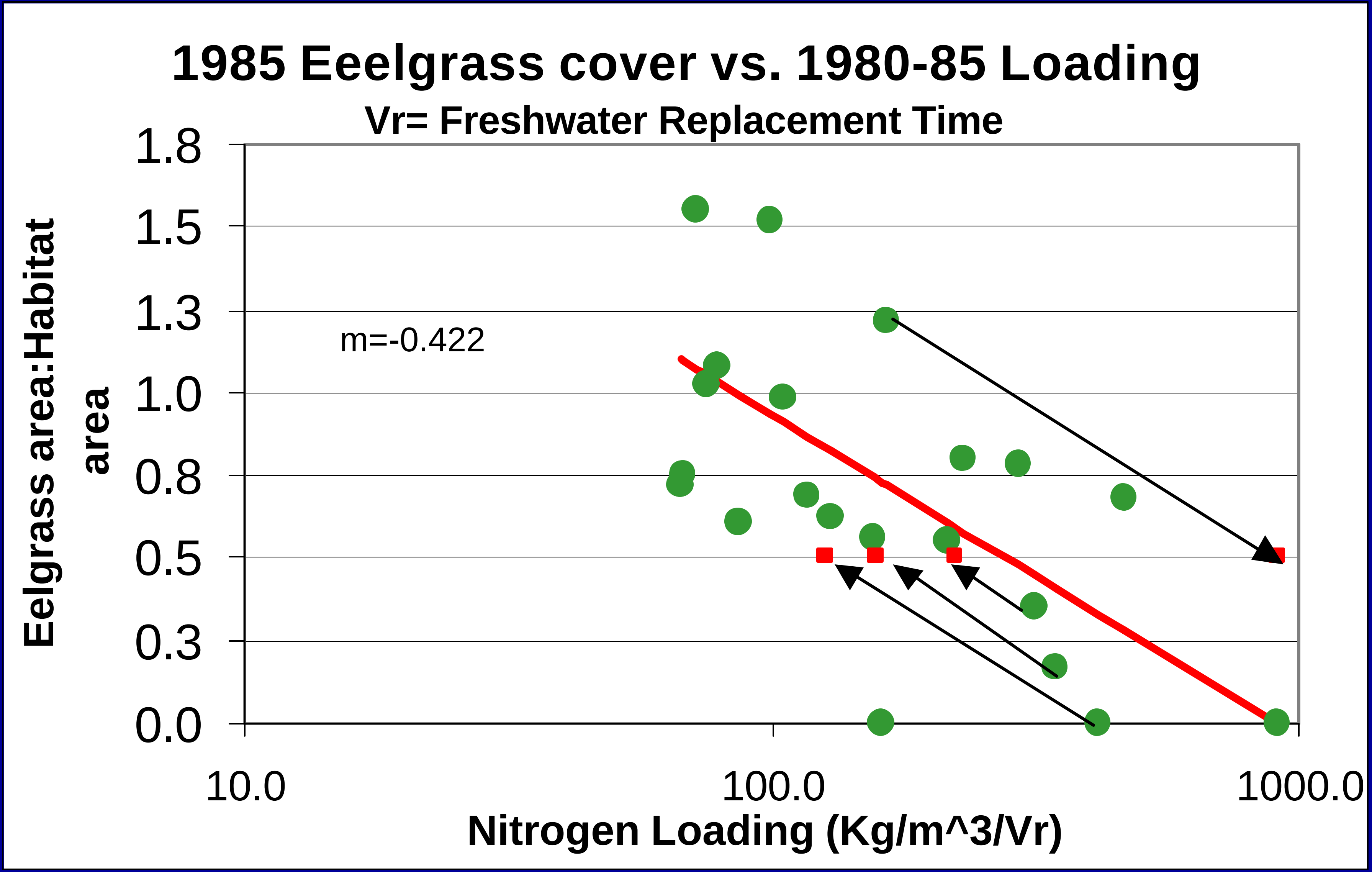
Waquoit Eelgrass versus Nitrogen Loading



Eelgrass Cover versus Nitrogen Loading

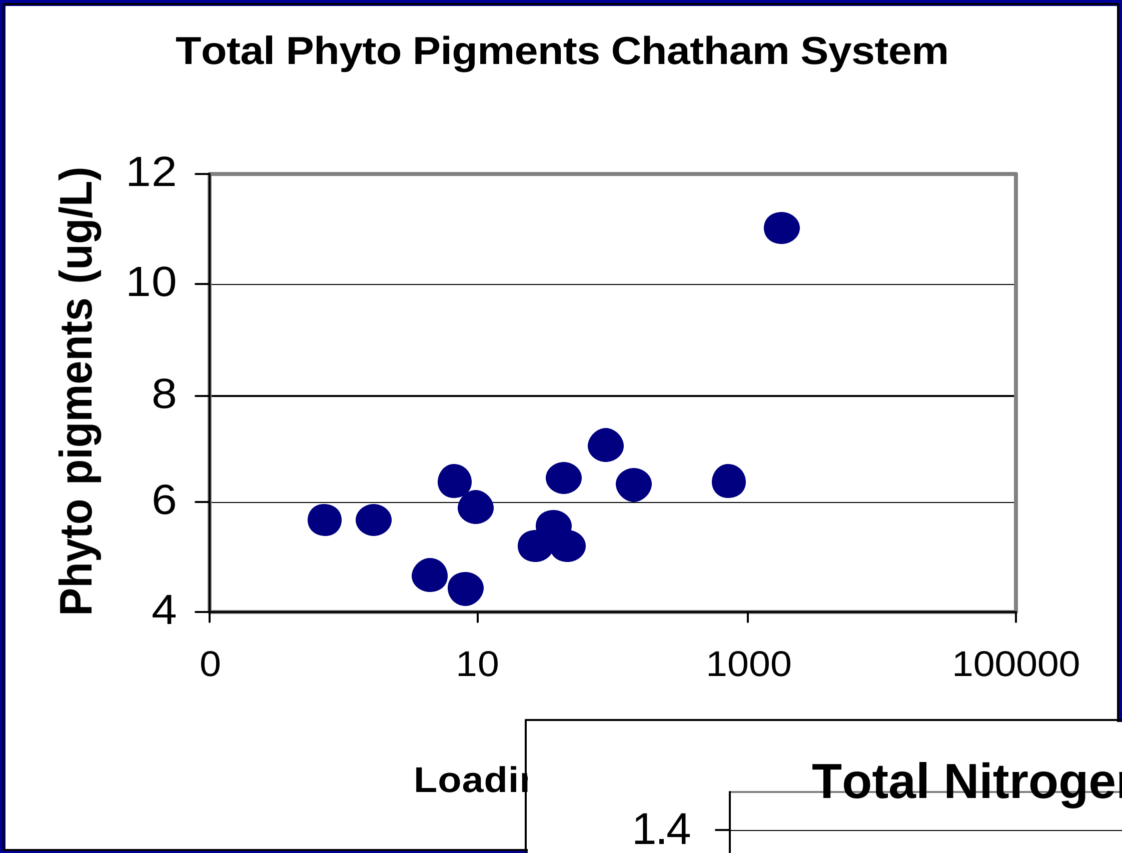


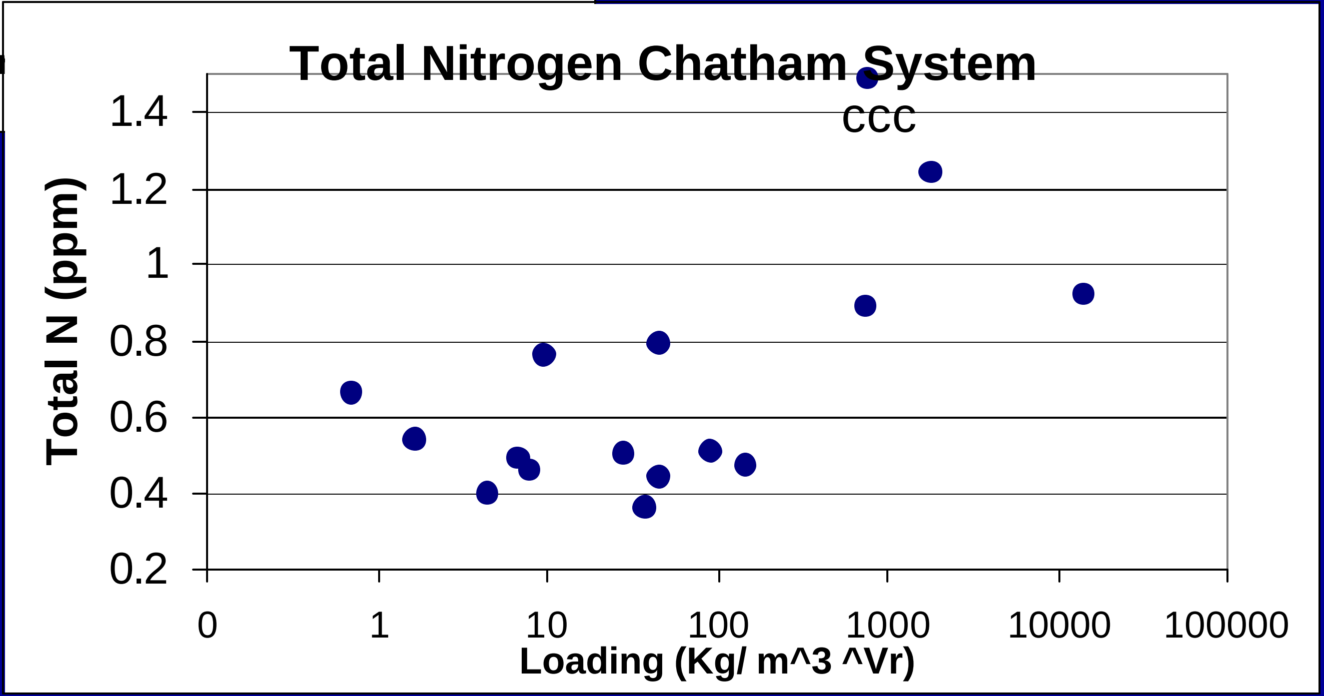
Alternative Flushing Scale



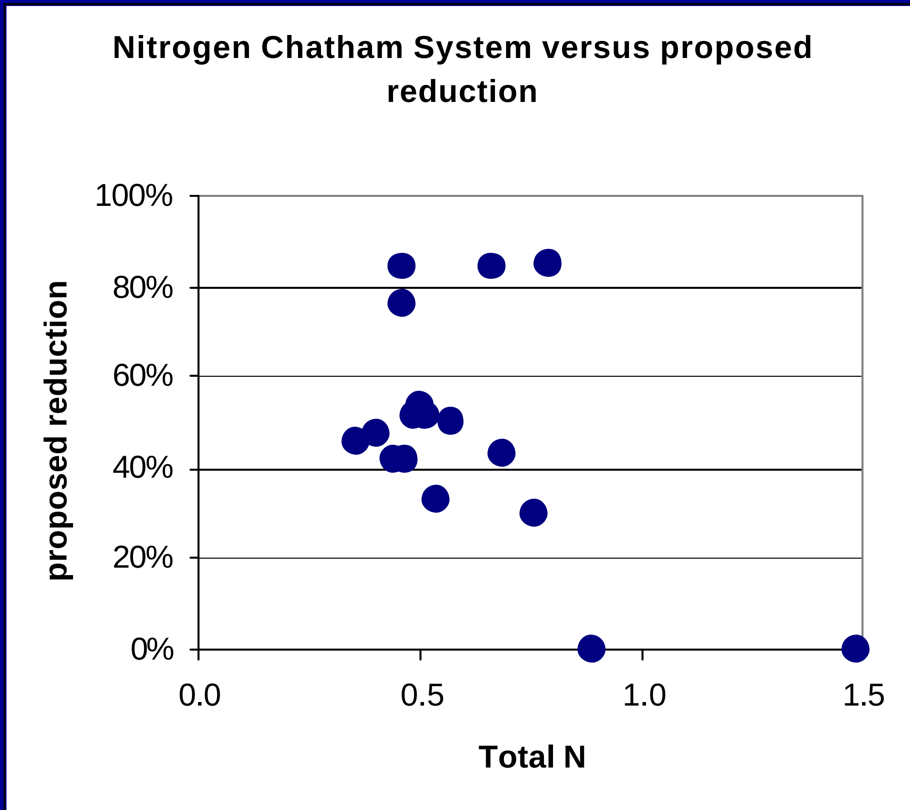
Simple alternative to residence time: Freshwater replacement time

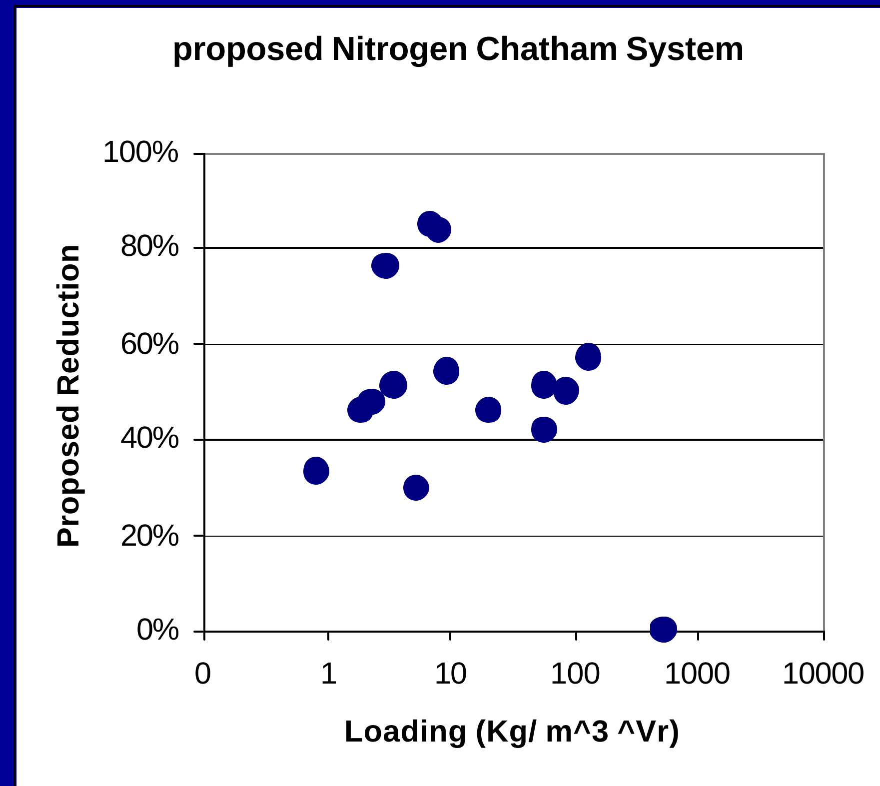
Chatham Comparison





Chatham Recommended reductions





Does not match Buzzards Bay Project model (nor should it)

Large areas will need to be sewered to meet water quality goals

Conclusion

During the past two decades, ecosystem models have advanced considerably, but local regulatory tools for controlling NPS nitrogen changed little. In some cases, the science is well ahead of the management and political capacity to address the problem.

Do not confuse scientific and management issues when developing TMDLs.

Good modeling takes time, money, and measurements of tidal flow. However, an assessment of existing conditions (summertime for nitrogen loading) is generally the first step in any TMDL process. This of course a role for EMAP.

TMDLS based on existing conditions and known empirical relationships between loading and ecosystem response among similar embayments can be an important start, and providing a reasonable first approximation of the magnitude of nitrogen reductions needed for impacted sites.