NITROGEN

The 21st century coastal environmental challenge

Presented by:

William E. Brown, P.E.

Michael D. Giggey, P.E.

WRIGHT-PIERCE

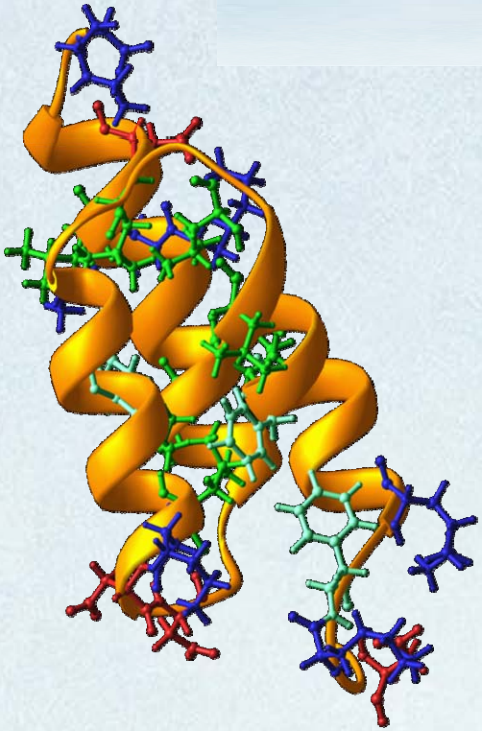
Engineering a Better Environment

Overview

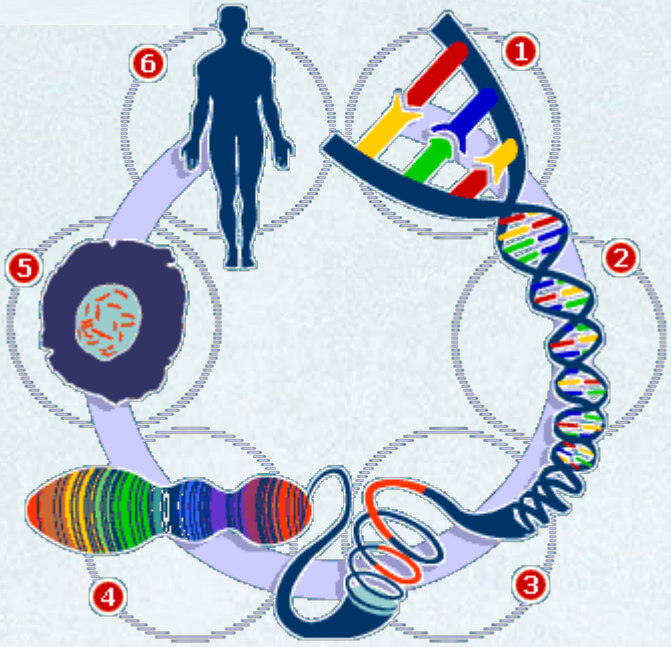
- Importance of nitrogen
- How nitrogen cycles through the environment
- What happens when there is too much nitrogen
- Where the excess nitrogen comes from
- What makes an estuary sensitive to nitrogen
- Strategies to protect our coastal waters

Nitrogen

One of the most important elements on earth



N



WRIGHT-PIERCE
Engineering a Better Environment

Nitrogen

Nitrogen is essential for biological productivity

plant growth

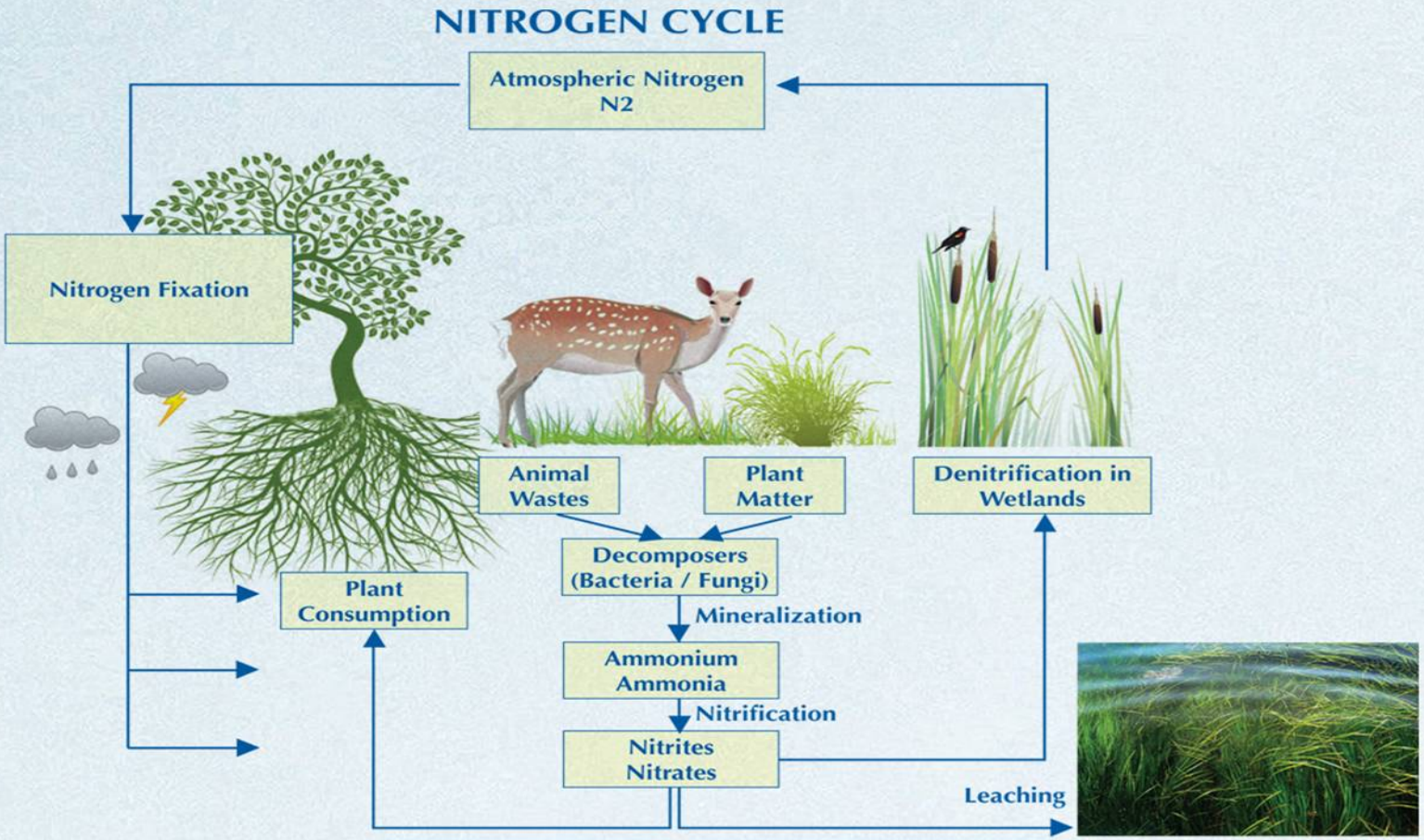
animal growth

your growth

Oxygen	65.00	% of body weight
Carbon	18.00	
Hydrogen	10.00	
Nitrogen	3.00	
Calcium	1.50	

WRIGHT-PIERCE
Engineering a Better Environment

Nitrogen Cycle



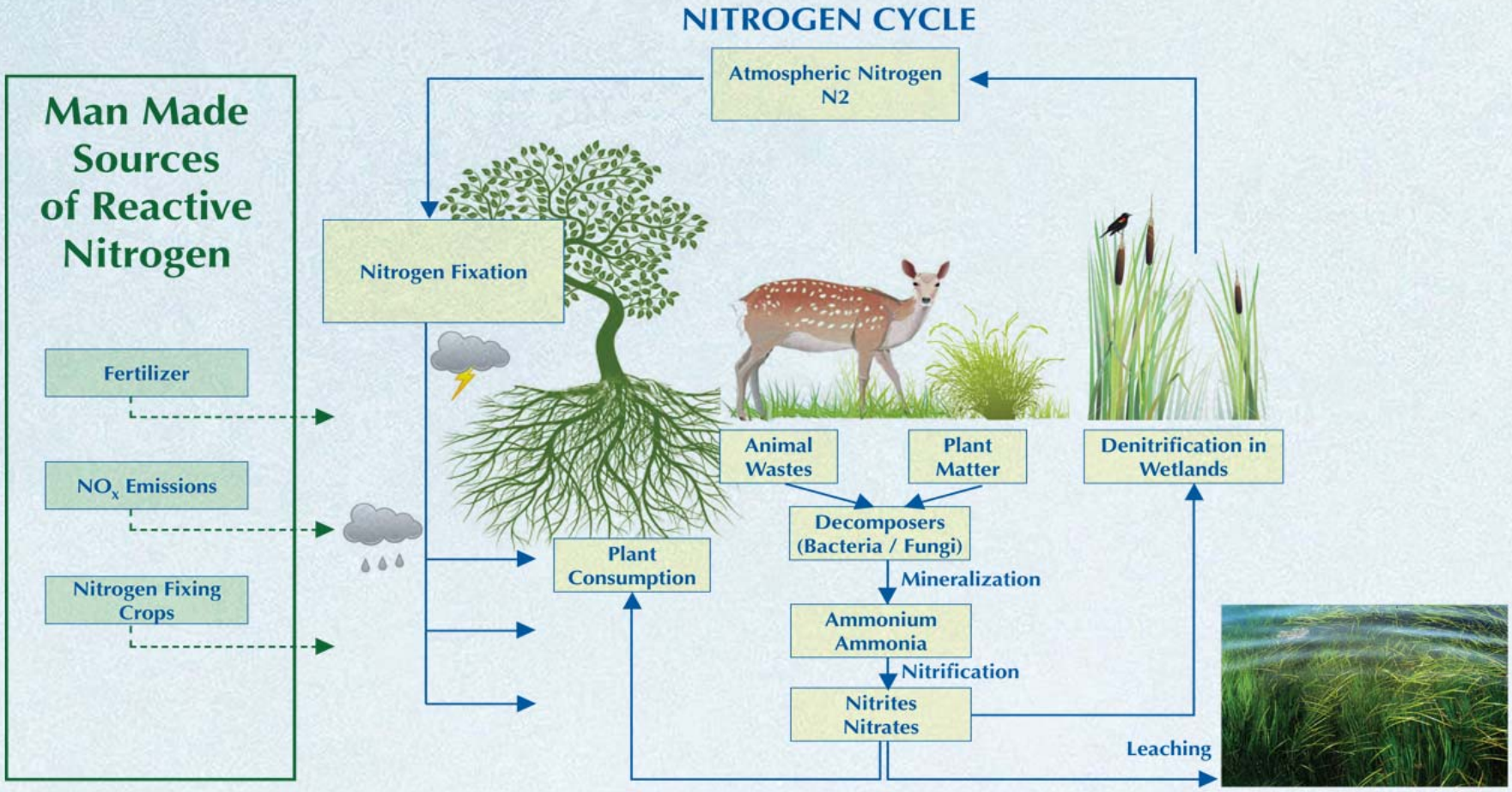
WRIGHT-PIERCE
Engineering a Better Environment

Nitrogen is also a pollutant

- Too much of a good thing is bad
- Nitrogen is very mobile
- Cascades through the environment

WRIGHT-PIERCE
Engineering a Better Environment

Nitrogen cycle with man-made sources



WRIGHT-PIERCE
Engineering a Better Environment

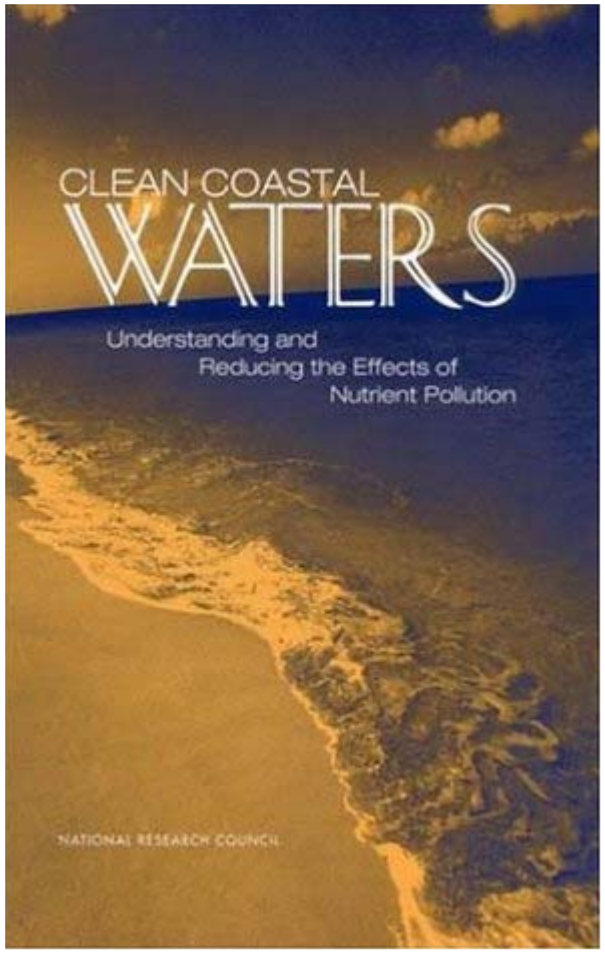
Limiting nutrient

Nitrogen is typically the limiting nutrient in estuarine environment

WRIGHT-PIERCE
Engineering a Better Environment

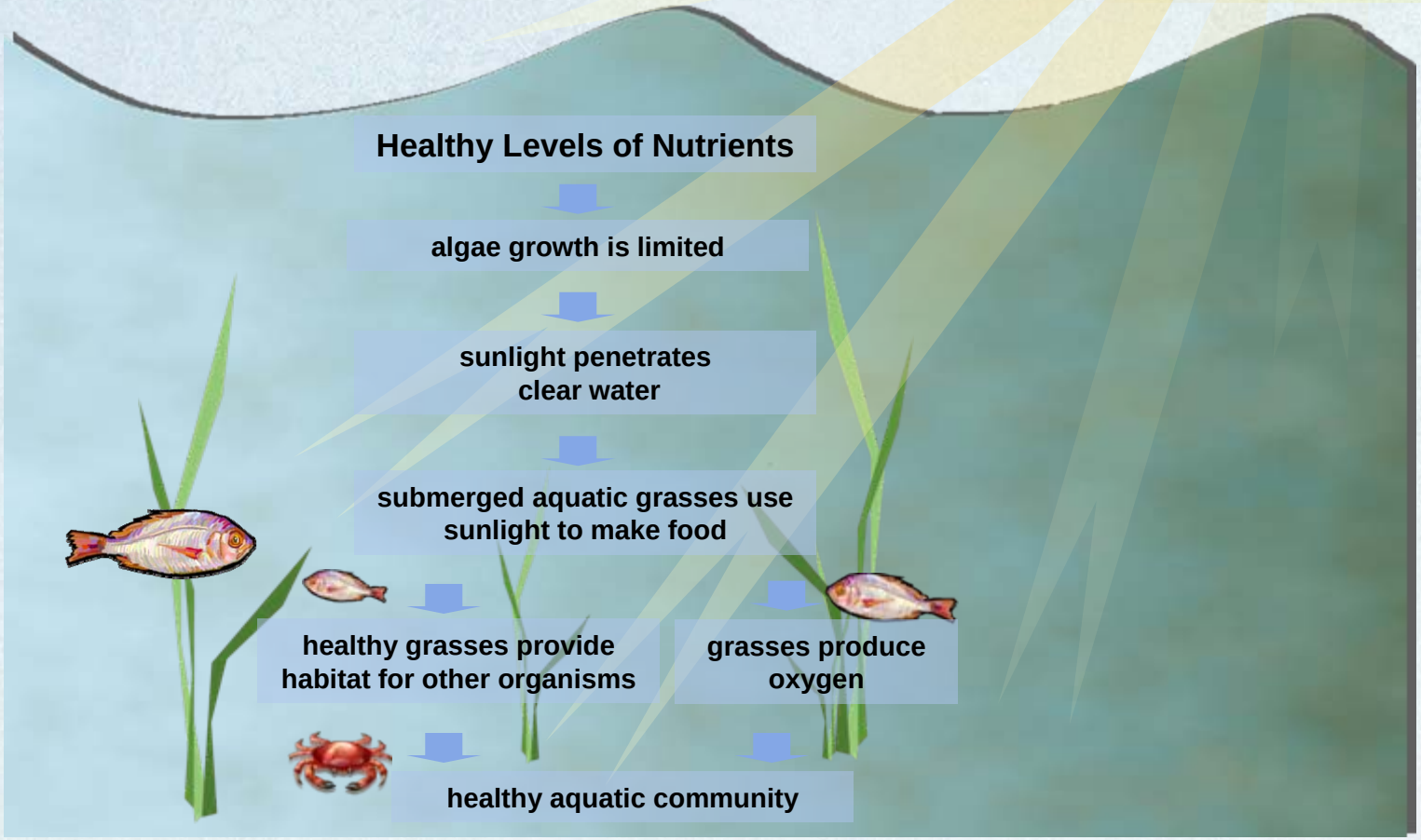
NRC 2000

- Nitrogen is now the largest pollution problem in the coastal waters of the United States
- Two thirds of coastal rivers and bays are moderately to severely degraded from nitrogen pollution.



WRIGHT-PIERCE
Engineering a Better Environment

Effects of nutrients in coastal waters



Effects of nutrients in coastal waters

Excess Levels of Nutrients

↓

algae use nutrients to grow and reproduce rapidly

↓

algae cloud water and block sunlight

↓

bacteria feed on dead algae

↓ ↓

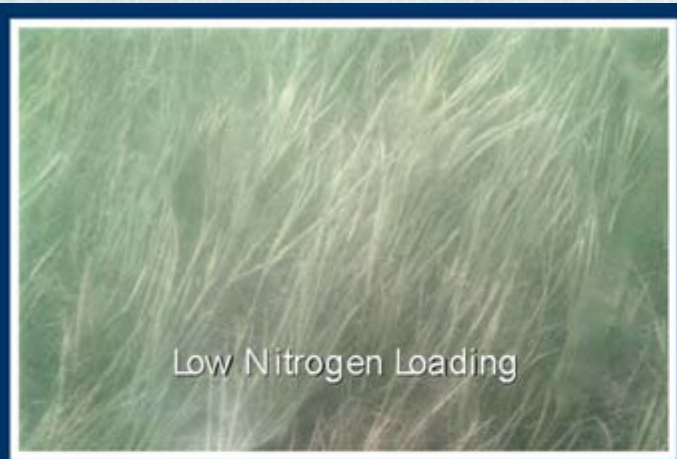
loss of grasses habitat

dissolved oxygen levels are decreased

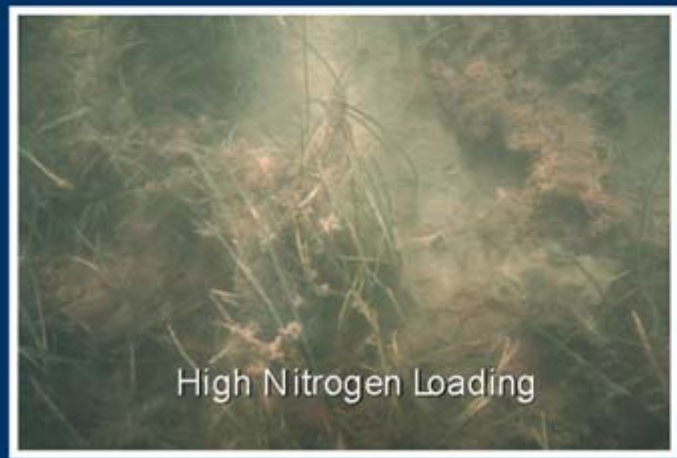
↓ ↓

bay organisms that breathe oxygen or live in grasses are stressed or die

Decline in marine habitat



As nitrogen loading increases, healthy eelgrass and diverse animal communities decline as algae replace eelgrass and smother animal communities; eelgrass disappears and fisheries decline.



Excessive algal growth

WRIGHT-PIERCE
Engineering a Better Environment

Algal impact on water clarity

WRIGHT-PIERCE
Engineering a Better Environment

Algal impact on water clarity

WRIGHT-PIERCE
Engineering a Better Environment

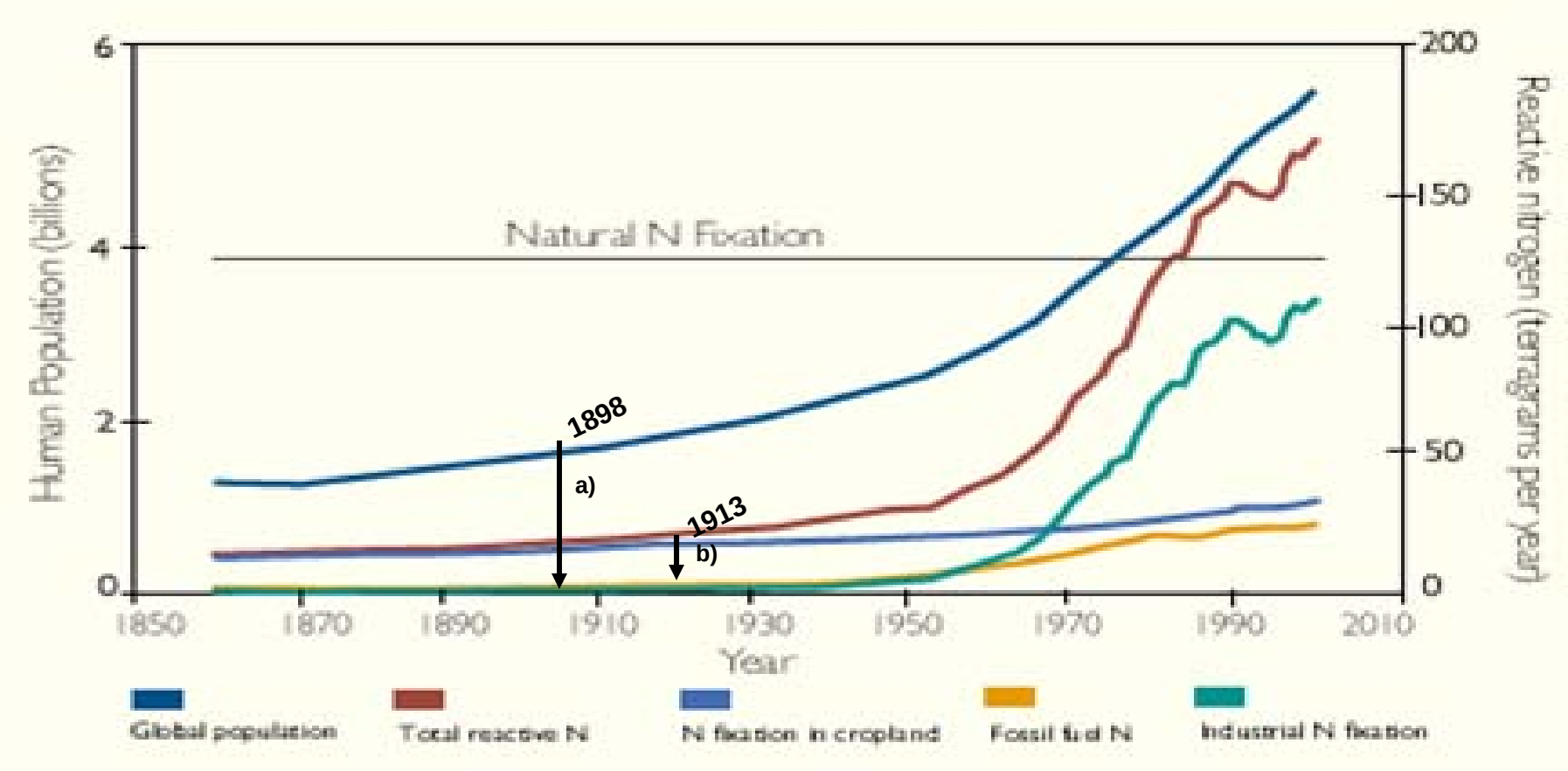
Excess nitrogen in an estuary

Causes cascading impacts

- Proliferation of algae
- Reduced water clarity
- Reduced light penetration
- Eelgrass loss
- Loss of habitat
- Reduced dissolved oxygen
- Less productive ecosystem

WRIGHT-PIERCE
Engineering a Better Environment

Global population and reactive nitrogen trends



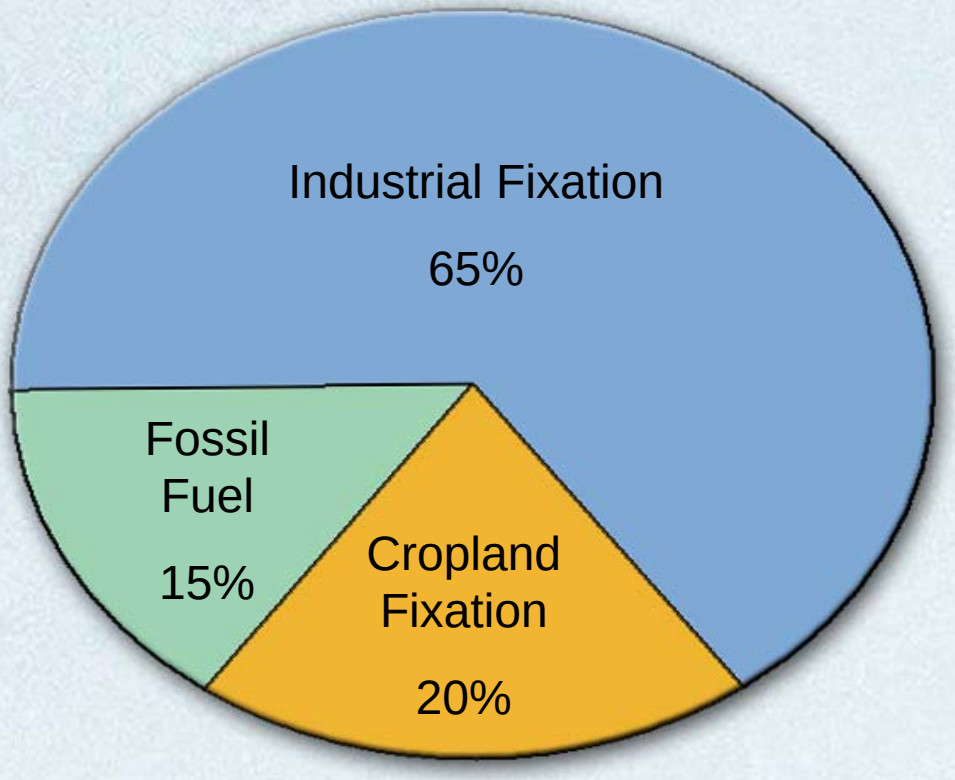
Source: Galloway and Cowling

a) **World-wide nitrogen shortage predicted**

b) **Haber-Bosch process invented**

WRIGHT-PIERCE
Engineering a Better Environment

Global man-made sources of reactive nitrogen

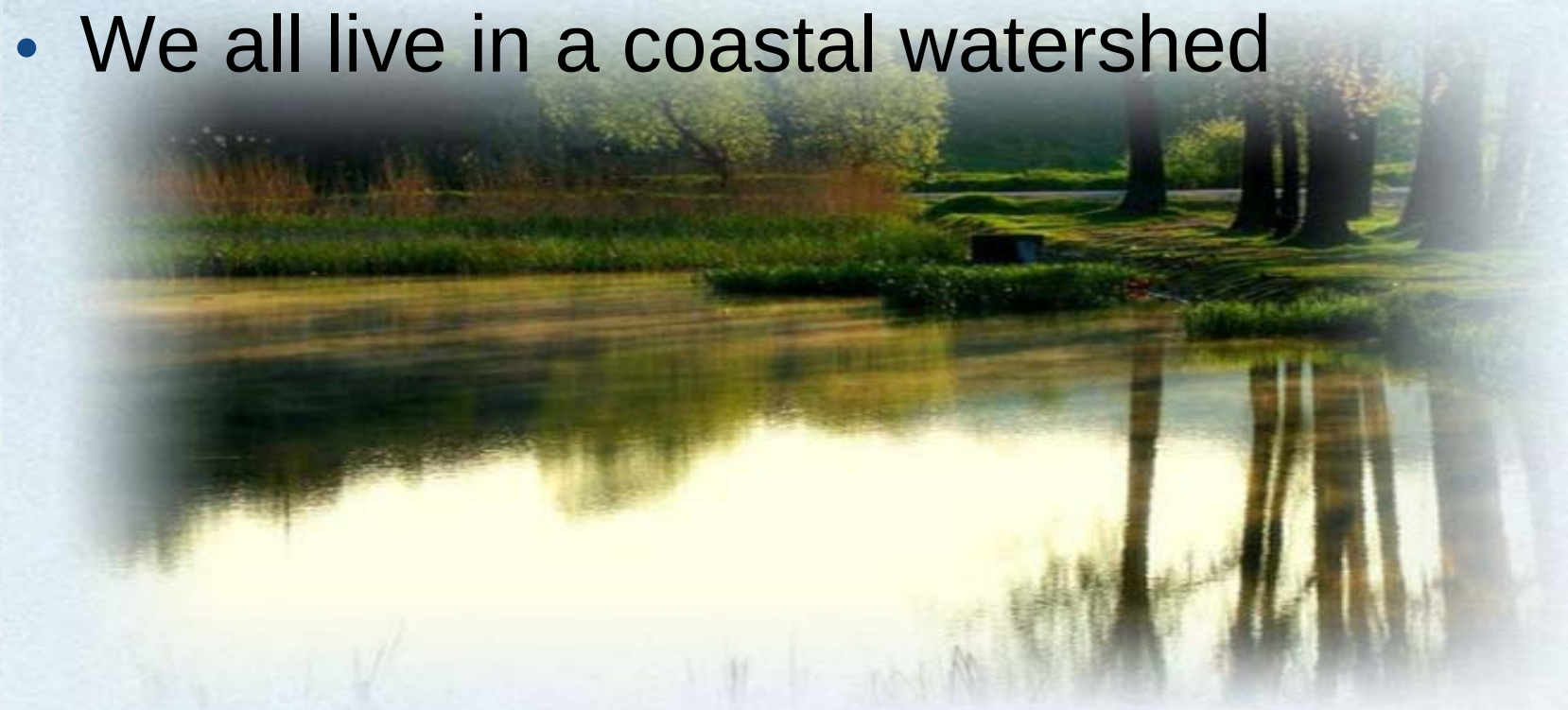


Source: Galloway and Cowling

WRIGHT-PIERCE
Engineering a Better Environment

Bad news is . . .

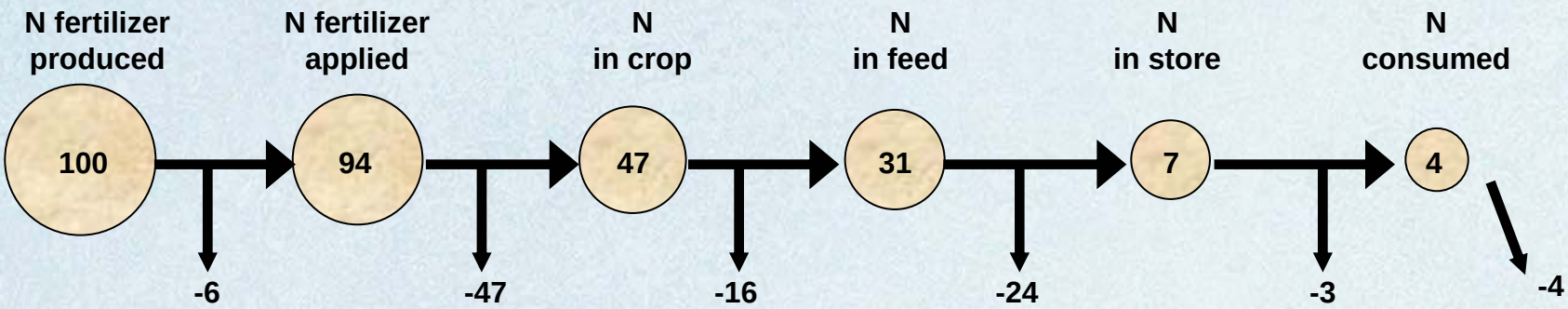
- Nitrogen is a growing problem in coastal waters
- We all live in a coastal watershed



WRIGHT-PIERCE
Engineering a Better Environment

Efficiency of nitrogen use in food production

Animal (meat) Production



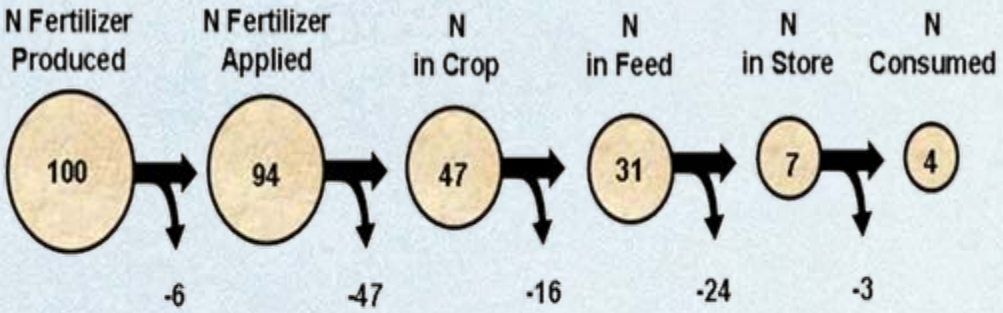
	Factory	Field	Crop	Feed	Meat Products	Mouth
step losses	**6% Loss** • Production • Transportation • Storage • Distribution • Handling	**50% Loss** • Groundwater • Surface water • Atmosphere	**34% Loss** • Crop residue • Atmosphere • Production	**77% Loss** • Manure • Production • Animal residue	**43% Loss** • Spoilage • Waste	**100% Loss** • Wastewater
cumulative losses	**6%**	**53%**	**69%**	**93%**	**96%**	**100%**

Source: Galloway and Cowling

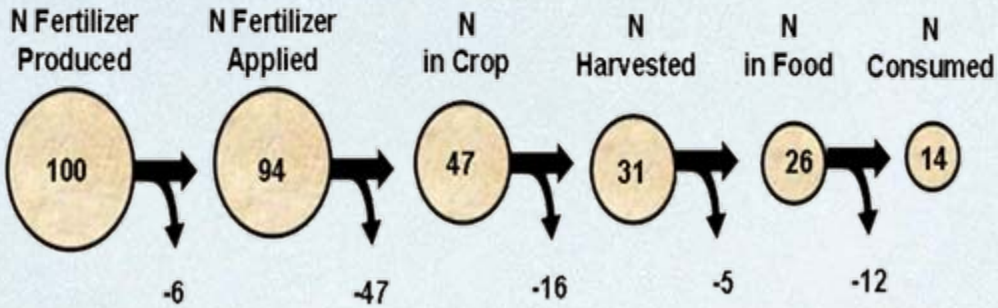
WRIGHT-PIERCE
Engineering a Better Environment

Efficiency of nitrogen use in food production

Animal (meat) Production



Vegetable / Grain Production



WRIGHT-PIERCE
Engineering a Better Environment

Human nitrogen needs / consumption

Average nitrogen consumption

~ **13 gm/cap-day**

Nitrogen needed

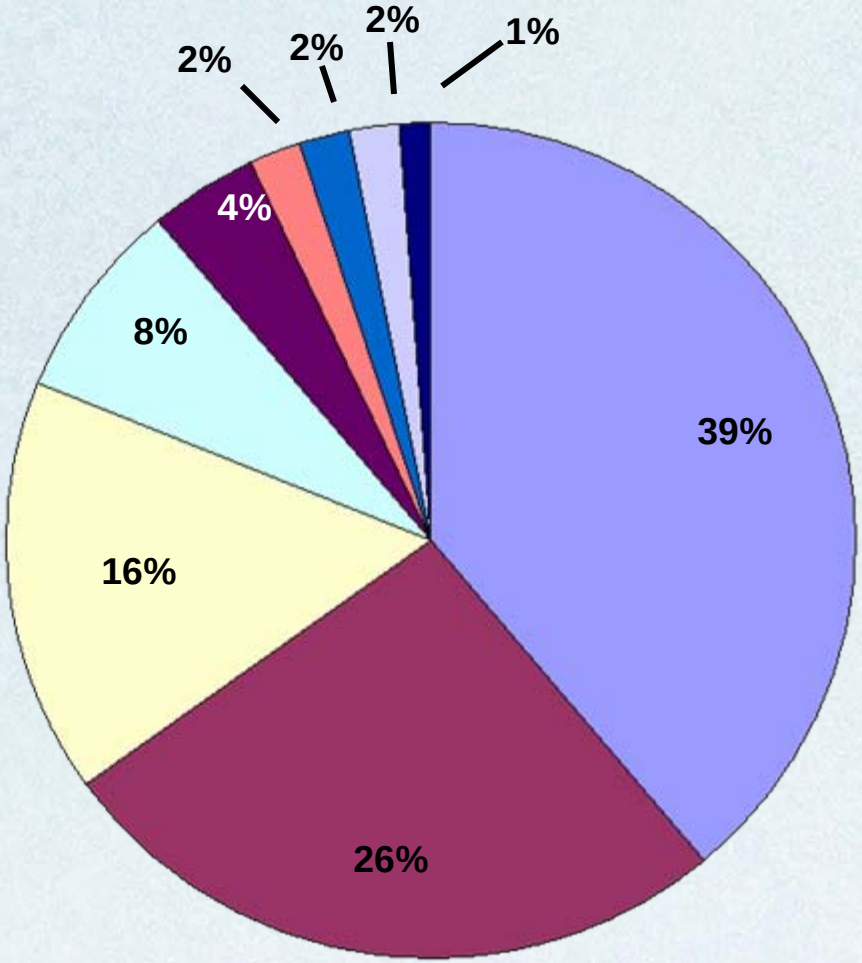
~ **2 gm/cap-day**

We consume much more nitrogen than we need.

Source: Galloway and Cowling

WRIGHT-PIERCE
Engineering a Better Environment

U.S. sources of atmospheric nitrogen emissions



Source: Driscoll et al

WRIGHT-PIERCE
Engineering a Better Environment

How much estuary nitrogen is too much

- Typical threshold nitrogen concentration
  ~ **0.2 to 0.5 ppm**
- Governed by:
  - Dissolved oxygen
  - Eelgrass
  - Habitat protection

WRIGHT-PIERCE
Engineering a Better Environment

How does this threshold estuary concentration compare with typical watershed sources of nitrogen

• threshold concentration in estuary	0.2-0.5 ppm
• rain	0.75 ppm
• forested recharge	0.05 ppm
• urban runoff	2-15 ppm
• agricultural runoff	3-10 ppm
• lawn runoff	3-8 ppm
• secondary treatment plant	32 ppm
• septic tank effluent	35 ppm
• drinking water standard	10 ppm

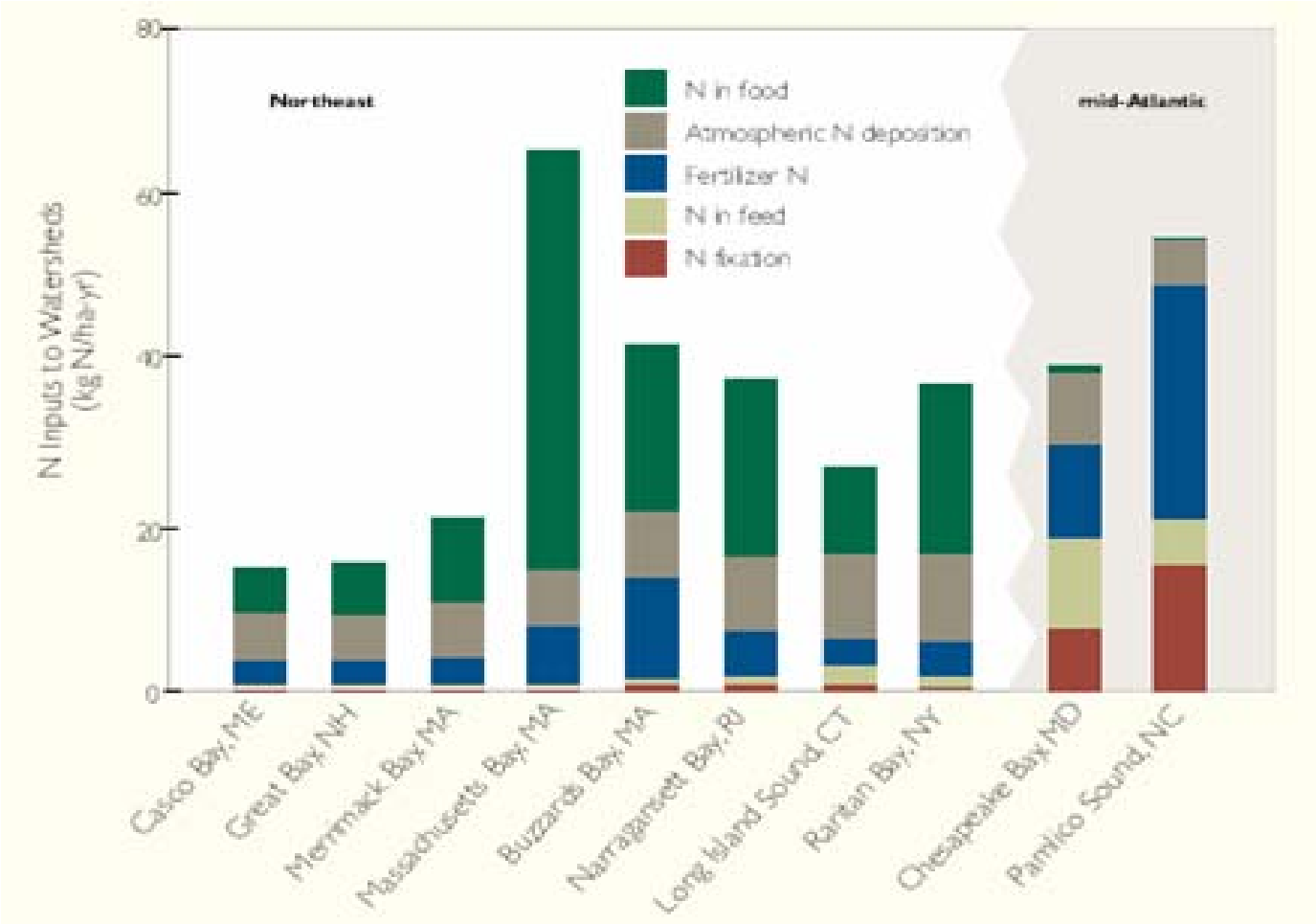
WRIGHT-PIERCE
Engineering a Better Environment

What controls the nitrogen concentration in an estuary?

- Watershed nitrogen loading
- Nitrogen attenuation in watershed
- Hydrodynamics of estuary
- Quality of ocean water

WRIGHT-PIERCE
Engineering a Better Environment

Regional nitrogen loadings/sources



Source: Driscoll et al

WRIGHT-PIERCE
Engineering a Better Environment

Regional nitrogen sources

Nitrogen Loadings

Kg N/ha-yr (% of total)

	Great Bay**	Merrimack Bay	Narragansett Bay	Long Island Sound
Food (Wastewater)	6.1 (40%)	10.7 (51%)	21.5 (58%)	10.0 (37%)
Atmospheric deposition	5.4 (35%)	6.8 (32%)	8.8 (24%)	10.8 (40%)
Fertilizer	2.3 (15%)	2.0 (10%)	5.0 (13%)	2.3 (9%)
Agricultural *	1.6 (10%)	1.5 (7%)	2.0 (5%)	3.8 (14%)
TOTAL	**15.4**	**21.0**	**37.3**	**26.9**

* Animal feed and crop fixation

** Being updated by NHDES

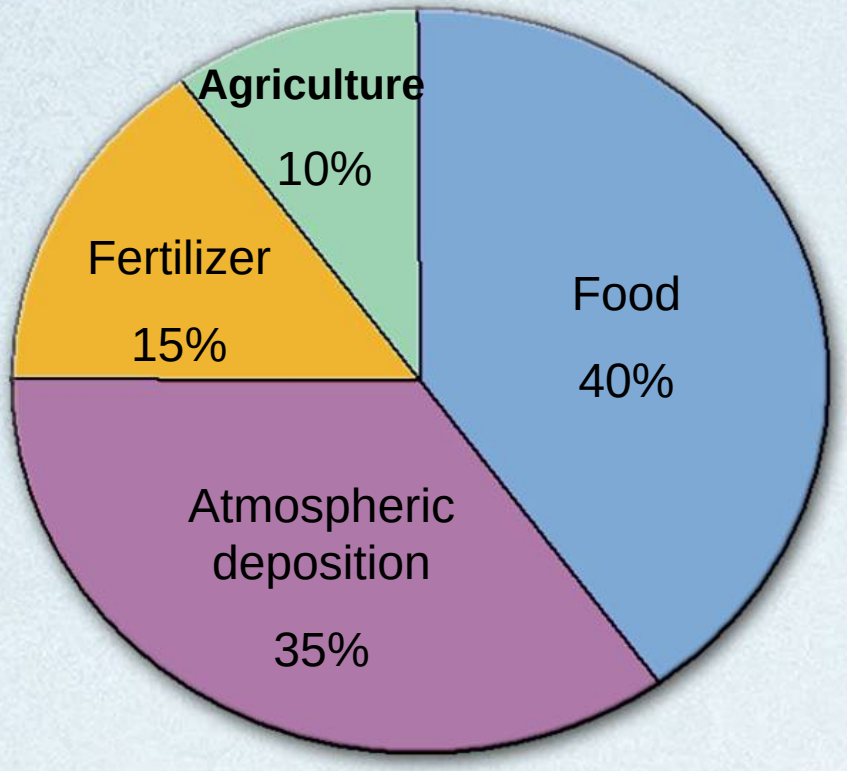
Source: Driscoll et al

WRIGHT-PIERCE
Engineering a Better Environment

NE regional nitrogen sources different than global average

- Little food production in region
- Higher population densities
- Downwind of mid west power plants

Great Bay Nitrogen Inputs



Total 15.4 Kg-N / ha-yr

Source: Driscoll et al

WRIGHT-PIERCE
Engineering a Better Environment

Nitrogen attenuation

- Only a fraction of the nitrogen loadings flow to downstream estuaries
- U.S. average of about 25% of nitrogen inputs are exported (75% attenuation)
- Attenuation highly variable and watershed specific (10% to 80%)

WRIGHT-PIERCE
Engineering a Better Environment

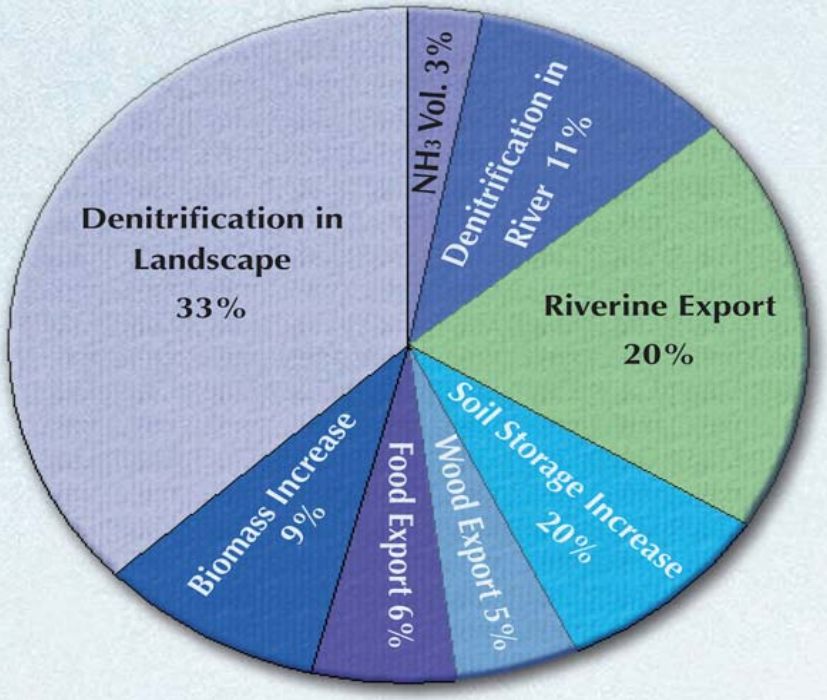
Nitrogen attenuation mechanisms

- Storage
  - Soil
  - Plants
  - Groundwater
- Removed from watershed
  - Crops
  - Wood
- Volatilized to atmosphere (ammonia)
- Denitrification
  - Soil
  - Wetlands
  - Ponds
  - Streams/rivers
  - Wastewater Treatment Facilities

WRIGHT-PIERCE
Engineering a Better Environment

Nitrogen attenuation

Average of 16 large non-urban watersheds in northeastern U.S.



Source: Van Breeman et al

WRIGHT-PIERCE
Engineering a Better Environment

Nitrogen attenuation

	Great Bay*	Merrimack Bay	Narragansett Bay	Long Island Sound
Total N input (kg N/ha-yr)	15.4	21.0	37.3	26.9
Output N (kg N/ha-yr)	7.7	8.4	20.4	10.4
Attenuation	50%	60%	45%	61%

* Being updated by NHDES

Source: Driscoll et al

WRIGHT-PIERCE
Engineering a Better Environment

Importance of attenuation

Watershed #1

N input = 500 1bs/day

N output =100 lbs/day

Watershed #2

N input = 500 lbs/day

N output = 400 lbs/day

WRIGHT-PIERCE
Engineering a Better Environment

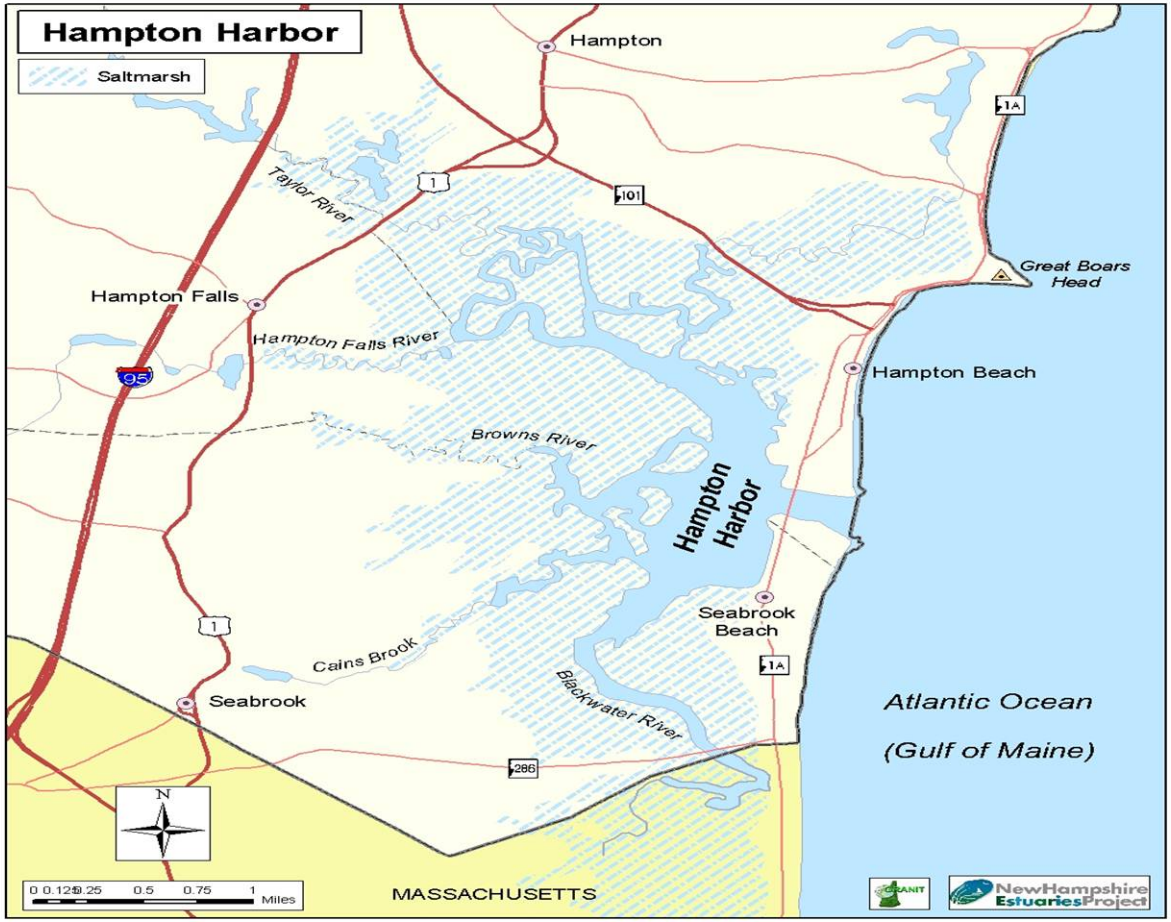
Hydrodynamics – flushing rates

WRIGHT-PIERCE
Engineering a Better Environment

Great Bay is poorly flushed

WRIGHT-PIERCE
Engineering a Better Environment

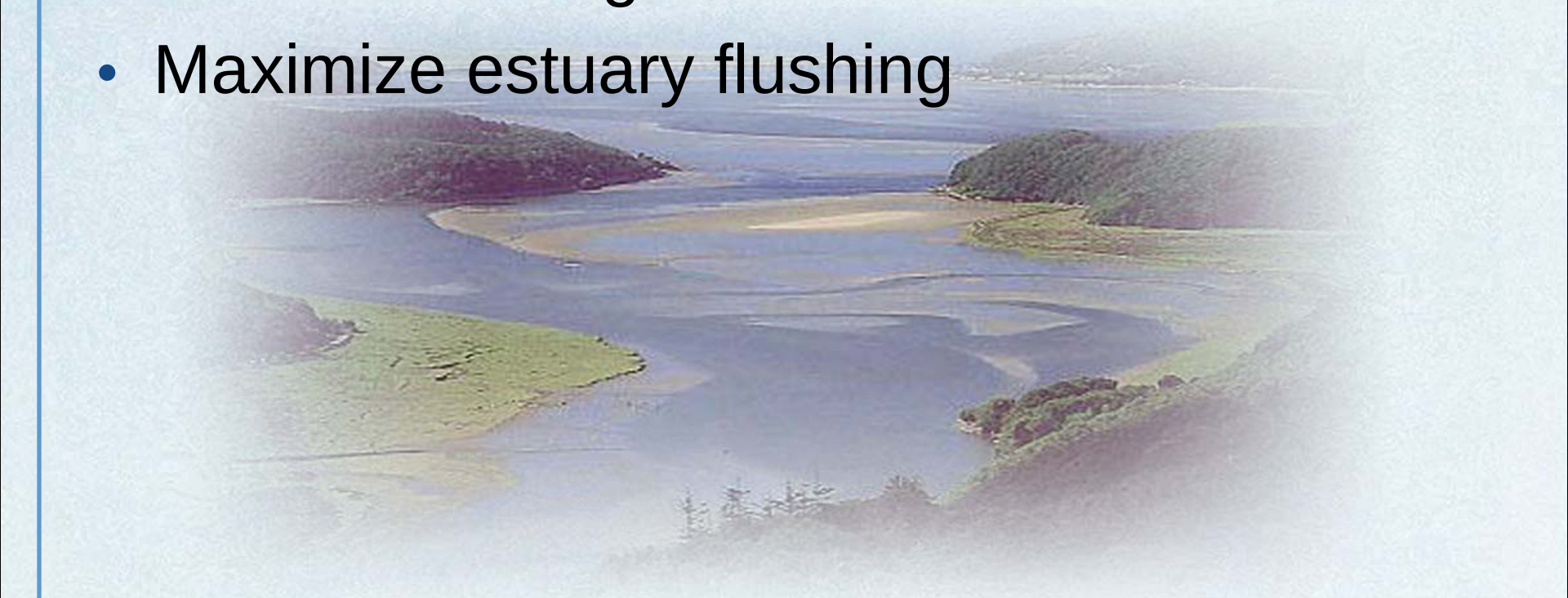
Hampton Harbor is well flushed



WRIGHT-PIERCE
Engineering a Better Environment

Estuary nitrogen control

- Reduce nitrogen inputs
- Maximize nitrogen attenuation
- Maximize estuary flushing



WRIGHT-PIERCE
Engineering a Better Environment

Global strategies to reduce watershed nitrogen inputs

- Reduce fertilizer use
  - Improve efficiency of food production
  - Recycle/make productive use of waste products
- Reduce air emissions
  - Electricity conservation
  - Use of nitrogen neutral fuels
  - More efficient vehicles
  - Public transportation
  - Heating system efficiency improvements

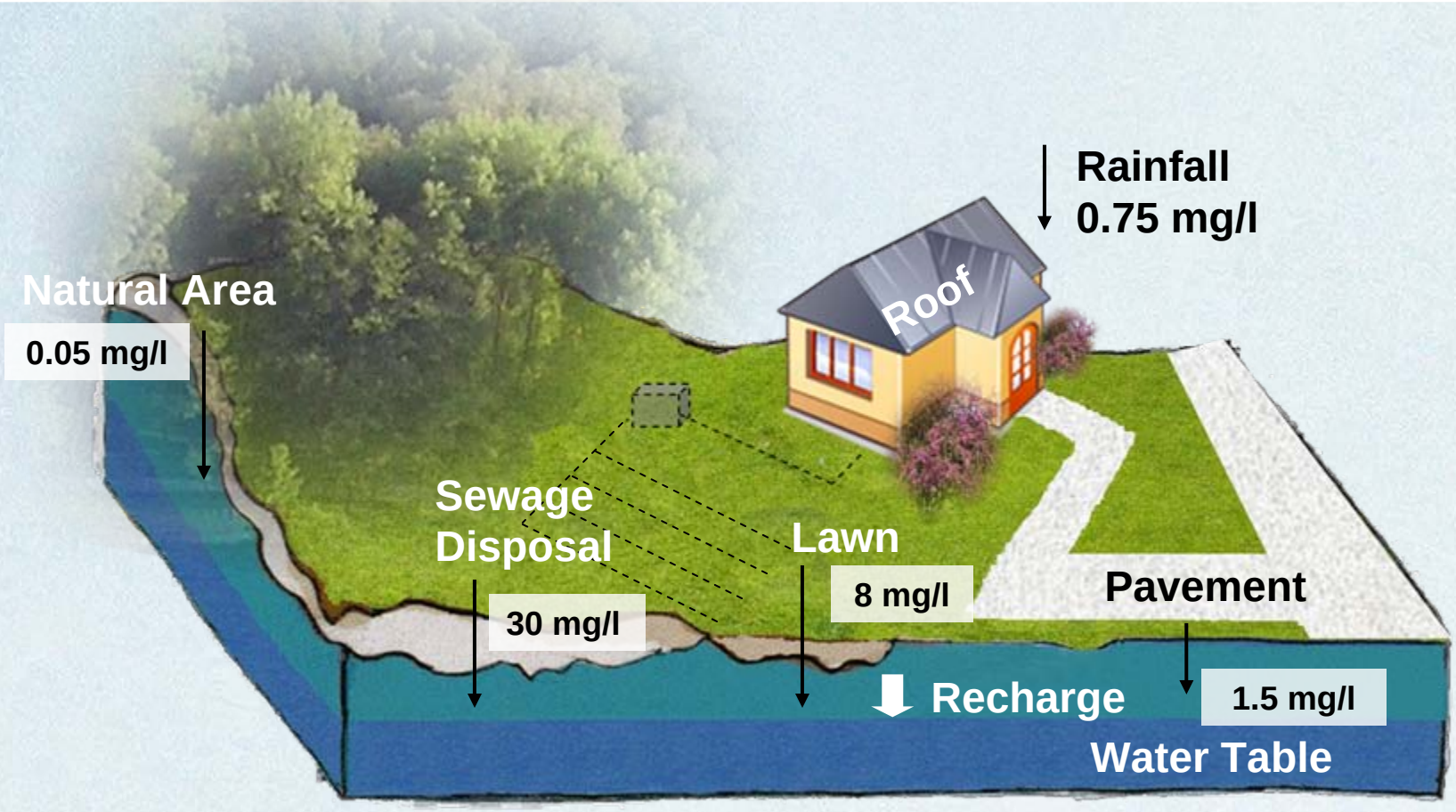
WRIGHT-PIERCE
Engineering a Better Environment

NE regional strategies to reduce watershed nitrogen inputs

- Limit food inputs
  - Population density control for undeveloped land / land use zoning
  - Minimize food waste
- Limit air emissions
  - Electricity conservation
  - Use of nitrogen neutral fuels
  - More efficient vehicles
  - Public transportation
  - Heating system efficiency improvements
- Limit fertilizer use
  - Best management practices
    - Agriculture; Golf Courses; Homeowners
  - Less lawn area

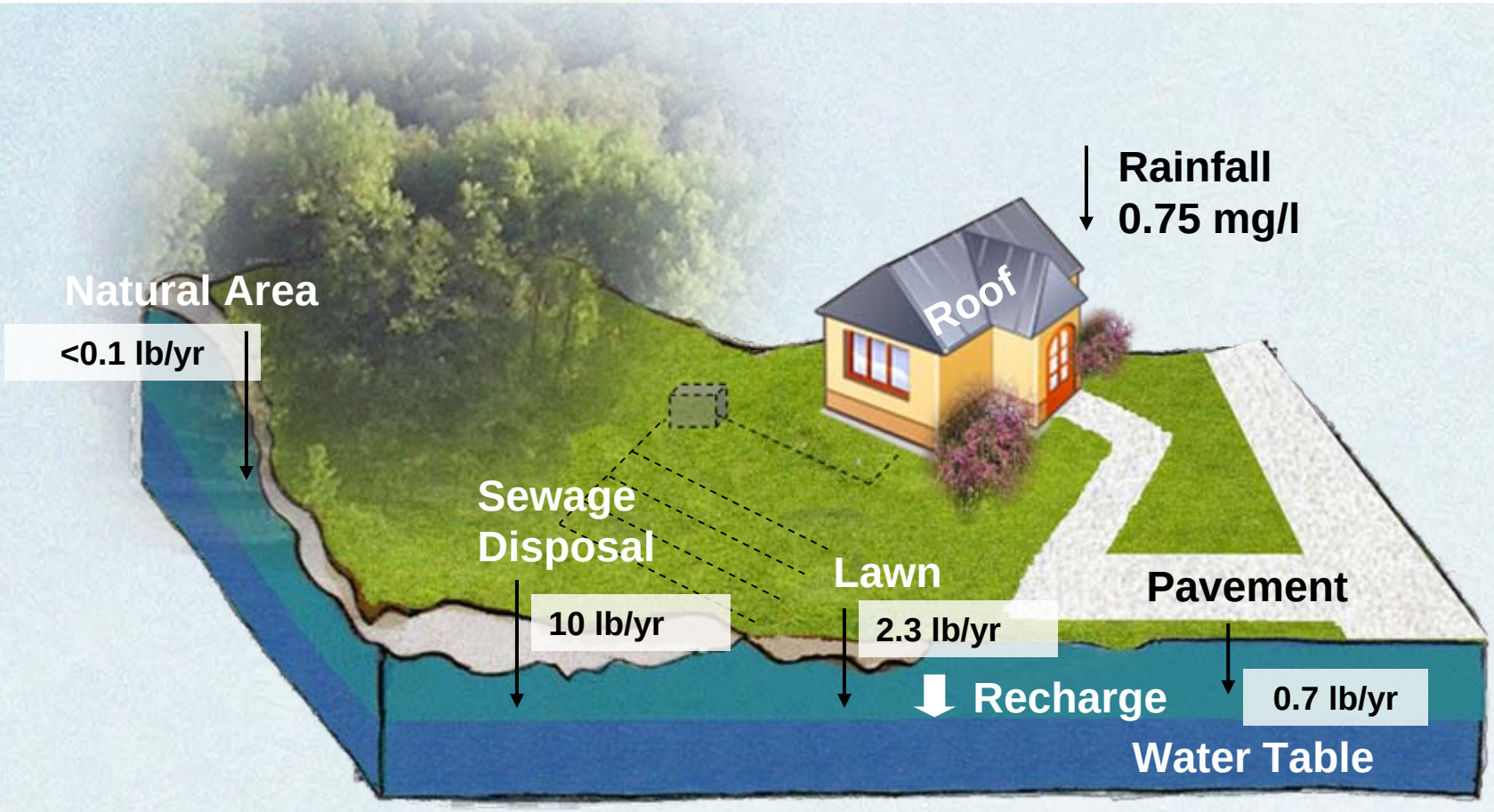
WRIGHT-PIERCE
Engineering a Better Environment

Nitrogen sources on typical residential lot – concentrations



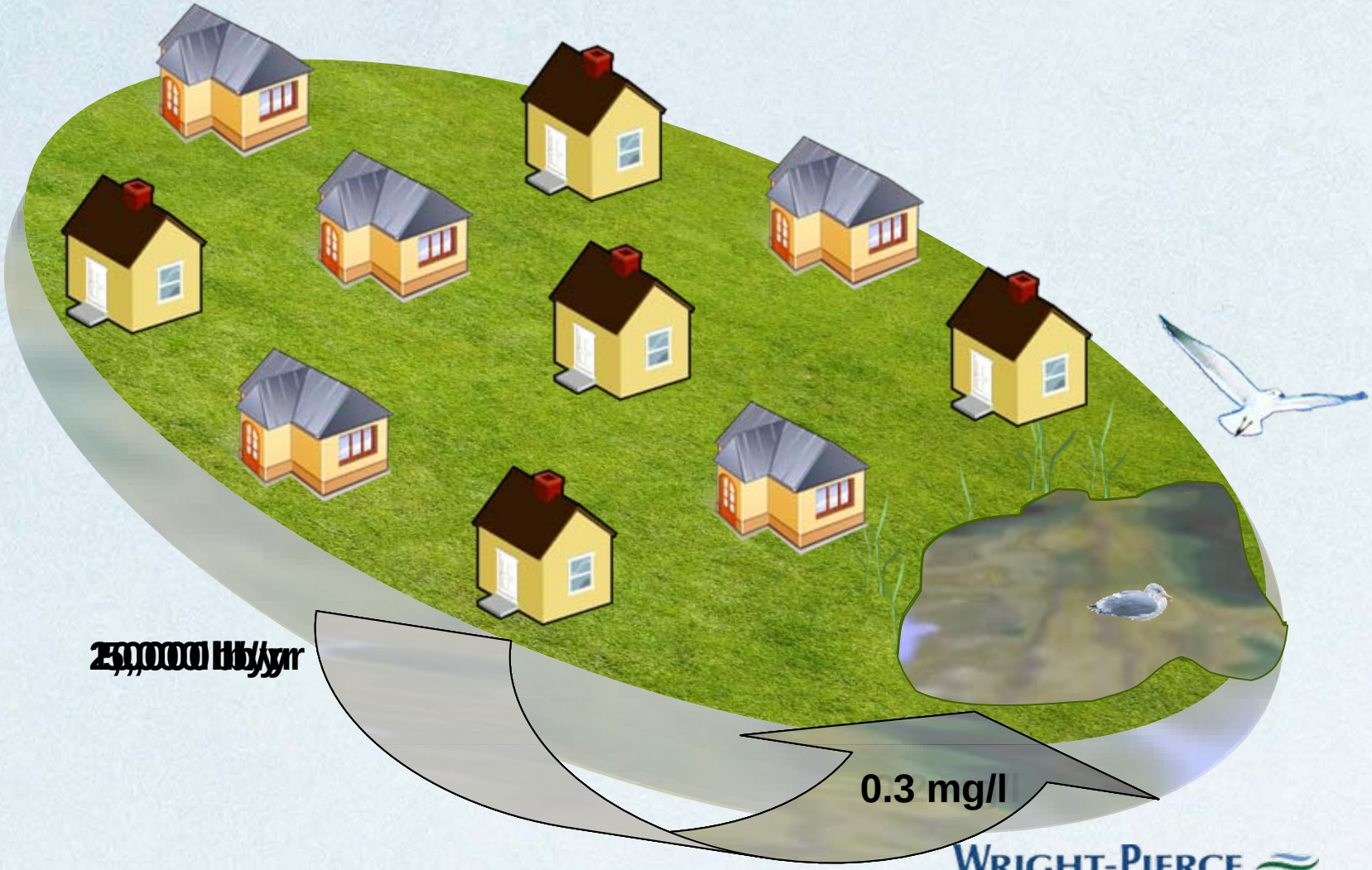
WRIGHT-PIERCE
Engineering a Better Environment

Nitrogen sources on typical residential lot – mass basis



WRIGHT-PIERCE
Engineering a Better Environment

Relative nitrogen thresholds



WRIGHT-PIERCE
Engineering a Better Environment

A Vineyard lawn

WRIGHT-PIERCE
Engineering a Better Environment

Golf course fertilization

Organic

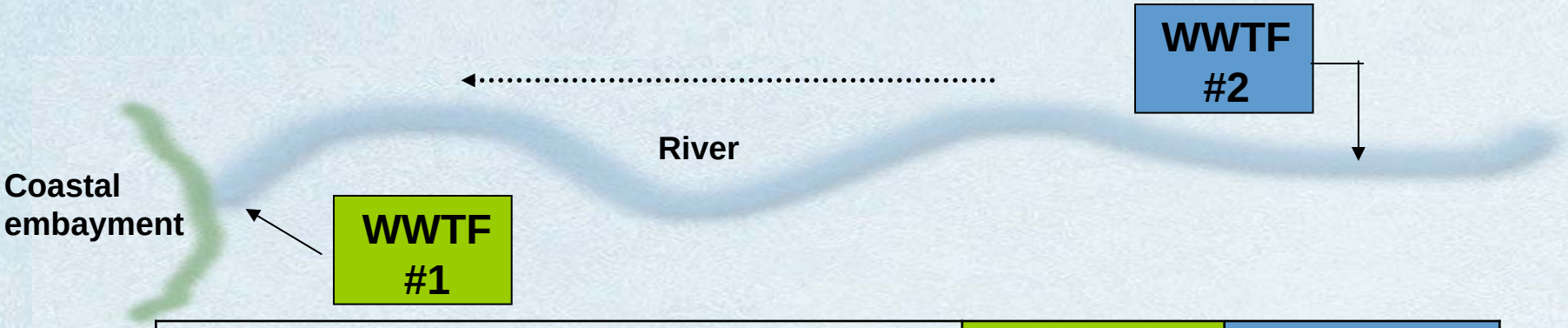
Non-organic

WRIGHT-PIERCE
Engineering a Better Environment

Strategies to maximize nitrogen attenuation

- Maximize natural denitrification
  - Protect/restore wetlands and other waterways
- Nutrient removal at wastewater facilities
- Productive effluent and biosolids re-use
- Productive re-use of agricultural/food wastes
- Creative on-lot wastewater disposal solutions
- Improved storm water management
- Best management agricultural practices
- Low impact development
- Land use ordinances / nitrogen based zoning.

Importance of prioritization



	WWTF #1	WWTF #2
Effluent TN, lbs/day	500	500
Attenuation factor	0	0.70
TN to bay	500	150
BNR upgrade (5ppm,80lbs/day) costs	$20M	$20M
TN to bay after upgrade, lbs/day	80	24
TN reduction to bay, lbs/day	420	126
Cost/lb/day TN reduction	$47,619/lb	$158,730/lb

WRIGHT-PIERCE
Engineering a Better Environment

Important to thoroughly define N problem

- Understand all sources of watershed N
- Understand attenuation factors
- Understand maximum allowable N loading
- Identify N load reduction required
- Prioritize N reduction opportunities($/lb)

WRIGHT-PIERCE
Engineering a Better Environment

Need a watershed-wide approach

- Nitrogen issues are complex
- Control strategies require a watershed approach
- Very challenging public policy issues

WRIGHT-PIERCE
Engineering a Better Environment

Conclusions

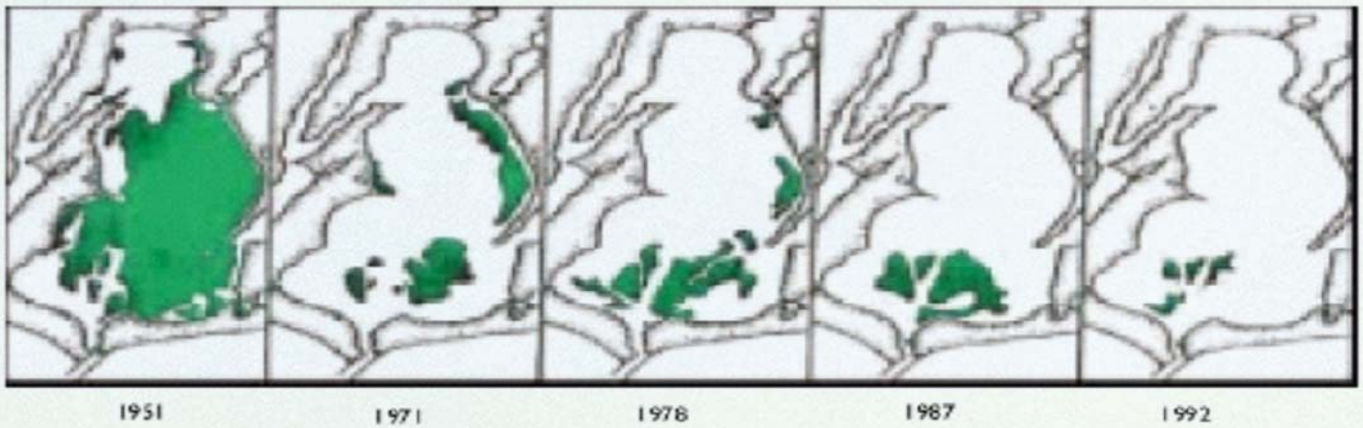
- Nitrogen is a real threat to our coastal waters.
- The problem relates directly to population density, energy use, land use, etc.
- Solutions are required to protect our valued coastal resources
- Solutions are expensive
- Creative funding and prioritization will be critical.
- Solutions will require a watershed approach and involvement from all stakeholders.

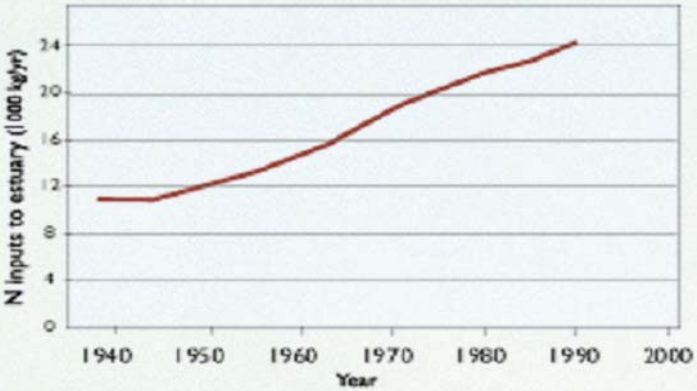
WRIGHT-PIERCE
Engineering a Better Environment

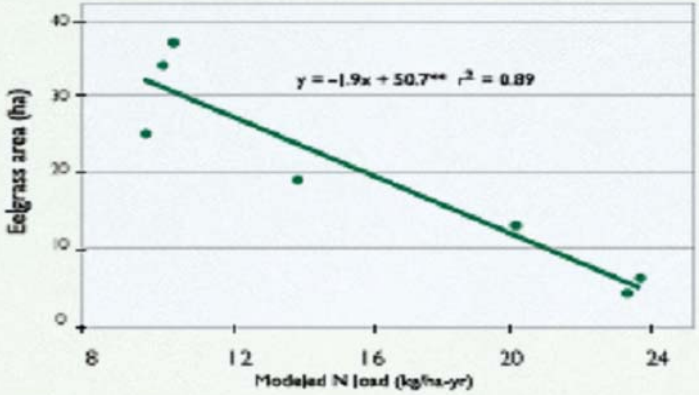
Questions & Answers

WRIGHT-PIERCE
Engineering a Better Environment

Nitrogen and eelgrass coverage Waquoit Bay, MA







Source: Valiela et al

WRIGHT-PIERCE
Engineering a Better Environment