Linking River-Reach Nitrogen Loads with Groundwater "Reachsheds" to Identify Areas for Possible Nitrogen Reduction, Cape Cod, Massachusetts

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USGS New England Water Science Center

SNEP Symposium
5/18/2022

USGS science for a changing world

Preliminary Information-Subject to Revision. Not for Citation or Distribution

EPA United States Environmental Protection Agency

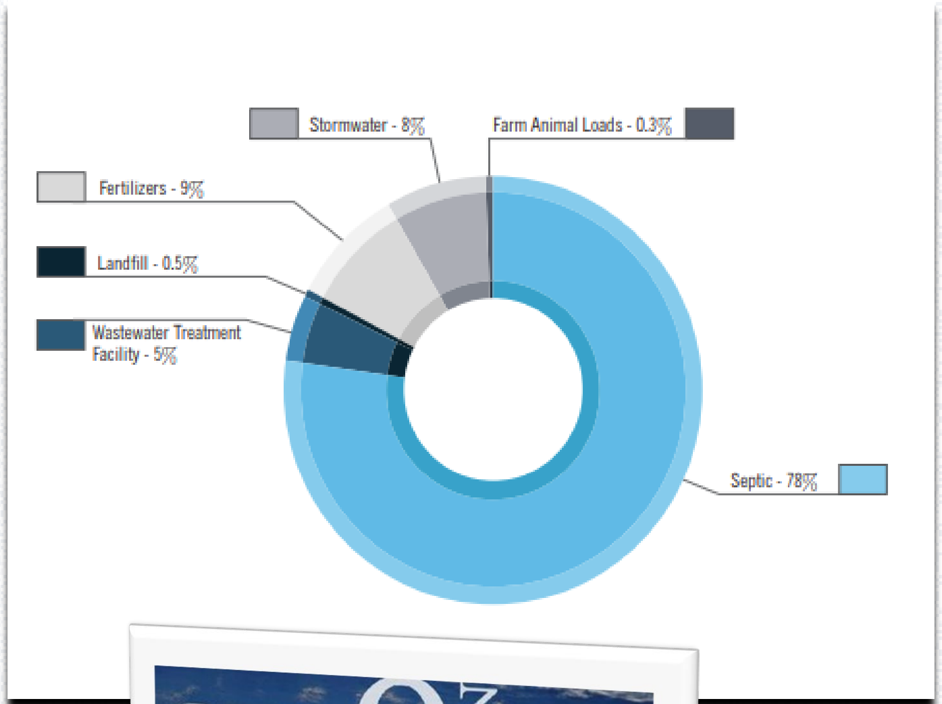
Southeast New England Program (SNEP)

Background

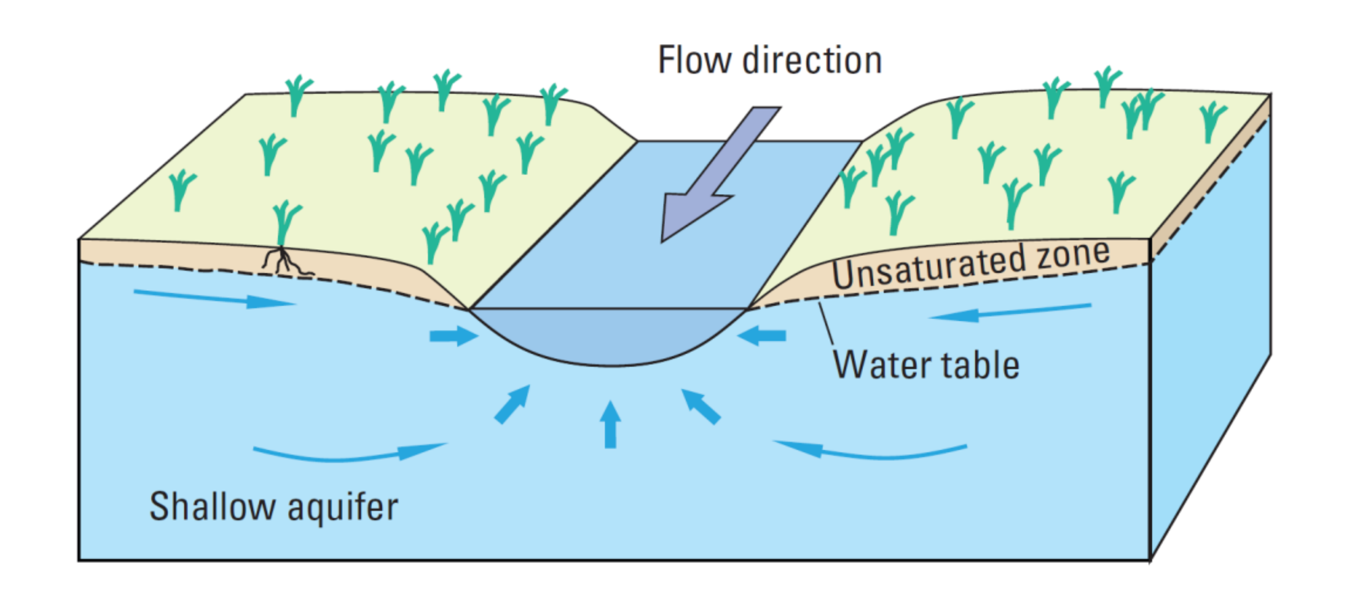
- Excessive nitrogen is causing eutrophication in a majority of Cape Cod's estuaries

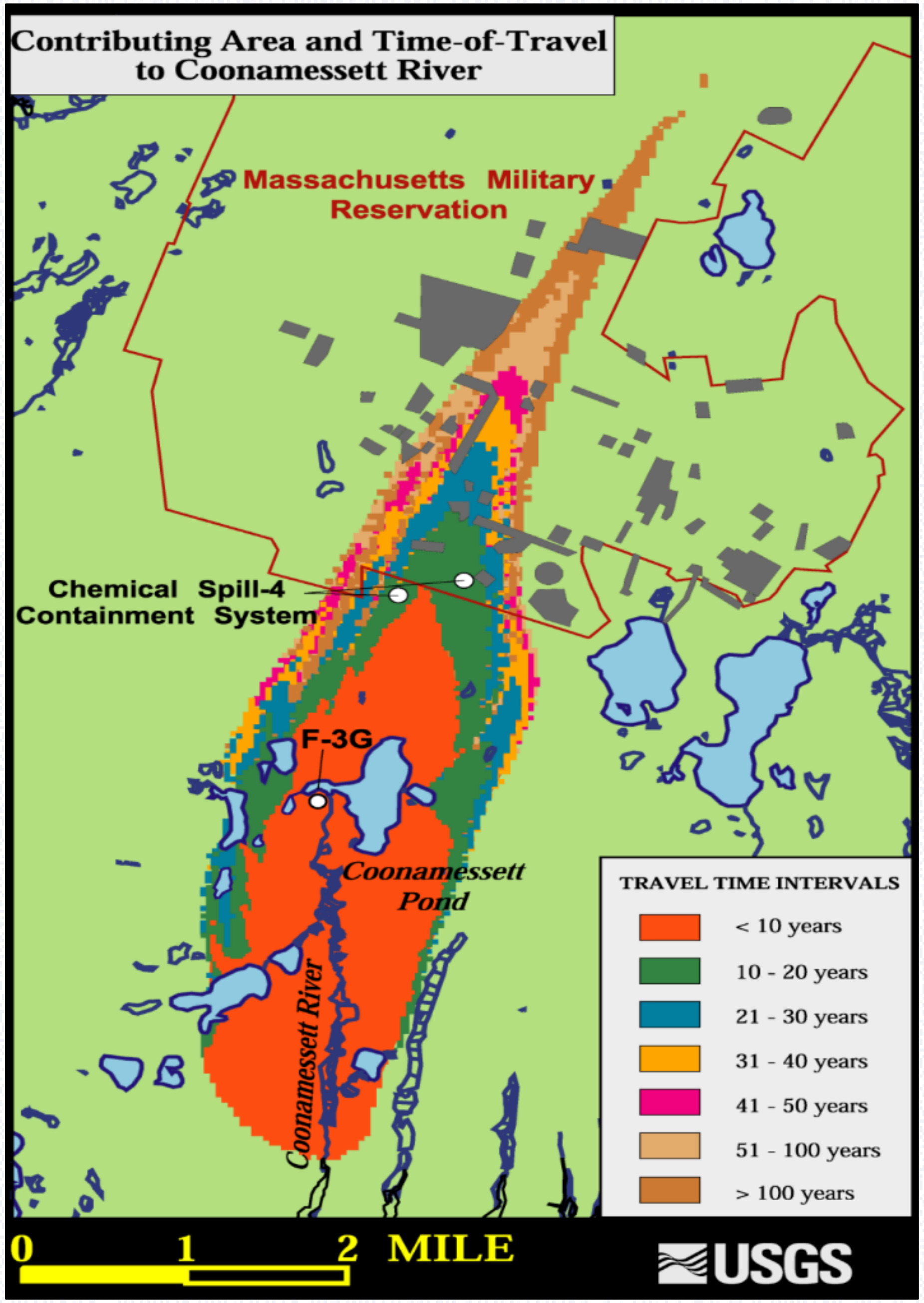
- Towns are planning and implementing nitrogen mitigation actions to meet TMDLs

- TMDLs and planning tools are scaled to embayments/subembayments based on regional GW flow models



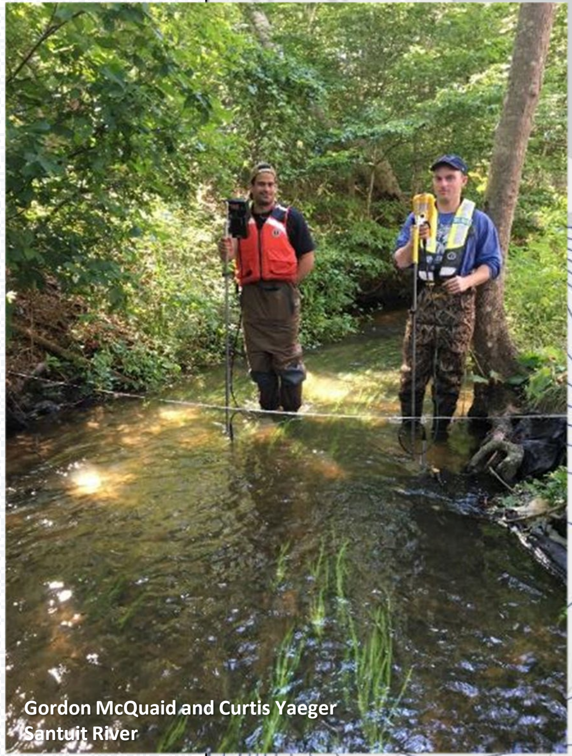
Can we use river water quality to identify source areas in the groundwater watershed to prioritize actions for nitrogen reduction?





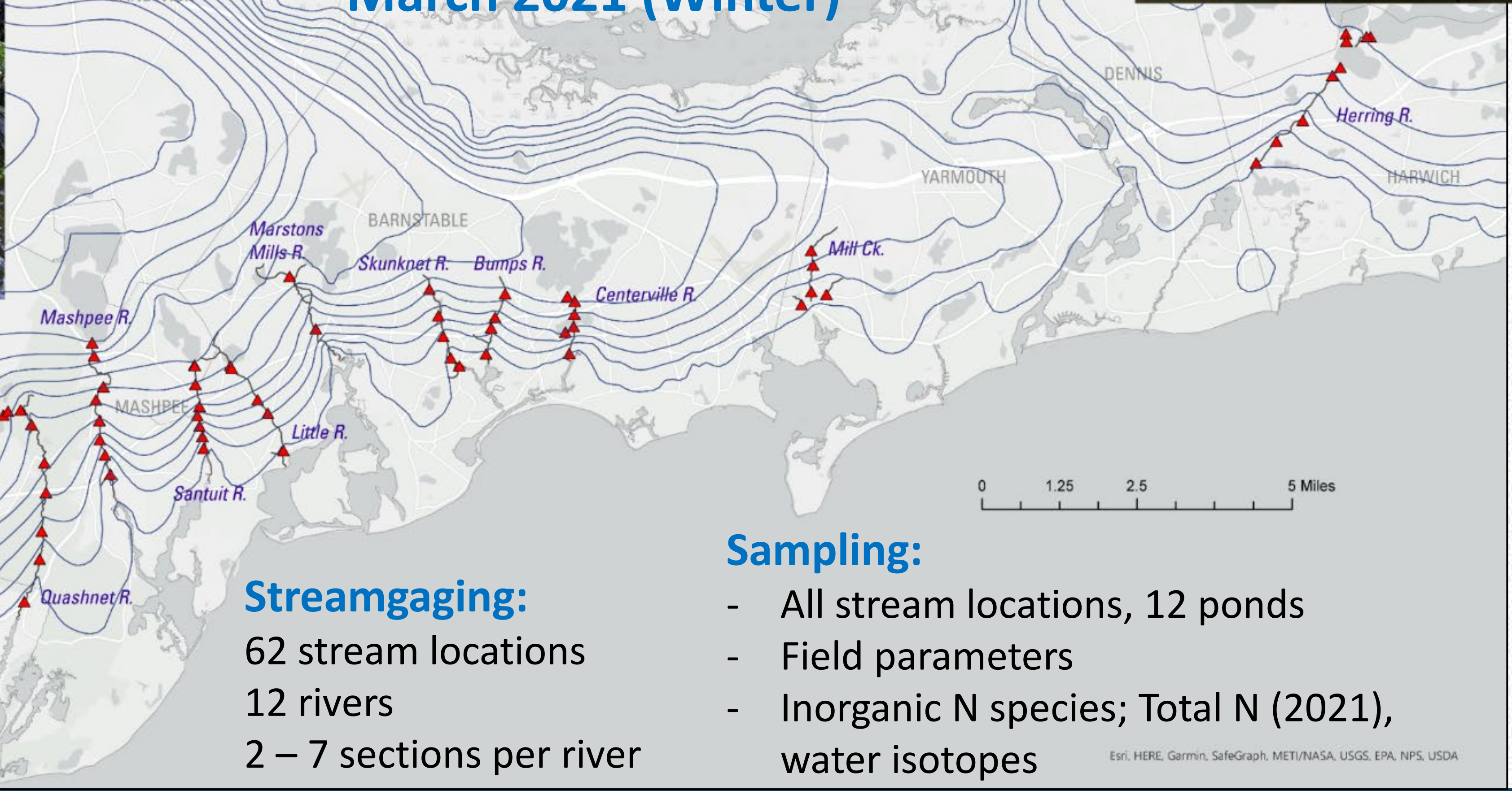
Upper and Mid Cape River Surveys
(“Seepage run” with sampling)

September 2019 (Summer)
March 2021 (Winter)



Gordon McQuaid and Curtis Yaeger
Santuit River

Kyle Fronte -Mashpee River



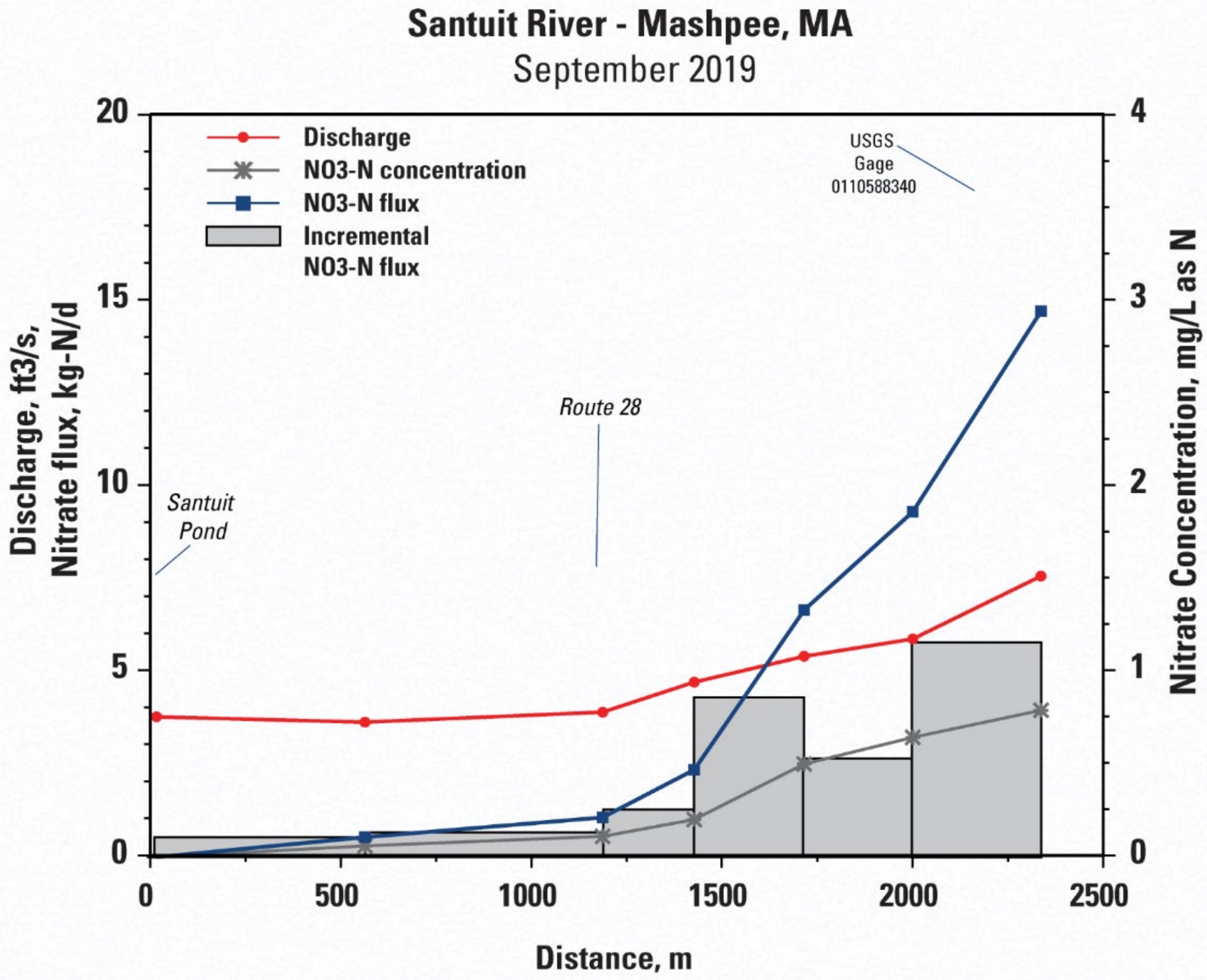
Streamgaging:

62 stream locations
12 rivers
2 – 7 sections per river

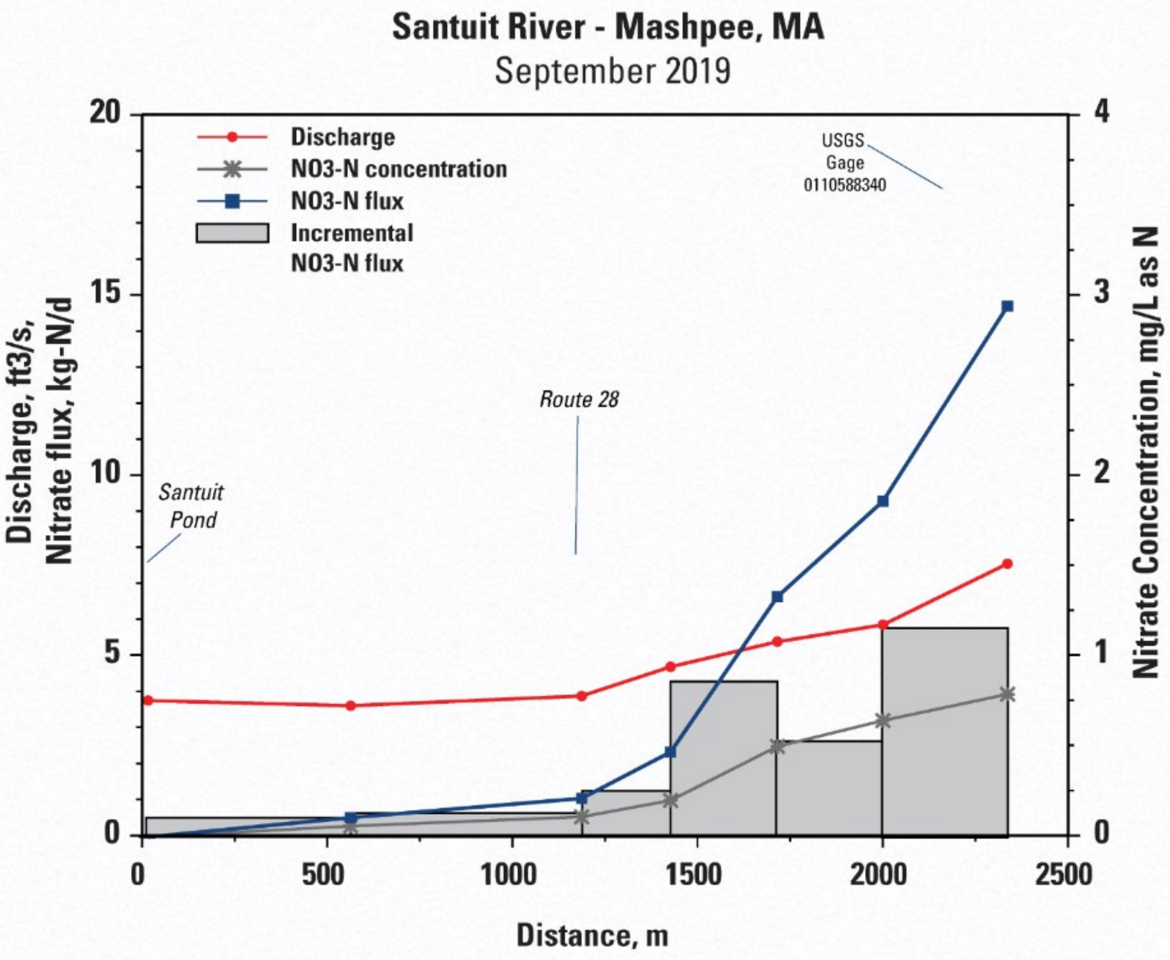
Sampling:

- All stream locations, 12 ponds
- Field parameters
- Inorganic N species; Total N (2021), water isotopes

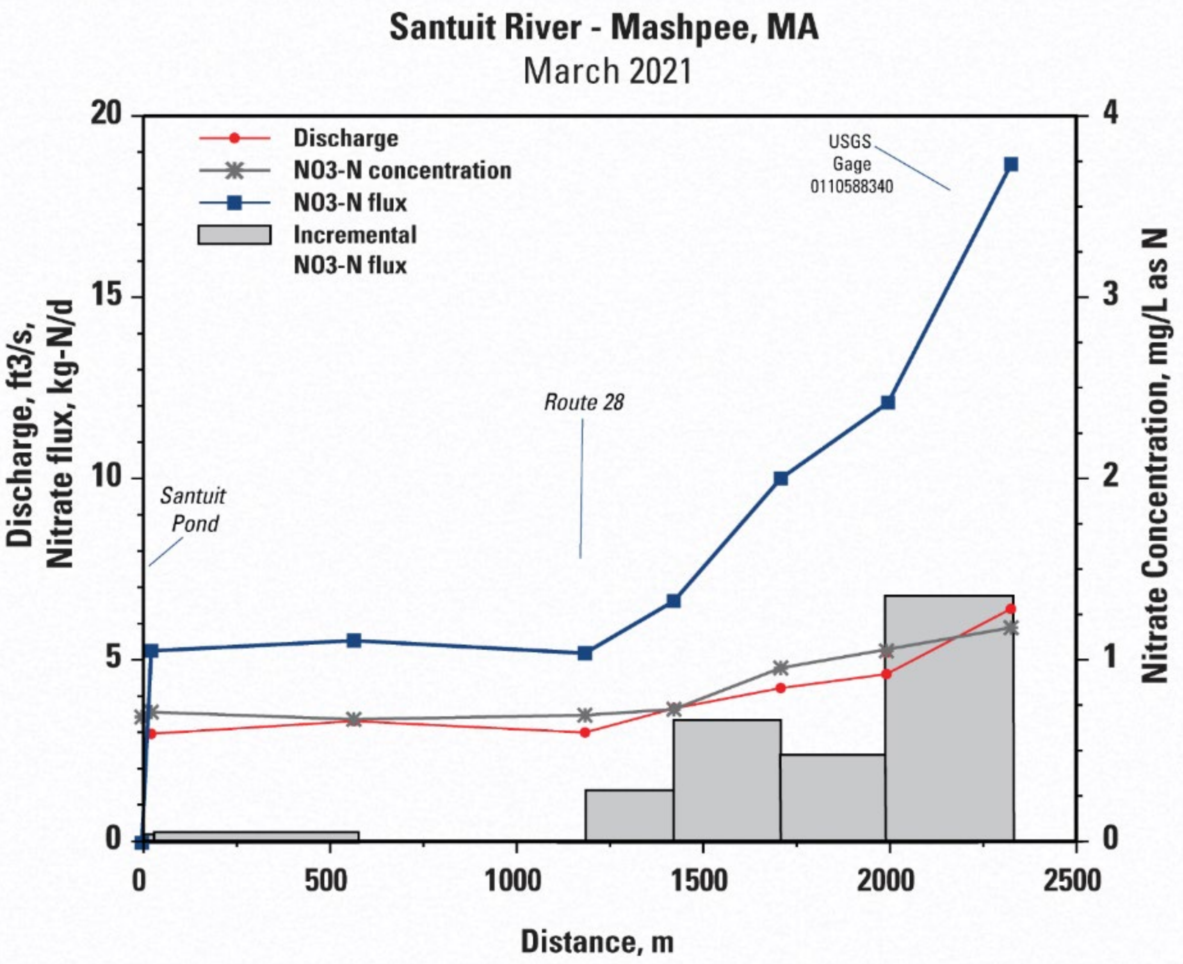
Field Results - River Profile of Santuit River



Summer

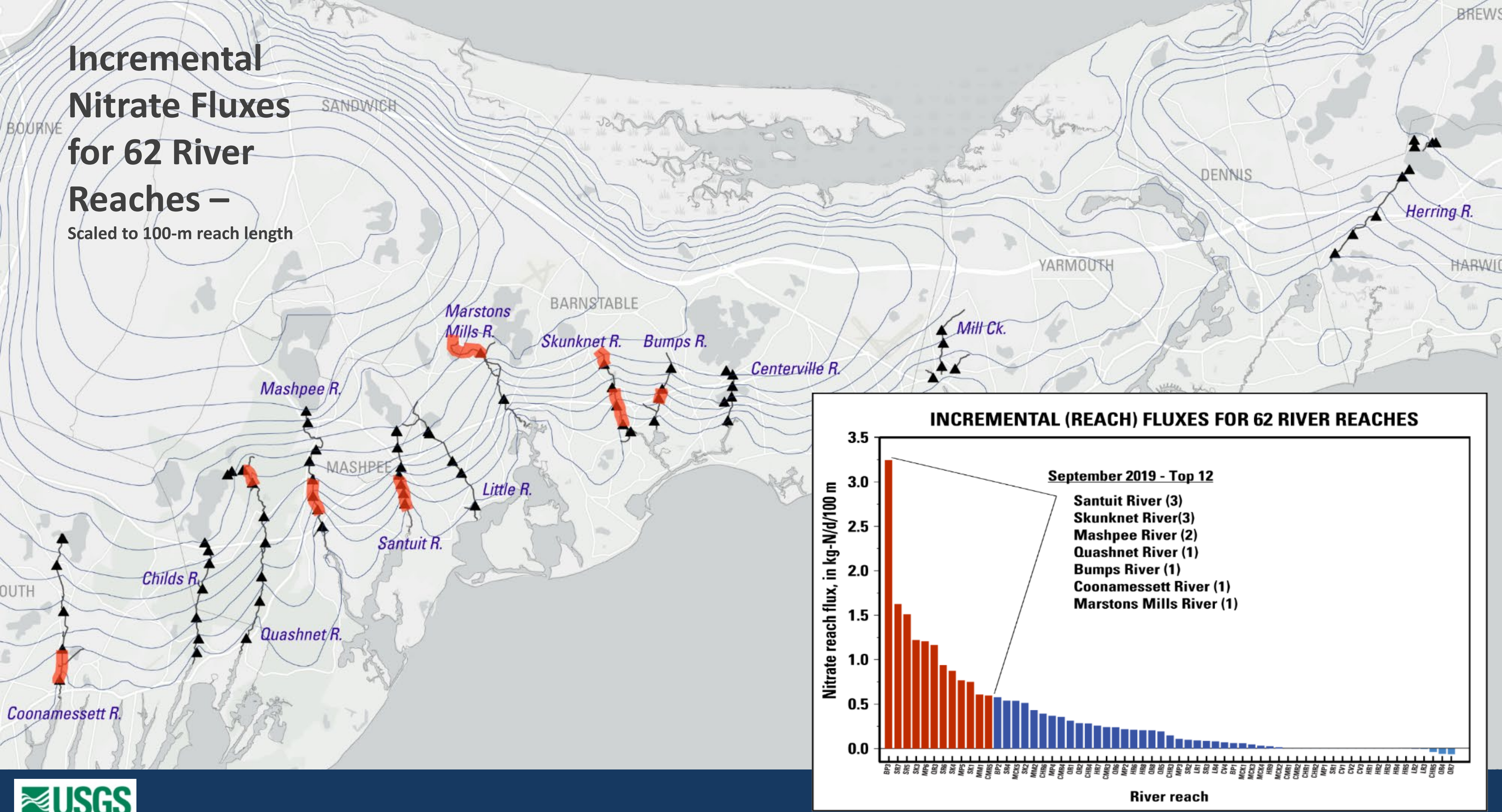


Winter

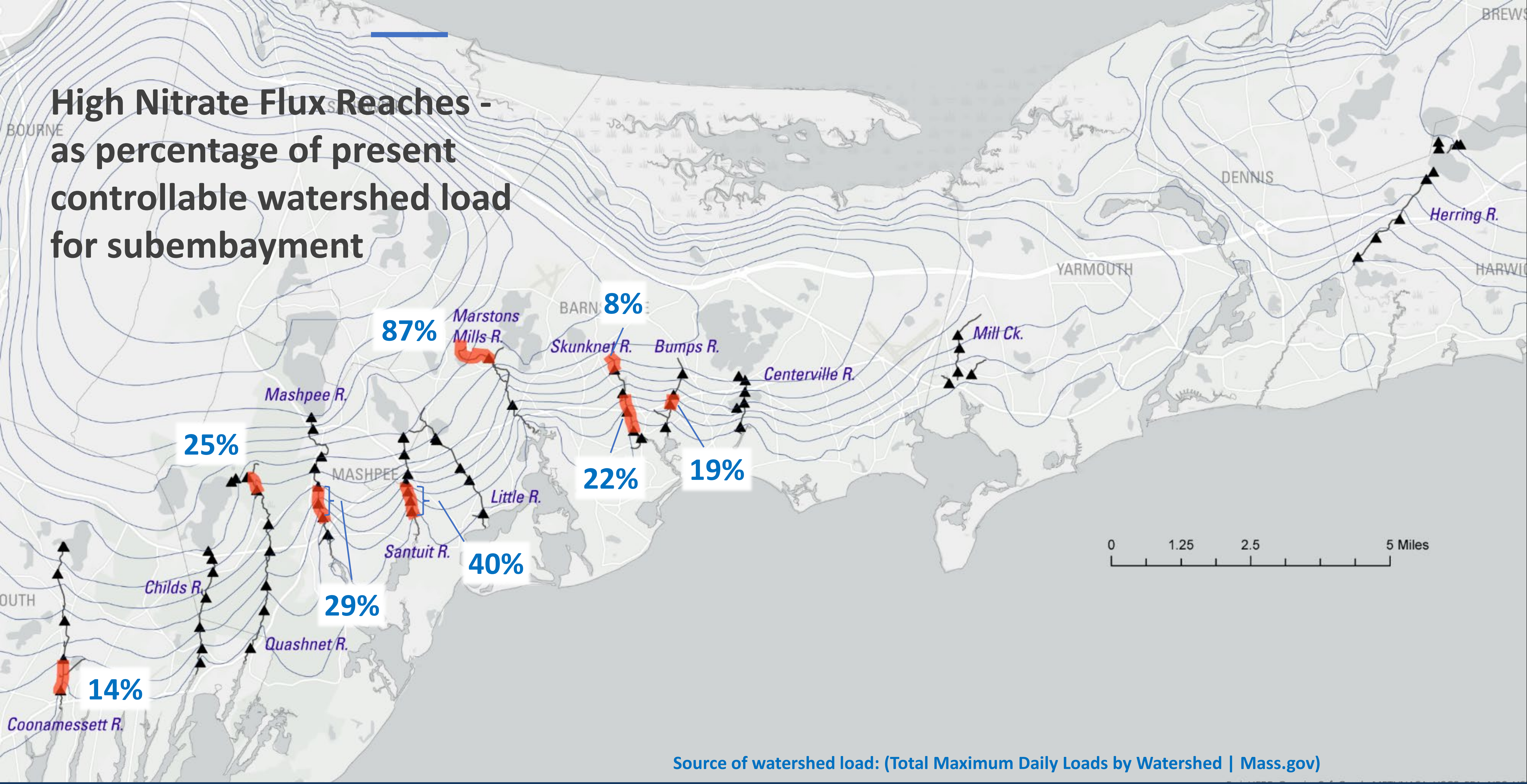


Incremental Nitrate Fluxes for 62 River Reaches –

Scaled to 100-m reach length



High Nitrate Flux Reaches - as percentage of present controllable watershed load for subembayment



Source of watershed load: (Total Maximum Daily Loads by Watershed | Mass.gov)

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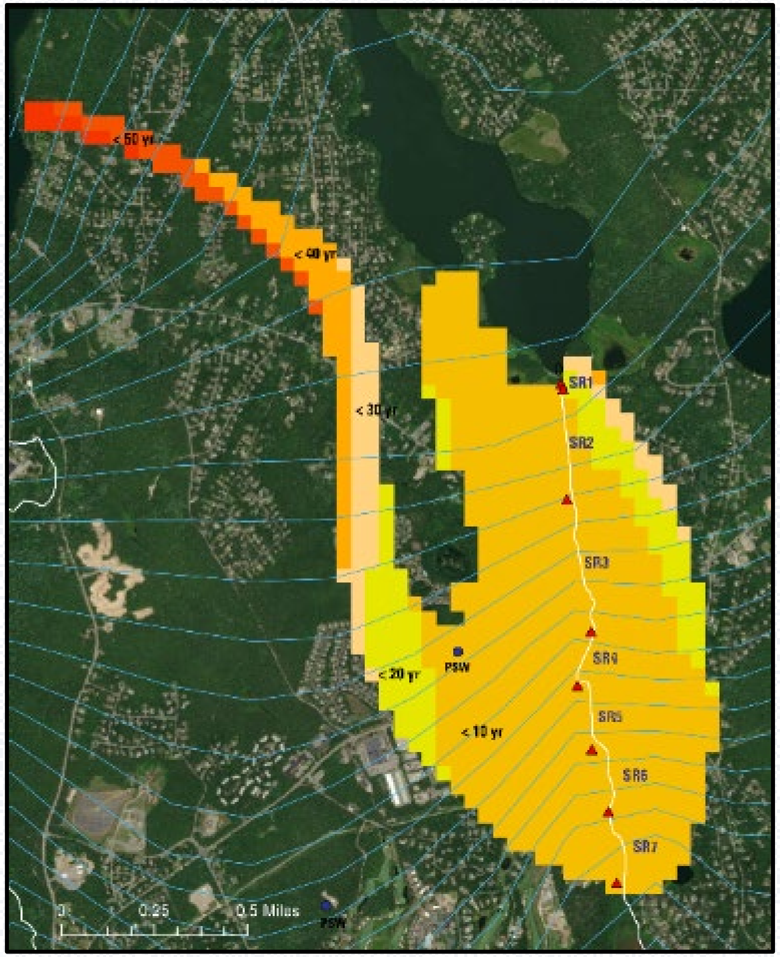
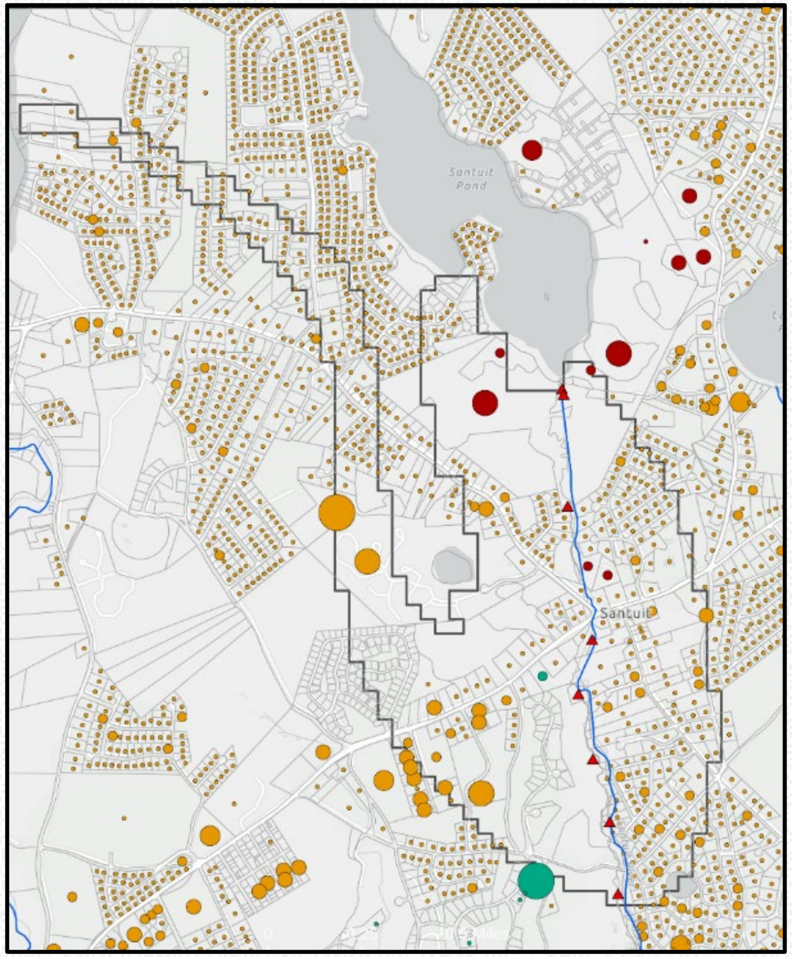


Steady-state regional groundwater flow model

- Groundwater contributing area to river
- Groundwater travel times

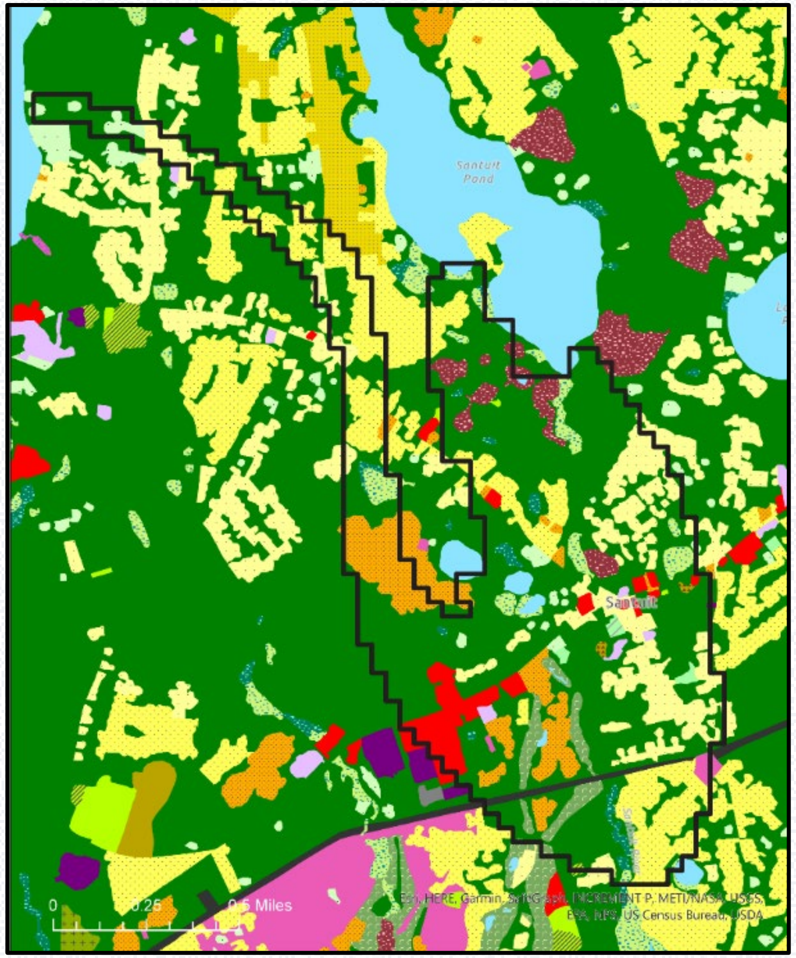
USGS: McCobb and Walter, 2019



Cape Cod Commission WatershedMVP database

- Parcel-scale water use
- Parcel-scale wastewater flows
- Parcel-scale nitrogen loads

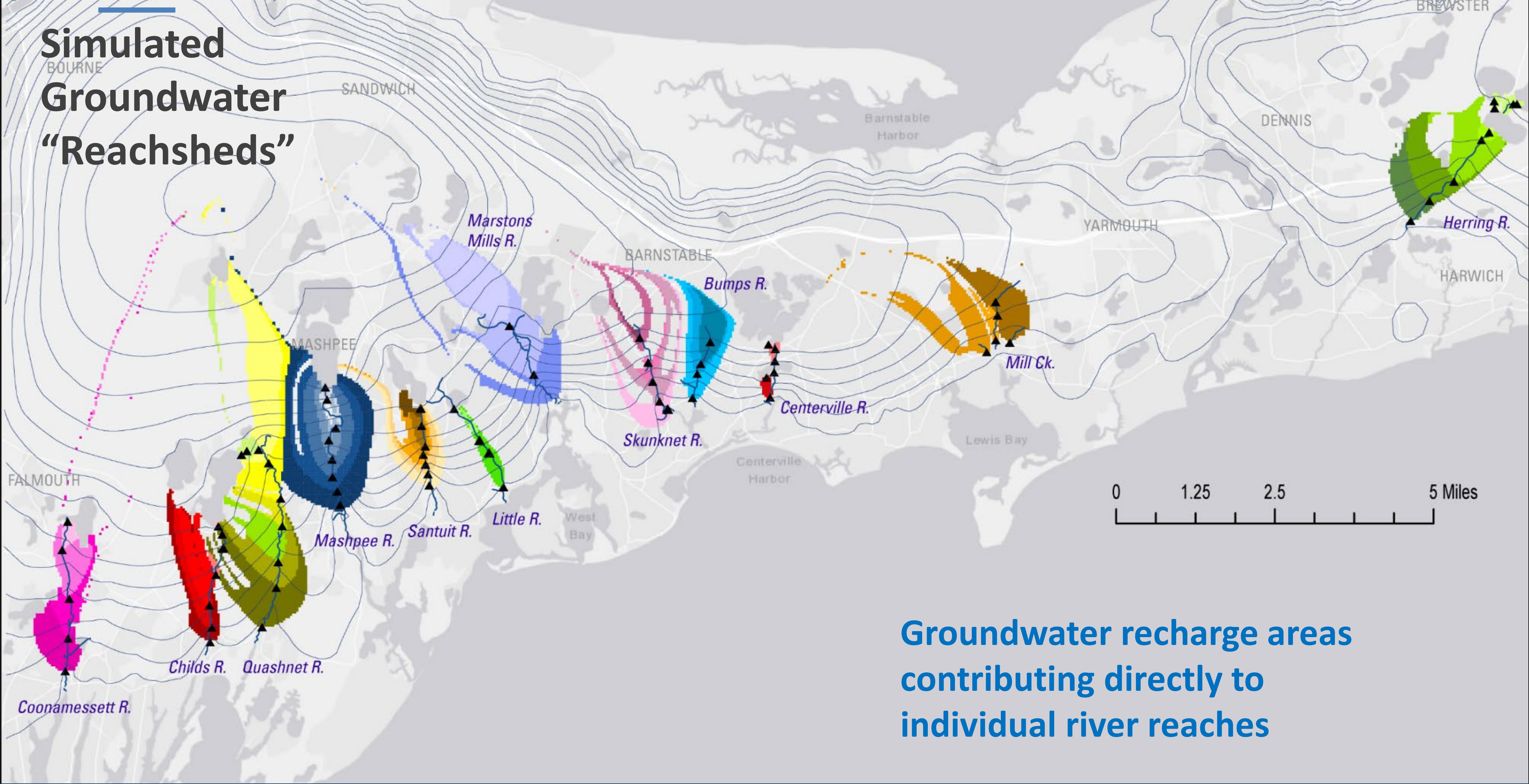
CCC: www.watershedmvp.org



MassGIS land use dataset

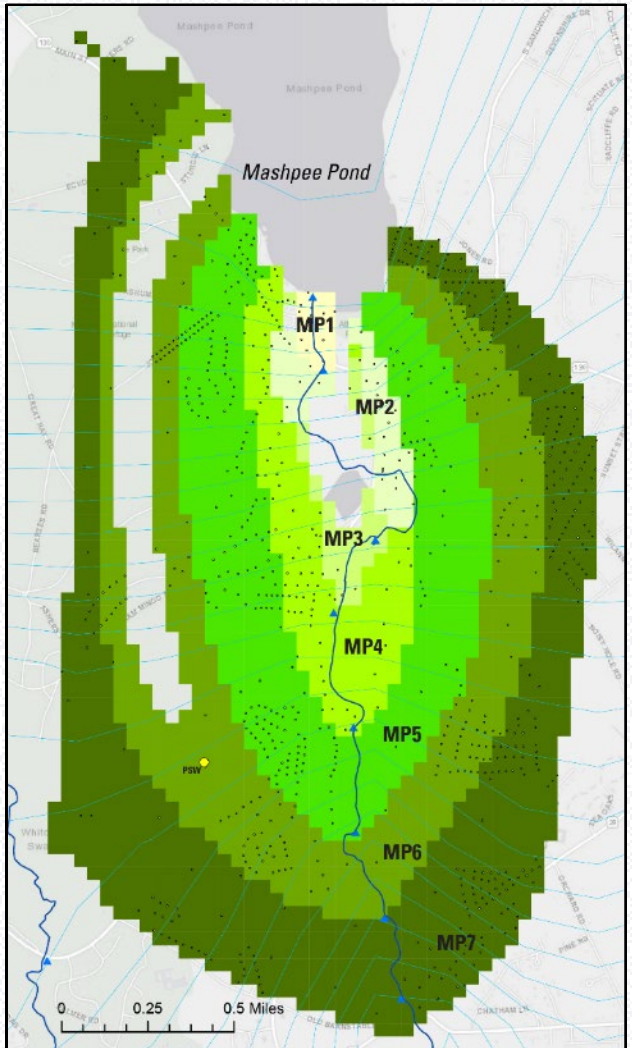
MassGIS:https://docs.digital.mass.gov/dataset/massgis-data-layers

Simulated Groundwater "Reachsheds"



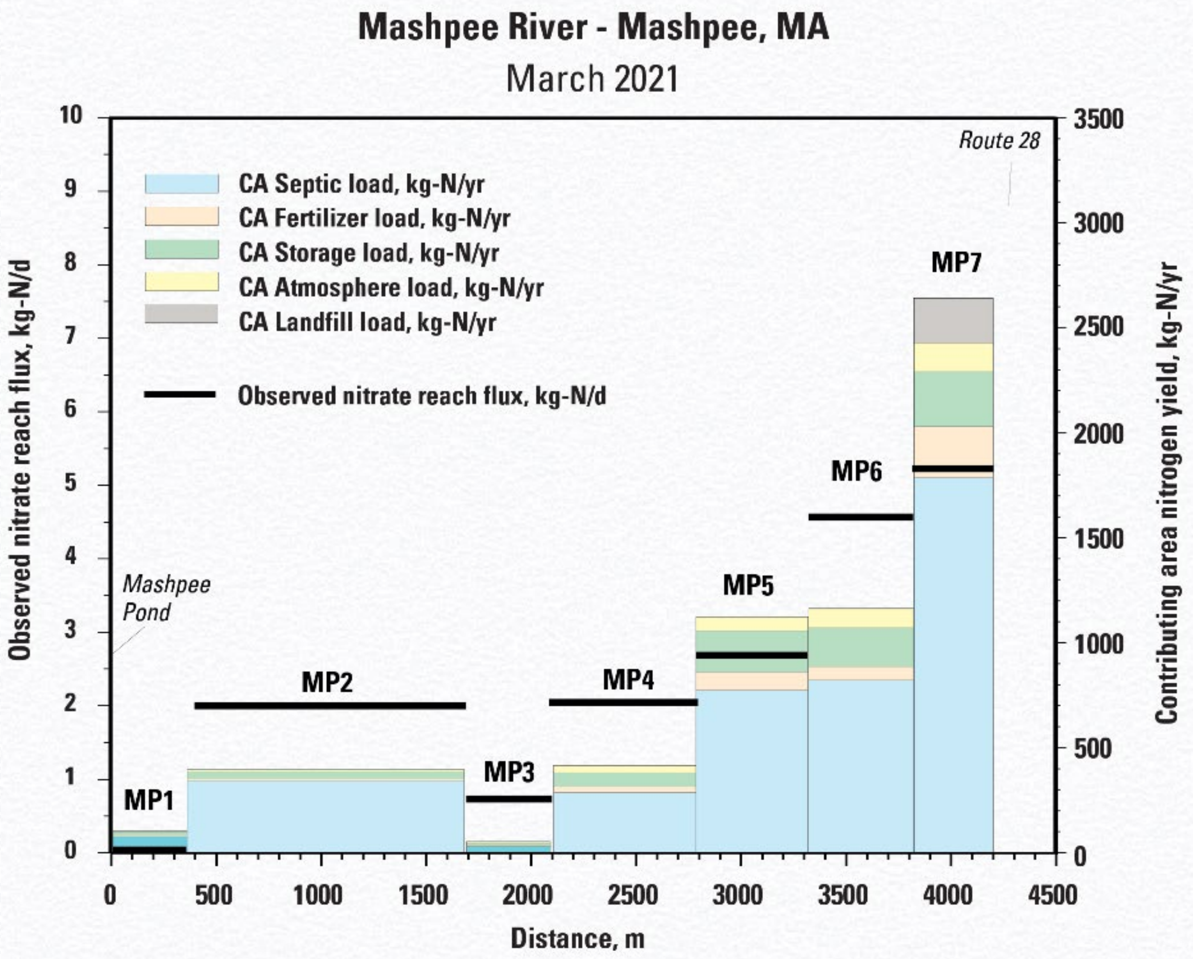
Groundwater recharge areas contributing directly to individual river reaches

Comparison of Contributing Area (CA) Load Factors to Reach Observations



Mashpee River reachsheds

- **Factors include:**
- Nitrogen yield
- Land use/development
- Wastewater flow
- Number of septic systems
- Recharge area



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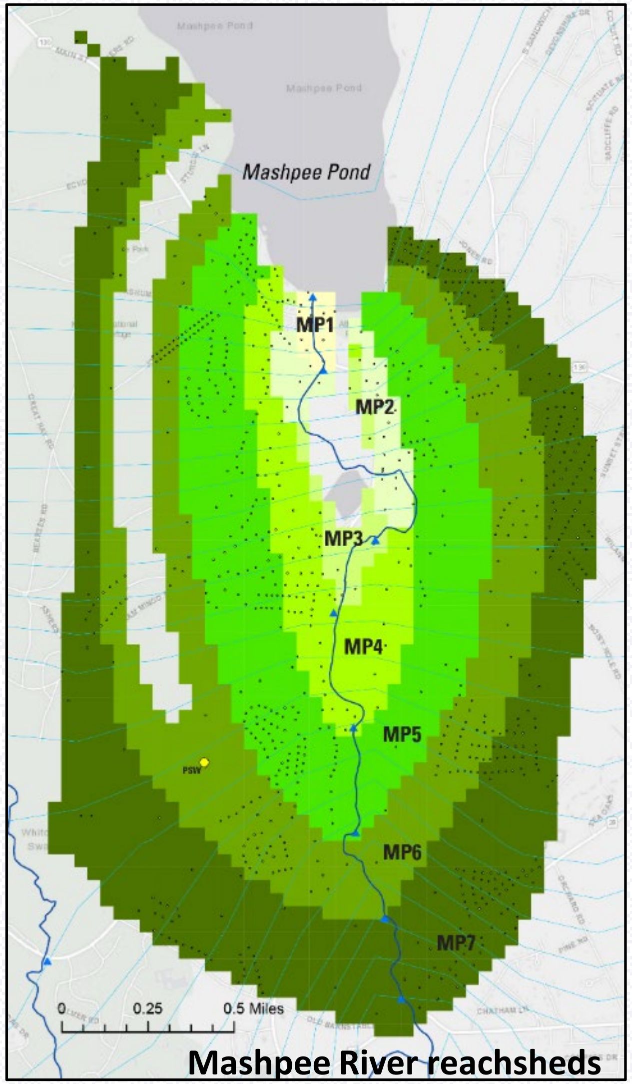

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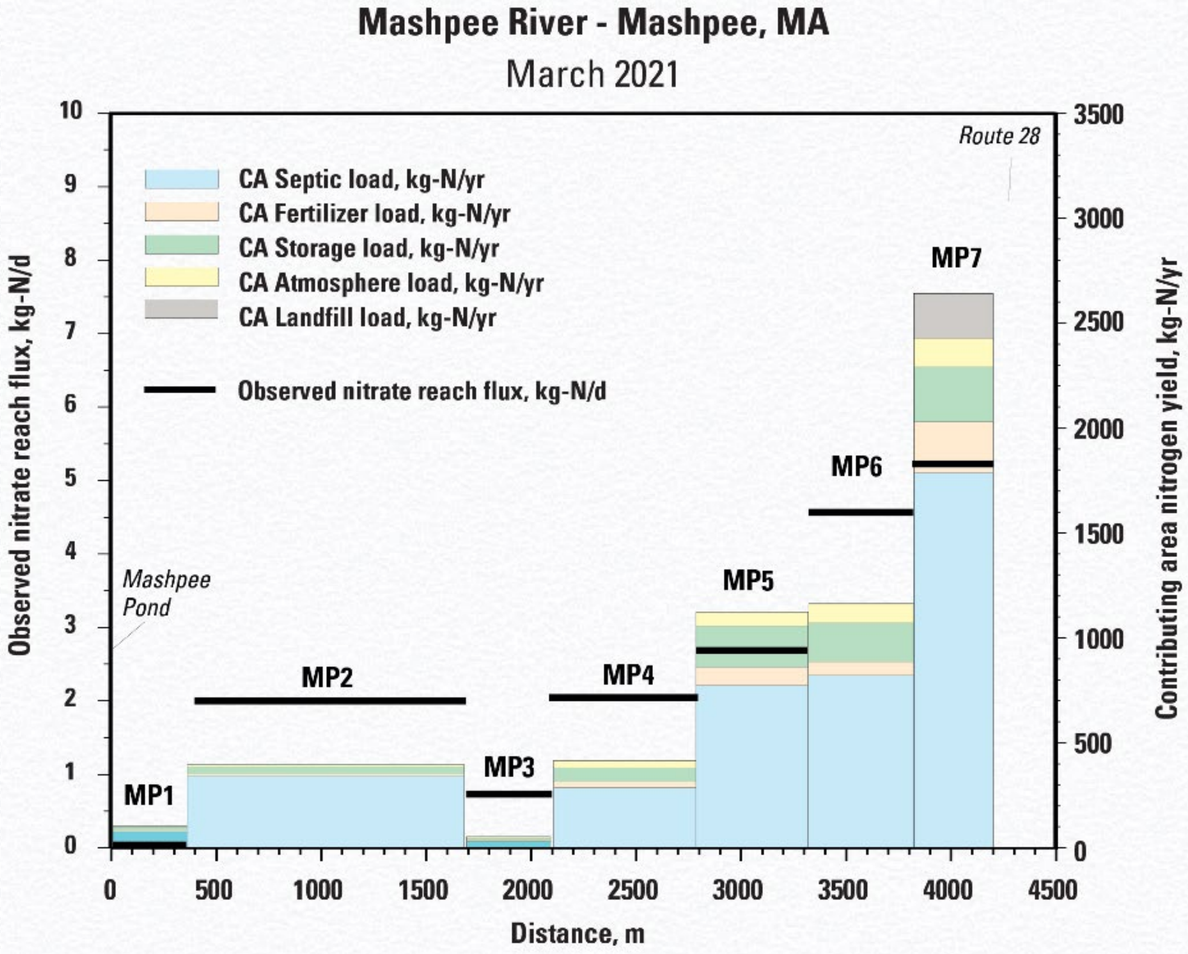
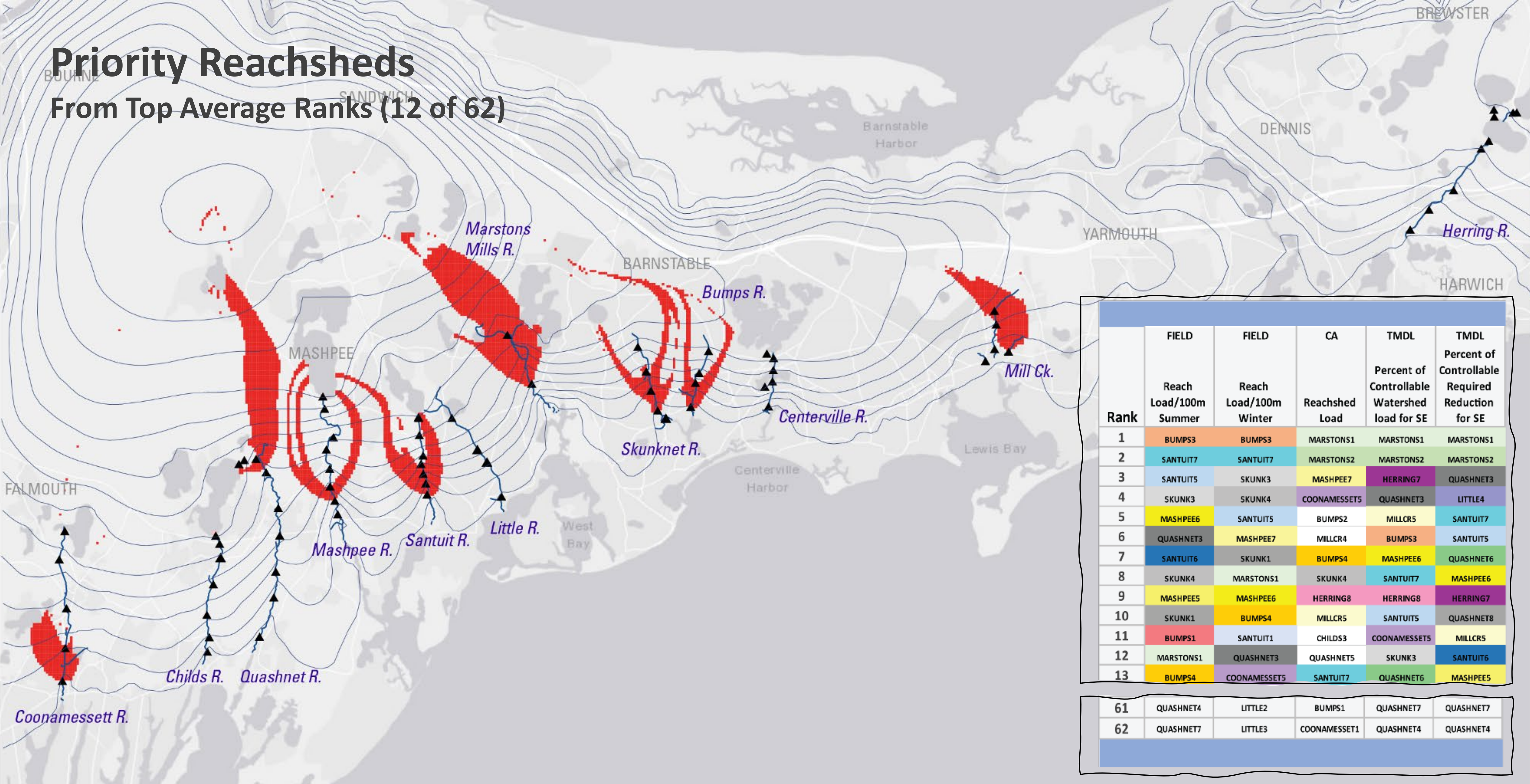


For all 62 reaches:
Moderate to strong positive correlation of
observed reach loads and most contributing area load factors

Priority Reachsheds

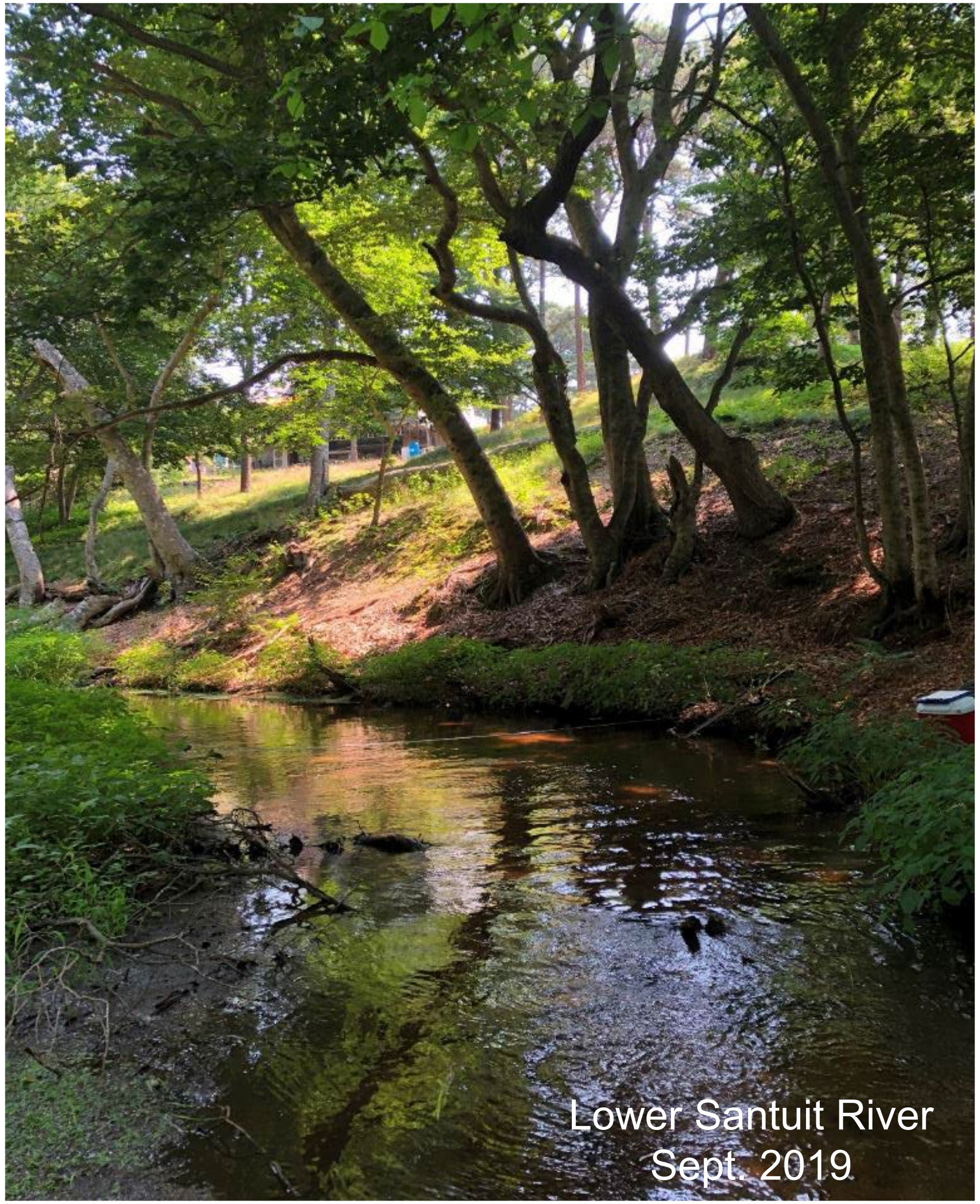
From Top Average Ranks (12 of 62)



Rank	FIELD Reach Load/100m Summer	FIELD Reach Load/100m Winter	CA Reachshed Load	TMDL Percent of Controllable Watershed load for SE	TMDL Percent of Controllable Required Reduction for SE
1	BUMPS3	BUMPS3	MARSTONS1	MARSTONS1	MARSTONS1
2	SANTUIT7	SANTUIT7	MARSTONS2	MARSTONS2	MARSTONS2
3	SANTUIT5	SKUNK3	MASHPEE7	HERRING7	QUASHNET3
4	SKUNK3	SKUNK4	COONAMESSET5	QUASHNET3	LITTLE4
5	MASHPEE6	SANTUIT5	BUMPS2	MILLCR5	SANTUIT7
6	QUASHNET3	MASHPEE7	MILLCR4	BUMPS3	SANTUIT5
7	SANTUIT6	SKUNK1	BUMPS4	MASHPEE6	QUASHNET6
8	SKUNK4	MARSTONS1	SKUNK4	SANTUIT7	MASHPEE6
9	MASHPEE5	MASHPEE6	HERRING8	HERRING8	HERRING7
10	SKUNK1	BUMPS4	MILLCR5	SANTUIT5	QUASHNET8
11	BUMPS1	SANTUIT1	CHILDS3	COONAMESSET5	MILLCR5
12	MARSTONS1	QUASHNET3	QUASHNET5	SKUNK3	SANTUIT6
13	BUMPS4	COONAMESSET5	SANTUIT7	QUASHNET6	MASHPEE5
61	QUASHNET4	LITTLE2	BUMPS1	QUASHNET7	QUASHNET7
62	QUASHNET7	LITTLE3	COONAMESSET1	QUASHNET4	QUASHNET4

Approach Considerations

- Temporal snapshot - expect variability in flow and concentrations
  - Errors in differential flow measurements increase with decreasing reach length
- Steady state regional flow model
  - CAs are simulated for average conditions
  - Errors associated with regional grid size
- Not a nitrogen transport model – based on direct measurement of groundwater load to rivers
- GW traveltime and nitrogen source history



Summary

- Seepage run effective method for measuring loads to identify groundwater inputs to streams
- Clear linkage between river observations and groundwater contributing area inputs (reachsheds)
- Prioritizing groundwater reachsheds is possible to maximize nitrogen reduction efforts
- Technique may be useful for siting alternative reduction approaches such as PRBs, I/A septic systems

Contact:
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T4

T3

T2

T1

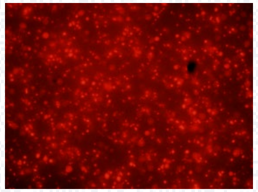
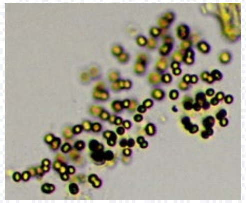
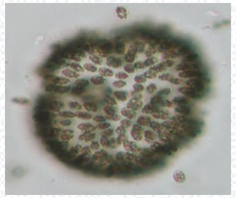
Welcome to the World of Cyanobacteria

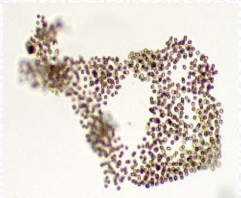
Population Ecology & Ecophysiology

Assessment model and ecological indicators

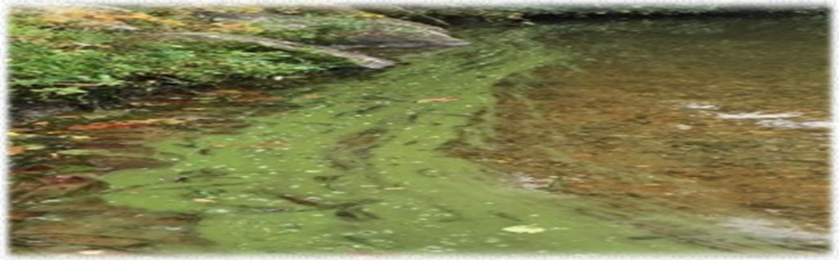
The Martha's Vineyard Experience

Common cyanobacteria in SNEP region

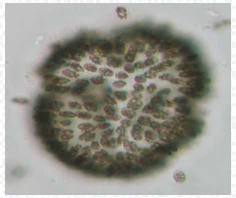
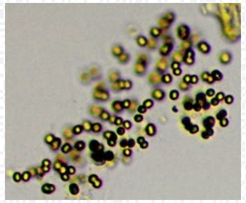
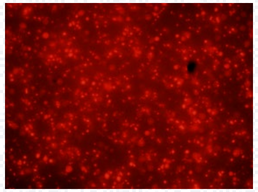




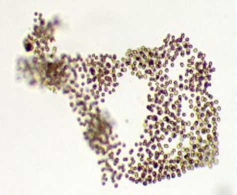




Ecology


Common cyanotoxins

Ecotoxicology

e

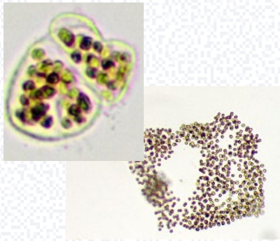
Additional research needed:

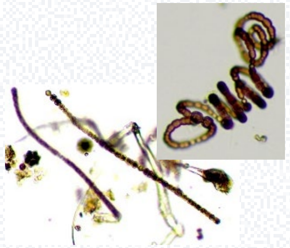
) Human health and ecological risks associated with picocyanobacteria

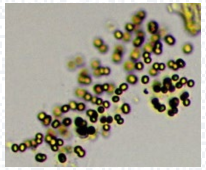
2) Triggers of toxin production

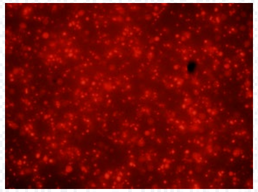
3) Purpose of toxin production (chemical defense, micronutrient scavenger, nutrient source)

Cyanobacteria Assessment Model:









Genus

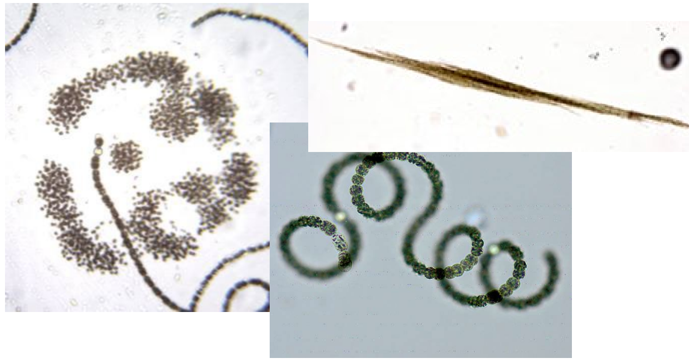
Size

Ecology

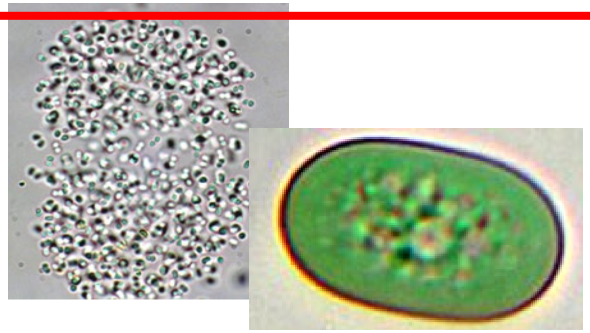
I.D.
Method

Ecological niches suggest
use as indicator organisms

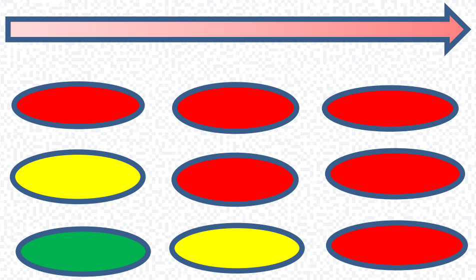
The bloom forming cyanobacteria (BFC) = slow-growing, specialized niches

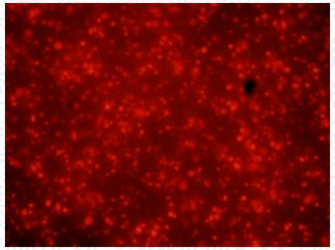


The picocyanobacteria (Picos) = fast-growing, highly adaptive, niche diversification

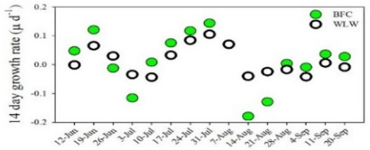


Methods



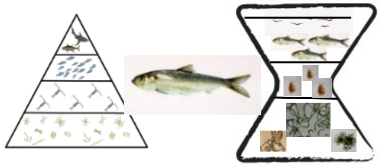


Biomass growth rates



Toxin levels

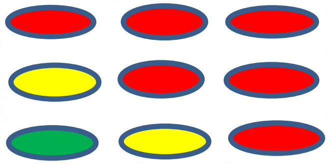
Trophic influences

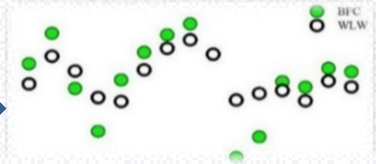


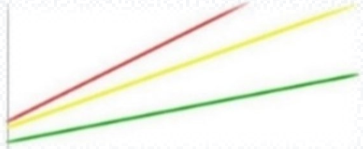
Food webs

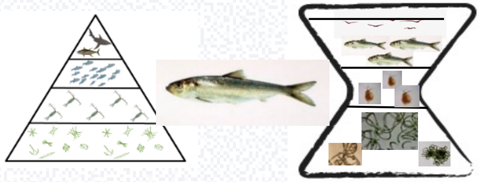
Aerosolization

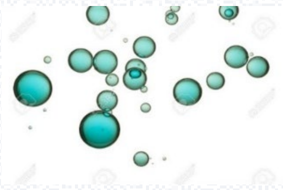
Community Composition = Pigment Fingerprinting











<u>Freshwater applications on Cape Cod:</u>

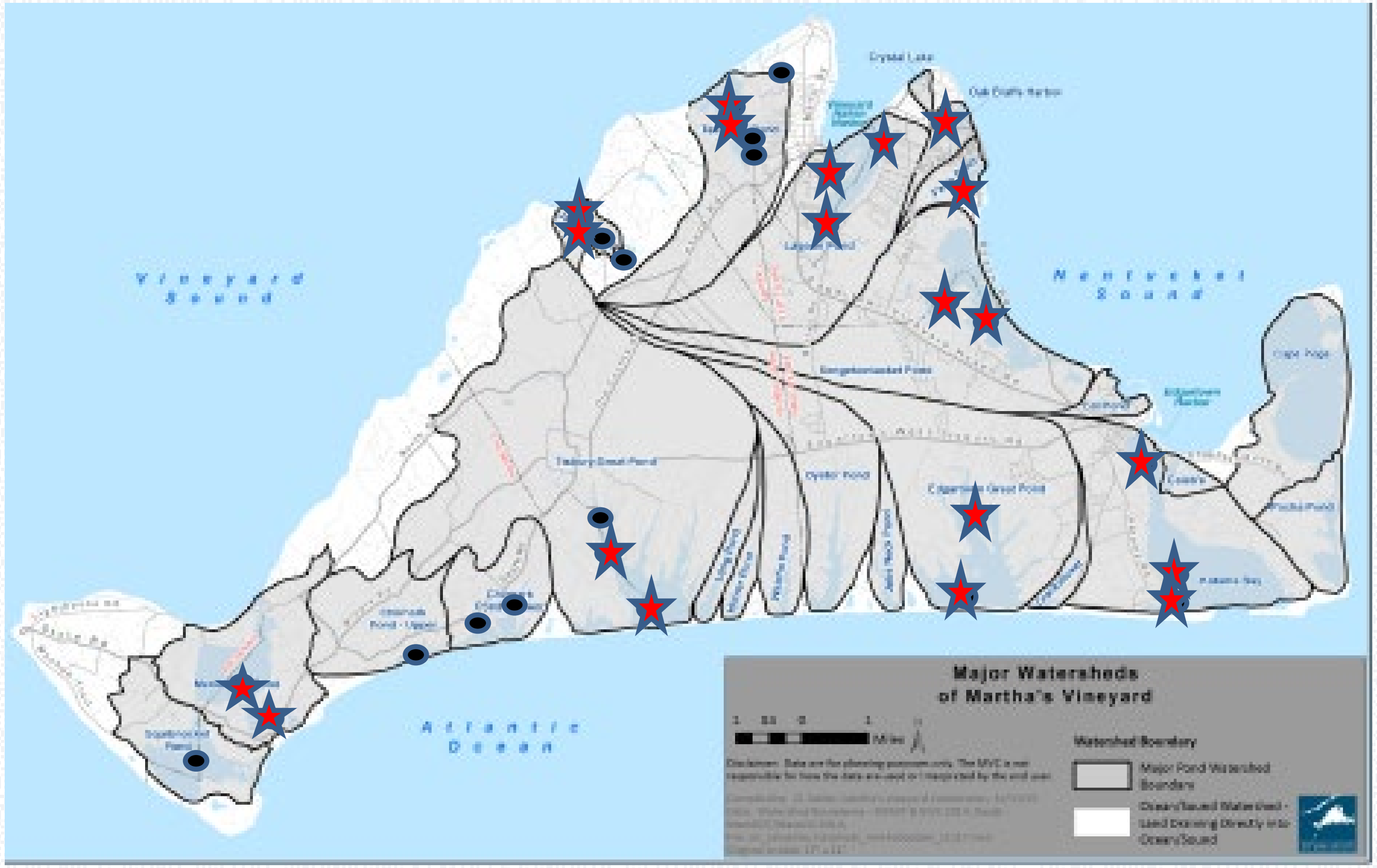
Easy to use
Low cost
Reliable
Repeatable
Transferable

<u>Brackish systems:</u>

Pigment fingerprinting could replace more expensive techniques for picocyanobacteria (epifluorescence, flow cytometry, qPCR)

The Martha's Vineyard Experience

Microcystis



Cyanobacterial Assessment Model

30+ sampling sites in 2021

Light microscopy and fluorometry:

Community composition response to salinity

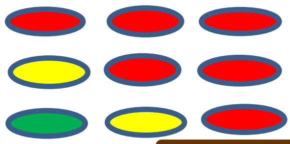
<1 ppt: BFC's present in all systems

1-15 ppt: Halotolerant BFC's at some sites

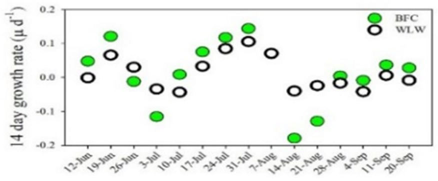
<15 ppt: Picos dominate cyanobacterial biomass

Ecological indicators

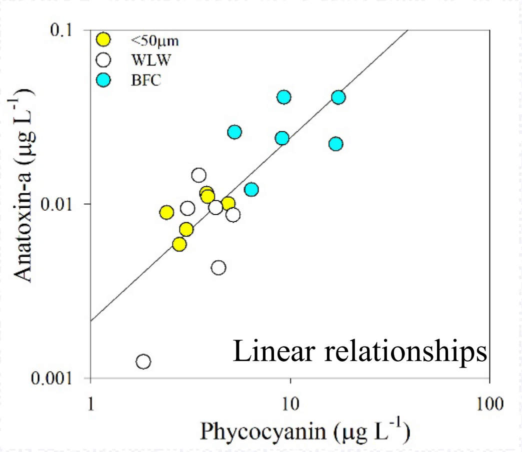
Diversity indices

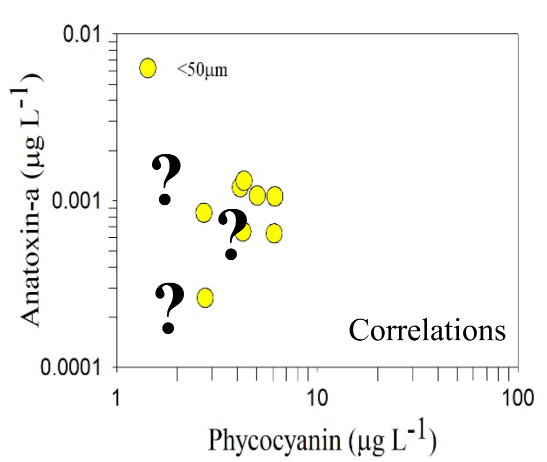


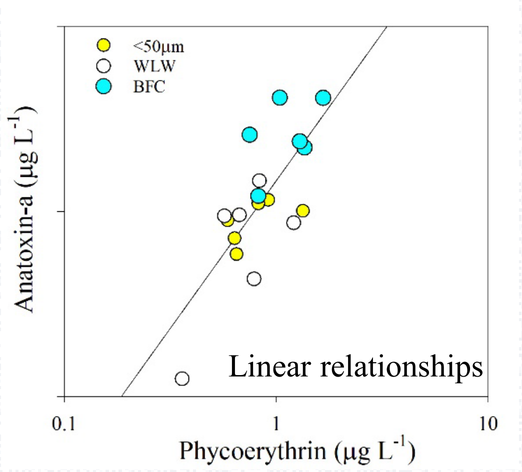
Biomass growth rates

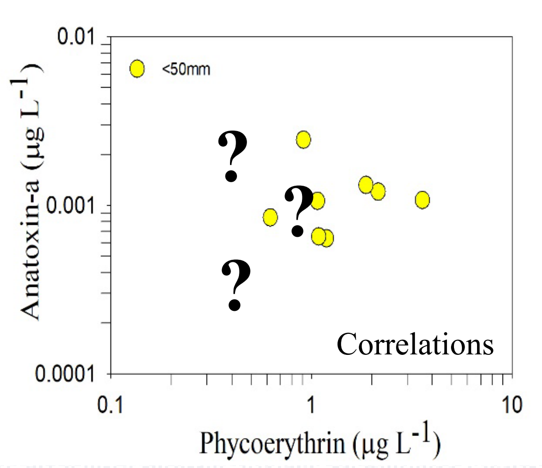


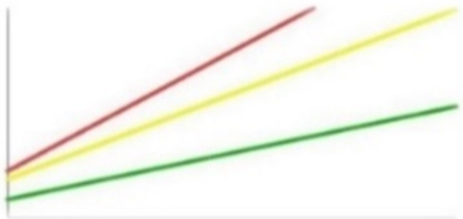
Toxin levels











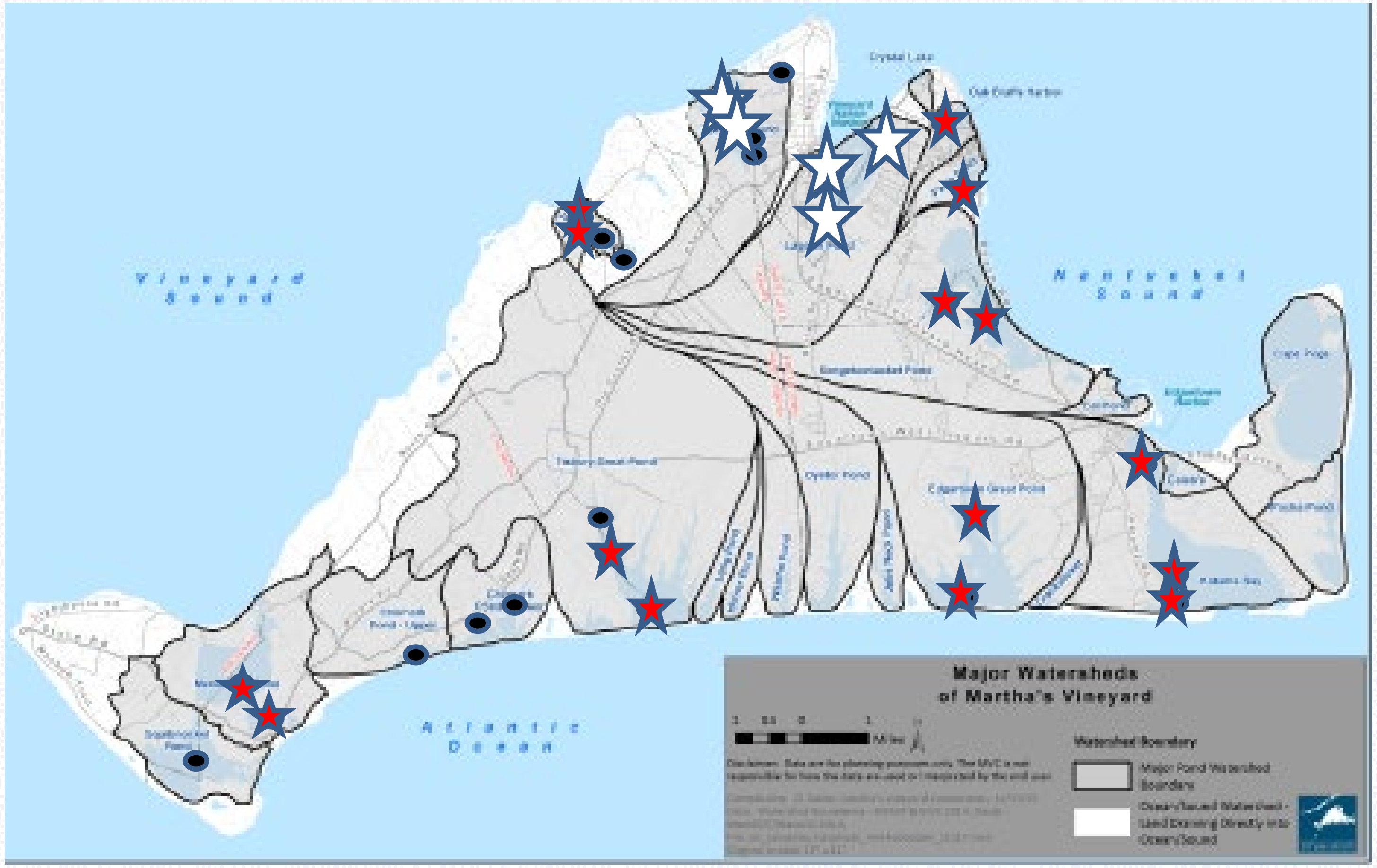
Picocyanobacteria as ecological indicator of toxin concentration…

- In freshwater systems our interpretation may be enhanced by including picos
- In brackish systems, our interpretation requires the inclusion of picos

…while opening the door to other assessments

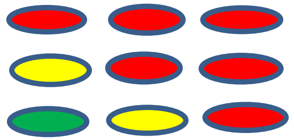
What ahead for the future?

Microcystis



Cyanobacteria as a response variable for stormwater control measures

Diversity indices



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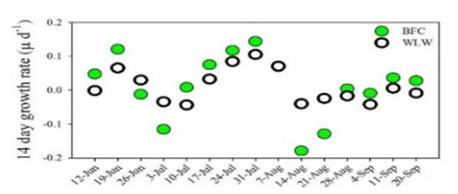
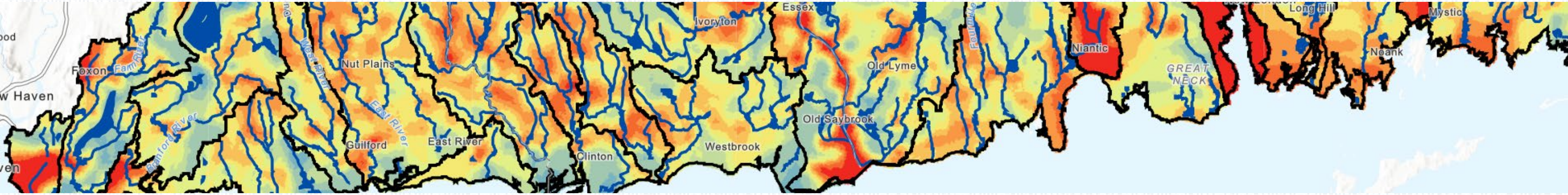


Toxin levels

Aerosolization

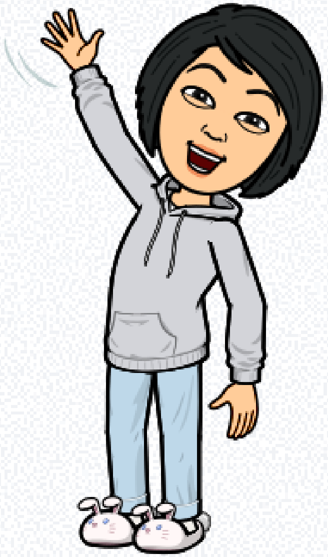
Thank-you!



N-Sink

a Tool to Inform Land Use Decisions in Coastal Watersheds

Cary Chadwick
Qian (Rachel) Lei-Parent
Chet Arnold



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Extension
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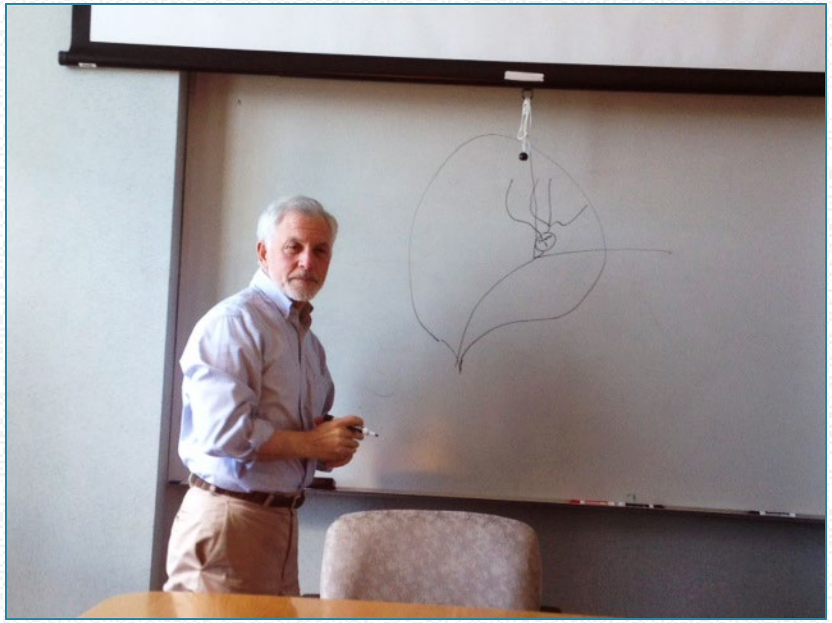
Project Partners

- University of Rhode Island Dept. of Natural Resources Science
  - *Art Gold, Q Kellogg*
- UConn Center for Land Use Education & Research
  - *Chet Arnold, Cary Chadwick, Rachel Lei, Emily Wilson, Dave Dickson*
- EPA Office of Research & Development (Ada, OK and Narragansett, RI)
  - *Ken Forshay, Jeff Hollister*
- EPA Region 1
  - *Mark Voorhees, Ian Dombroski*



Art Gold diagrams the game-winning play (Hollister to the post) at a recent N-Sink team meeting…

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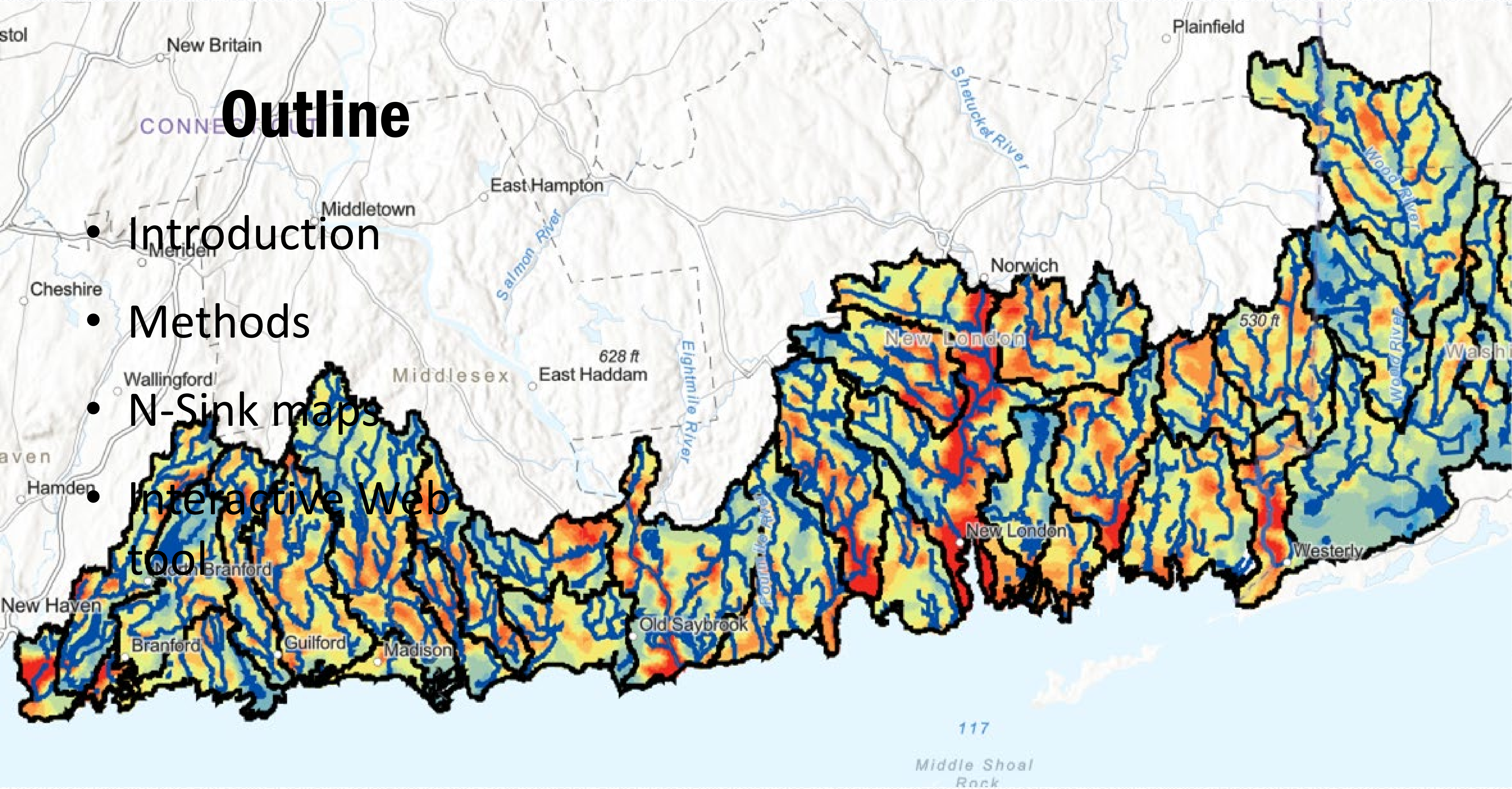
EPA

Outline

- Introduction
- Methods
- N-Sink maps
- Interactive Web tool



Background

- **Nitrogen(N) pollution is a major threat to coastal watersheds and the communities within their watersheds.**
- **It is crucial for decision makers to understand the relationships between land use and the fate and transport of N.**

N-Sink Goals

- **Create a planning and visualization tool for users to explore the relationship of land use to N pollution of their coastal waters**
  - ✓ broad applicability
  - ✓ easy to use/understand
  - ✓ accessible online

- **Anchor the tool in a land use context by identifying specific areas in watersheds important to N pollution management.**
  - ✓ sink areas (wetlands, riparian areas, ponds & lakes)
  - ✓ areas with high likelihood of efficient N transport

Caveats, explanations, disclaimers

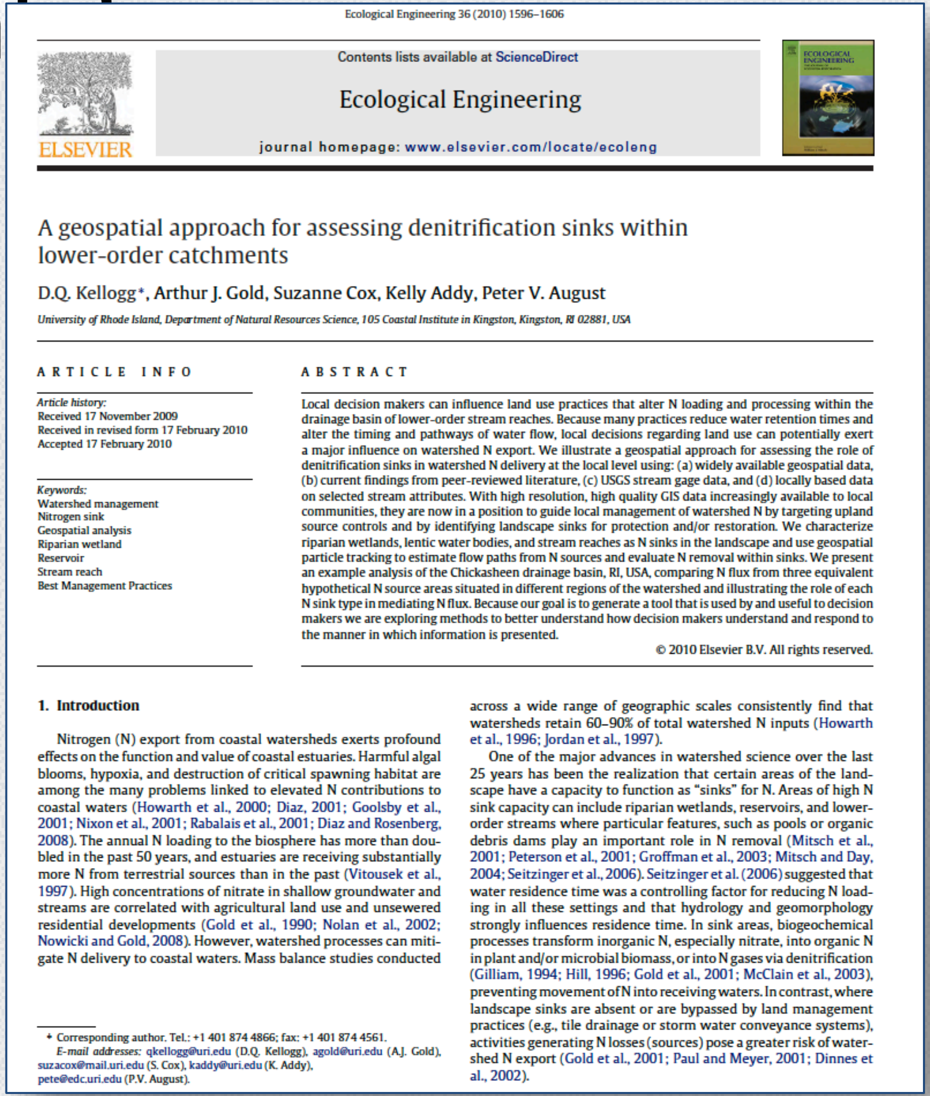
N-Sink:

- **is a <u>decision support tool</u>, not a rigorous model**
- **uses <u>widely available national datasets</u> rather than field data**
- **focuses on <u>sinks and their importance</u> rather than calculations of sources/loadings**

Shifts attention to the watershed, rather than the receiving waters

So, what is N-Sink?

- N-Sink is an R-package and a web tool
  - uses **particle tracking** to estimate N pathway from source to receiving water
  - estimates N removal based on characteristics of **landscape sinks** along that pathway, **based on best available science**
  - **examines** watersheds at the **HUC-12** level
  - uses **national geospatial data**



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A geospatial approach for assessing denitrification sinks within lower-order catchments

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ABSTRACT

Local decision makers can influence land use practices that alter N loading and processing within the drainage basin of lower-order stream reaches. Because many practices reduce water retention times and alter the timing and pathways of water flow, local decisions regarding land use can potentially exert a major influence on watershed N export. We illustrate a geospatial approach for assessing the role of denitrification sinks in watershed N delivery at the local level using: (a) widely available geospatial data, (b) current findings from peer-reviewed literature, (c) USGS stream gage data, and (d) locally based data on selected stream attributes. With high resolution, high quality GIS data increasingly available to local communities, they are now in a position to guide local management of watershed N by targeting upland source controls and by identifying landscape sinks for protection and/or restoration. We characterize riparian wetlands, lentic water bodies, and stream reaches as N sinks in the landscape and use geospatial particle tracking to estimate flow paths from N sources and evaluate N removal within sinks. We present an example analysis of the Chickasheen drainage basin, RI, USA, comparing N flux from three equivalent hypothetical N source areas situated in different regions of the watershed and illustrating the role of each N sink type in mediating N flux. Because our goal is to generate a tool that is used by and useful to decision makers we are exploring methods to better understand how decision makers understand and respond to the manner in which information is presented.

1. Introduction

Nitrogen (N) export from coastal watersheds exerts profound effects on the function and value of coastal estuaries. Harmful algal blooms, hypoxia, and destruction of critical spawning habitat are among the many problems linked to elevated N contributions to coastal waters (Howarth et al., 2000; Diaz, 2001; Goolsby et al., 2001; Nixon et al., 2001; Rabalais et al., 2001; Diaz and Rosenberg, 2008). The annual N loading to the biosphere has more than doubled in the past 50 years, and estuaries are receiving substantially more N from terrestrial sources than in the past (Vitousek et al., 1997). High concentrations of nitrate in shallow groundwater and streams are correlated with agricultural land use and unsewered residential developments (Gold et al., 1990; Nolan et al., 2002; Nowicki and Gold, 2008). However, watershed processes can mitigate N delivery to coastal waters. Mass balance studies conducted across a wide range of geographic scales consistently find that watersheds retain 60–90% of total watershed N inputs (Howarth et al., 1996; Jordan et al., 1997).

One of the major advances in watershed science over the last 25 years has been the realization that certain areas of the landscape have a capacity to function as "sinks" for N. Areas of high N sink capacity can include riparian wetlands, reservoirs, and lower-order streams where particular features, such as pools or organic debris dams play an important role in N removal (Mitsch et al., 2001; Peterson et al., 2001; Groffman et al., 2003; Mitsch and Day, 2004; Seitzinger et al., 2006). Seitzinger et al. (2006) suggested that water residence time was a controlling factor for reducing N loading in all these settings and that hydrology and geomorphology strongly influences residence time. In sink areas, biogeochemical processes transform inorganic N, especially nitrate, into organic N in plant and/or microbial biomass, or into N gases via denitrification (Gilliam, 1994; Hill, 1996; Gold et al., 2001; McClain et al., 2003), preventing movement of N into receiving waters. In contrast, where landscape sinks are absent or are bypassed by land management practices (e.g., tile drainage or storm water conveyance systems), activities generating N losses (sources) pose a greater risk of watershed N export (Gold et al., 2001; Paul and Meyer, 2001; Dinnes et al., 2002).

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https://clear.uconn.edu/projects/nsink/about.htm

Geospatial Data Sources

Uses widely available (national) spatial datasets

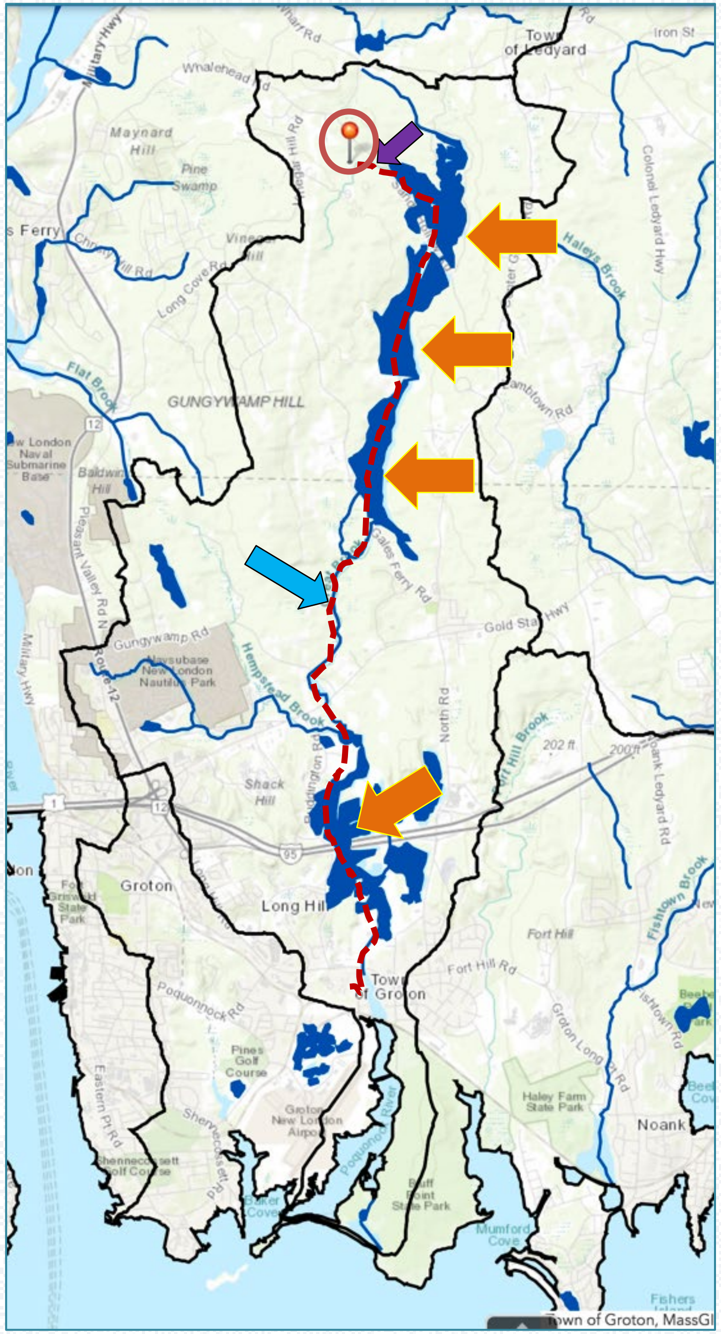
1. **Hydrography (NHD-Plus V2)**
   a. NHD, NED, WBD
   b. Catchment characteristics, cumulative drainage area characteristics, flow direction, flow accumulation, elevation grids
   c. Flow rate & velocity for each reach in the stream network
2. **Soils** from Soil Survey Geographic (SSURGO) Database
3. **Land cover** from 2016 National Land Cover Data (NLCD 2016)

A focus on retention time

- **Wetlands (hydric soils)**
  - Based on % hydric in soil mapping units (SSURGO)
  - Use NLCD to exclude impervious cover

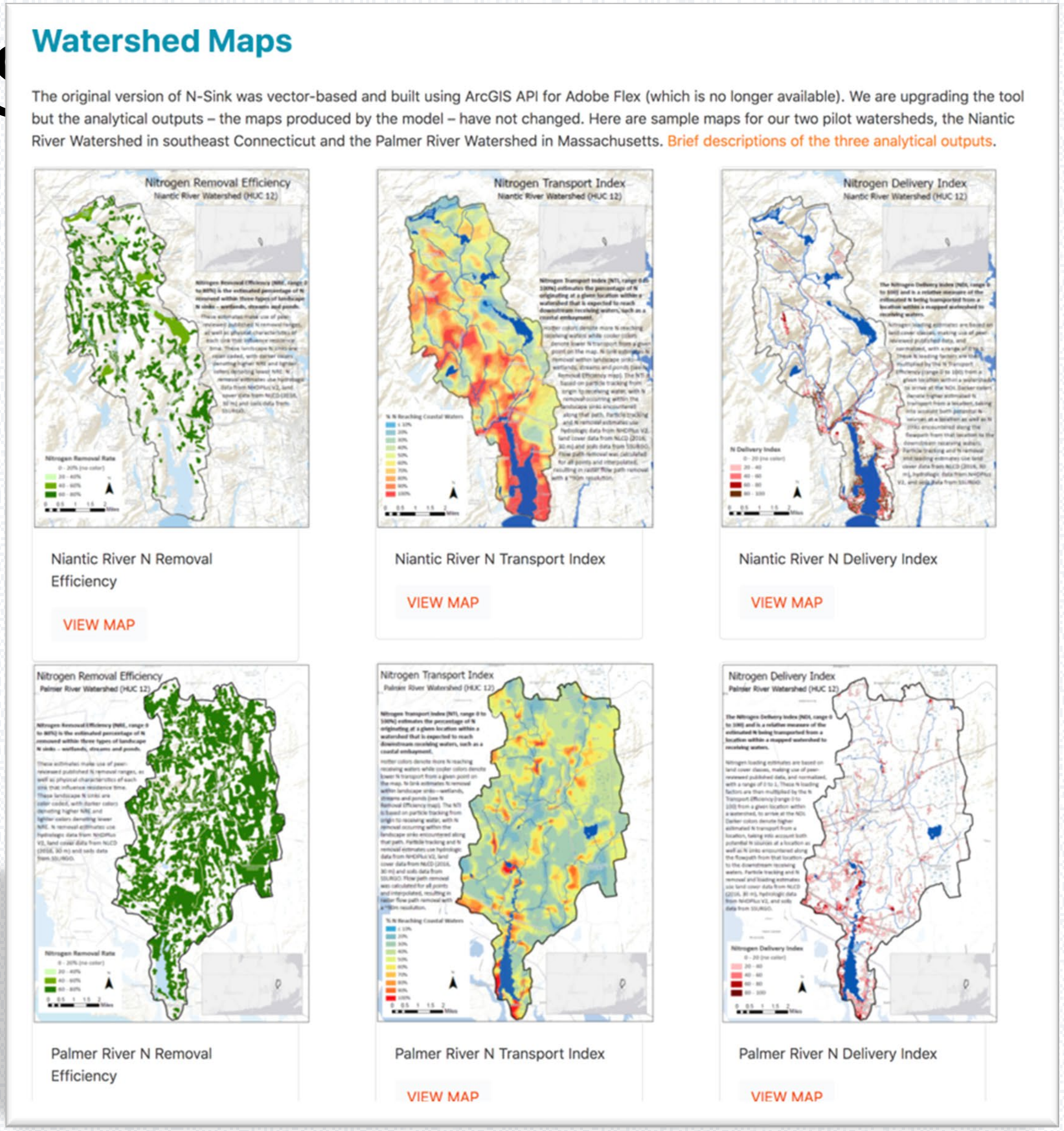
- **Ponds/lakes/reservoirs**
  - Based on Pond area/Catchment area (NHD Plus V2)

- **Stream reaches**
  - Based on velocity in stream reach (NHD Plus V2)



The N-S

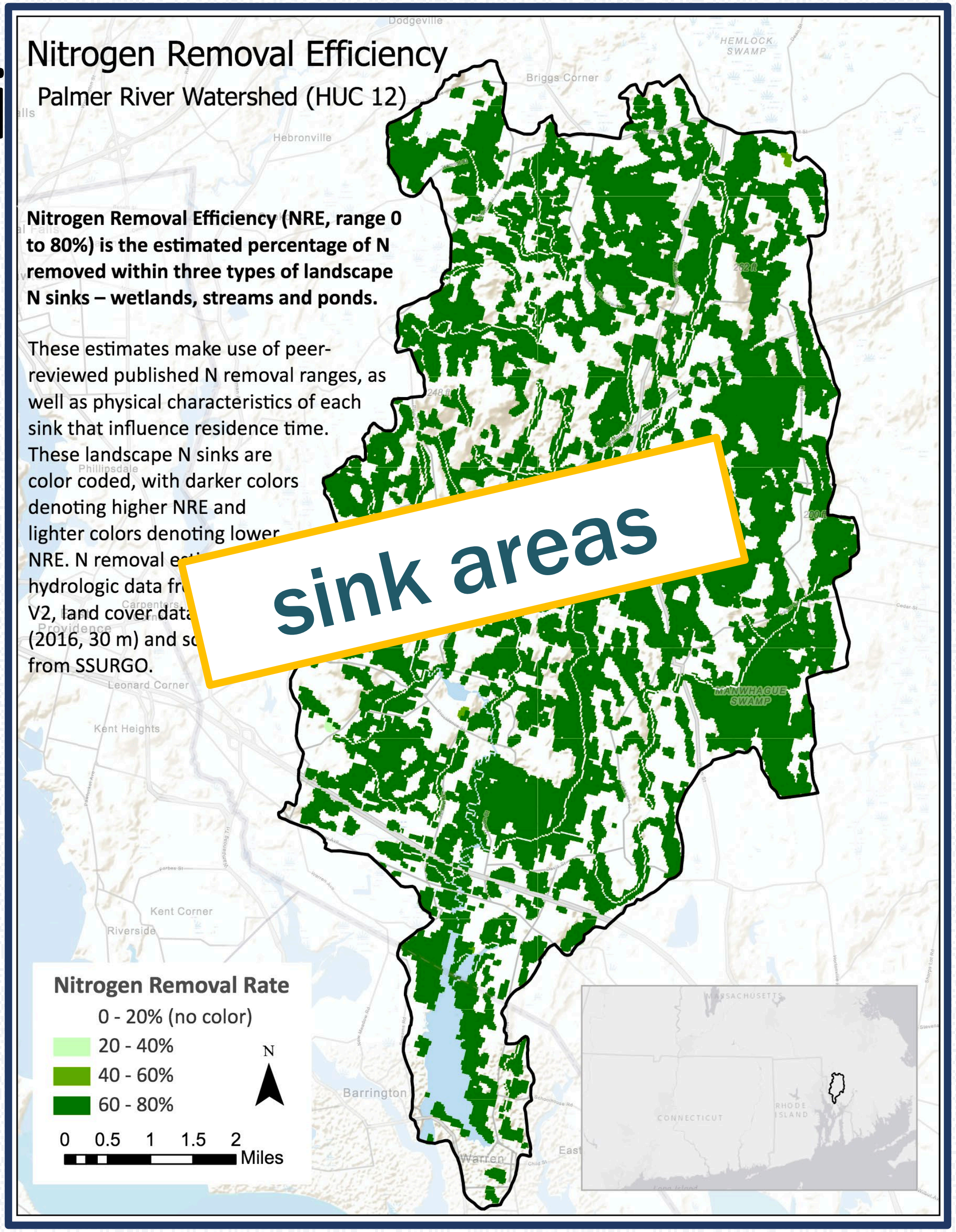
1. **Removal Efficiency**
2. **Transport Index**
3. **Delivery Index**



https://clear.uconn.edu/projects/nsink/watershed.htm

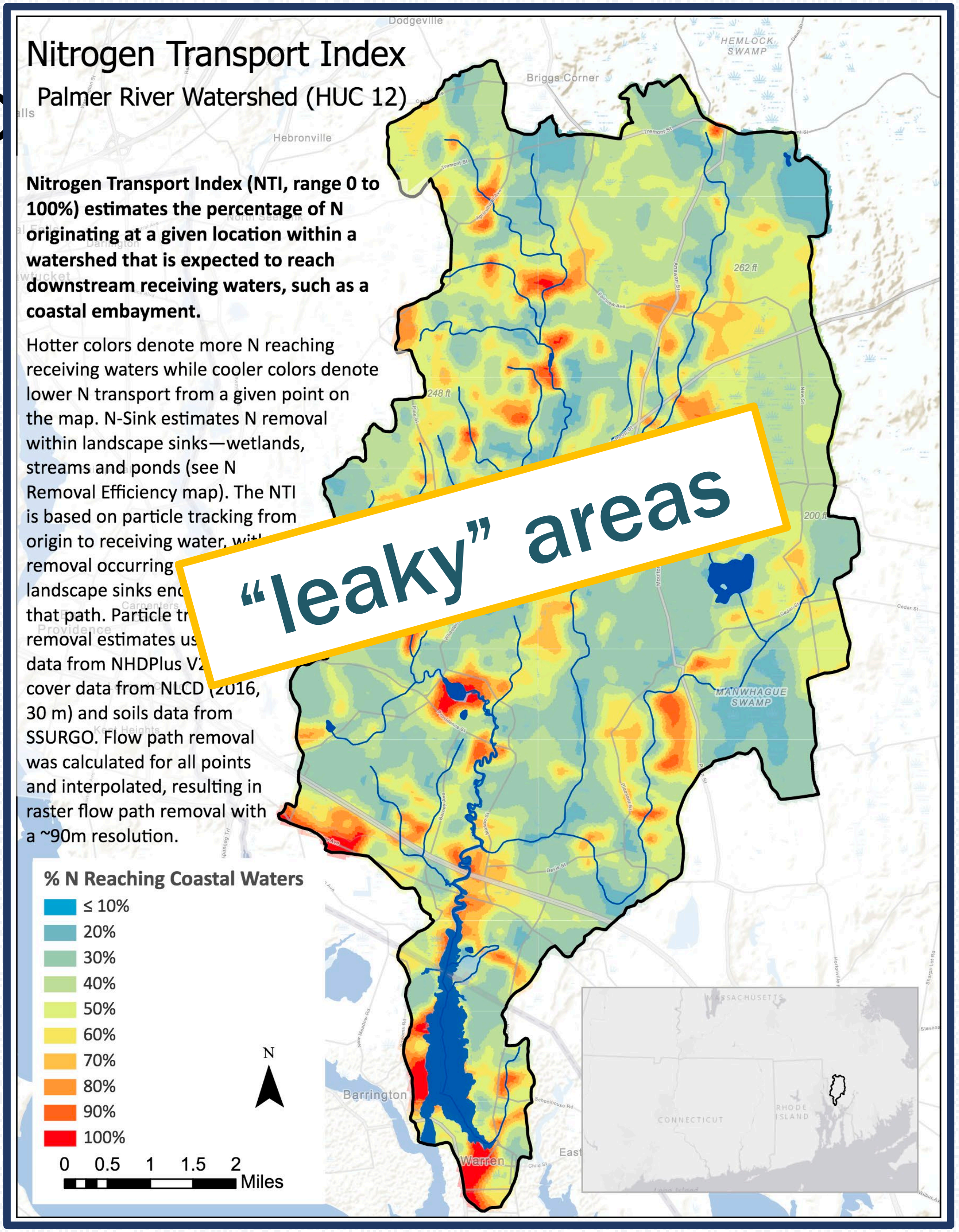
Removal Effi

- **Estimates percent of N removal in landscape sinks**
- **Removal rates are based on research results from the literature**
- **Darker green color indicates higher percent of N removal.**
- **Focus is on conservation priorities**



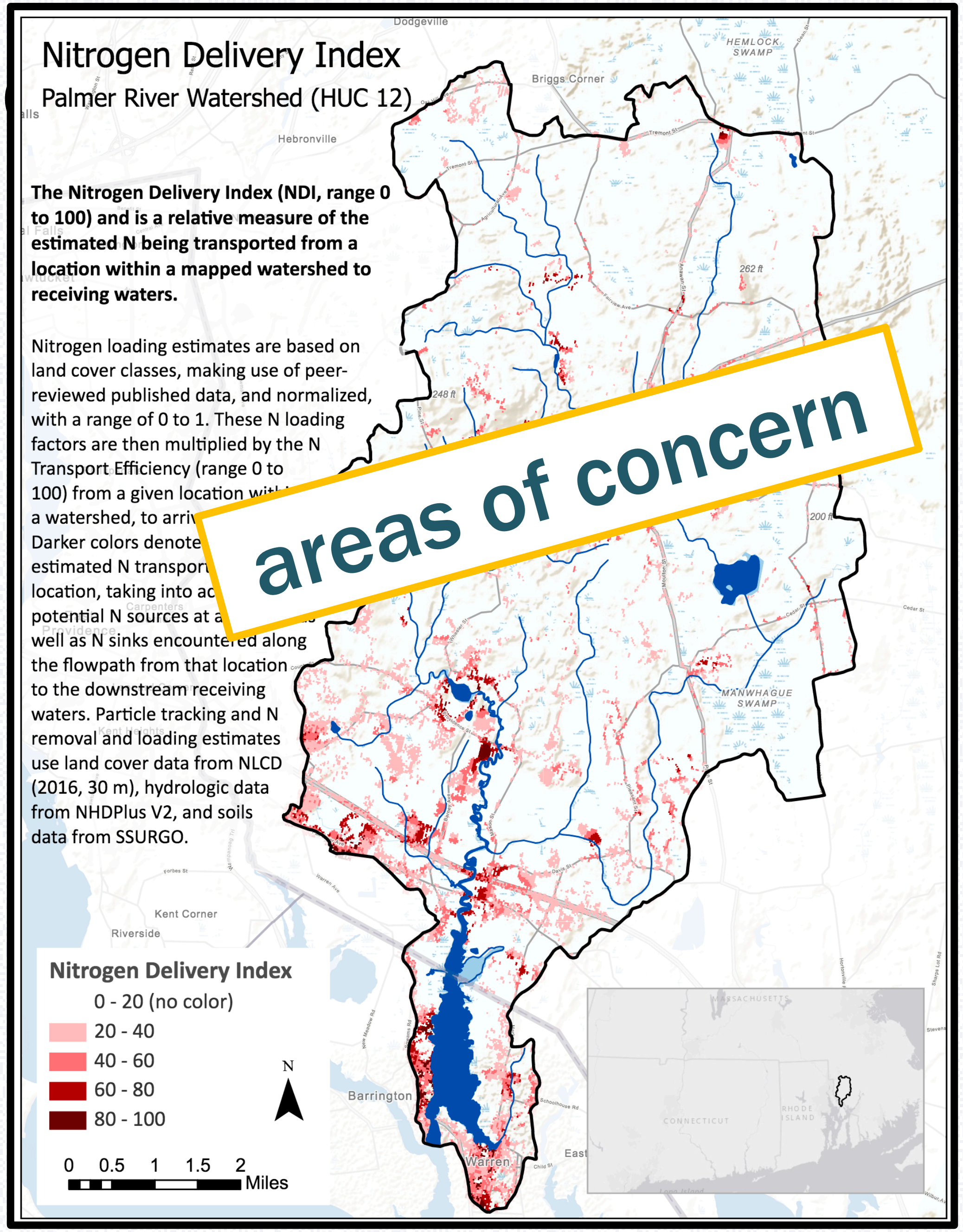
Transport Ind

- **Uses particle tracking to calculate cumulative N removal along the pathway originating at a given location**
- **Estimates percent of N reaching downstream receiving water**
- **Warmer color indicates higher N leakiness.**
- **Focus is on areas to prevent future N inputs and/or reduce current inputs**

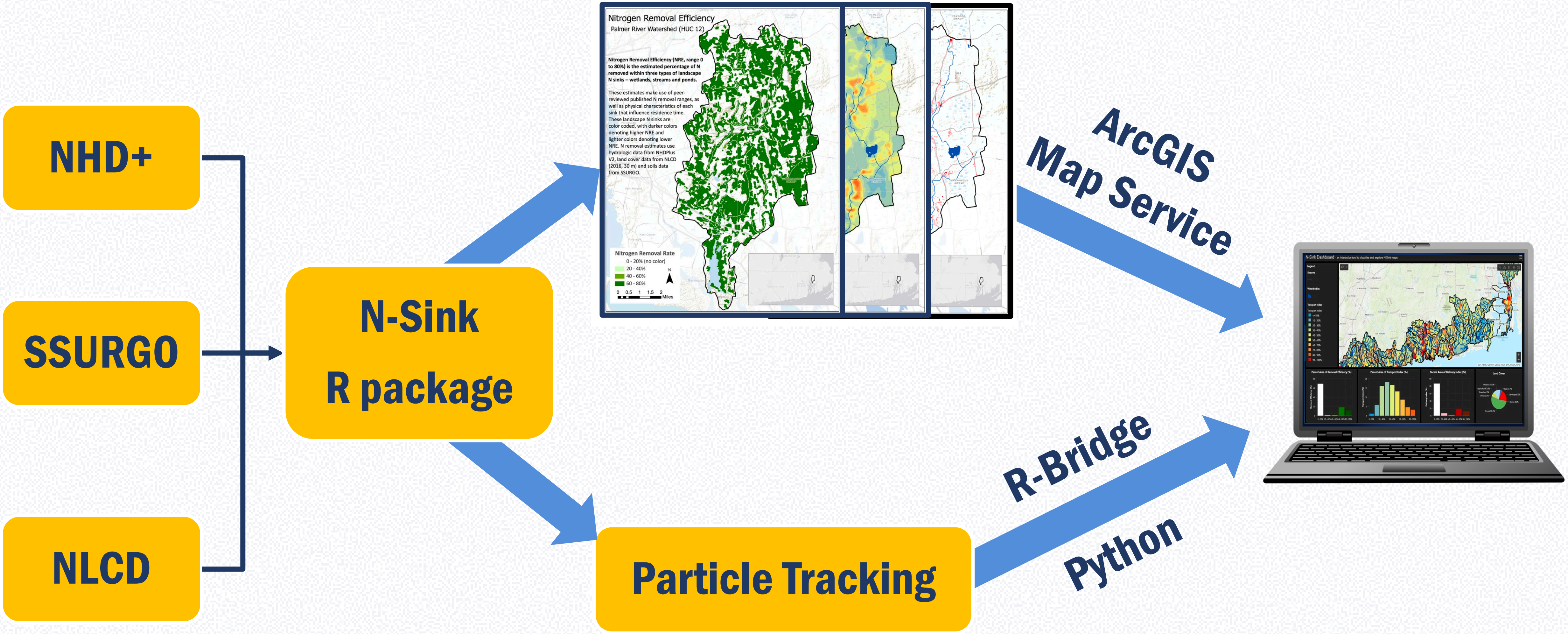


Delivery Ind

- **Estimates percent of N being transported from a given location to receiving water**
    1. **Estimates <u>N loading</u> rates based on NLCD**
    2. **Calculate <u>Delivery Index</u> by multiplying <u>N loading</u> by <u>Transport Index</u>**
- **Darker red color indicates higher levels of N delivered to receiving water**
- **Focus is on source controls, best practices, monitoring**



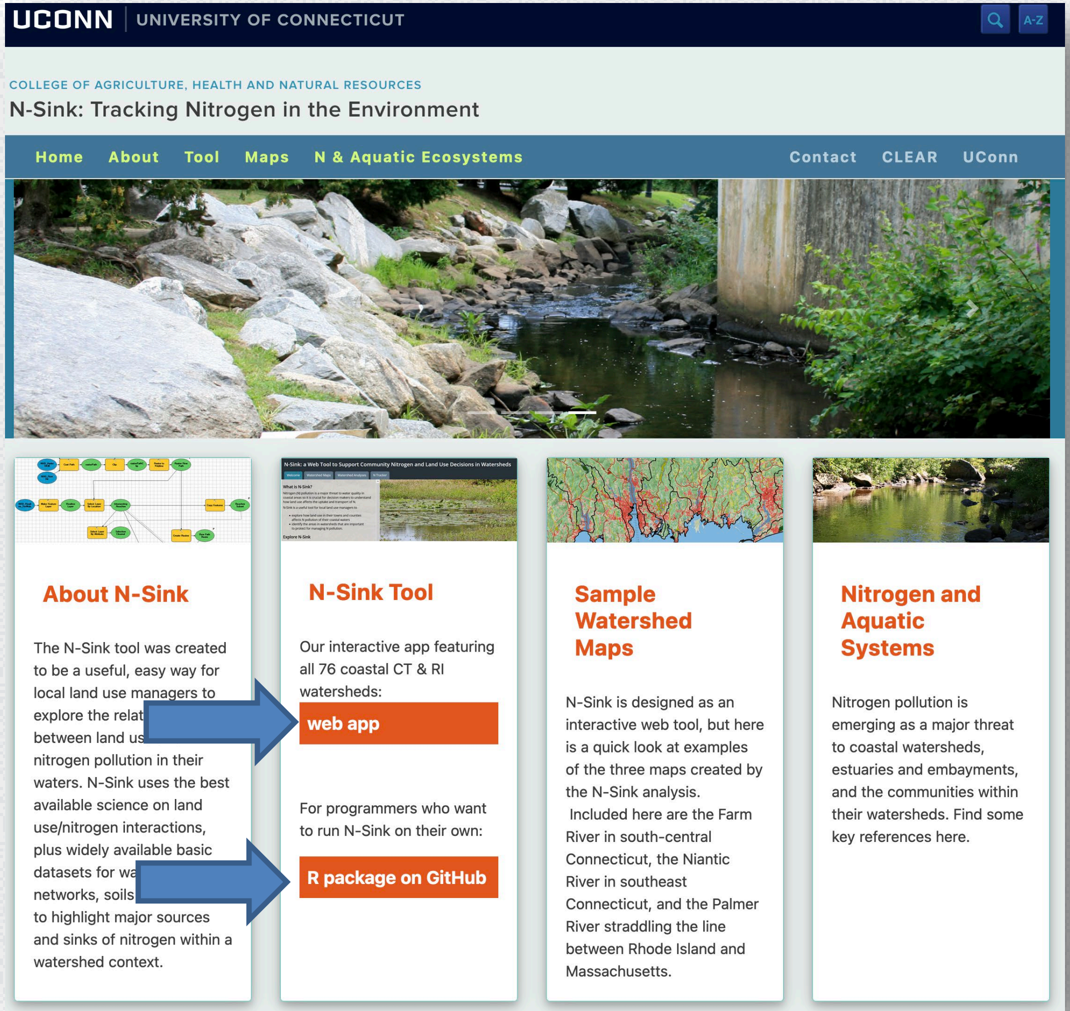
Workflow: from R to Arc



So, *where* is N-Sink?

https://clear.uconn.edu/projects/nsink/

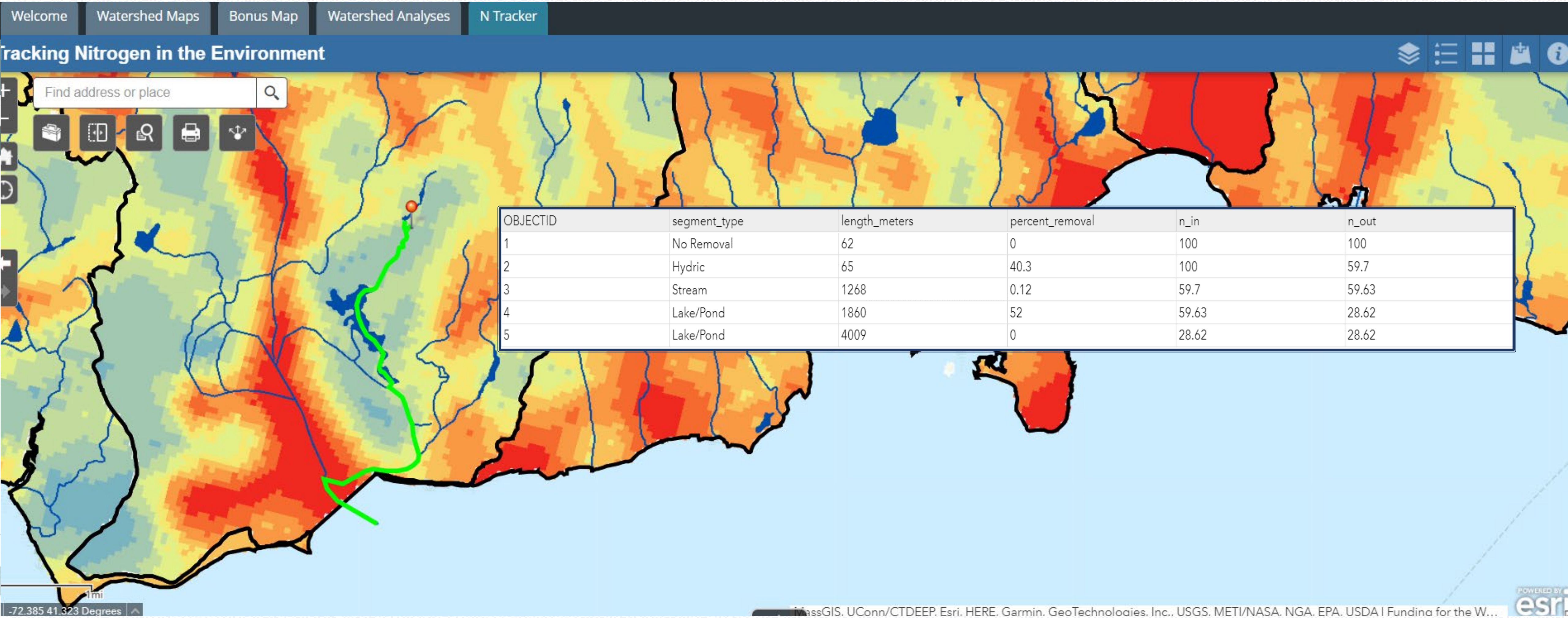
- **N-Sink R package**
  - **For R users**
  - **Downloadable from GitHub**
  - https://github.com/jhollist/nsink
  - Run on HUC-12 extent
- **N-Sink Web App**
  - **Covers all 76 HUC-12's along the CT and RI shorelines**
  - **An interactive decision support tool to visualize, explore and analyze N-Sink maps online**



N-Sink Web Apps

https://s.uconn.edu/nsink

Incudes 3 interactive N-Sink maps, watershed analysis dashboard, and N tracker tool



OBJECTID	segment_type	length_meters	percent_removal	n_in	n_out
1	No Removal	62	0	100	100
2	Hydric	65	40.3	100	59.7
3	Stream	1268	0.12	59.7	59.63
4	Lake/Pond	1860	52	59.63	28.62
5	Lake/Pond	4009	0	28.62	28.62

THANK YOU

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