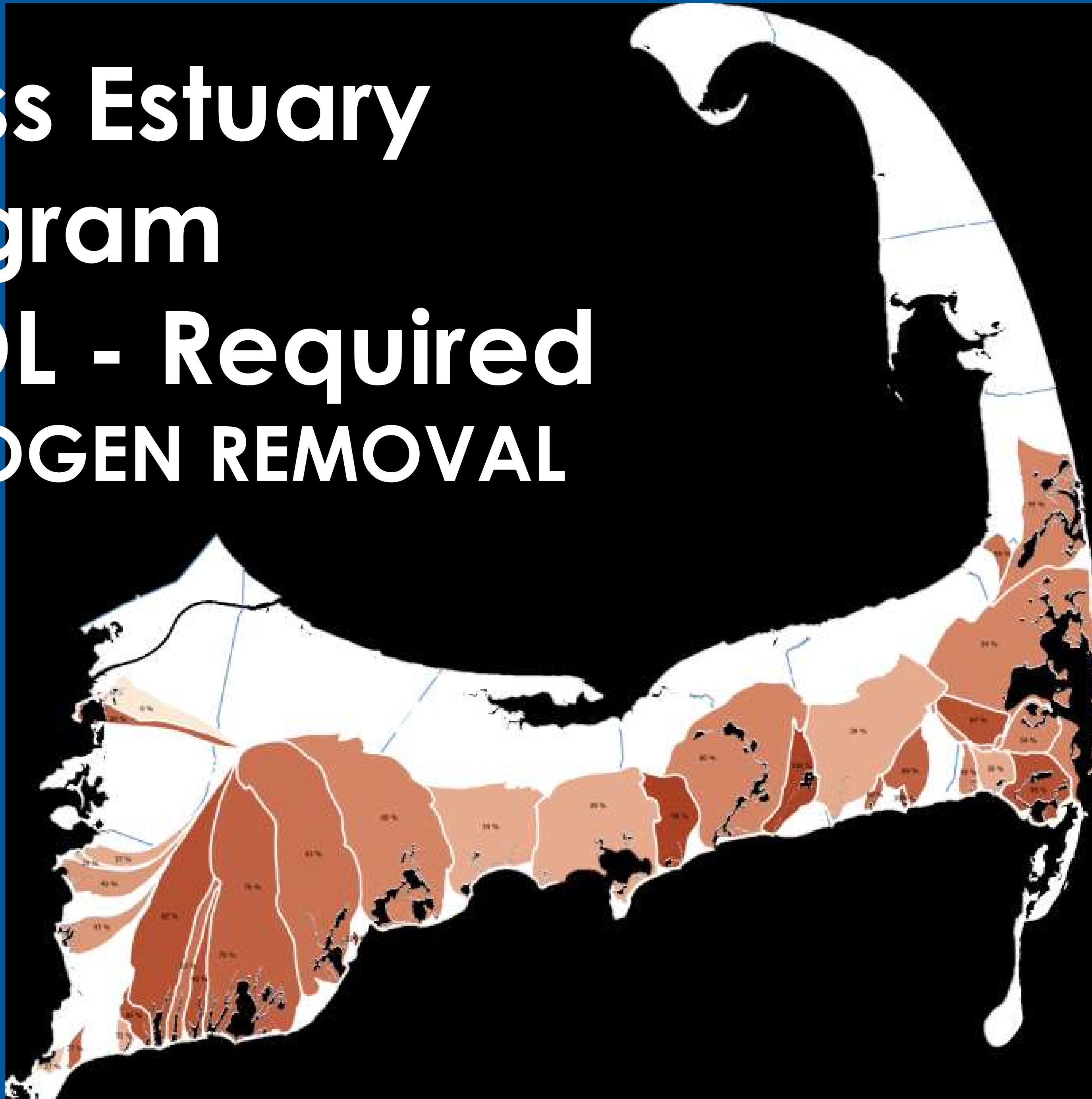
208 PLAN

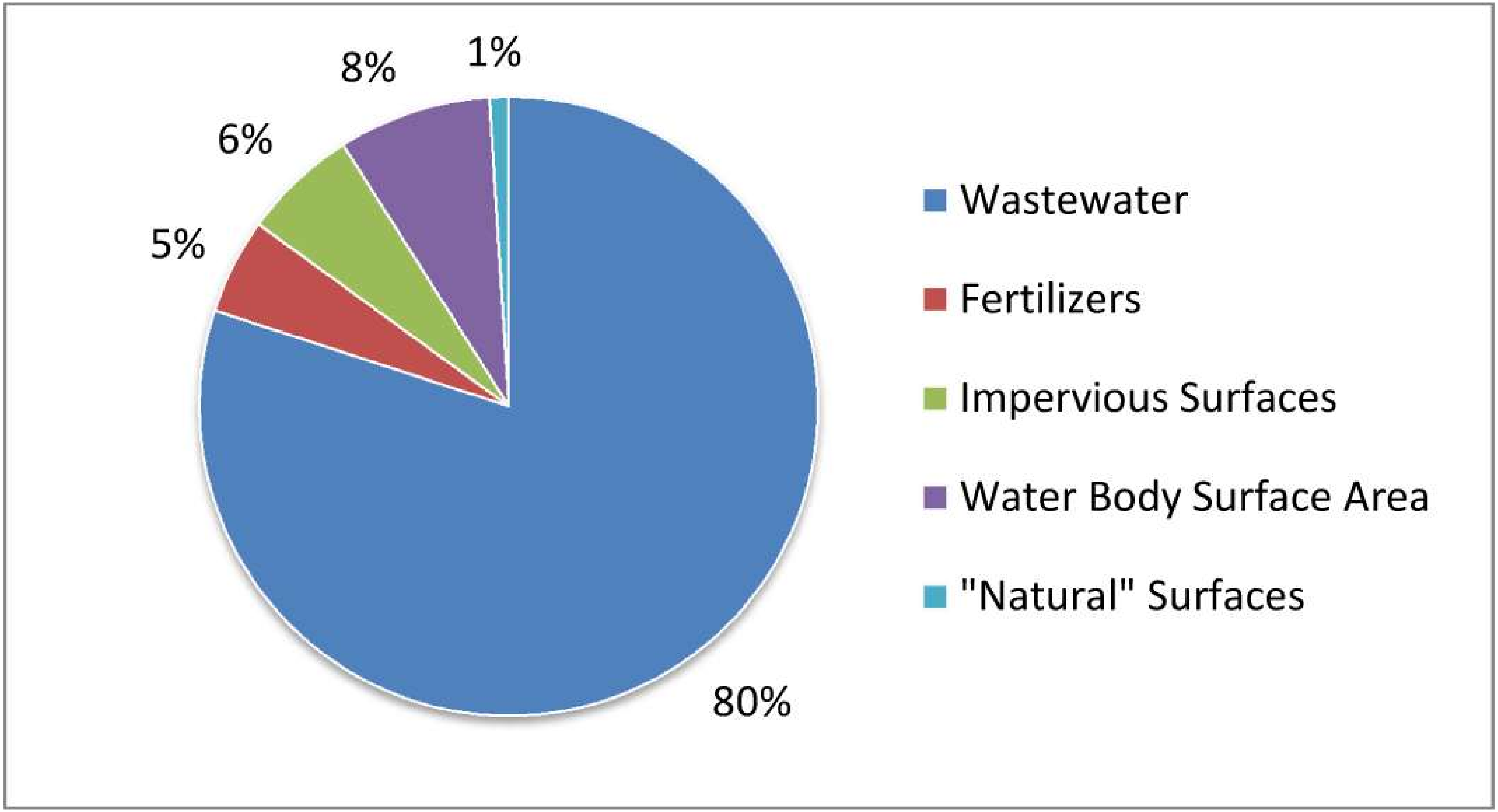
Cape Cod Area Wide Water Quality Management Plan Update

Mass Estuary Program TMDL - Required

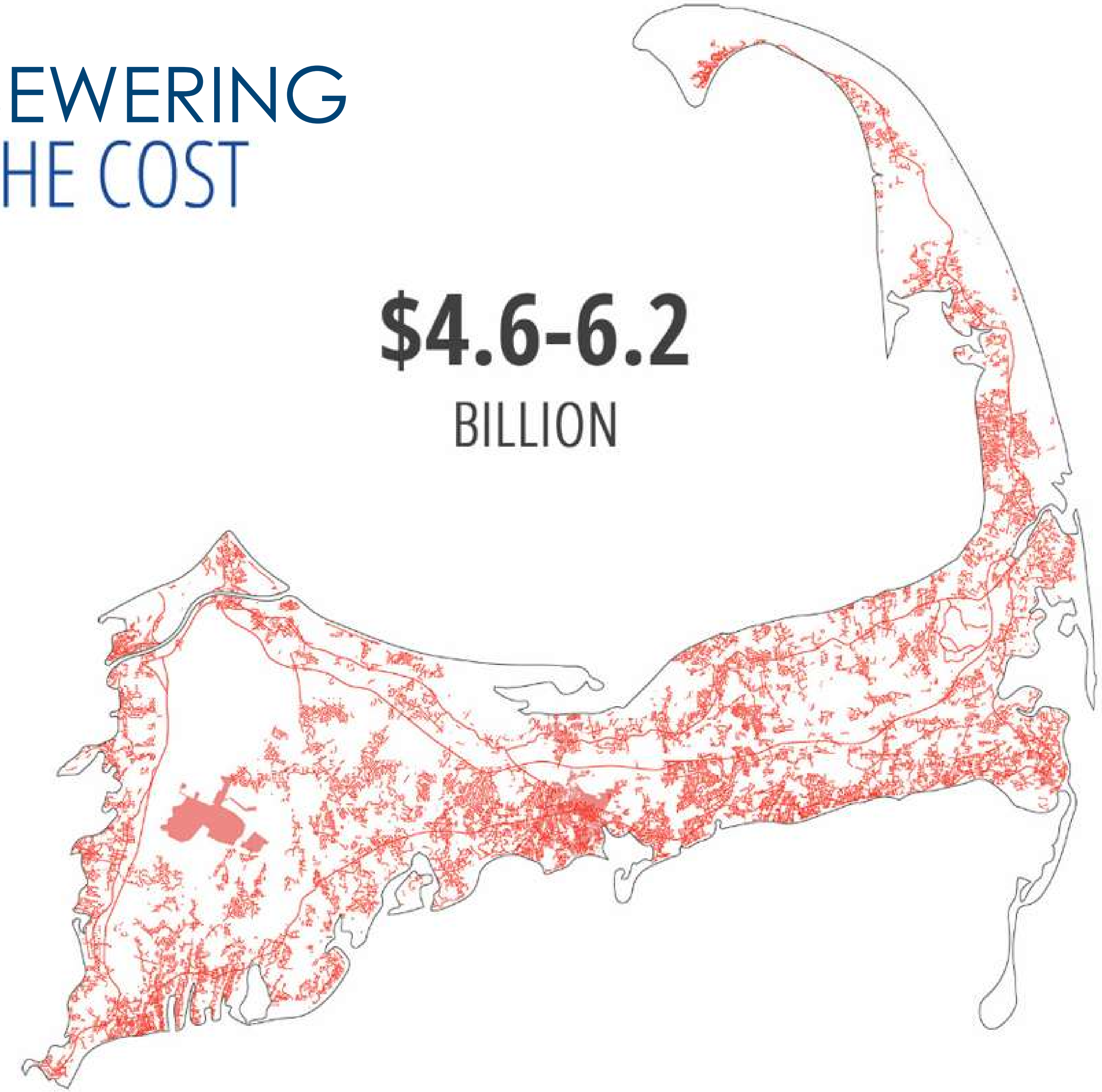
NITROGEN REMOVAL



Sources of Watershed Nitrogen

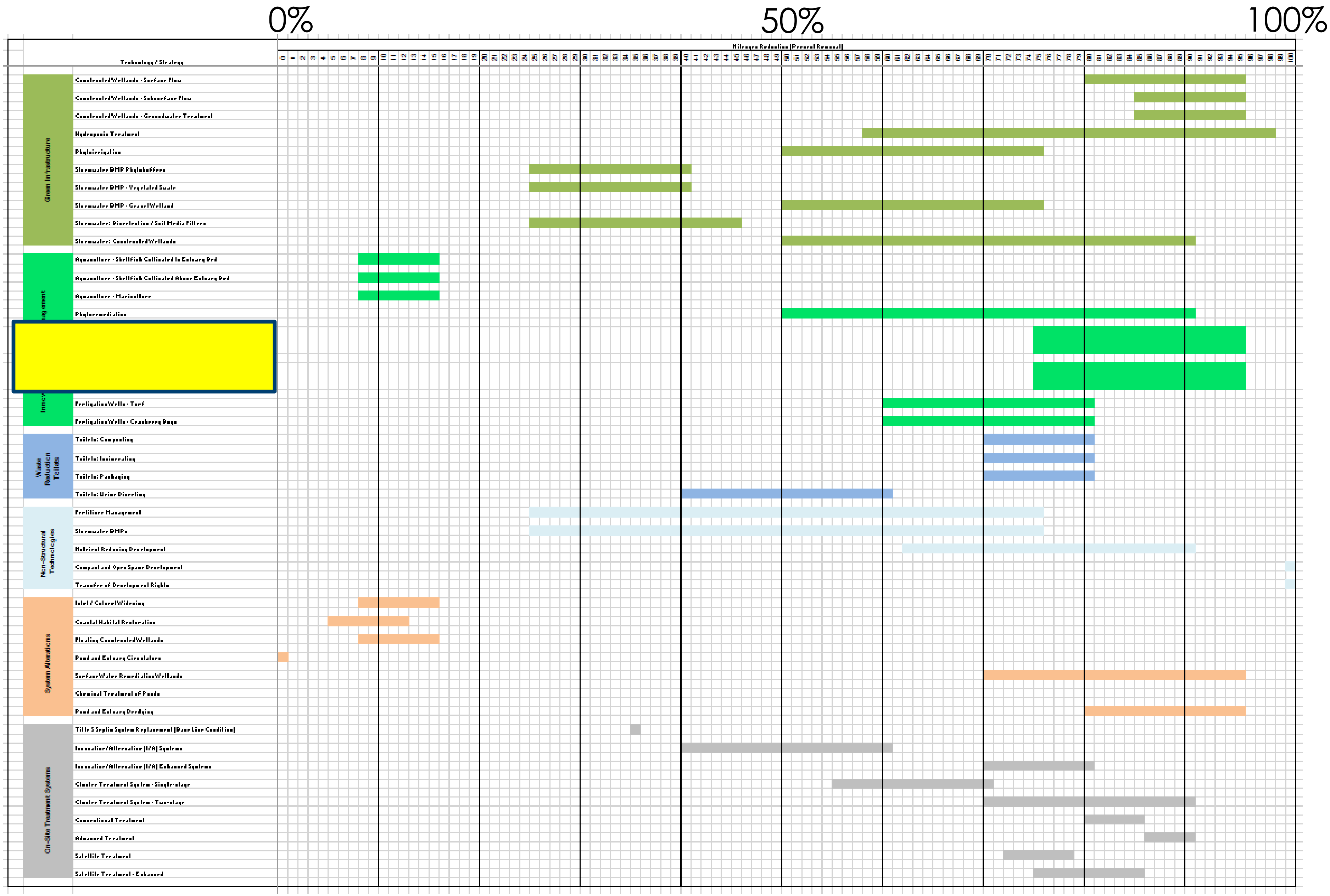


SEWERING
THE COST




Site Scale
Neighborhood
Watershed
Cape-Wide
Reduction
Treatment before disposal to ground
Remediation
Treatment in groundwater
Restoration
Treatment in water body
Title 5
Standard Title 5 Systems
IA
I/A Title 5 Systems
I/A Enhanced Systems
Toilets: Composting, Incinerating, Packaging, Urine Diverting
Hydroponic Treatment
Cluster Treatment System: Single- or Two-stage
Satellite Treatment
Nutrient Reducing Development
TDR
Transfer of Development Rights
Conventional Treatment
Advanced Treatment
N+P+K MGMT
Fertilizer Management
Compact and Open Space Development
Constructed Wetlands
Phytoirrigation
Stormwater Best Managment Practices (BMPs)
BMPs
PRB
Permeable Reactive Barrier (PRB)
Phytoremediation
Stormwater: Bioretention / Soil Media Filters
Fertigation Wells: Turf, Cranberry Bogs
N+P
Stormwater: Constructed Wetlands
Aquaculture/Shellfish Farming
Coastal Habitat Restoration
Inlet / Culvert Widening
Constructed Wetlands: Floating
Pond and Estuary Circulators
Surface Water Remediation Wetlands
SWR
Pond and Estuary Dredging
Policy

Ranges of Percent Nitrogen Removal by Technology



Bookend Solutions

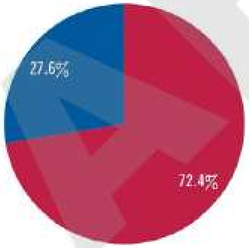
Traditional & Non-Traditional Scenarios

Non-Traditional

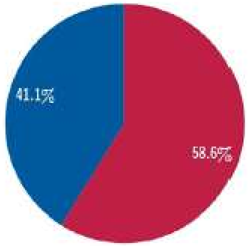
UNIT OF APPLIED TECHNOLOGY	ATTENUATED NITROGEN REMOVED IN KG/Y
25 % Nitrogen Reduction - Fertilizer Management	1,597
25 % Nitrogen Reduction - Stormwater Mitigation	1,541
1,000 Linear Feet - Permeable Reactive Barrier (PRB) (Capture load calculated by wMVP: 896.6 kg/Y)	650
150 Acres - Fertigation - Turf	600
10 Acres - Fertigation - Cranberry Bogs	120
Inlet Widening	1,930
22 Acres - Aquaculture/Oyster Beds	5,238
9 Acres - Coastal Habitat Restoration	880
2,063 Square Feet - Floating Constructed Wetlands	713
547 Units - Ecotoilets (UD & Compost)	1,213
839 Units - I & A Systems	1,213
466 Units - Enhanced I & A Systems	1,213
TOTAL	17,263[1]

Traditional

CENTRALIZED TREATMENT WITH DISPOSAL INSIDE THE WATERSHED



CENTRALIZED TREATMENT WITH DISPOSAL OUTSIDE THE WATERSHED



Septic Load to be Removed

Remaining Septic Load

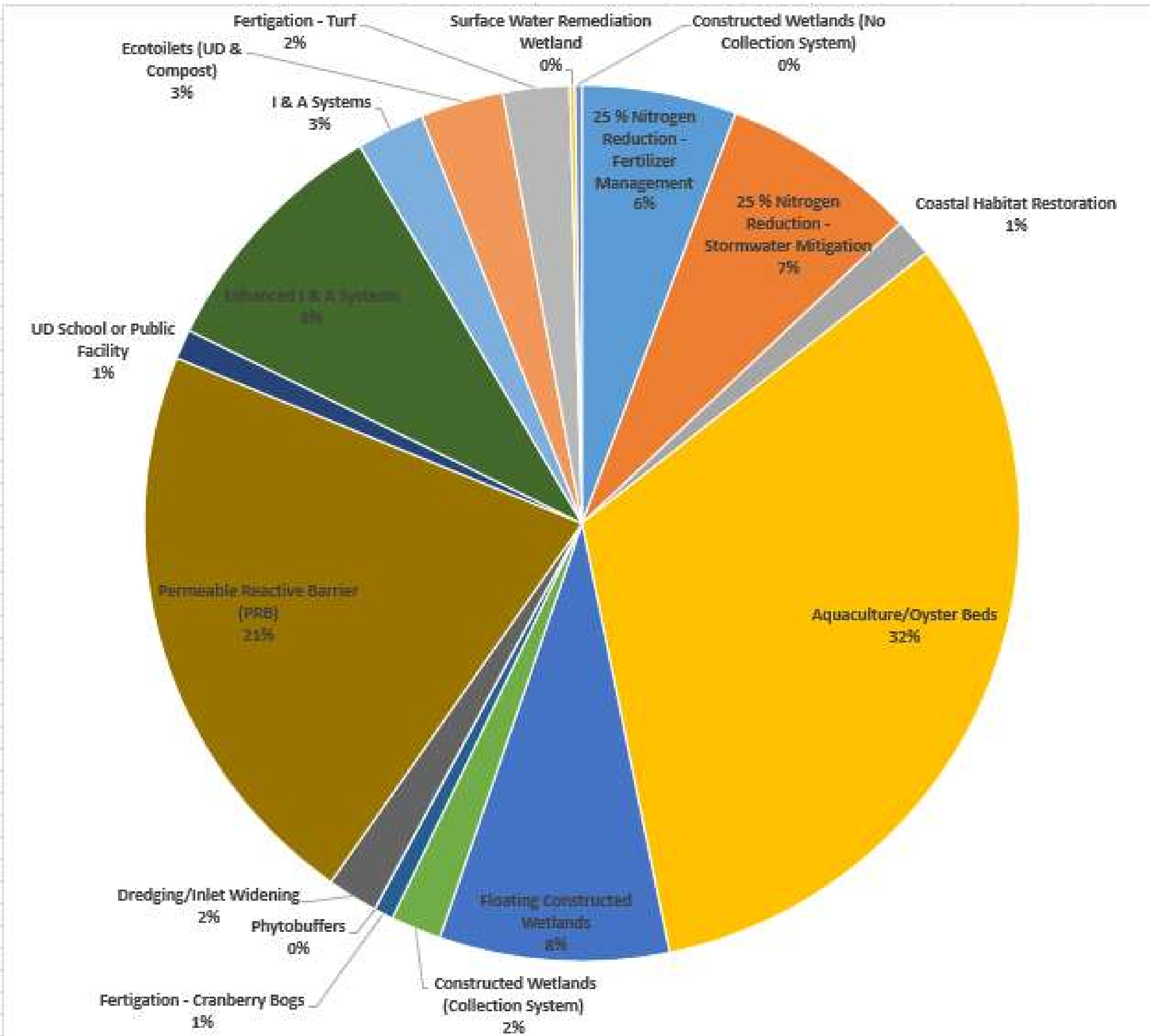
Assumes load to be collected and treated is disposed in the watershed, requiring additional collection to offset the load. Reductions as a result of sewering reflect return wastewater loads treated to 10 parts per million (ppm).

Assumes that the load to be collected and treated is removed from the watershed so no offset is required.

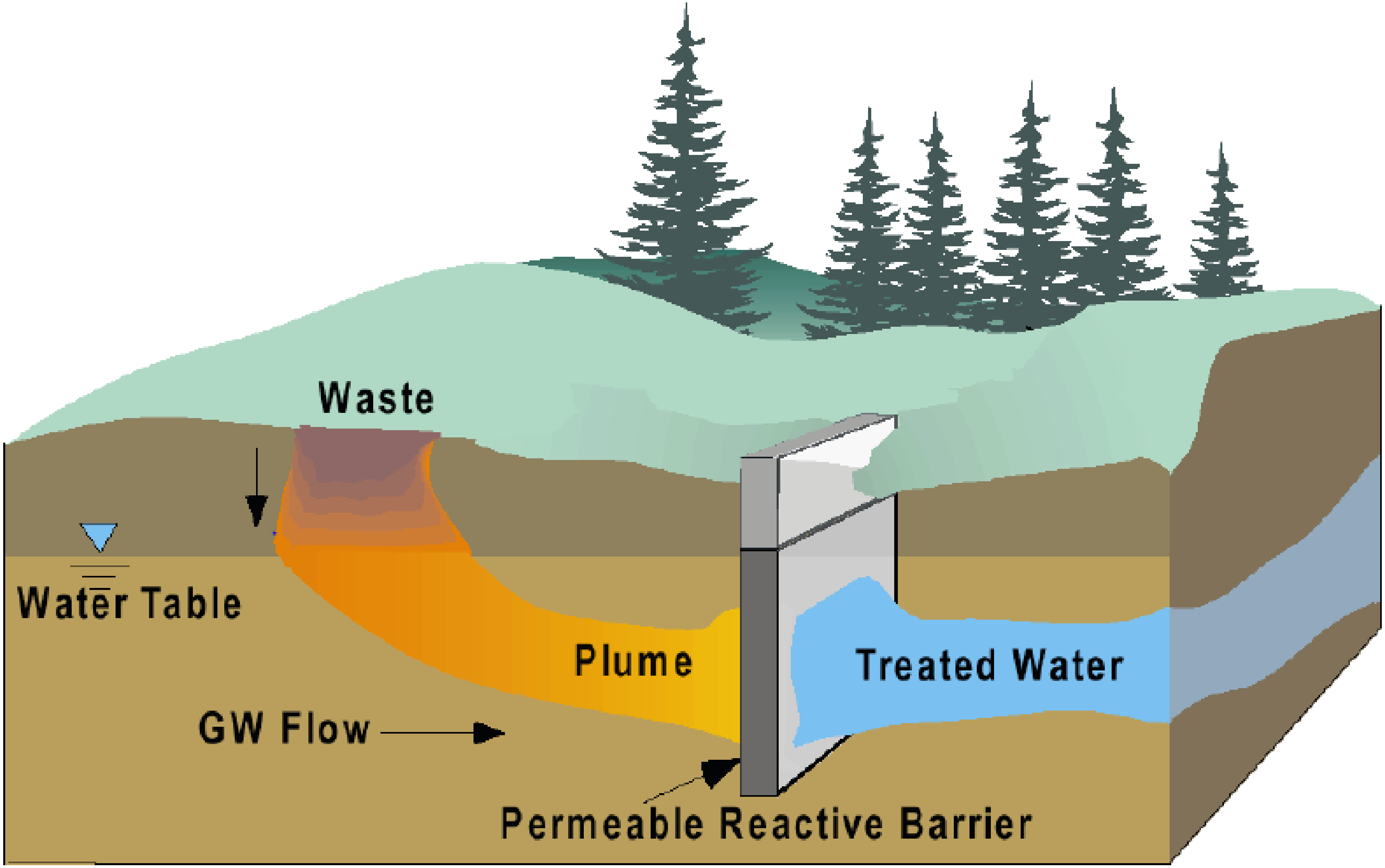
1. When sewering, already proposed by the Chatham CWMP, in the amount of 10,097 kg/yr is combined with this non-traditional scenario removal of 17,263 kg/yr, the resulting total removal is 27,360 kg/yr. Reductions as a result of sewering reflect return wastewater loads treated to 10 parts per million (ppm). In this scenario the non-traditional scenario overachieves because the scenario targets removals are based on separate thresholds for each sub-watershed. Fertilizer and stormwater credits cause overachievement in sub-watershed where no NT interventions are proposed and where Chatham proposes to sewer.

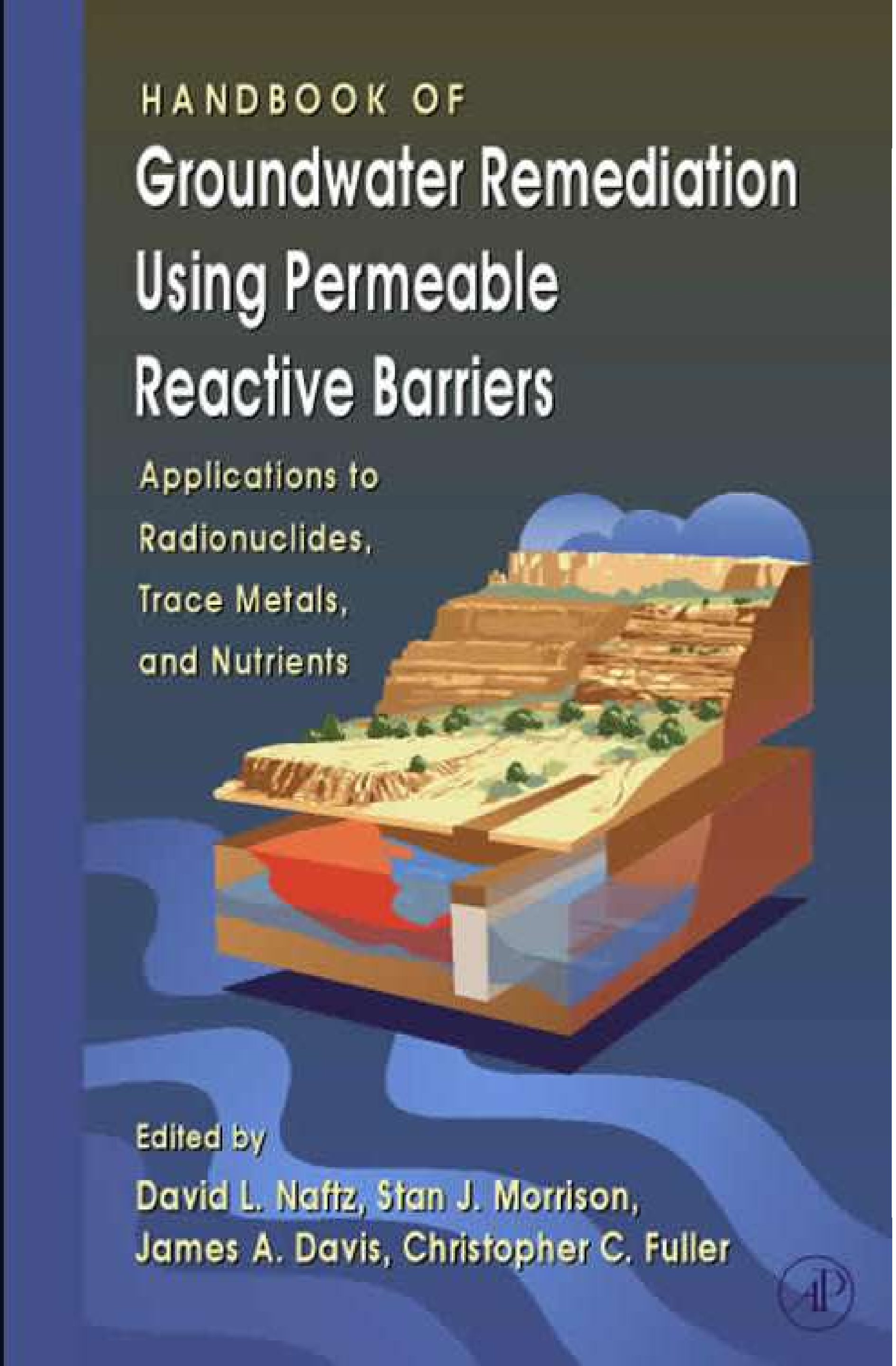
11.00 x 8.50 in

NT Technologies Percent Kg removal



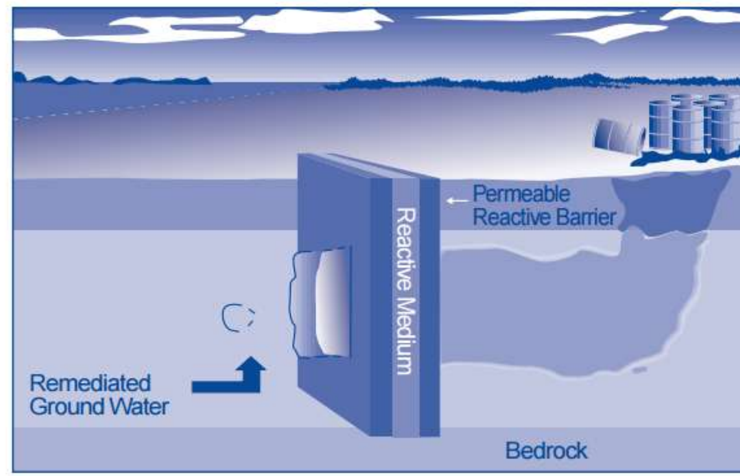
The PRB Technology





Technical/Regulatory Guidelines

Regulatory Guidance for Permeable Reactive Barriers Designed to Remediate Inorganic and Radionuclide Contamination



September 1999

Final Report on the

DEEP GRANULAR IRON PERMEABLE REACTIVE BARRIER FIELD DEMONSTRATION AT MASSACHUSETTS MILITARY RESERVATION

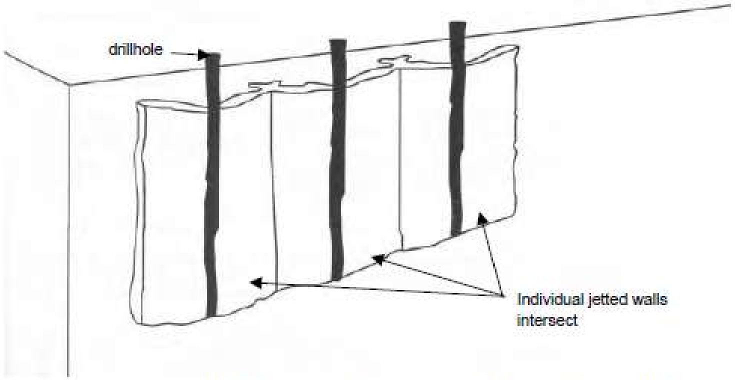
by

David W. Hubble, M.Sc., P. Eng.

and

Robert W. Gillham, Ph.D., Principal Investigator

Institute for Groundwater Research
Department of Earth Sciences, University of Waterloo
Waterloo, Ontario, Canada, N2L 3G1
Email: dwhubble@uwaterloo.ca



a) **Schematic of Thin Diaphram Wall Concept** (after Shoemaker *et al.*, 1996)

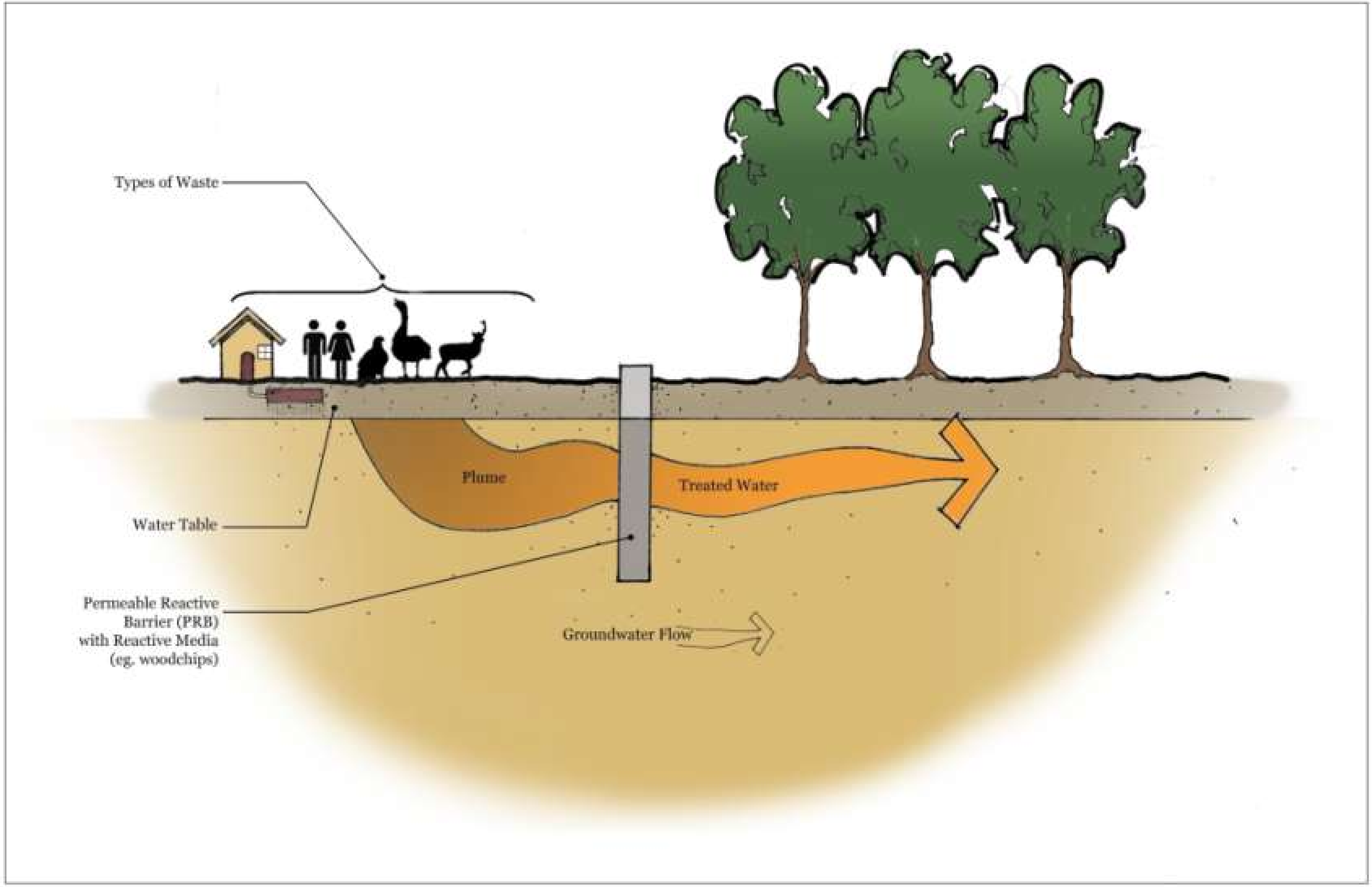
b) **High-Pressure Jetting Equipment at Shallow Test Site** (photo from DuPont Inc.)

Figure 2-7 High-Pressure Hydraulic Jetting Equipment

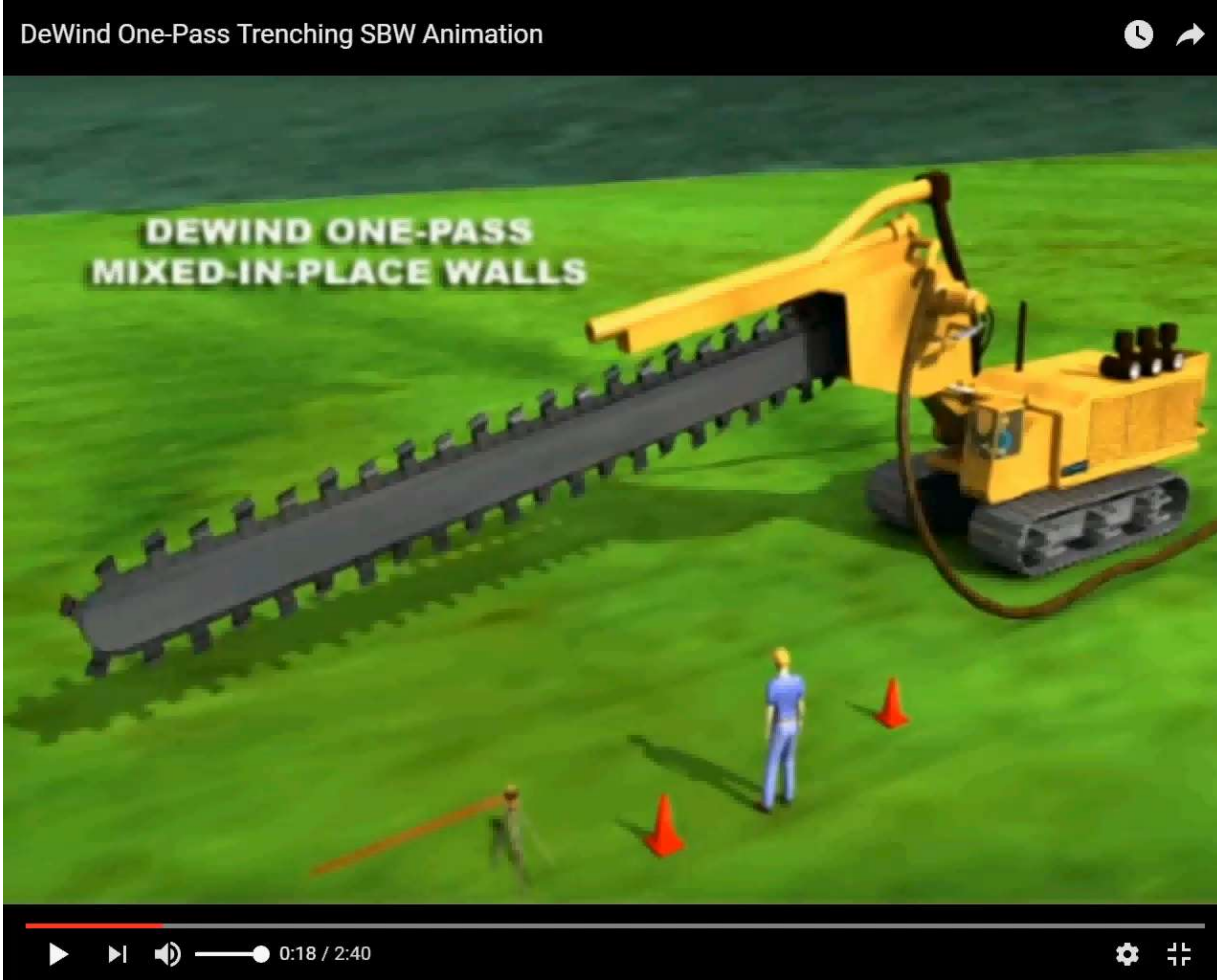
PRBs

- Passive Operation
- Reaction zone emplaced in the groundwater
  - Zero-valent Iron
  - Carbon
- It does not impede Groundwater flow

PRB Trench



Types of Waste
Plume
Treated Water
Water Table
Permeable Reactive
Barrier (PRB)
with Reactive Media
(eg. woodchips)
Groundwater Flow

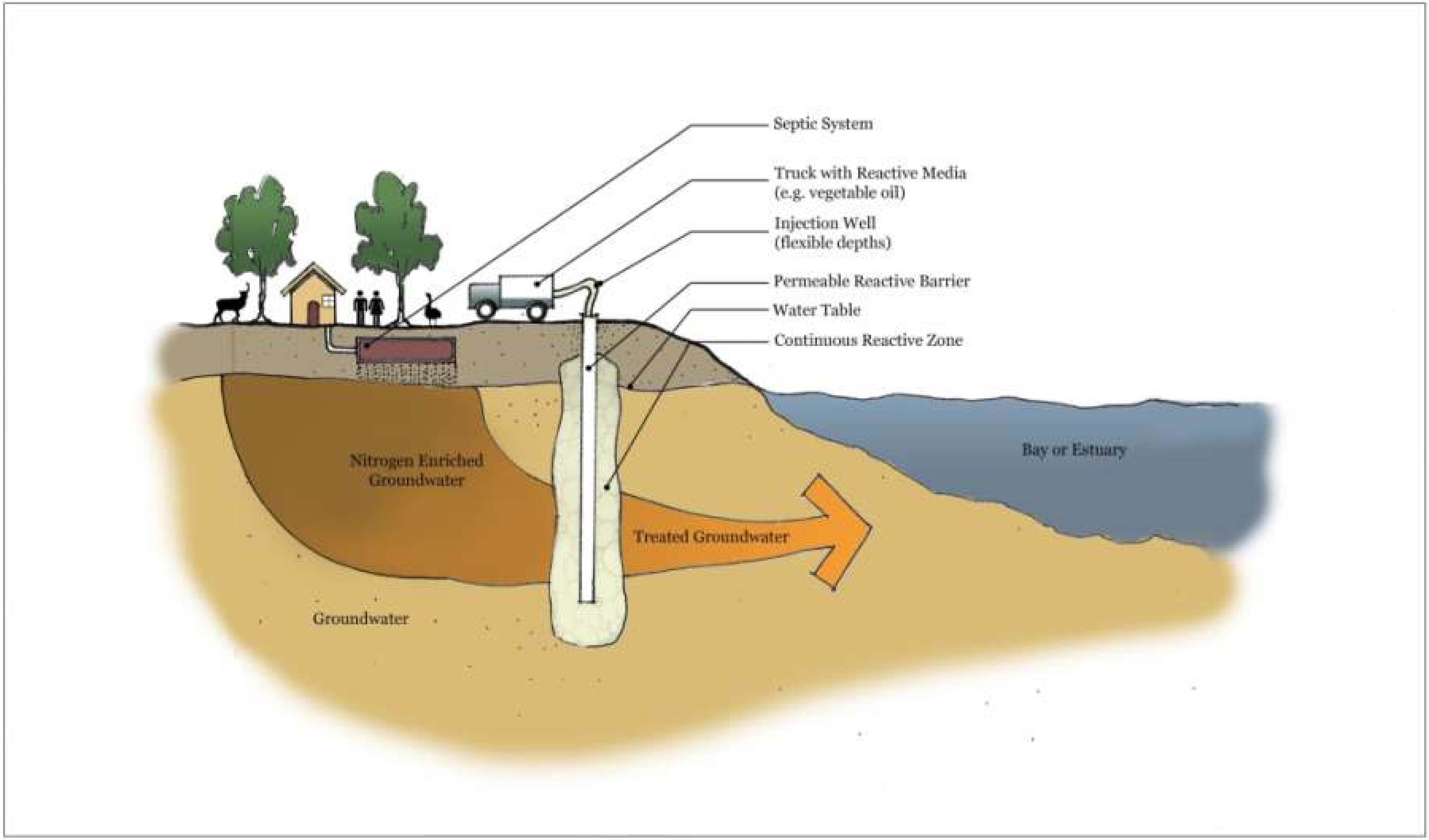

DeWind One-Pass Trenching SBW Animation
DEWIND ONE-PASS
MIXED-IN-PLACE WALLS
0:18 / 2:40

DeWind One Pass Trenching MT2000 Trencher Installing Soil Bentonite Cutoff Wall

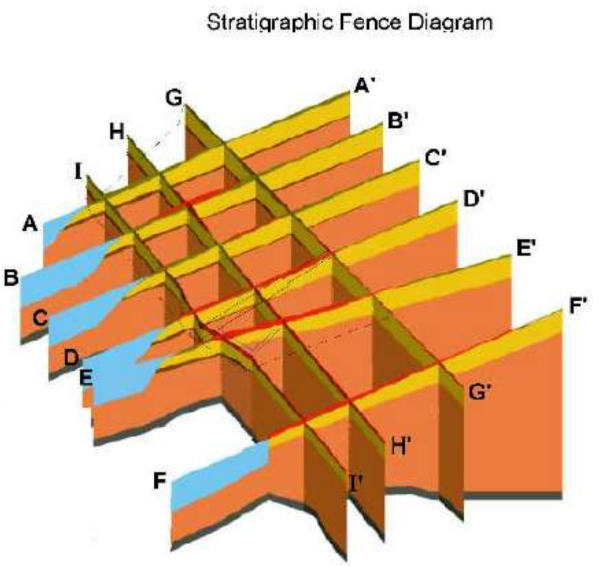
2:42 / 4:39


CAT
Sunnyvale, CA

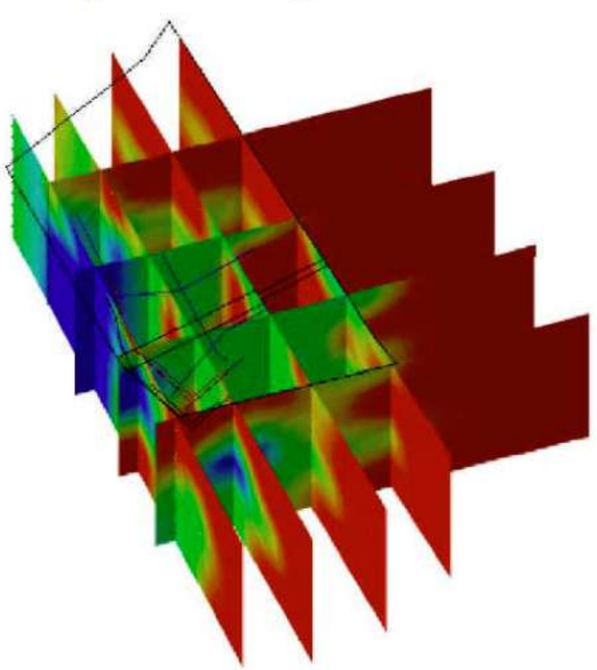
Injection


Septic System
Truck with Reactive Media
(e.g. vegetable oil)
Injection Well
(flexible depths)
Permeable Reactive Barrier
Water Table
Continuous Reactive Zone
Bay or Estuary
Nitrogen Enriched
Groundwater
Treated Groundwater
Groundwater

Key Design Considerations



Site Characterization – Subsurface Geology

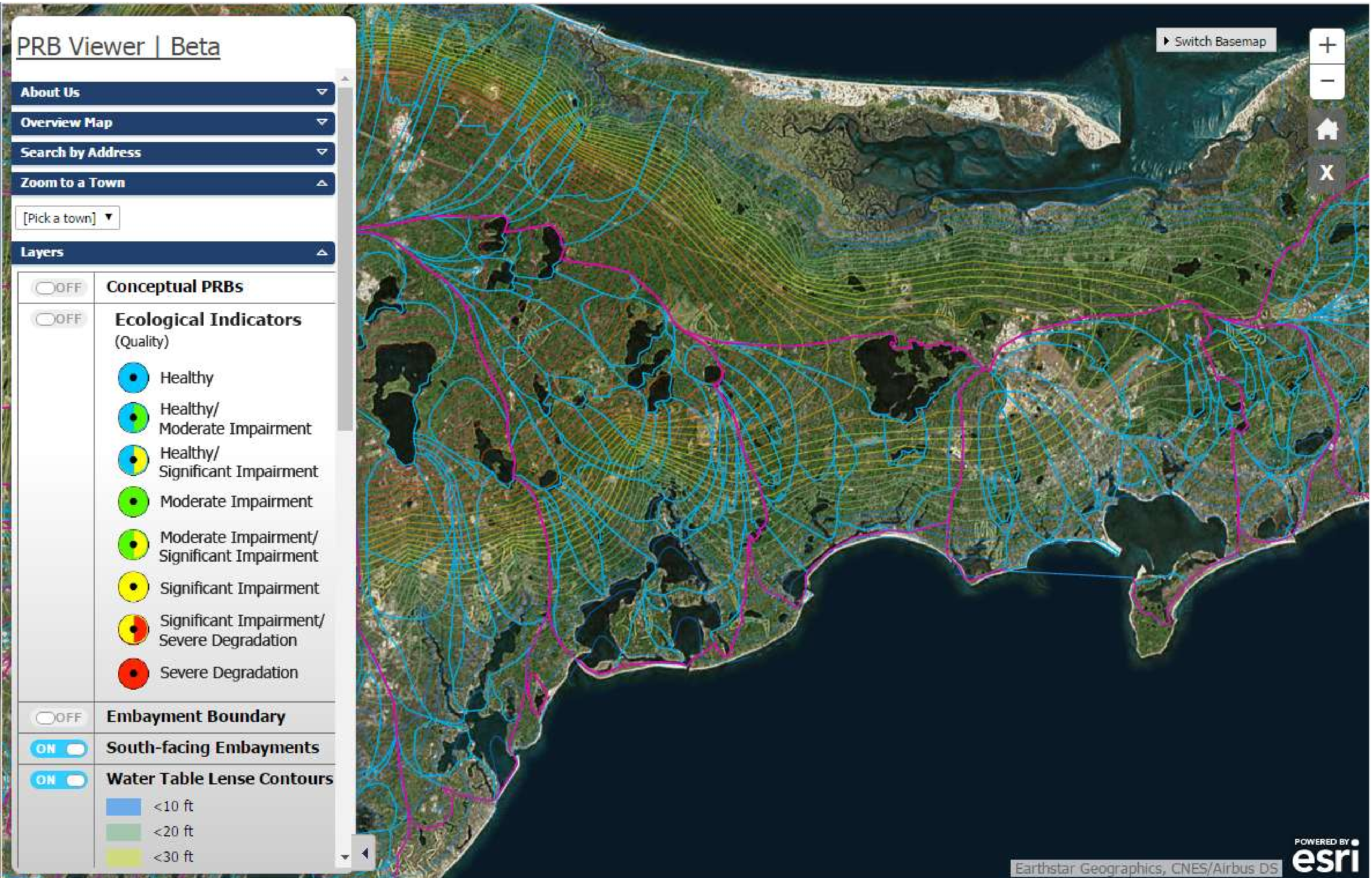


Site Characterization – Geochemistry

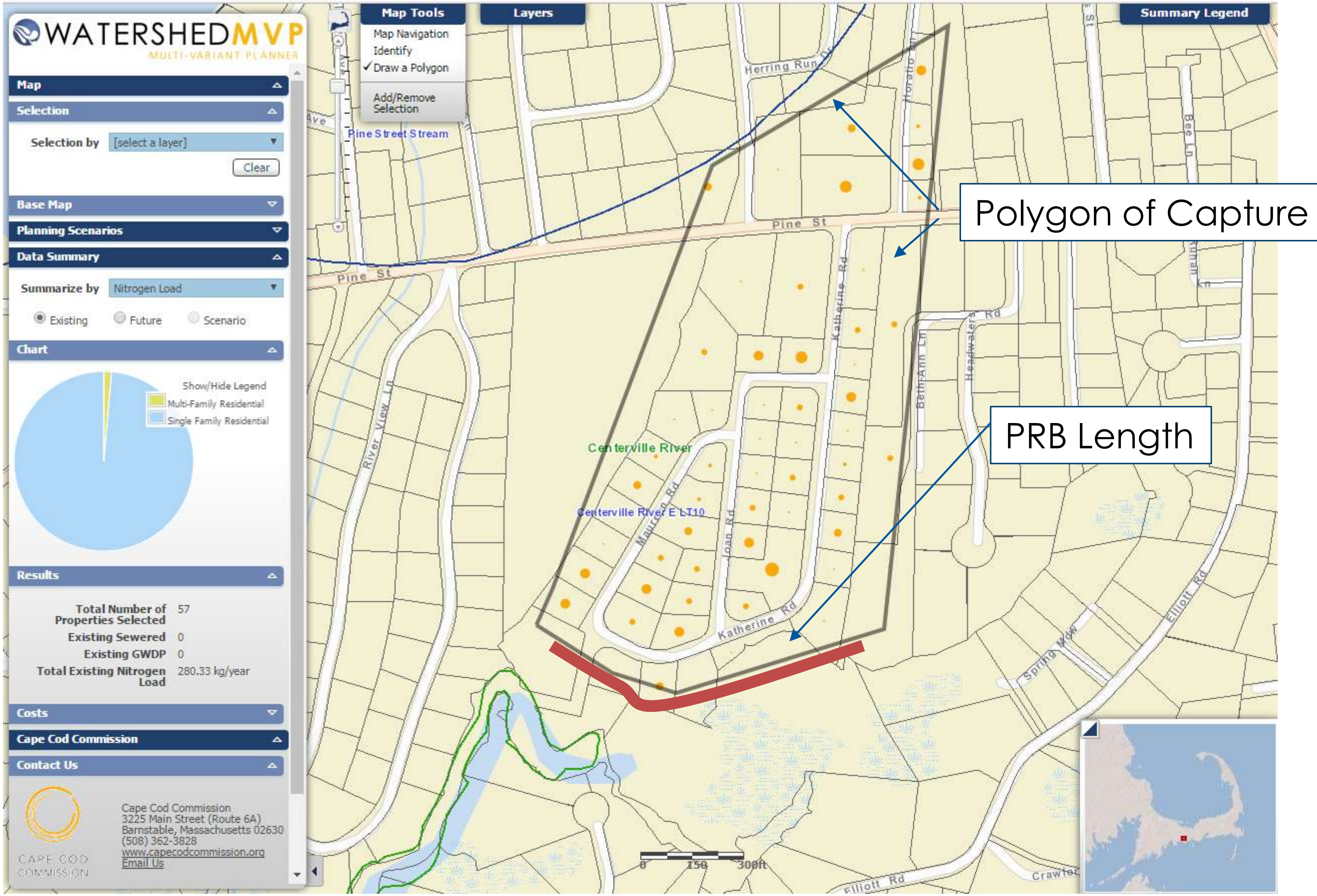
Why are PRBs Applicable to Cape Cod?

- Sole Source Aquifer
- Groundwater flow determines the fate of all contaminants
- Groundwater flows ultimately to the marine waters (Gravity)
- Groundwater flow rates are generally high ~1 ft/d
- Cape Groundwater Chemistry is predictable…..

208 PRB Viewer



208 Watershed MVP

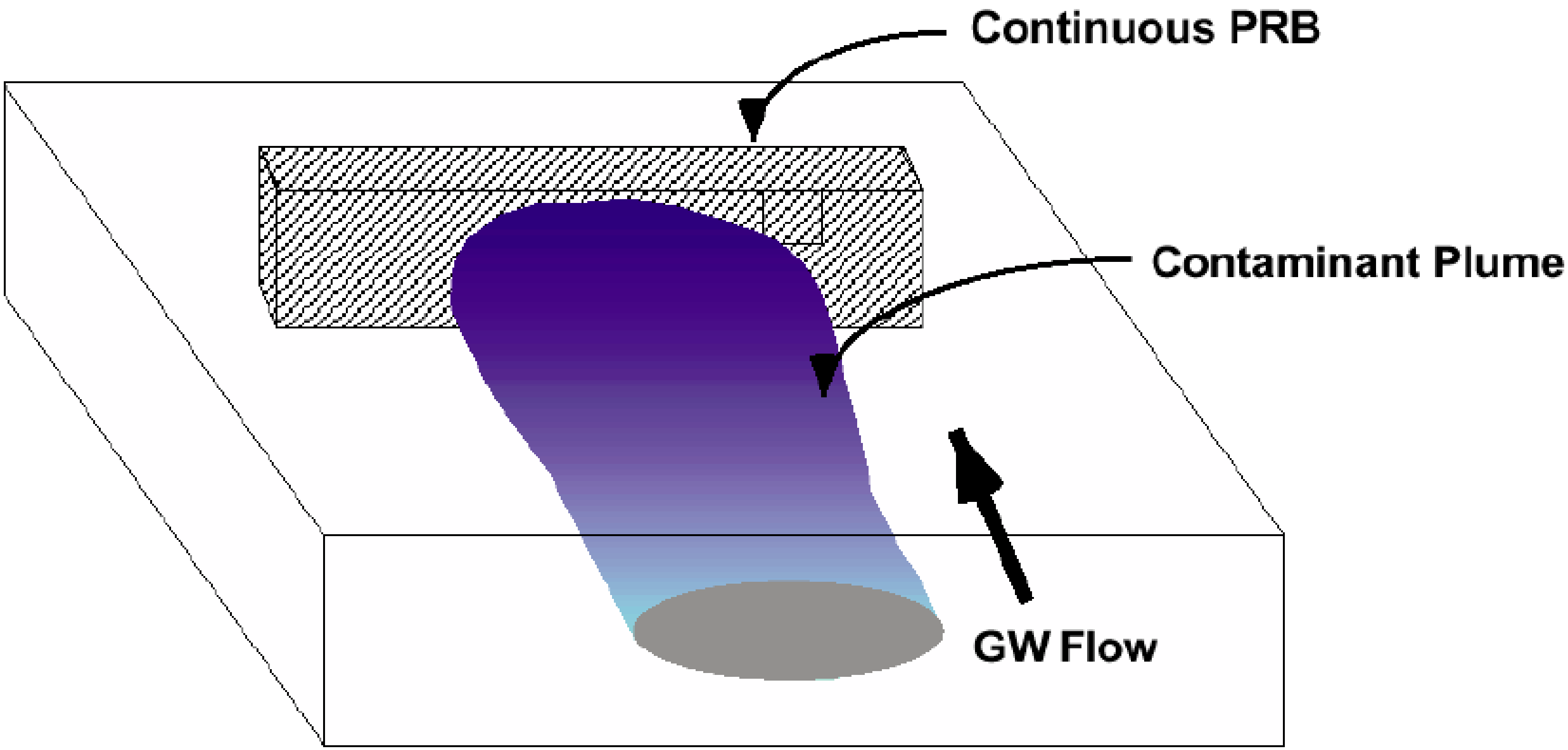


Watershed Nitrogen Loads MASS

- Conversion factors are applied to determine the Nitrogen Mass (Kg/d)

  - Wastewater
  - Fertilizers and leaching
  - Stormwater
  - Atmospheric

Cross Sectional "Area" of Treatment



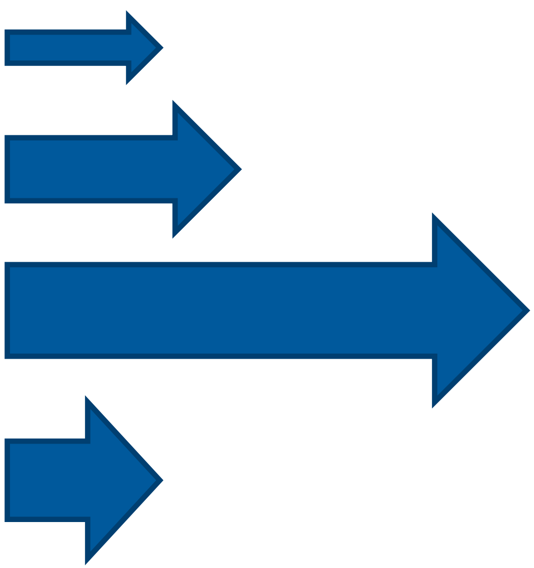
Mass = Volume x Concentration

Nitrogen Flux Rate

K- Aquifer Permeability (Hydraulic Conductivity)
i- Hydraulic Gradient (Slope of the water table)
A- Cross-Sectional Area

Q= KiA (gpd) x Nitrogen Concentration (mg/l)

<u>Mass Flux (kg/d)</u>	<u>Conditions</u>



Low Flow Rate, Low Concentration

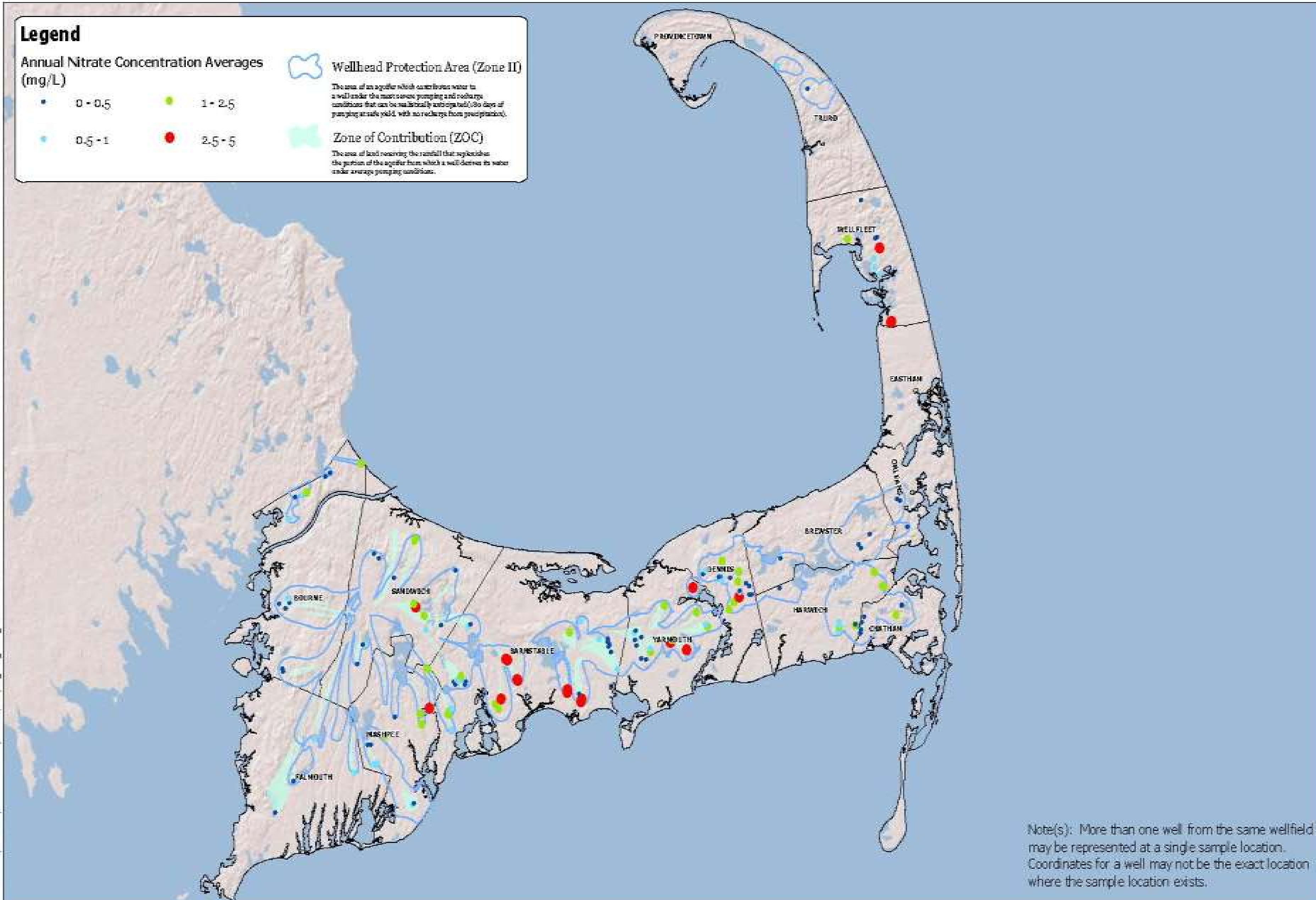
Moderate Flow Rate, High Concentration

High Flow Rate, High Concentration

Low Flow Rate, High Concentration

What do we know about nitrogen concentrations in groundwater that should be targeted for treatment?

- Public Water Supplies
- Private Wells
- Streams
- Groundwater Assessments



Nitrate Concentrations in Cape Cod Public Supply Wells

2 0 2 4 6
Miles

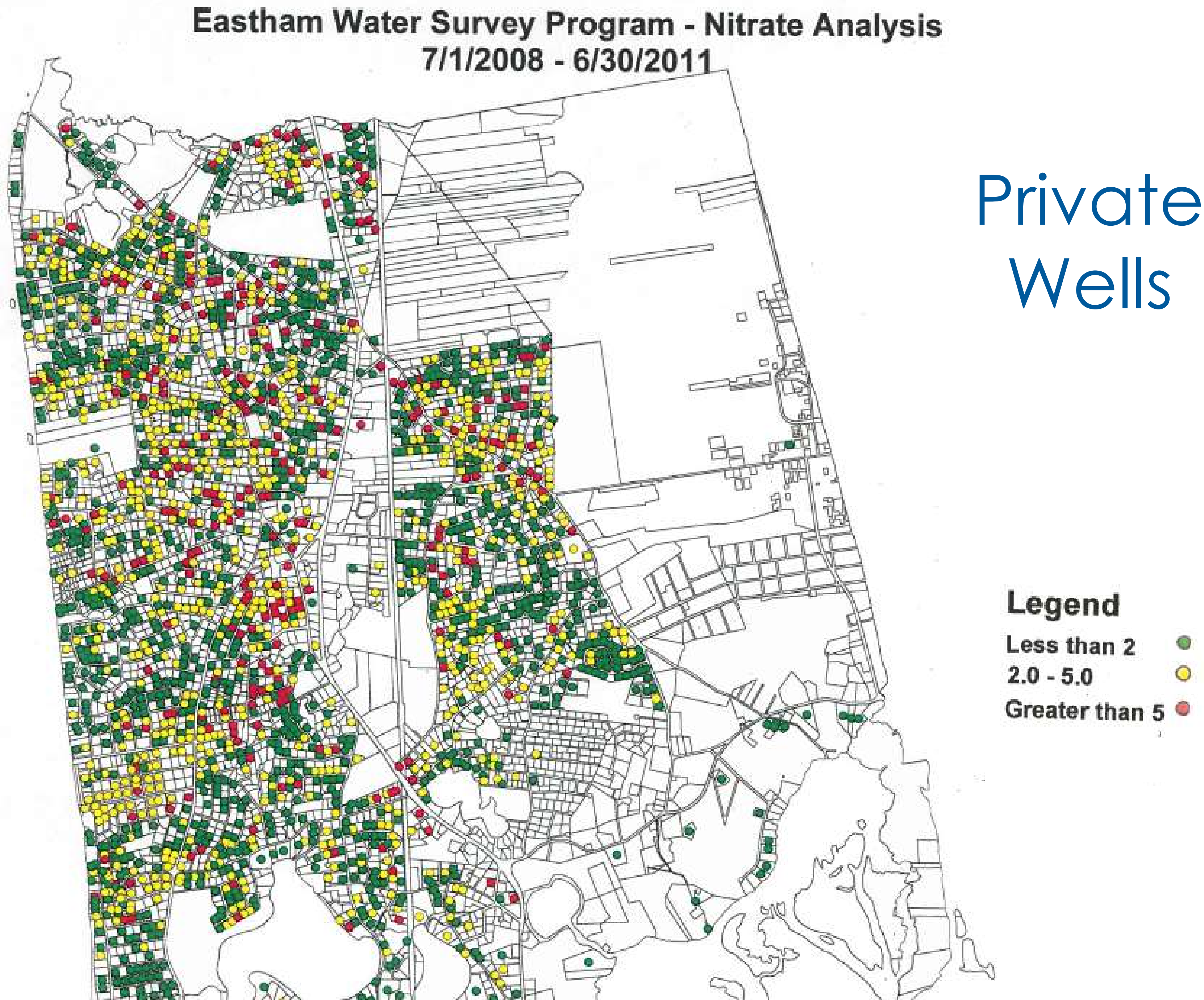
CAPE COD COMMISSION

Measured Nitrate in Cape Cod Streams

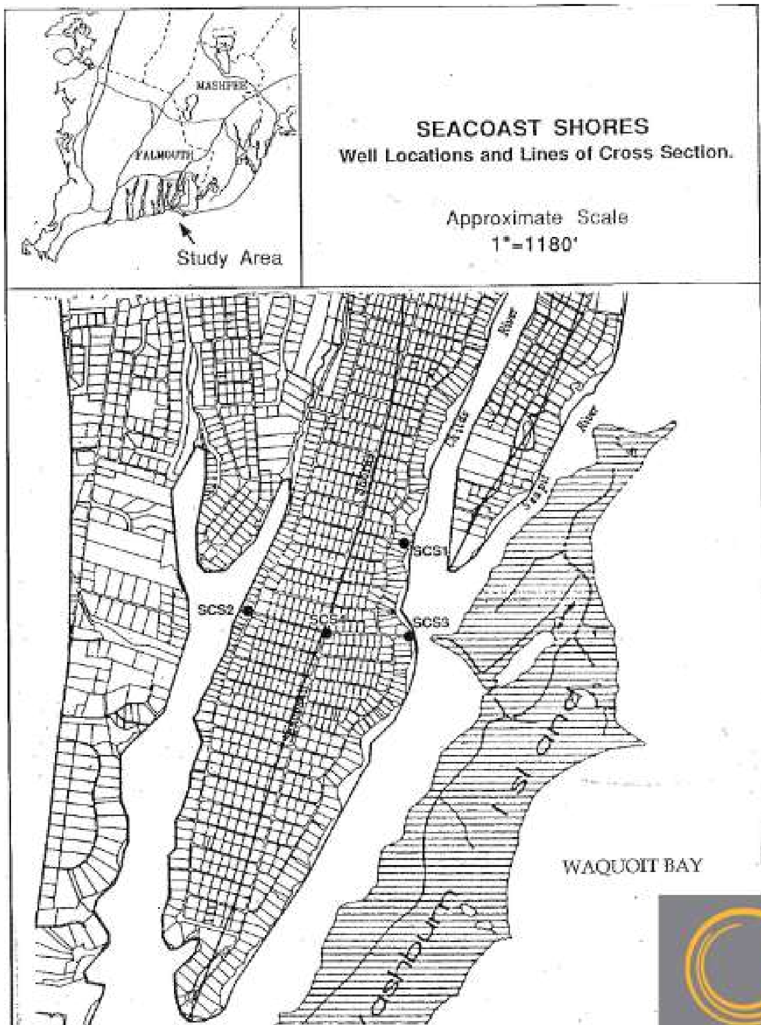
Background Nitrate concentration in pristine areas is <0.05 ppm

River	Flow m3/d	Nitrate Concentration (ppm)
Mashpee River	26233	0.318
Santuit River	13164	0.702
Bournes Brook	3766	0.543
Marstons Mills River	16000	0.480
Herring River (Wellfleet	28323	0.076
Quashnet River	41529	0.204
Coonamesset River	26593	0.565
Skunknett River	13925	1.130

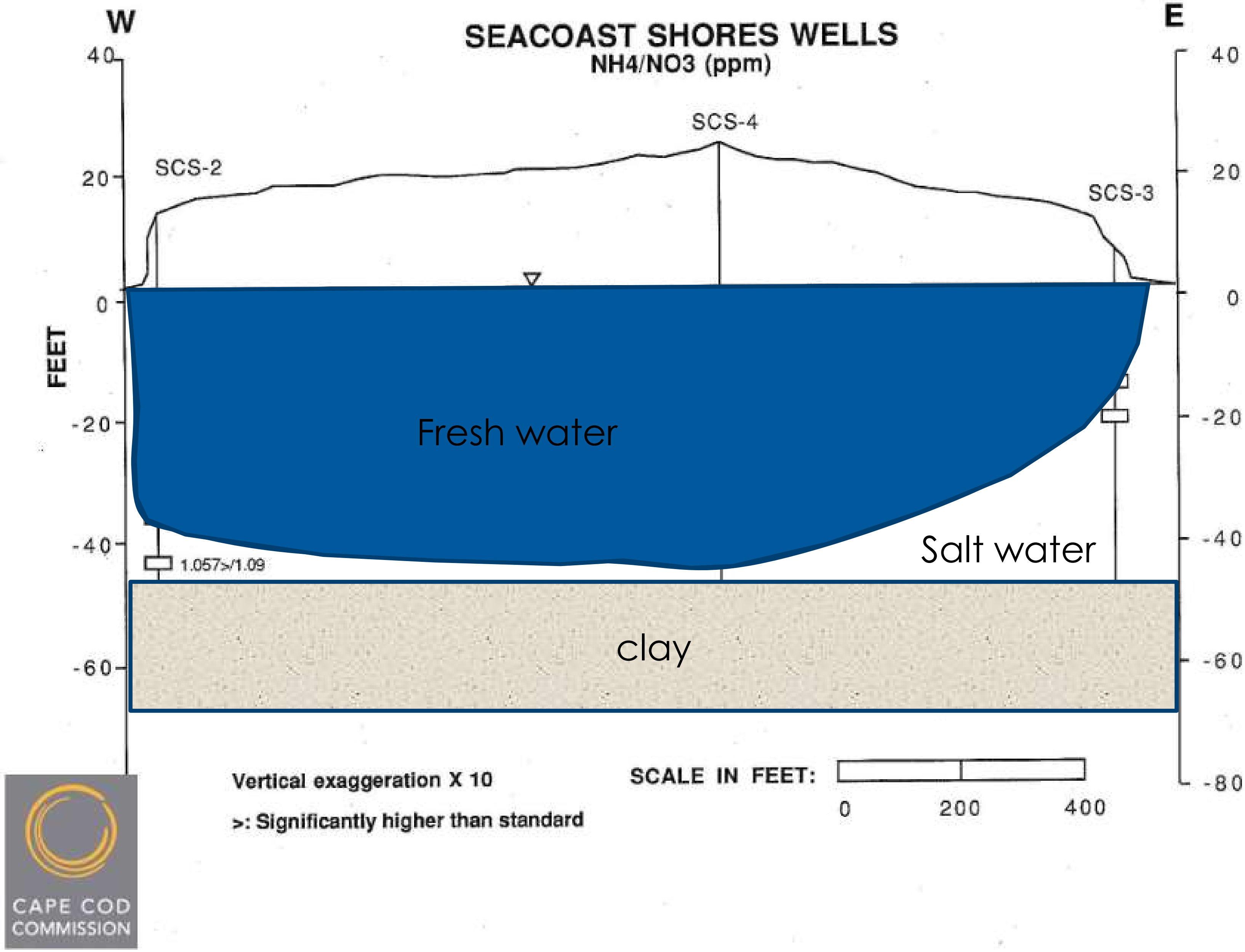
Private Wells

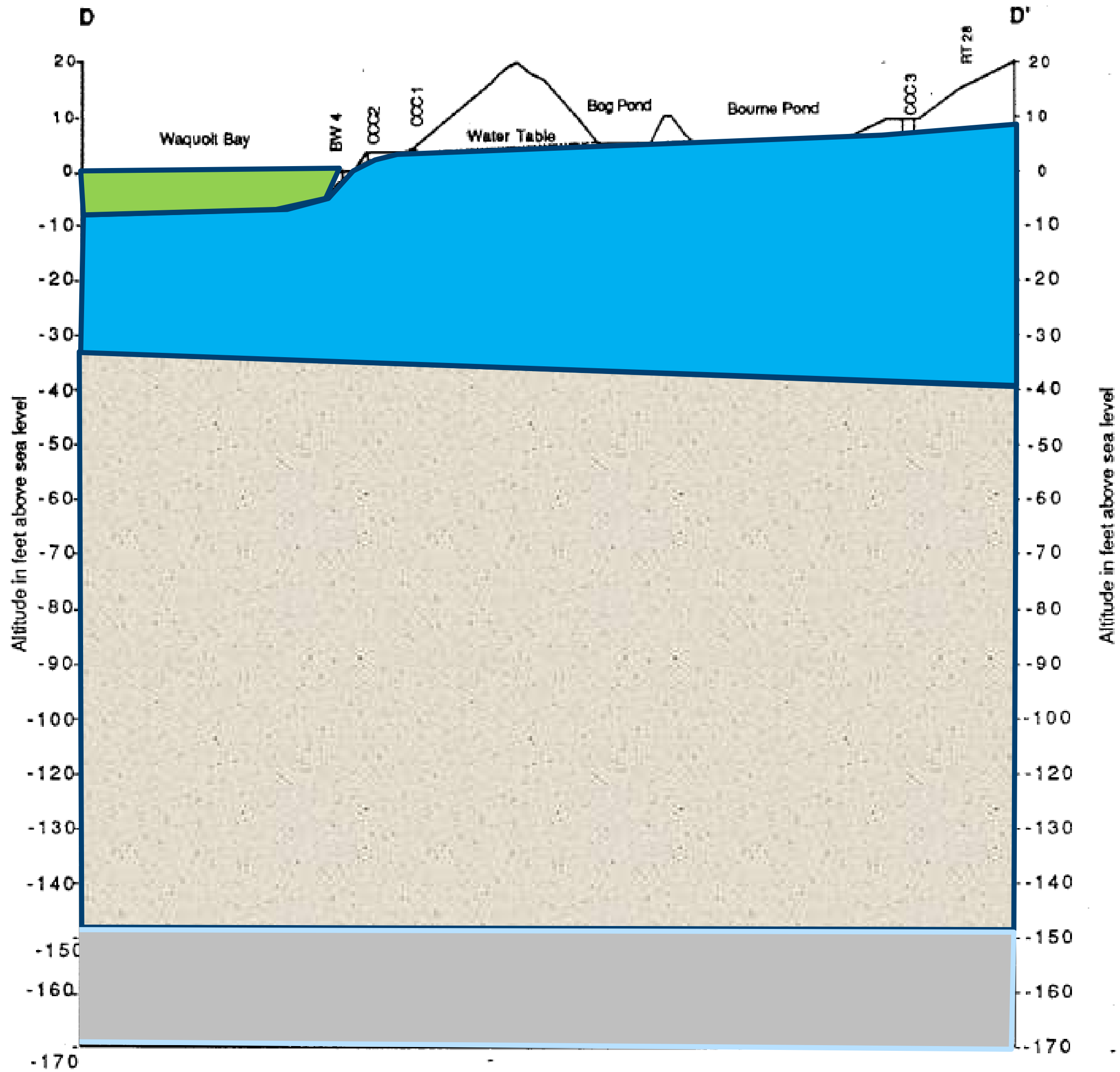


Assessing Non-point Source Nitrogen in Groundwater



CAPE COD COMMISSION


W
E
SEACOAST SHORES WELLS
NH4/NO3 (ppm)
SCS-2
SCS-4
SCS-3
FEET
40
20
0
-20
-40
-60
-80
1.057>/1.09
Fresh water
Salt water
clay
Vertical exaggeration X 10
>: Significantly higher than standard
SCALE IN FEET:
0
200
400
CAPE COD
COMMISSION



Vertical Exaggeration x 25

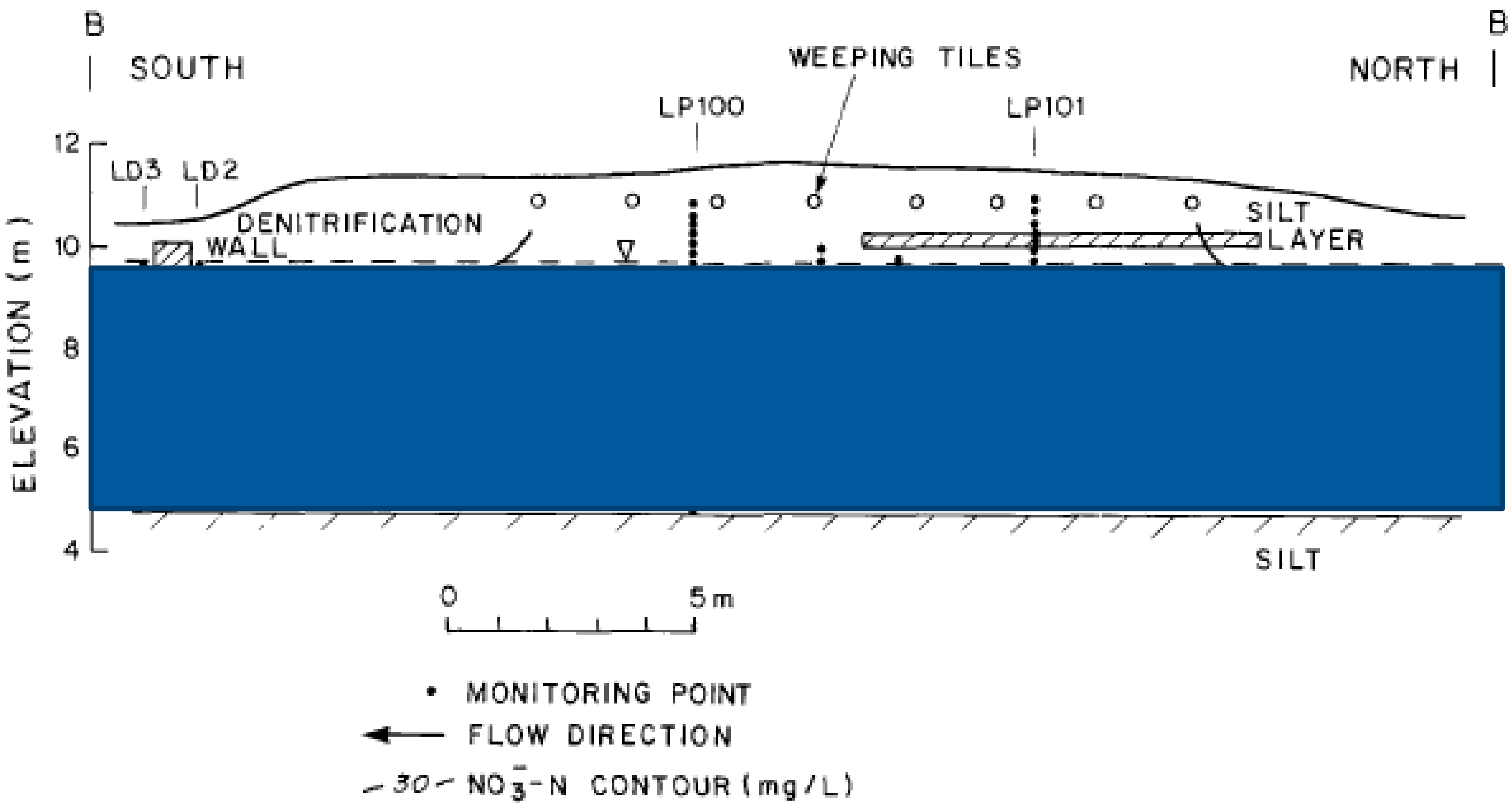
Scale
0 500 1000 Feet

Effect of Sewer Installation on Groundwater Quality on a Coastal Peninsula- Falmouth, MA

- Monitoring network in a densely-developed coastal neighborhood
- Assessing distribution of nitrogen in GW
- Evaluating impacts of sewering on reduction of nutrient loads to coastal ponds
- Examining occurrence of emerging contaminants from on-site wastewater systems

PRB for Wastewater Nitrogen

- 1995 – Robertson and Cherry
  - Groundwater V33 Shallow emplacements



PRBs for Nitrogen Remediation on Cape Cod

- Ashumet Valley Nitrogen Offsets Committee (1998)
- Waquoit Bay Nitrex Wood chip PRB pilot(s) MBL/Lombardo (2005)
- Mashpee CWMP 1st Proposal for Watershed application of Nitrex PRBs Lombardo (2008)
- 208 Plan Update Alternative Technologies (2013-2016)
- Falmouth WQAC PRB Study by CDM-Smith (2013)
- 208 Monitoring Committee –Protocols (2014)

Implementation of 208 Plan Update
PRBs on Cape Cod

- Falmouth Hydrogeological Assessment(s)
  Acapesket + Shorewood
  (2014 +2015)
- EPA Site Characterization of 5 Sites
  (June 2015)
- Eastham Preliminary Site Characterization at Salt Pond
  (June 2016)
- Orleans 250 ft PRB Pilot at Eldridge Park
  (November 2016)

PRB Linear Foot Costs over 20 years @ 5% Interest

- $4,300 Shallow PRB -CDM Cost
- $5,300 Deep PRB -CDM Cost
- $4,000 -208 Tech Matrix Cost
- $3,440 Orleans Pilot -AECOM

Cost per Kilogram Removed

Groundwater N Concentration (ppm-N)

$/lf	1	2	3	4	5
3,500	2,265	1,133	755	566	453
3,750	2,427	1,213	809	607	485
4,000	2,589	1,294	863	647	518
4,250	2,750	1,375	917	688	550
4,500	2,912	1,456	971	728	582
4,750	3,074	1,537	1,025	768	615
5,000	3,236	1,618	1,079	809	647

* Calculated as 20-yr PV per N removed over 20-yr planning period; assumes PRB is removing 72.5% of nitrogen from 75 gallons of groundwater per day per linear foot of PRB

Lesson Learned

- Site specific information is imperative
- Geology
  - Depth and stratigraphy
- Groundwater Flow
- Nitrogen concentrations
- Nitrogen Reduction Costs can be reduced under the right conditions

The End