Protecting Our Estuaries – Application of Permeable Reactive Barriers for Sustainable Nitrate Removal

NEWEA 2015 Annual Conference

Ed Sanderson, AICP, P.E.

Technical Session

No. 1

January 26, 2014

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Dwight Dunk

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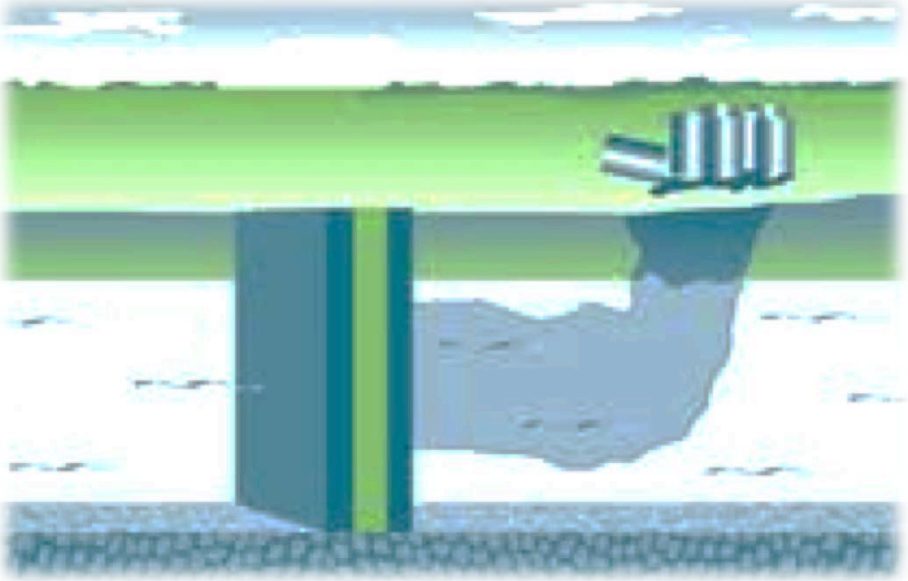
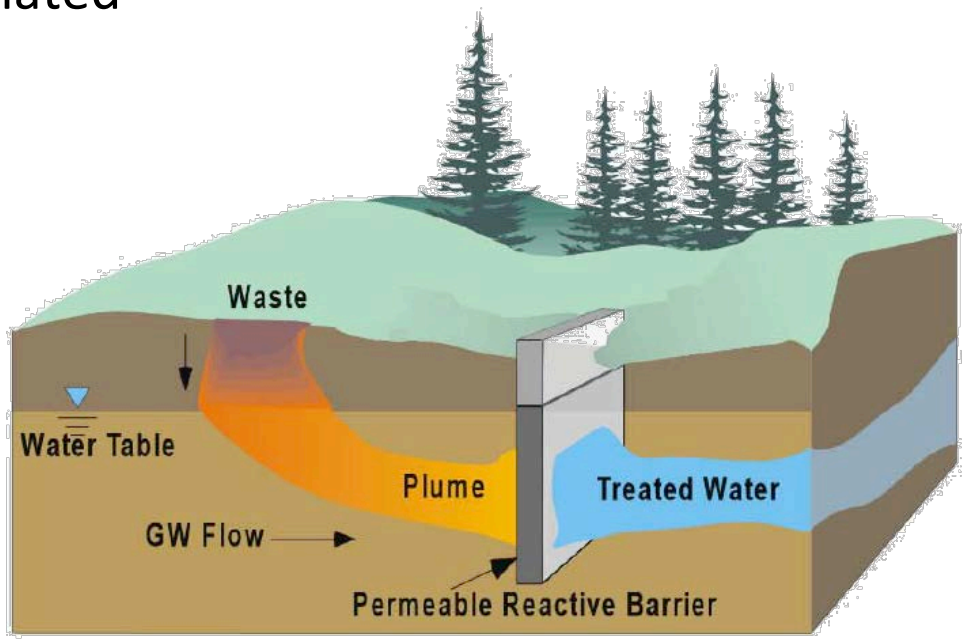
Outline

- Permeable Reactive Barriers (PRBs) defined
- Case study for application in Falmouth, MA



Permeable Reactive Barriers

- In-situ treatment zone
  - Intercept and treat contaminated groundwater
- Iron based PRBs
  - From innovative to accepted
  - Traditionally used for:
    - Chlorinated solvents
    - Metals
    - Radionuclides
- Biowalls
- Other media/construction types

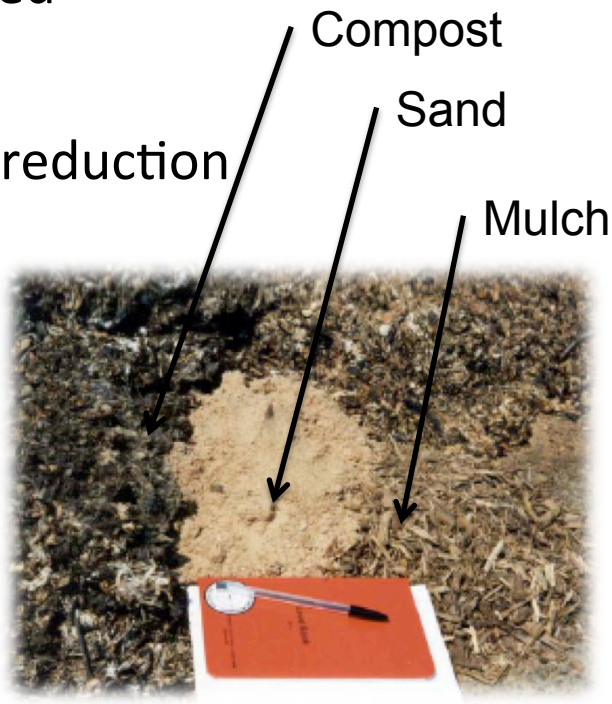


PRBs as a Sustainable Solution

- Perform under hydraulically passive means
- Groundwater is not removed or discharged
- Treatment material often consists of recycled media
  - Carbon sources
    - mulch
    - compost
    - sawdust
    - wheat straw
    - emulsified vegetable oil
- USEPA Green Remediation
  - Energy requirements
  - Air emissions
  - Material consumption and waste generation

PRBs for Nitrate Removal

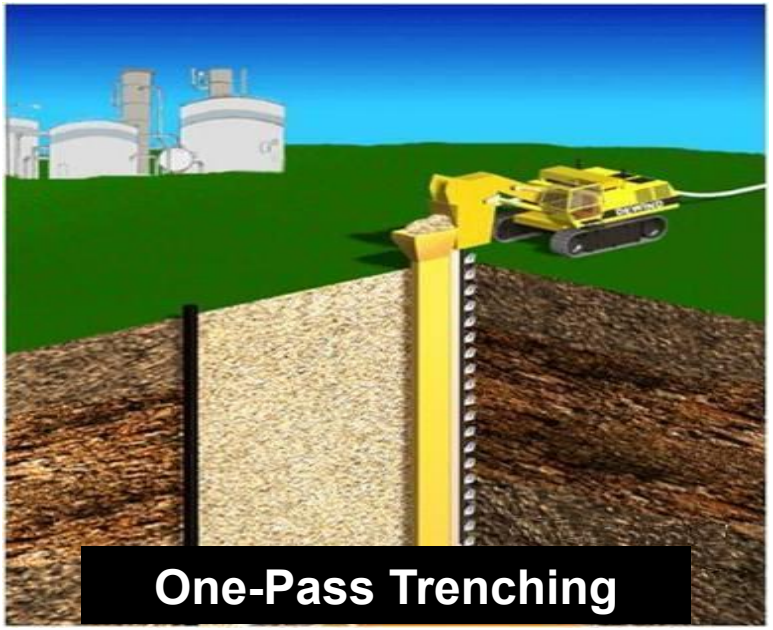
- Focus on PRBs implemented for nitrate removal
  - 17 pilot scale and 10 full scale examples
  - 70 to 100% nitrate removal can be achieved
- Reactive media
  - Wood-based organic media for biological reduction
  - Food-grade “emulsified” vegetable oil
- Depths
  - Typically 15 to 35’ – single pass method
  - Deeper with other techniques
  - Around 45’ – injection methods considered



PRB Media

Construction Techniques

One-Pass Trenching



One-Pass Trenching

Traditional Trenching

Traditional Trenching

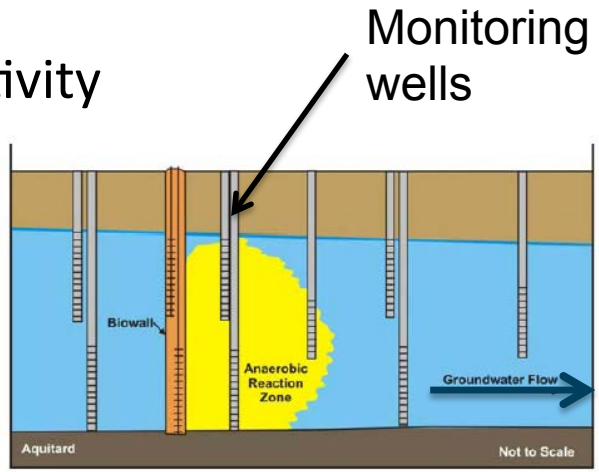
Construction Techniques

Augured Boreholes or Caissons

Injection Wells

Typical PRB Design Considerations

- Hydrogeological
  - Understanding GW flow to intercept nitrate plume
- Nitrate concentration
  - Position PRB to target highest concentration
- Infrastructure and land use
  - Avoid buildings or utilities that cannot be moved
- Aquifer properties
  - Geochemistry; matching hydraulic conductivity
- PRB media thickness



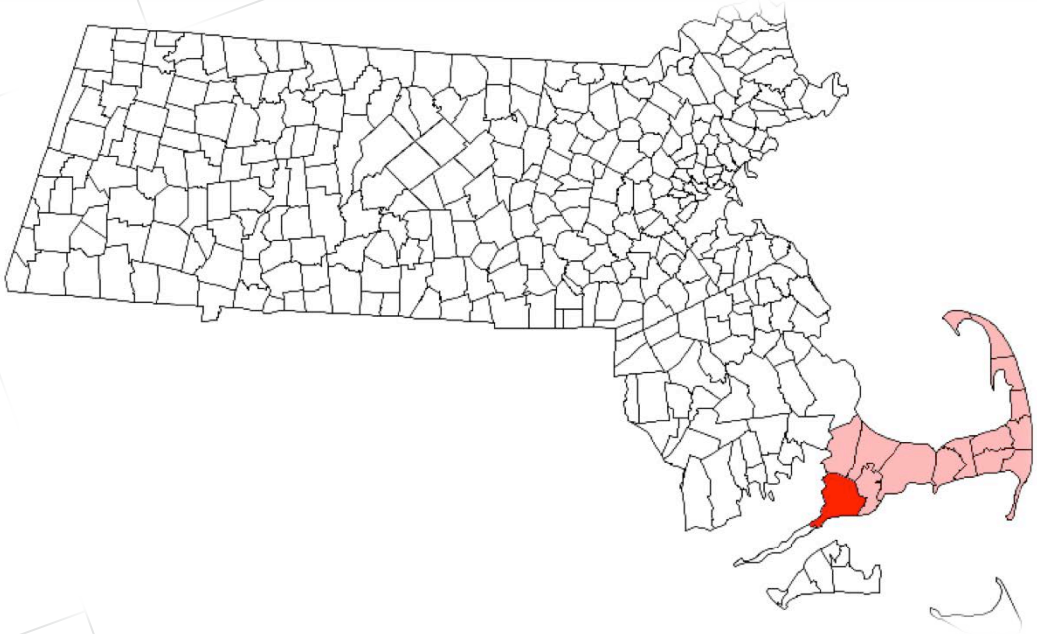
Potential Downgradient Impacts

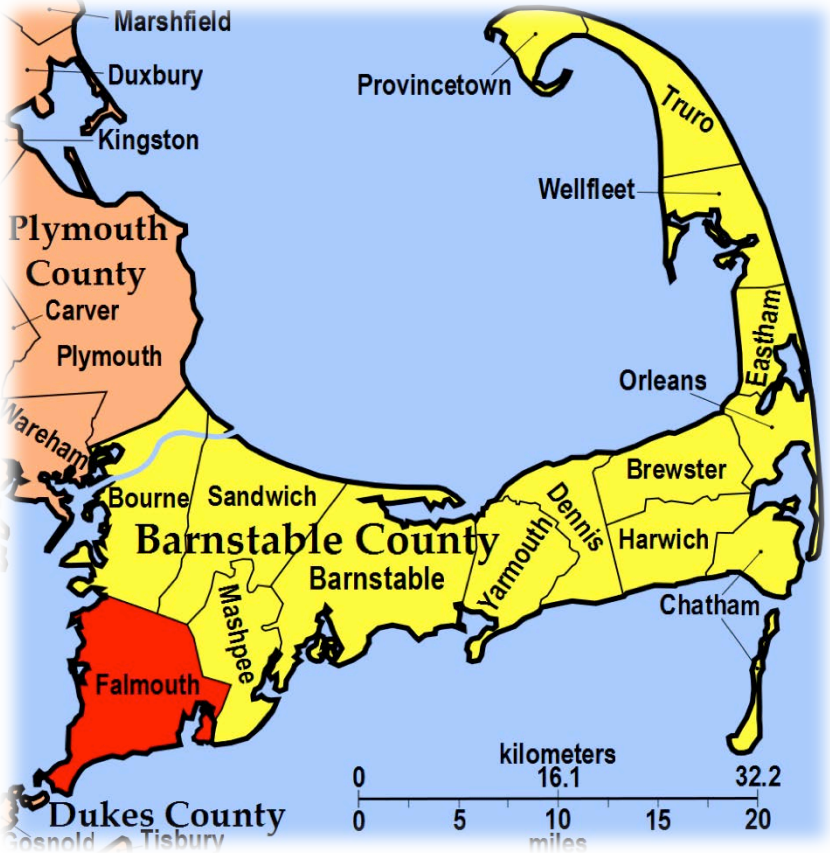
- Lessons learned from similar projects
  - Geochemical changes
    - Water quality impacts
    - Aesthetics
- Proper grading during construction

PRB Cost Drivers

- Construction
  - Construction technique
  - Depth of installation
  - Nature of the geologic materials present
  - Surface/subsurface obstructions (e.g., buildings and utilities)
  - Effectiveness of the media at treating the contaminants
- O&M
  - Effective lifespan of media
  - Long-term maintenance and monitoring

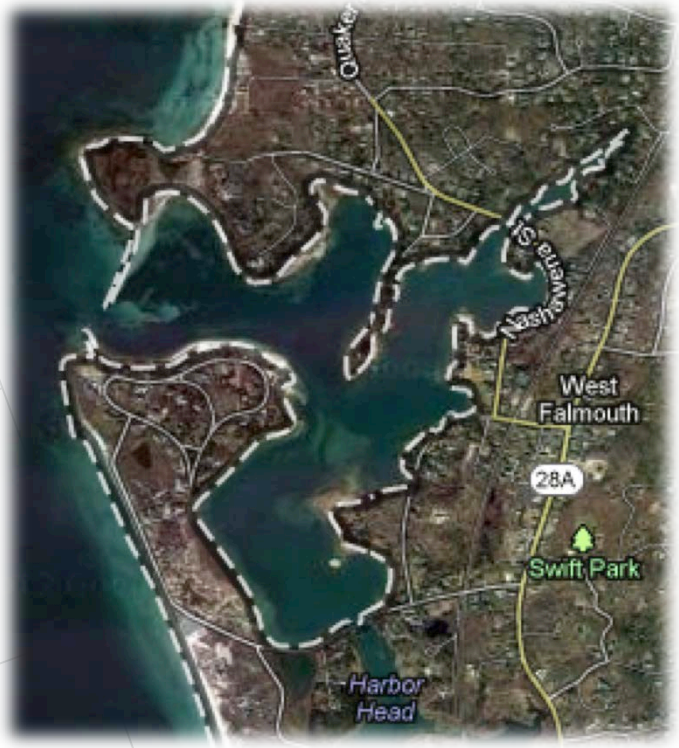
Falmouth, MA Case Study

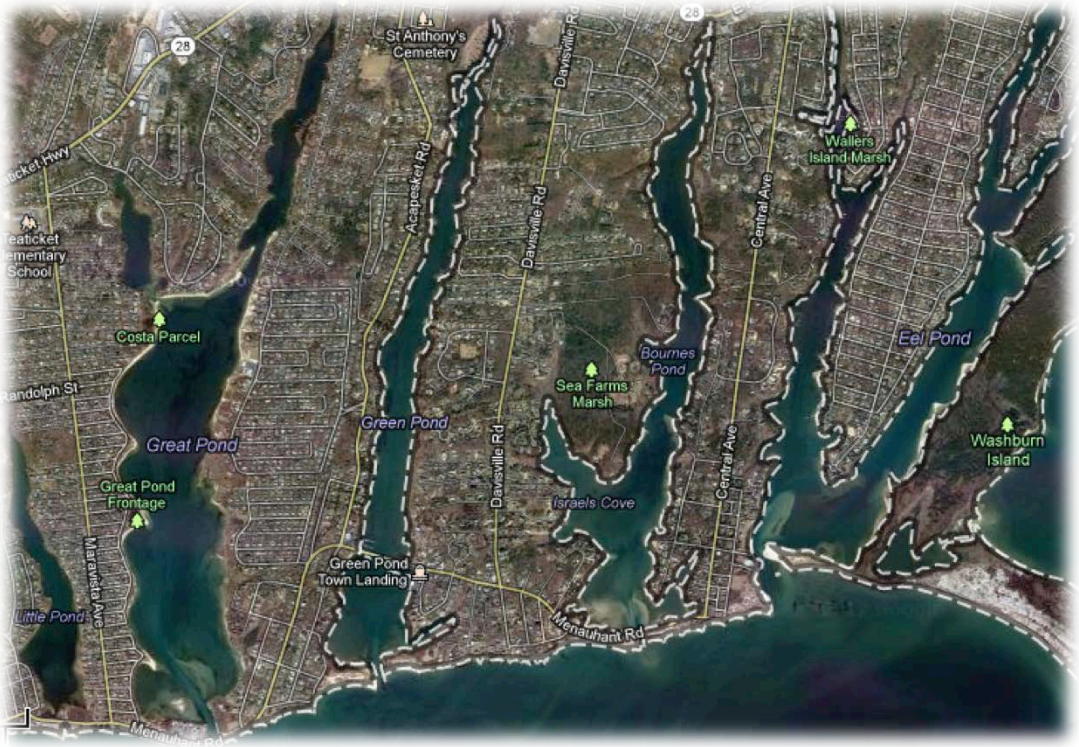




Falmouth Case Study: Problem Statement

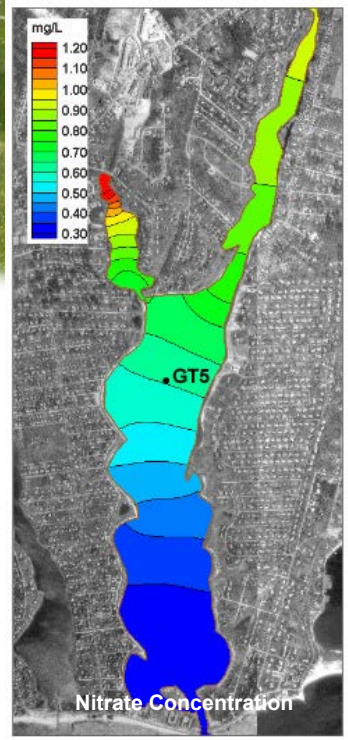
- Water quality issues in the estuaries along the south coast
- Plume from WWTP effluent in W. Falmouth Harbor





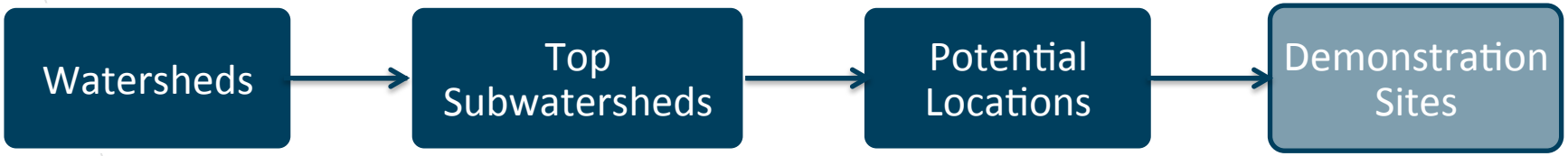
Project Goals

1. Confirm PRB technology is appropriate for nitrate removal
2. Select the two best locations for demonstration projects



Site Selection and Prioritization

- Two areas of Town (W. Falmouth; South Coast)
- Watersheds to top subwatersheds
- Top subwatersheds to 18 potential PRB locations
- Discussions and site visits
- 10 potential PRB locations prioritized
- 3 sites identified for preliminary design



Screening Step 1

- Step 1 criteria (watersheds to top subwatersheds)
  - Land use or housing density
  - Proximity to existing West Falmouth WWTF plume
  - Vertical Extent of Nitrate Contaminated groundwater

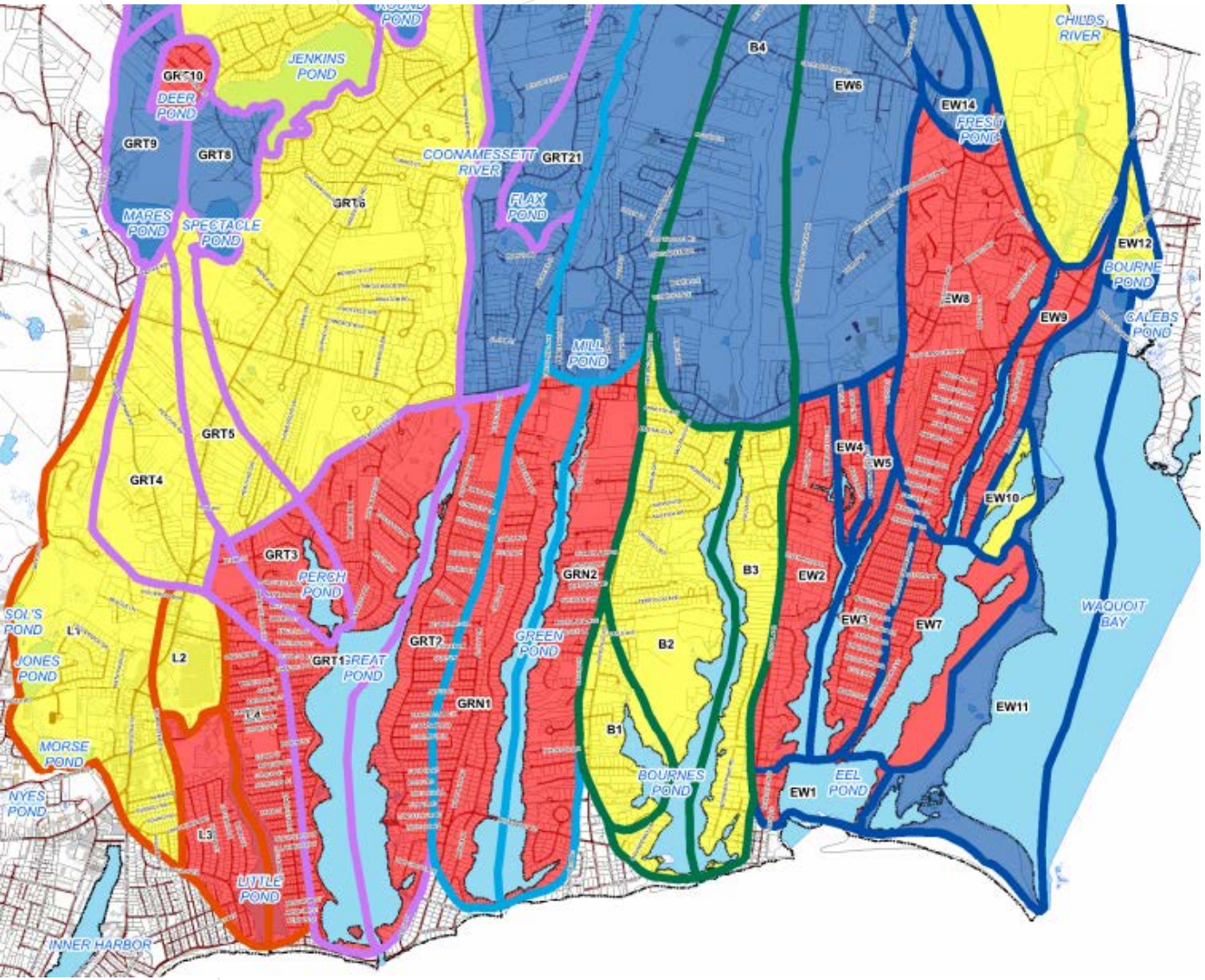
Rating

High

Medium

Low

Existing Land Use Density

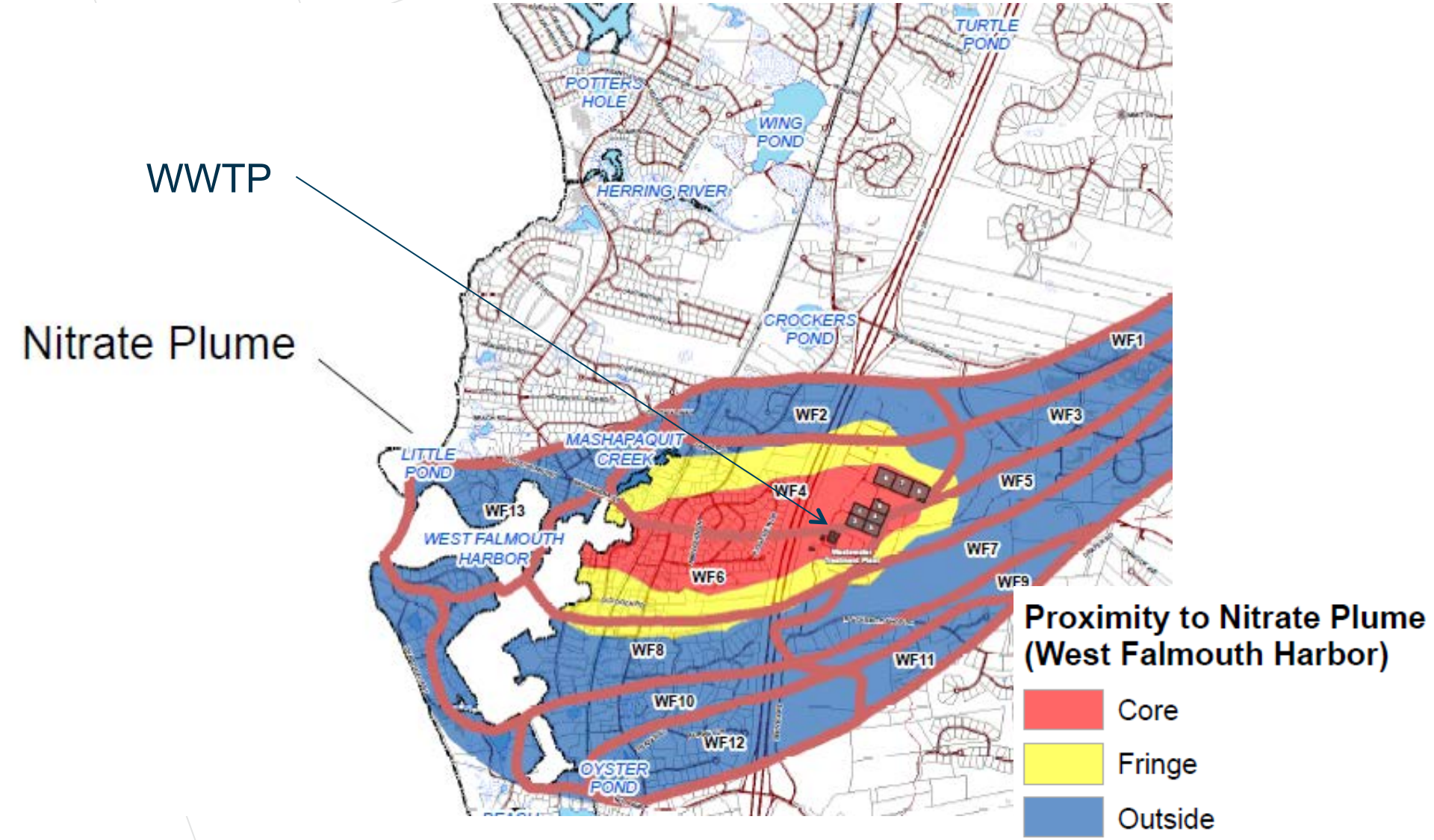


Parcels per Square Mile of Subwatershed Area (Ponds/Estuaries)

- >1000
- 500 - 1000
- < 500

- Bournes Pond
- Eel Pond and Waquoit West
- Great Pond
- Green Pond
- Little Pond
- Oyster Pond
- West Falmouth Harbor
- Town Boundary
- Lake/Pond
- Stream
- Wetland
- Roads
- Parcel Boundary

Nitrate Plume from WWTP



Screening Step 2

- Step 2 criteria (Top subwatersheds to potential PRB locations)
  - Property ownership
  - Availability of existing data and monitoring locations
  - Potential Funding/Collaboration

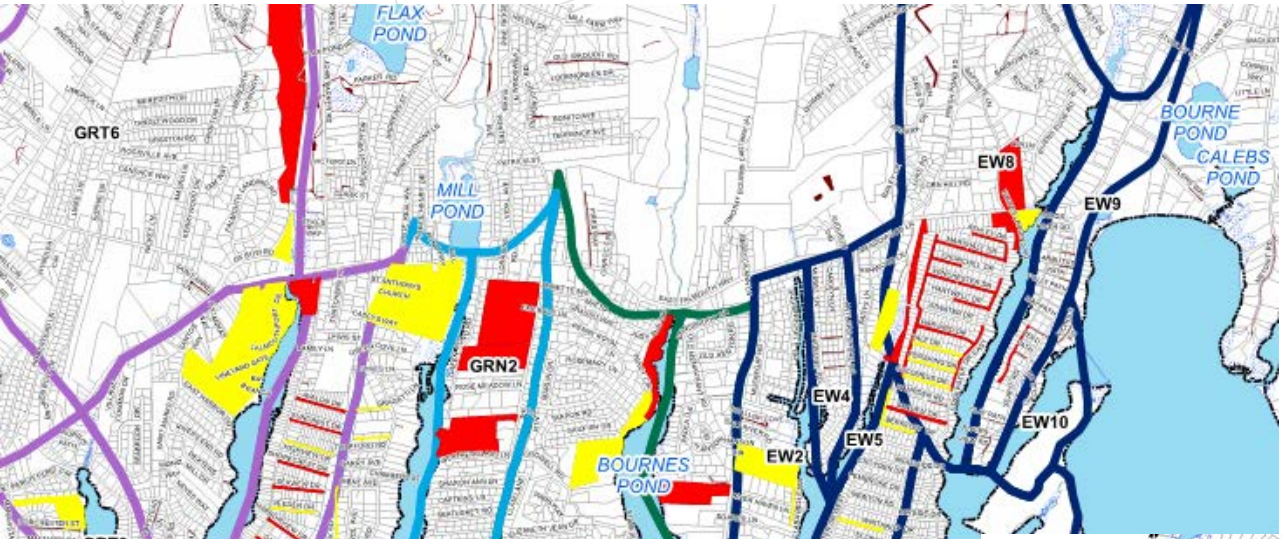
Rating

High

Medium

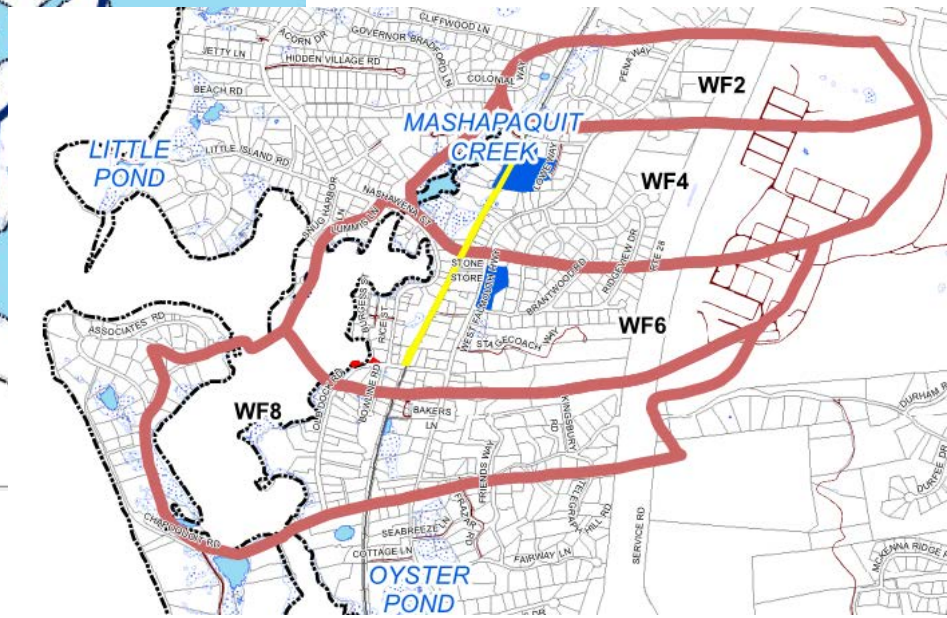
Low

Property Ownership

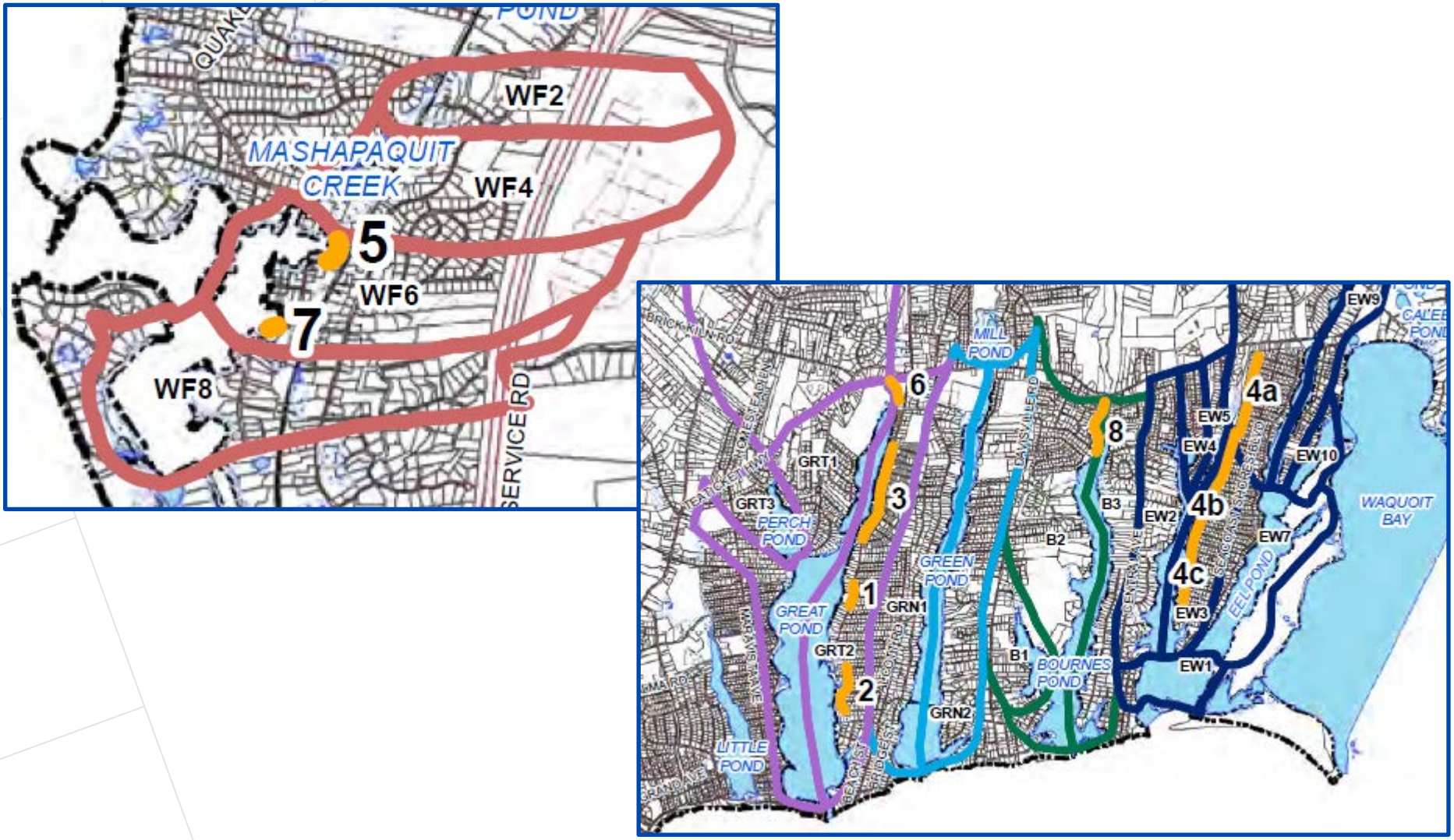


Property Ownership

- >500', Town Owned, Single or Adjacent Parcels Including Unpaved Roads
- >500', Non Town Owned, Single Parcel Including Unpaved Roads
- >500', Non Town Owned, Two Parcels

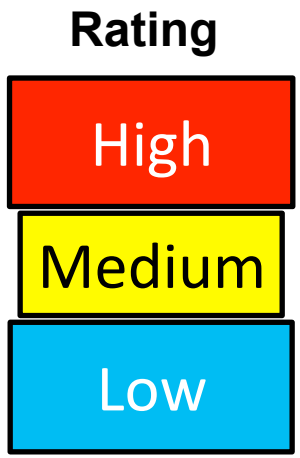


10 Potential PRB Locations



Screening Step 3

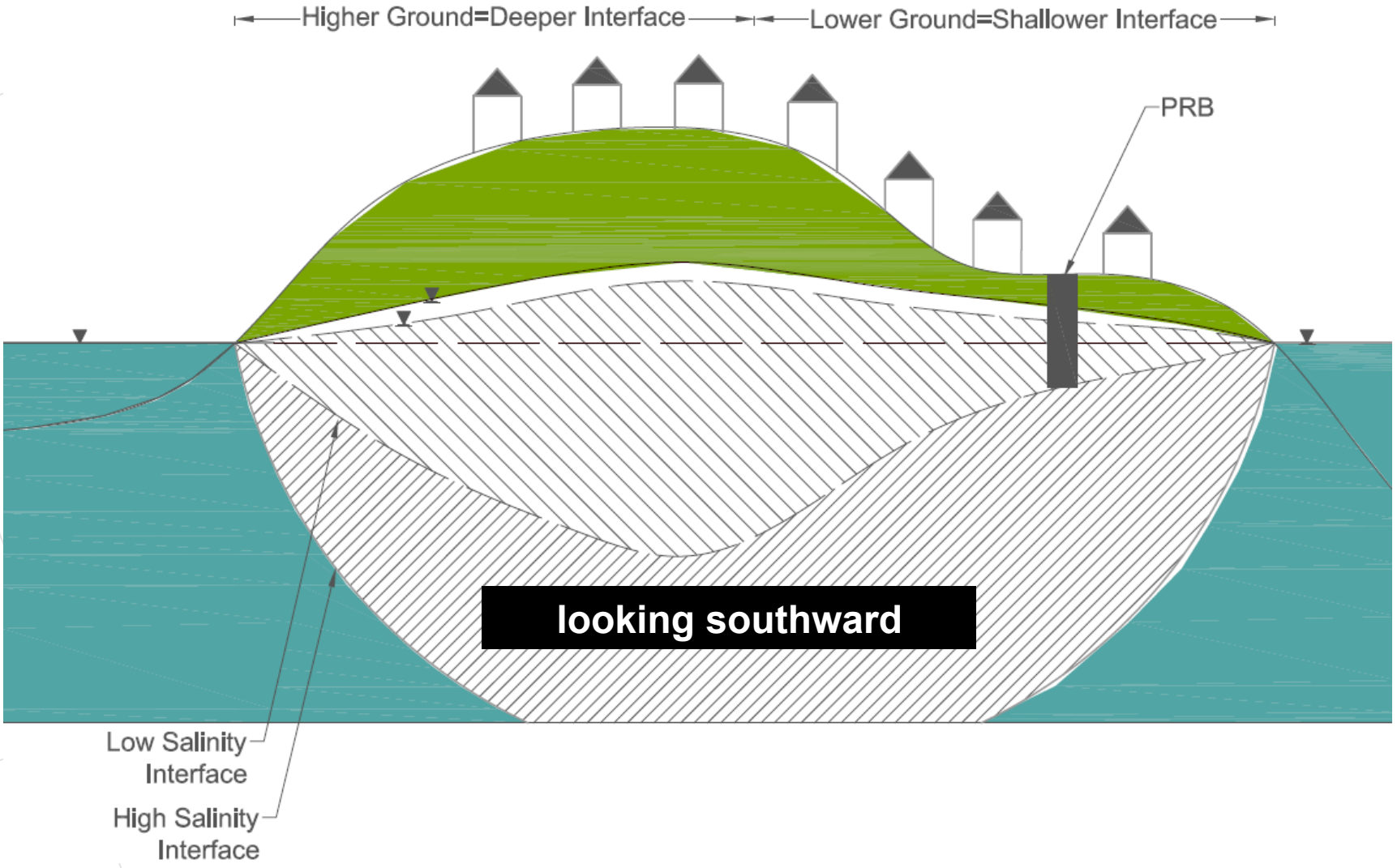
- Step 3 criteria (Prioritization of potential PRB locations)
  - Site accessibility
  - Applicability to other, future sites
  - *Surficial geologic mapping (W. Falmouth)*
  - Potential for utility conflicts
  - Ease of monitoring, existing wells and data
  - Permitting requirements
- Three sites – Great Harbors, Seacoast Shores, West Falmouth Harbor



Nitrate Removal

	South Coast		West Falmouth Harbor
	Great Harbors	Seacoast Shores	
Homes	41	46	
Nitrate removal (pounds/year)	300	350	1,600 - 2,250
Length of PRB (feet)	590	525	350

Groundwater/Saltwater Interface



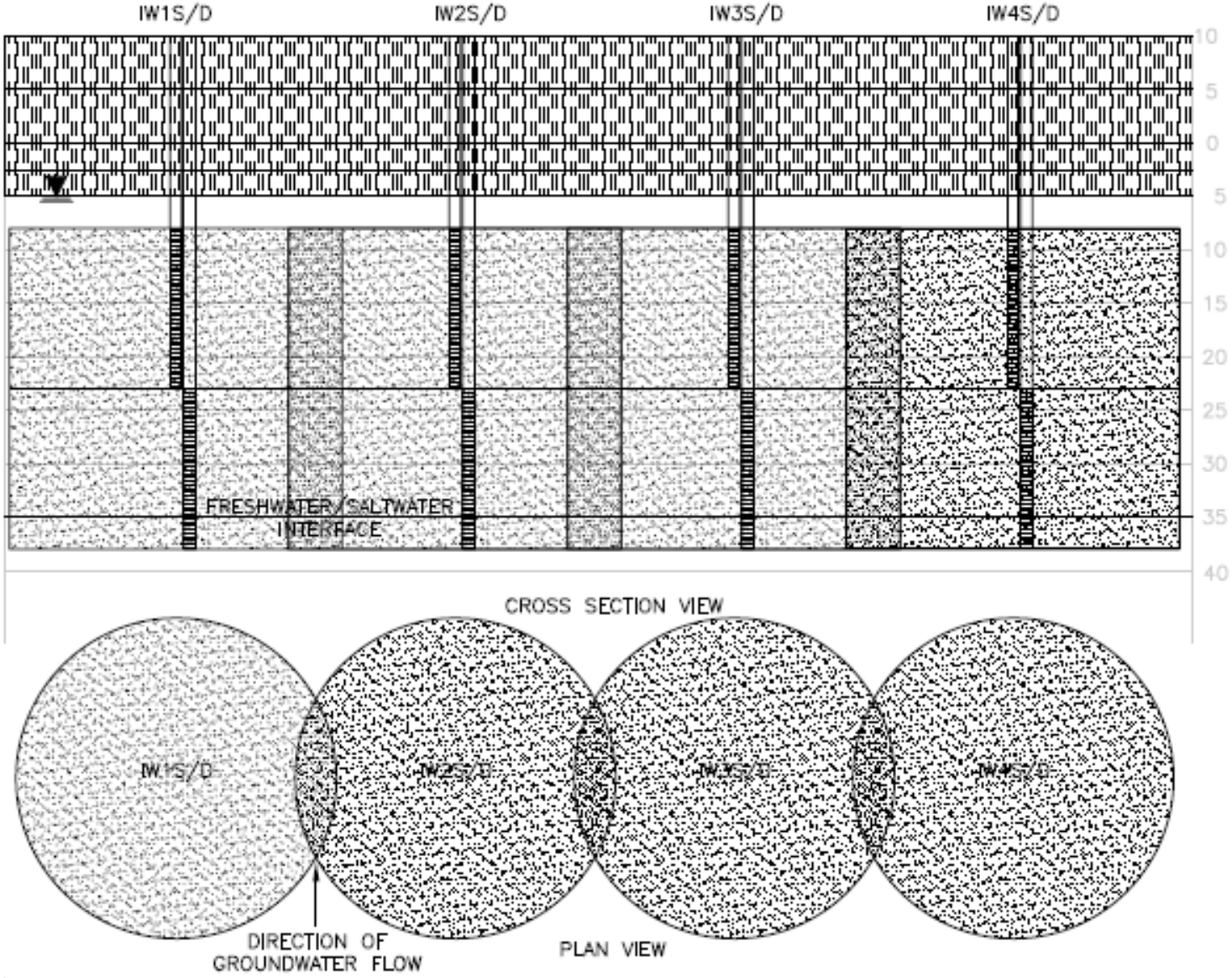
Injection Well PRB for Nitrate Reduction

- Radius of influence
- Emulsified vegetable oil
  - Re-inject every 3-5 years
  - EOS 100 or equivalent
    - Proven for nitrate treatment
    - Fully fermentable
    - Longer retention time

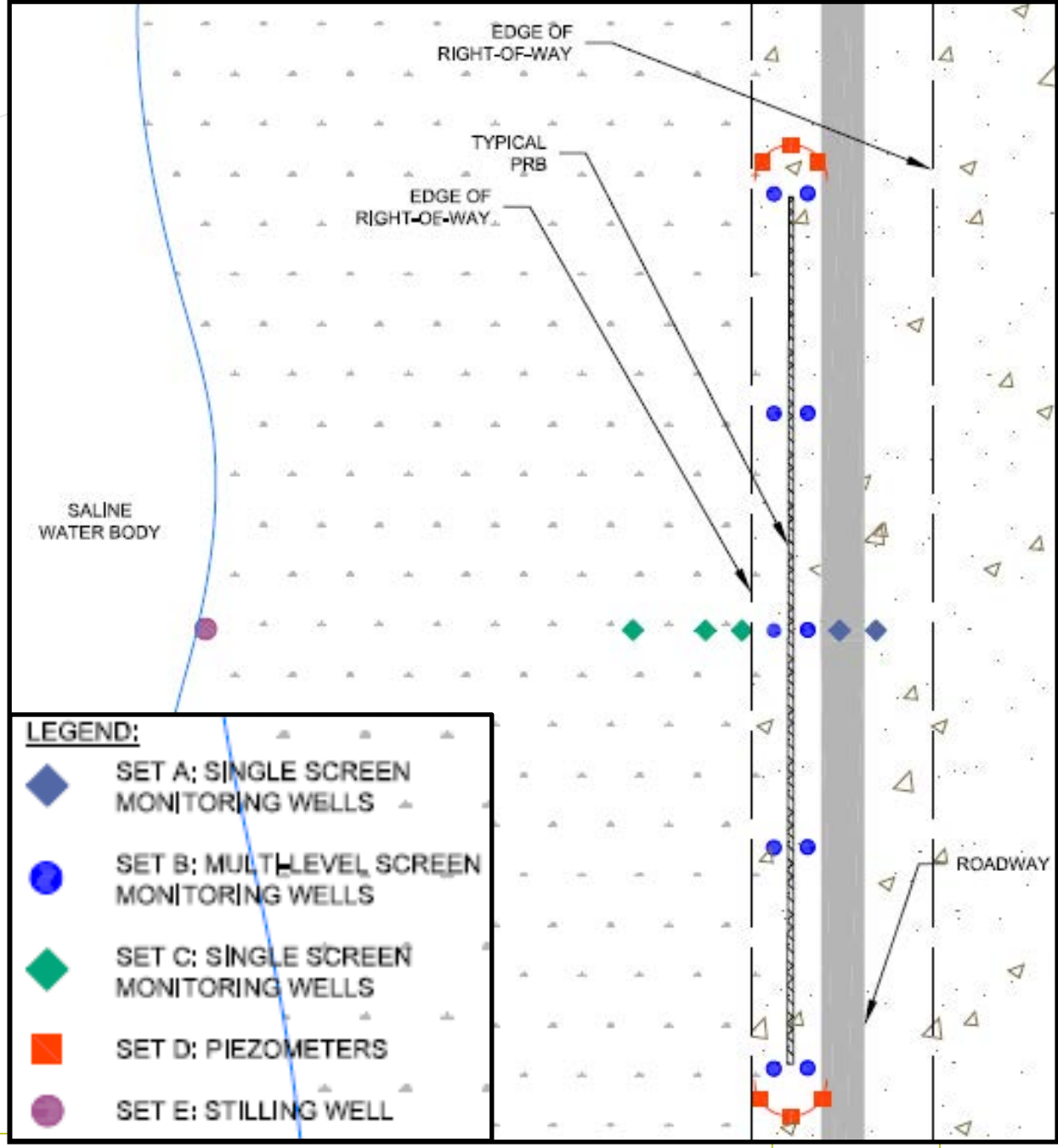
- Examples of injection well method PRB for nitrate reduction
  - Perchlorate as a surrogate
  - Various feedlots in the Midwest and Northwest
- Downgradient impacts

Seacoast Shores

Typical PRB Injection Well Array



Groundwater Monitoring Program



Construction Method Costs (Millions)

	Great Harbors	Seacoast Shores	West Falmouth (shallow)	West Falmouth (deep)
Continuous One-Pass Trench Excavation	$1.39	Not Applicable	$1.05	Not Applicable
Traditional Supported Trench Excavation	$1.32	$1.33	$0.89	Not Applicable
Caisson Installations	$2.74	$2.48	$1.61	Not Applicable
Injection Wells	**$0.67**	**$0.61**	**$0.40**	**$1.07**

Next Steps

- Design/Permitting
- Seek funding
- Construction
- Continuous monitoring

Take Away

- PRBs have potential for application in Falmouth, MA to reduce nitrate to estuaries
- Need for long-term full scale installation data
- Prove to regulatory agencies that PRBs are a sustainable, feasible option
- Need to understand freshwater/saltwater interface to capture nitrogen; critical to PRB depth

Comments & Questions

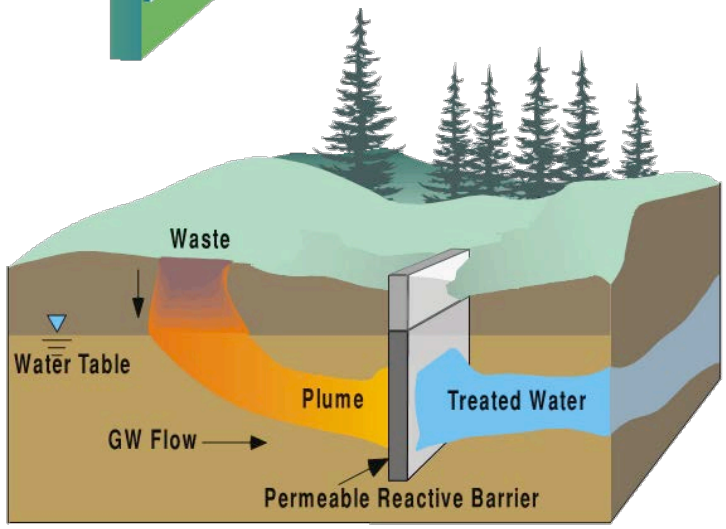
Final Report can be found on Town website at:

http://www.falmouthmass.us/waterq/PRB%20executive%20summary.pdf

Extra Slides

PRB Design Resources

- Interstate Technology and Resource Council
  - Permeable Reactive Barriers: Lessons Leaned/New Directions (2005)
  - Permeable Reactive Barrier: technology Update (2011)
- USEPA
  - Permeable Reactive Barrier Technologies for Contaminant Remediation (1998)

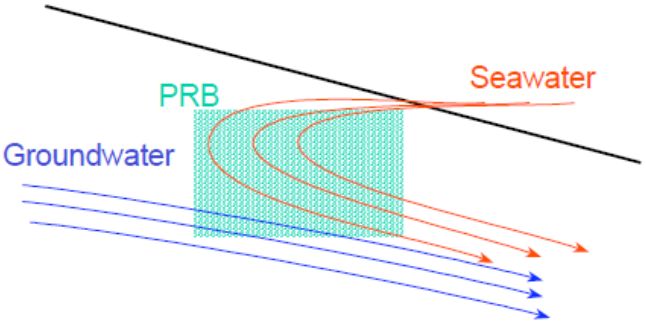


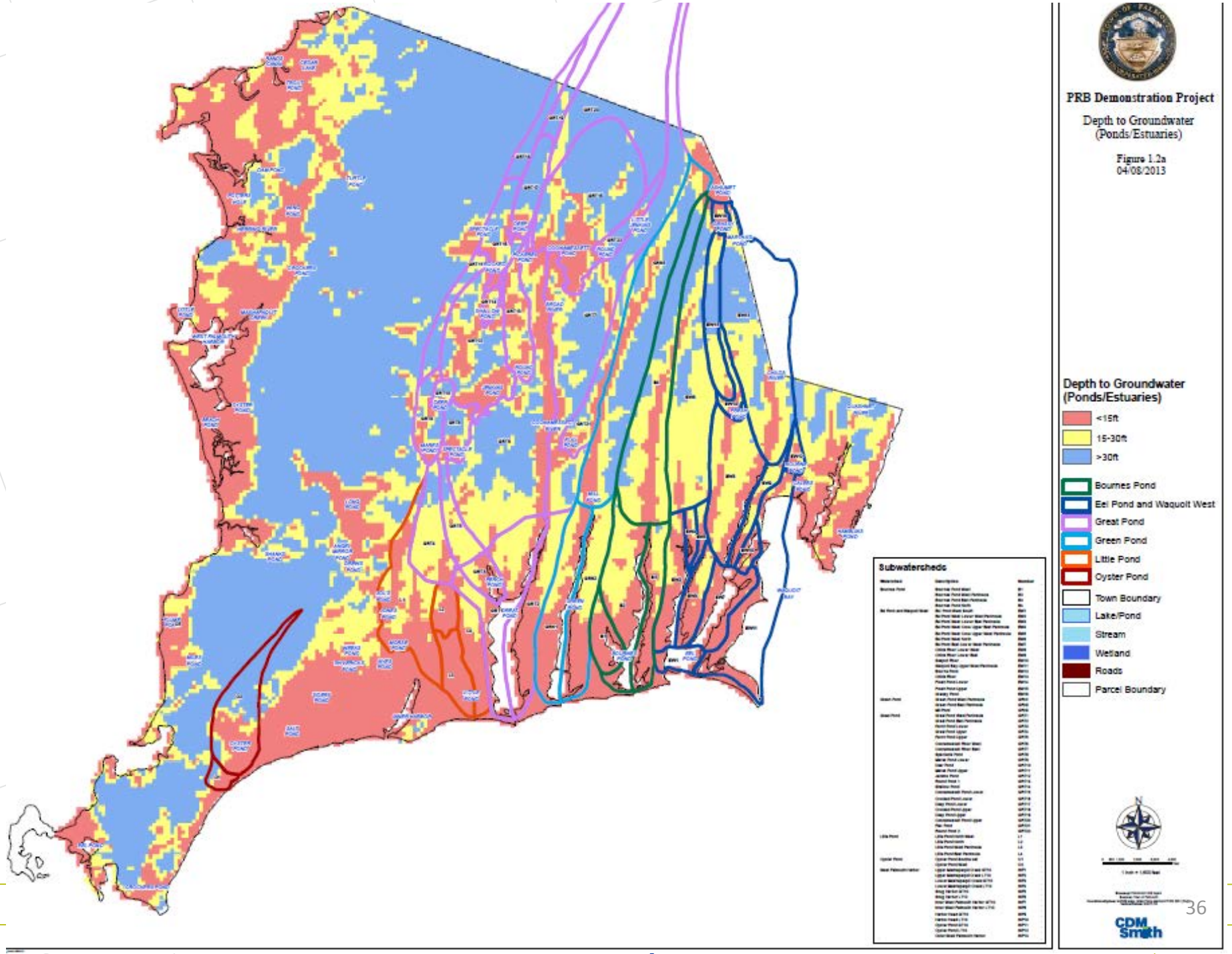
Summary of Previous Pilot Tests in Falmouth

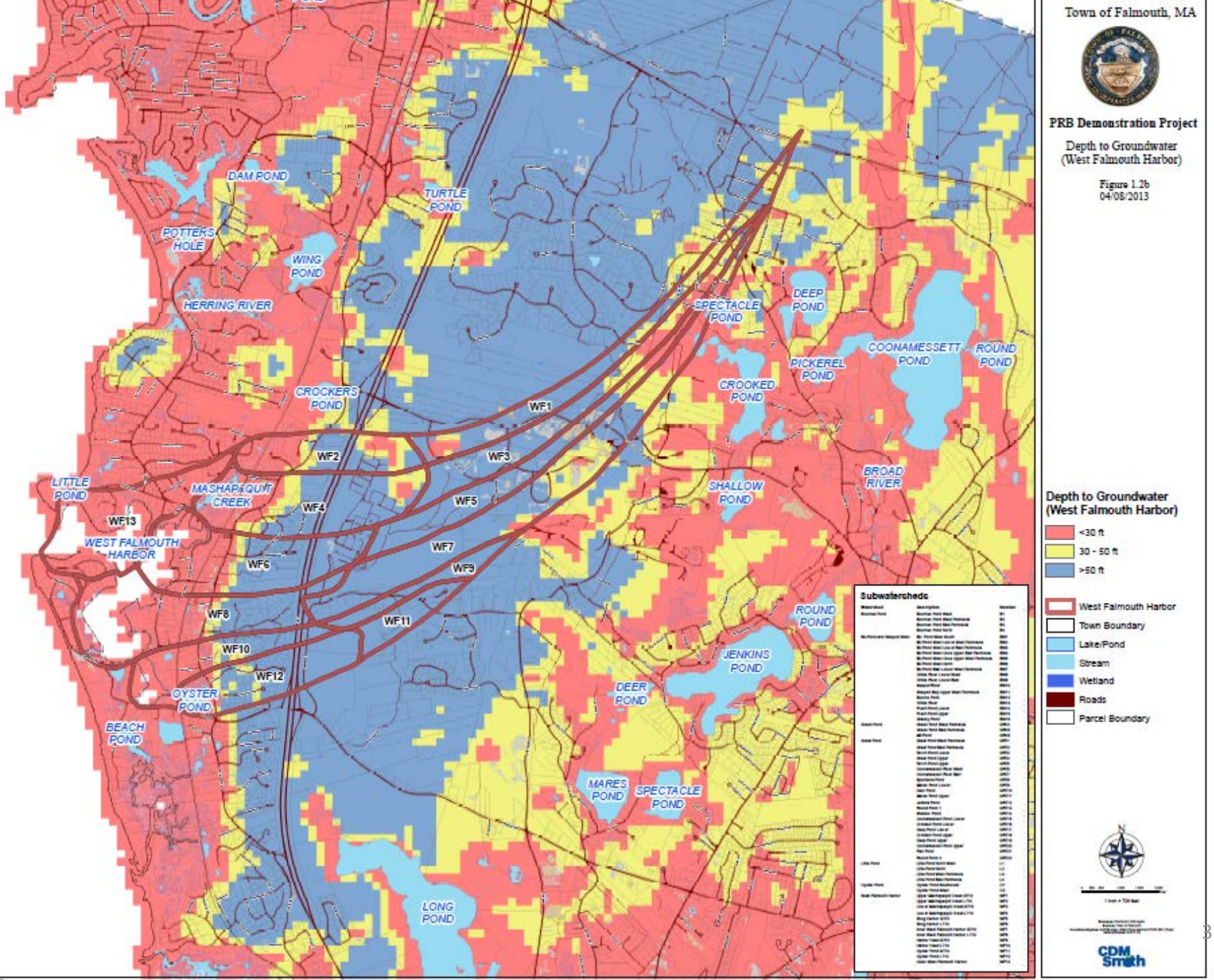
- Two NITREX™ PRBs installed in Falmouth in 2005
  - Waquoit Bay (nitrate ~12 mg/L)
  - Childs River (nitrate ~31 mg/L)
  - Dimensions:
    - Length 40-65’
    - Width 6-12’
    - Depth 6’
  - Depth to groundwater: 1.5’
  - Close proximity to coastal estuarine environments

Results of Previous Pilot Tests in Falmouth

- Nitrate leaving the PRBs averaged <0.1 mg/L
- However, consequences of tidal water flowing through the top of the biowall include:
  - Driving plume flow path downward
  - Advection of sulfate into PRB, causing sulfate reduction and significant hydrogen sulfide production
  - Only partial denitrification of nitrate into nitrogen gas; rather formation of ammonium
  - Potential decreased longevity of biowall
- Proximity to surface caused iron-oxide staining of beach




PRB Demonstration Project
Depth to Groundwater
(Ponds/Estuaries)
Figure 1.2a
04/08/2013
Depth to Groundwater
(Ponds/Estuaries)
<15ft
15-30ft
>30ft
Bournes Pond
Eel Pond and Waquoit West
Great Pond
Green Pond
Little Pond
Oyster Pond
Town Boundary
Lake/Pond
Stream
Wetland
Roads
Parcel Boundary
Subwatersheds
CDM Smith


Town of Falmouth, MA
PRB Demonstration Project
Depth to Groundwater
(West Falmouth Harbor)
Figure 1.2b
04/08/2013
DAM POND
TURTLE POND
POTTERS HOLE
WING POND
HERRING RIVER
SPECTACLE POND
DEEP POND
COONAMESSETT POND
ROUND POND
PICKEREL POND
CROOKED POND
CROCKERS POND
WF1
WF2
WF3
WF4
WF5
WF6
WF7
WF8
WF9
WF10
WF11
WF12
WF13
LITTLE POND
MASHAPAQUIT CREEK
WEST FALMOUTH HARBOR
SHALLOW POND
BROAD RIVER
OYSTER POND
BEACH POND
JENKINS POND
DEER POND
MARES POND
SPECTACLE POND
LONG POND
Subwatersheds
Depth to Groundwater
(West Falmouth Harbor)
<30 ft
30 - 50 ft
>50 ft
West Falmouth Harbor
Town Boundary
Lake/Pond
Stream
Wetland
Roads
Parcel Boundary
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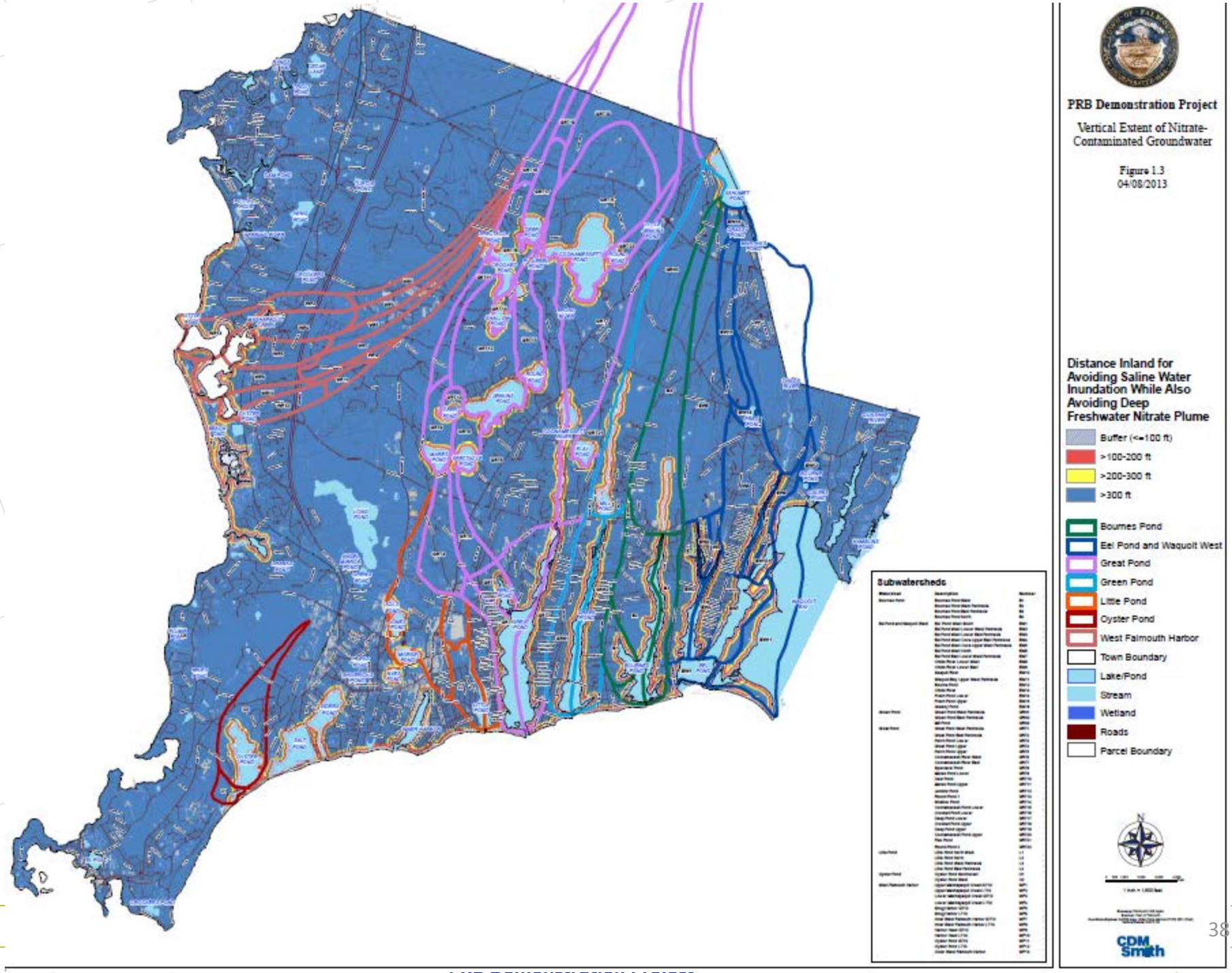
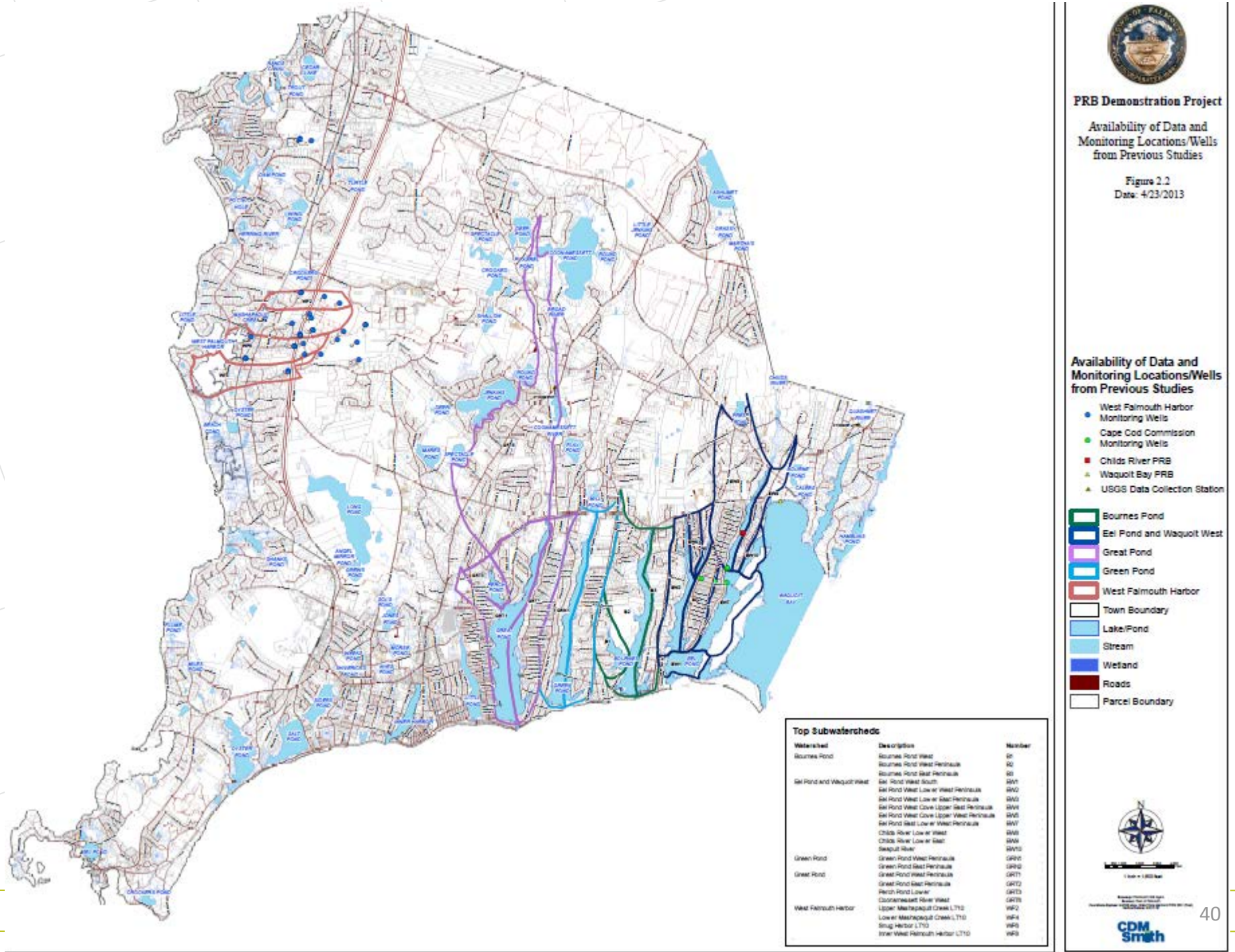
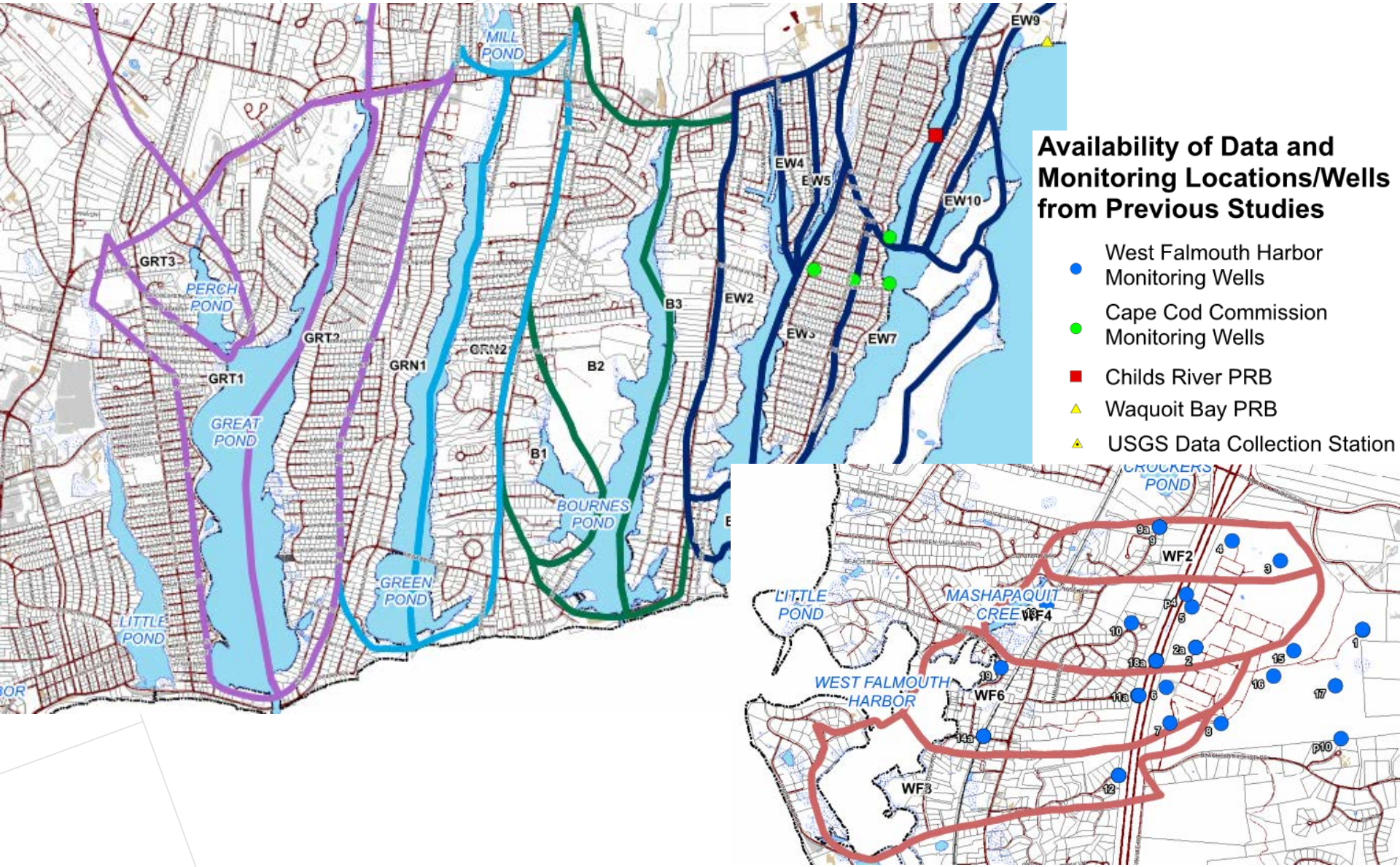

PRB Demonstration Project
Vertical Extent of Nitrate-Contaminated Groundwater
Figure 1.3
04/08/2013
Distance Inland for Avoiding Saline Water Inundation While Also Avoiding Deep Freshwater Nitrate Plume
Buffer (<=100 ft)
>100-200 ft
>200-300 ft
>300 ft
Bournes Pond
Eel Pond and Waquoit West
Great Pond
Green Pond
Little Pond
Oyster Pond
West Falmouth Harbor
Town Boundary
Lake/Pond
Stream
Wetland
Roads
Parcel Boundary
Subwatersheds
CDM Smith

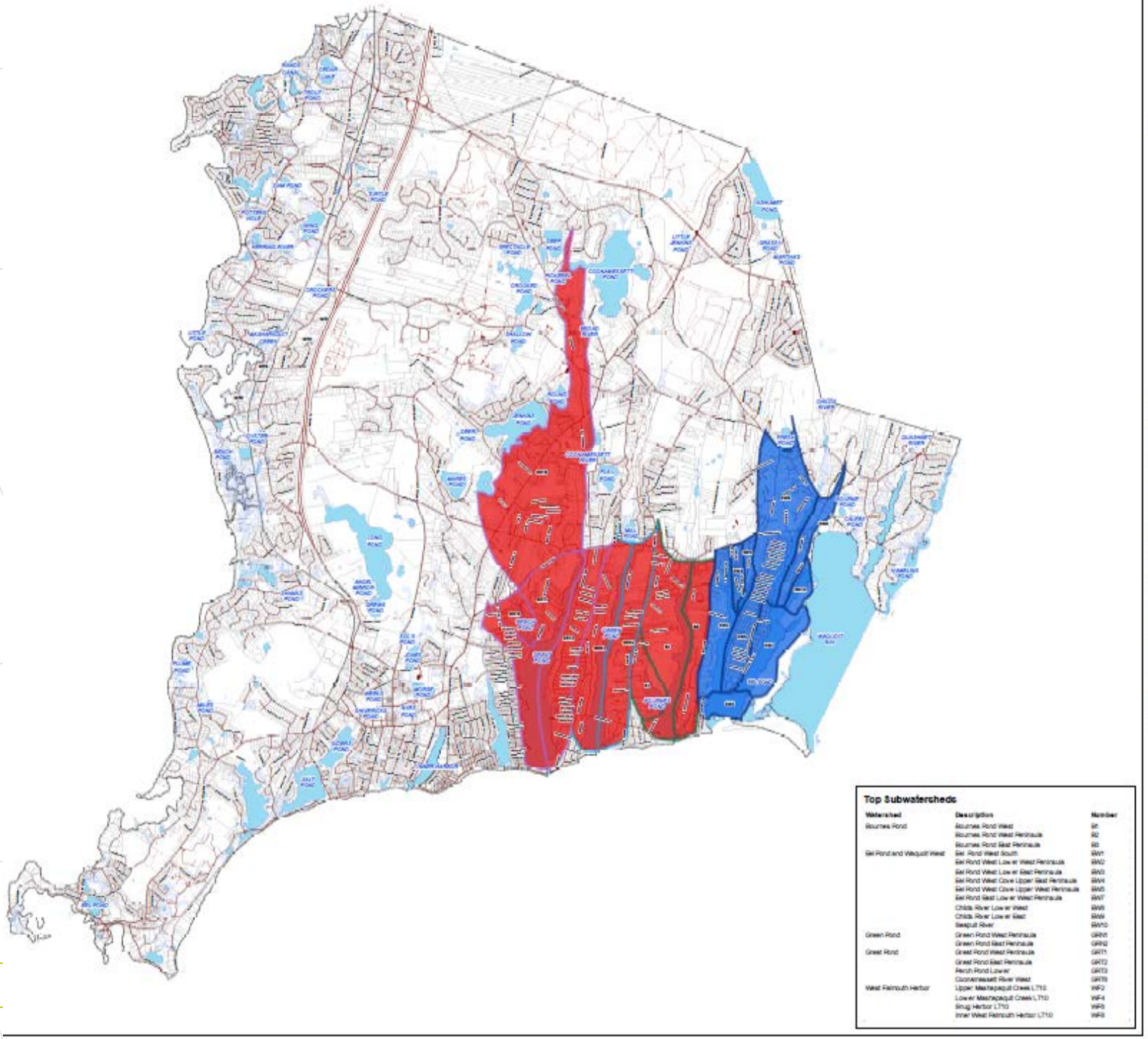
Distance Inland for Avoiding Saline Water Inundation While Also Avoiding Deep Freshwater Nitrate Plume

- Buffer (<=100 ft)
- >100-200 ft
- >200-300 ft
- >300 ft


PRB Demonstration Project
Availability of Data and Monitoring Locations/Wells from Previous Studies
Figure 2.2
Date: 4/23/2013
Availability of Data and Monitoring Locations/Wells from Previous Studies
West Falmouth Harbor Monitoring Wells
Cape Cod Commission Monitoring Wells
Childs River PRB
Waquoit Bay PRB
USGS Data Collection Station
Bournes Pond
Eel Pond and Waquoit West
Great Pond
Green Pond
West Falmouth Harbor
Town Boundary
Lake/Pond
Stream
Wetland
Roads
Parcel Boundary
Top Subwatersheds
Watershed
Description
Number
Bournes Pond
Bournes Pond West
Bournes Pond West Peninsula
Bournes Pond East Peninsula
Eel Pond and Waquoit West
Eel Pond West South
Eel Pond West Lower West Peninsula
Eel Pond West Lower East Peninsula
Eel Pond West Cove Upper East Peninsula
Eel Pond West Cove Upper West Peninsula
Eel Pond East Lower West Peninsula
Childs River Lower West
Childs River Lower East
Seapuit River
Green Pond
Green Pond West Peninsula
Green Pond East Peninsula
Great Pond
Great Pond West Peninsula
Great Pond East Peninsula
Perch Pond Lower
Coonamessett River West
West Falmouth Harbor
Upper Mashapaquit Creek LT10
Lower Mashapaquit Creek LT10
Snug Harbor LT10
Inner West Falmouth Harbor LT10
CDM Smith

Availability of existing data and monitoring locations

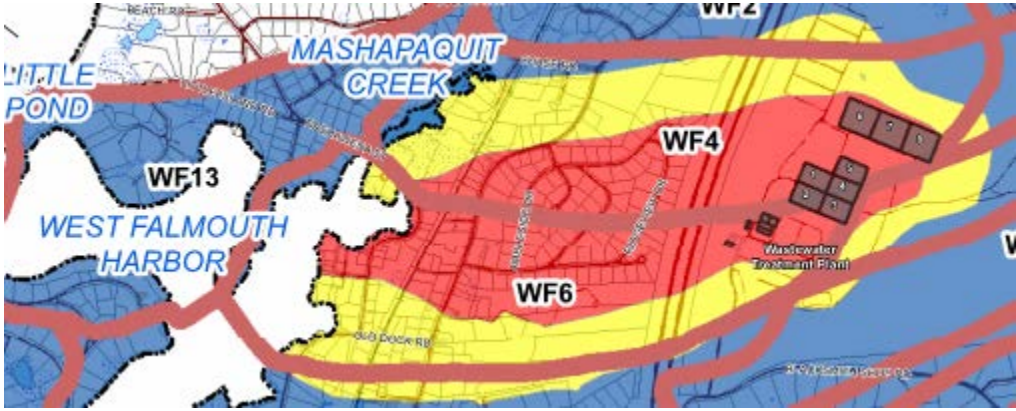



Town of Falmouth, MA
PRB Demonstration Project
Potential Funding/
Collaboration Opportunities
Figure 2.4
Date: 4/23/2013
Potential Funding/
Collaboration Opportunities
Great, Green, Bournes Pond Subwatersheds
Oyster Pond Subwatershed
No Funding
Bournes Pond
Eel Pond and Waquoit West
Great Pond
Green Pond
West Falmouth Harbor
Town Boundary
Lake/Pond
Stream
Wetland
Roads
Parcel Boundary
Top Subwatersheds
Watershed
Description
Number
Bournes Pond
Bournes Pond West
Bournes Pond West Peninsula
Bournes Pond East Peninsula
Eel Pond and Waquoit West
Eel Pond West South
Eel Pond West Lower West Peninsula
Eel Pond West Lower East Peninsula
Eel Pond West Cove Upper East Peninsula
Eel Pond West Cove Upper West Peninsula
Eel Pond East Lower West Peninsula
Childs River Lower West
Childs River Lower East
Seapuit River
Green Pond
Green Pond West Peninsula
Green Pond East Peninsula
Great Pond
Great Pond West Peninsula
Great Pond East Peninsula
Perch Pond Lower
Coonamessett River West
West Falmouth Harbor
Upper Mashapaquit Creek LT10
Lower Mashapaquit Creek LT10
Snug Harbor LT10
Inner West Falmouth Harbor LT10
CDM Smith

Nitrate Loading

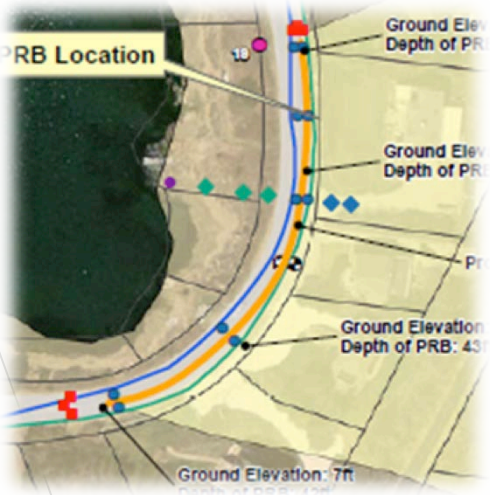
- South Coast Annual Nitrate Loading (lbs N/year)
  - (90%)*(X)*(Y_1)*(365 days/yr)+(Y_2)*(Z)
    - X: Total daily water usage for homes within potential capture zone, gal/day (values provided by CCC, calculated using MVP Model); wastewater from home is estimated to be 90% of water use
    - Y1: average nitrate concentration from septic system leaching fields
    - Y2: average nitrate concentration from lawn fertilization
    - Z: Number of homes

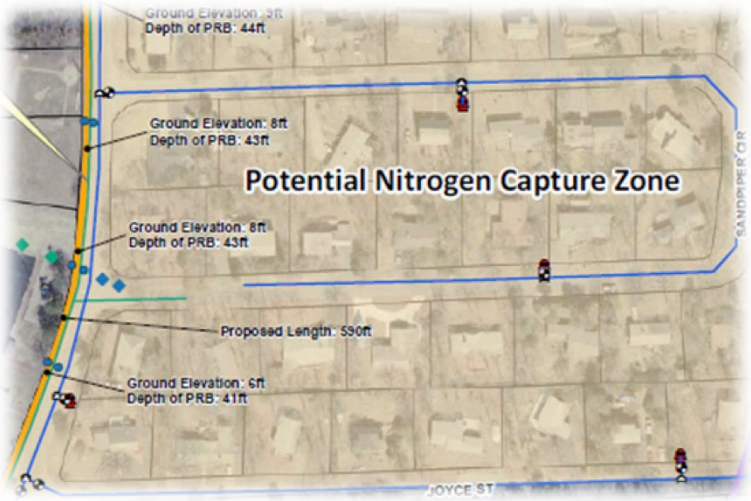
- West Falmouth Annual Nitrate Loading
  - Primarily dictated by GW flow and nitrate concentration in WWTF plume



Annual Nitrate Removal

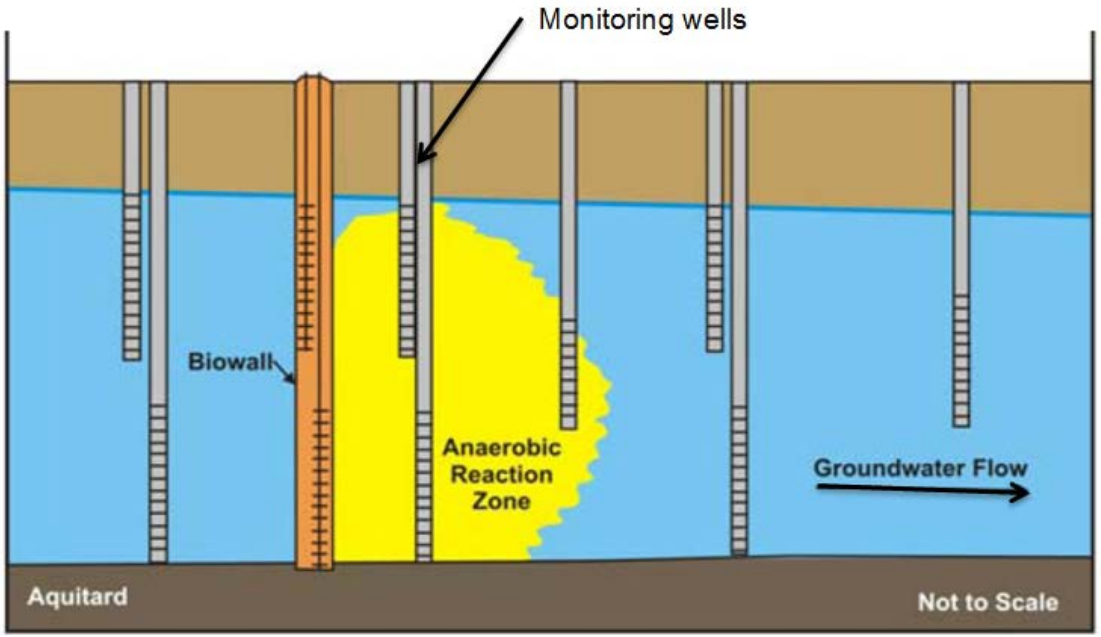
Total # of homes	Site 1 Great Harbors	Site 2 Seacoast Shores	Site 5 West Falmouth - Shallow	Site 5 West Falmouth - Deep
Total # of homes	41	46	73	73
Total N loading along the length	363	418	1,967	2,808
Total N Removal by PRB	**290**	**334**	**1,574**	**2,246**
lbs Removed/linear foot	**0.49**	**0.64**	**4.5**	**6.4**





Groundwater Monitoring Program

- Goals
  - Meet regulatory requirements
  - Demonstrate PRB effectiveness
- Water quality parameters
- Number, location, and spacing of monitoring wells
- Sampling frequency



Permitting Requirements

- Order of Conditions from Falmouth Conservation Commission
- Annual Chapter 91 permit from the harbor master
- Underground injection control registration through MassDEP
- Other general and local permits

Potential Environmental Permitting Requirements

- Federal
- State
- Local

Injection Well Method – Demonstration Costs

	Great Harbors	Seacoast Shores	West Falmouth (shallow)	West Falmouth (deep)
Cost per linear foot of installation ($/LF)	$1,650	$1,700	$1,950	$4,050
Cost per pounds N removed by PRB per year ($/lbs N removed/yr)	$3,350	$2,700	$450	$650
Cost per home ($/home)	$24,000	$20,000	Not Applicable