Circulation & Chemical Transport in Upper Narragansett Bay

Water Quality

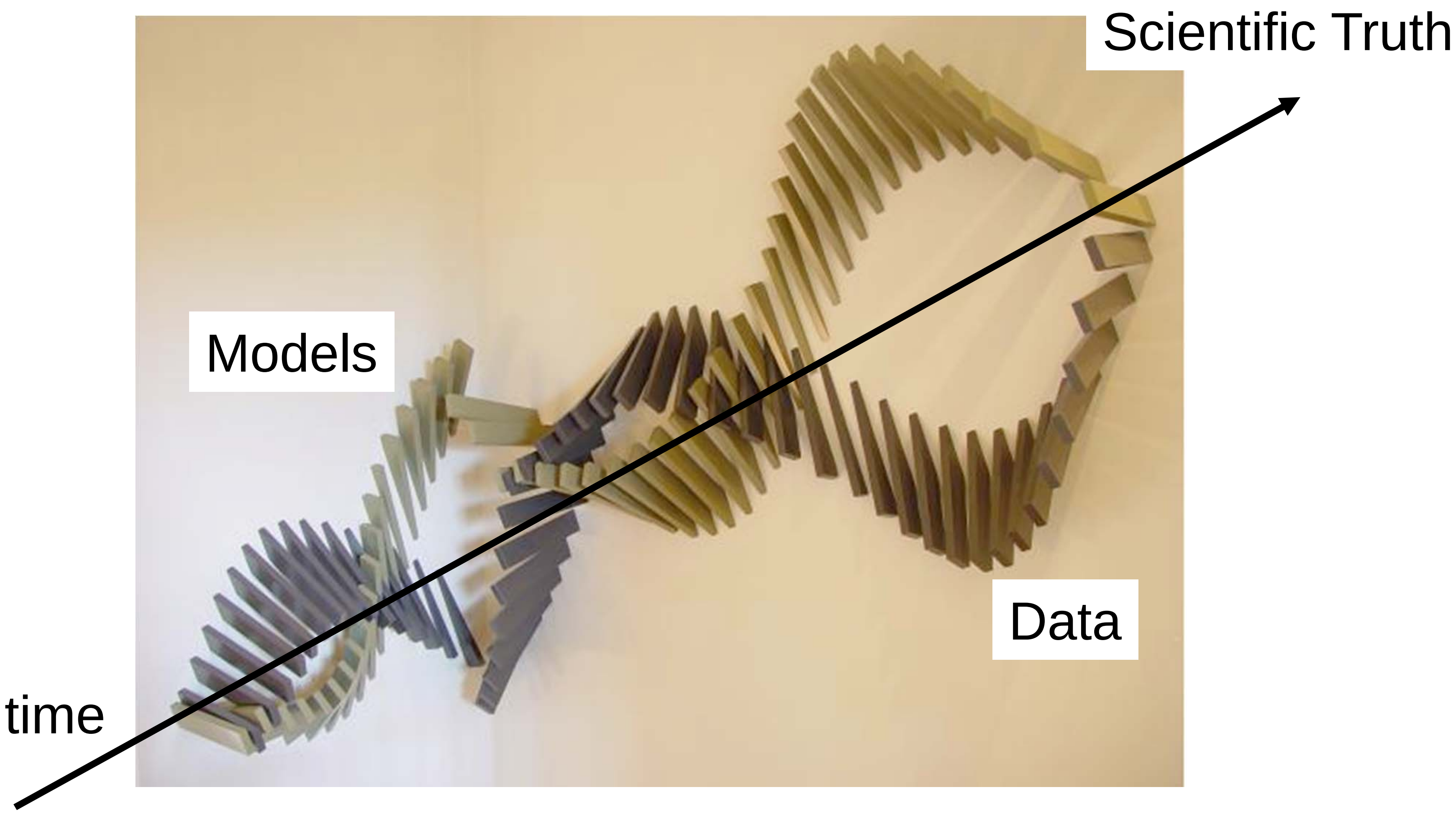
Circulation

Tides
Winds
Runoff
Density

Circulation & Chemical Transport in Upper Narragansett Bay

Hypothesis: Water quality controlled by lack of flushing from key regions

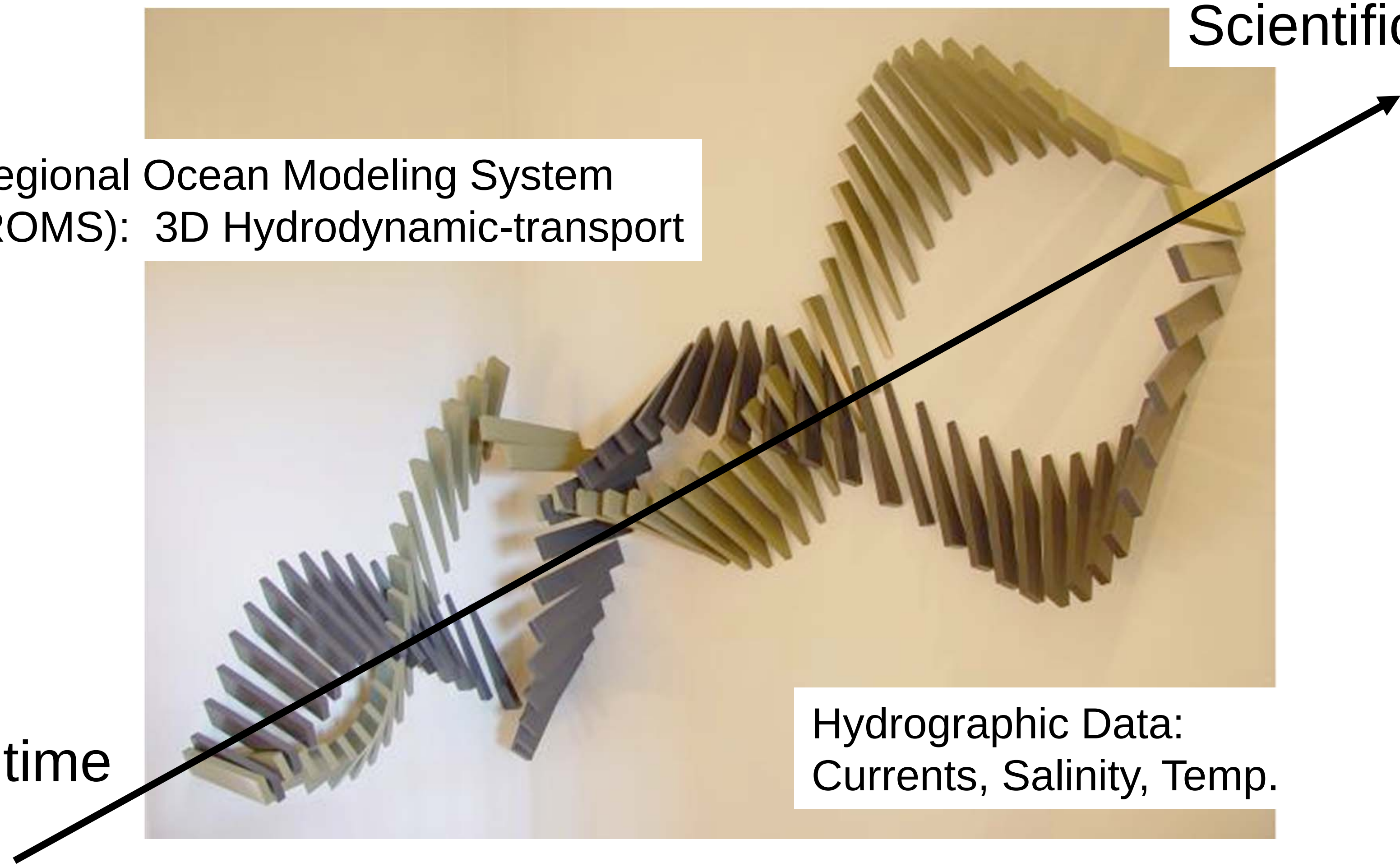
Theme of todays talk: The “scientific” cycle



Today the story of our scientific cycle for the Bay:

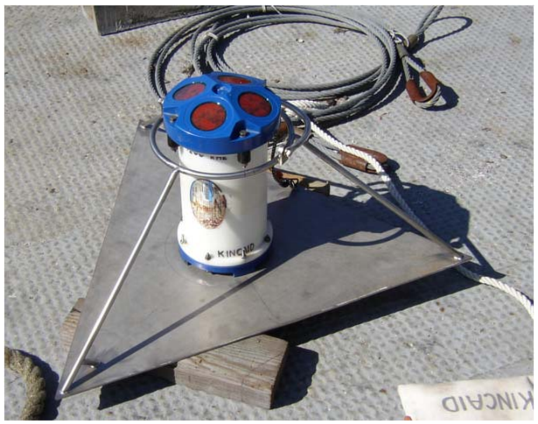
Supported by RI Sea Grant, NOAA Hypoxia Program & the Narragansett Bay Commission

Made possible by many graduate students
(Bergondo, Sullivan, Webster, Deleo, LaSota, Rogers, Balt, Pfeiffer-Herbert)



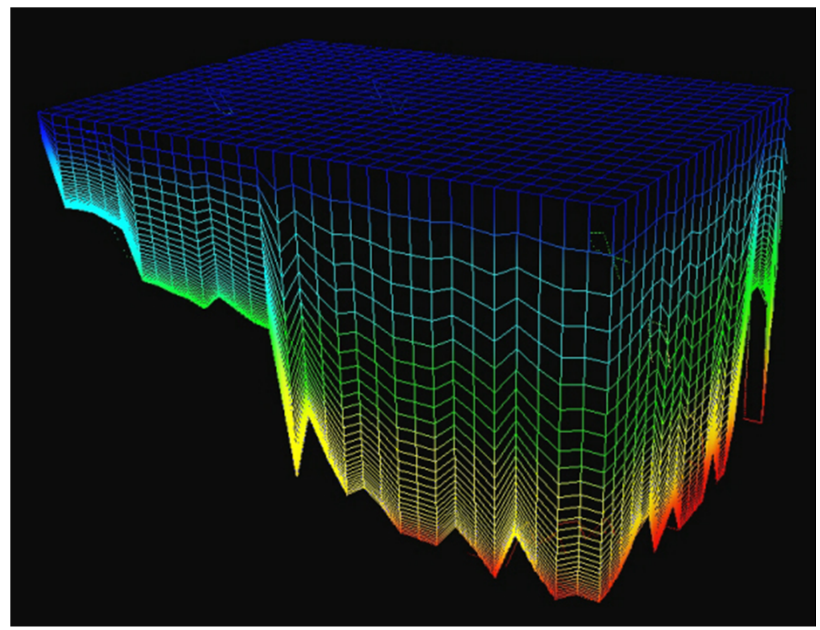
Advances in ROMS model & data sets have led to better predictive tools for RI waters & understanding of Bay processes

Hydrographic Data



Acoustic **D**oppler **C**urrent **P**rofilers (ADCP)

ROMS Hydrodynamic Computer Model

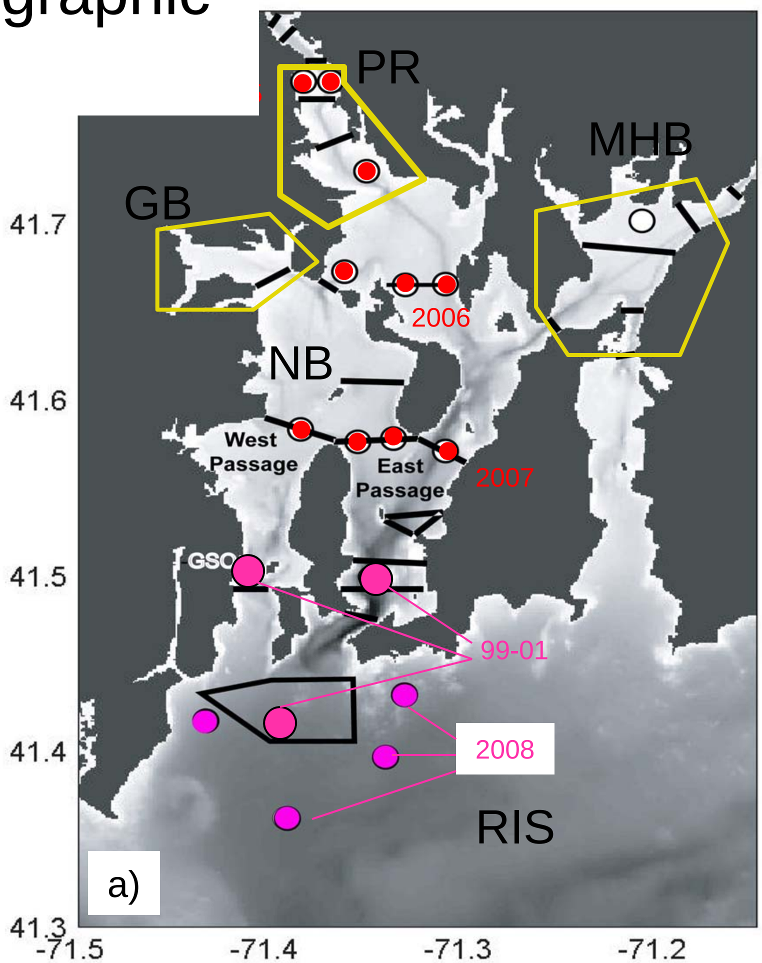


Estuary divided into numerical boxes
Coupled flow/transport equations solved

More than a decade of spatially-temporally detailed data

Four generations of ROMS model numerical grids for RI waters

Hydrographic Data



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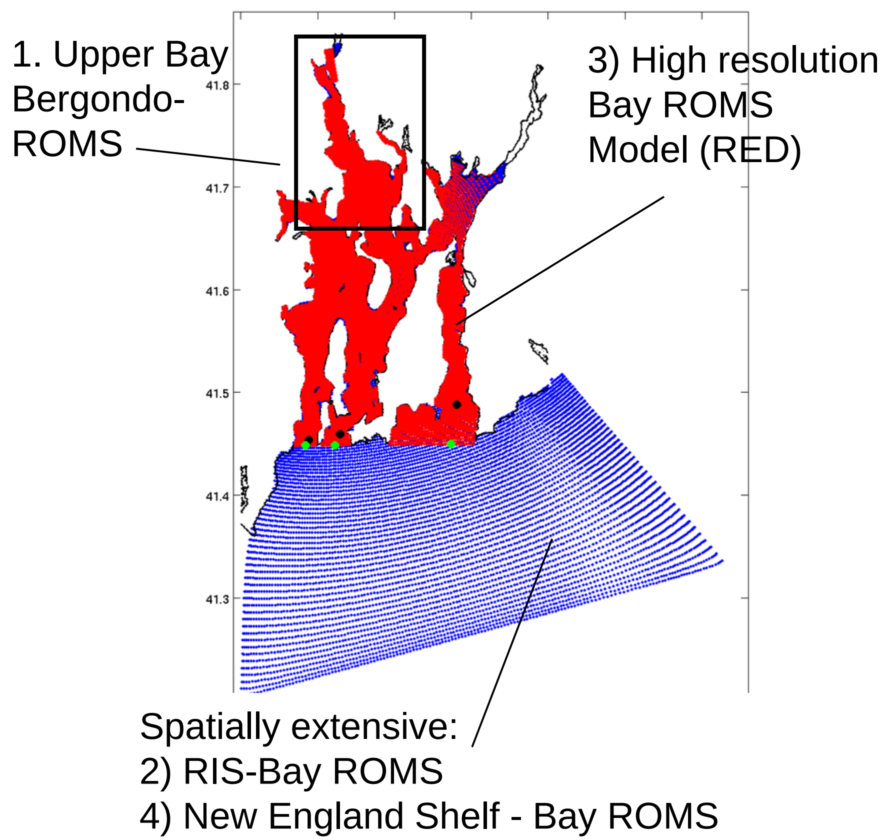
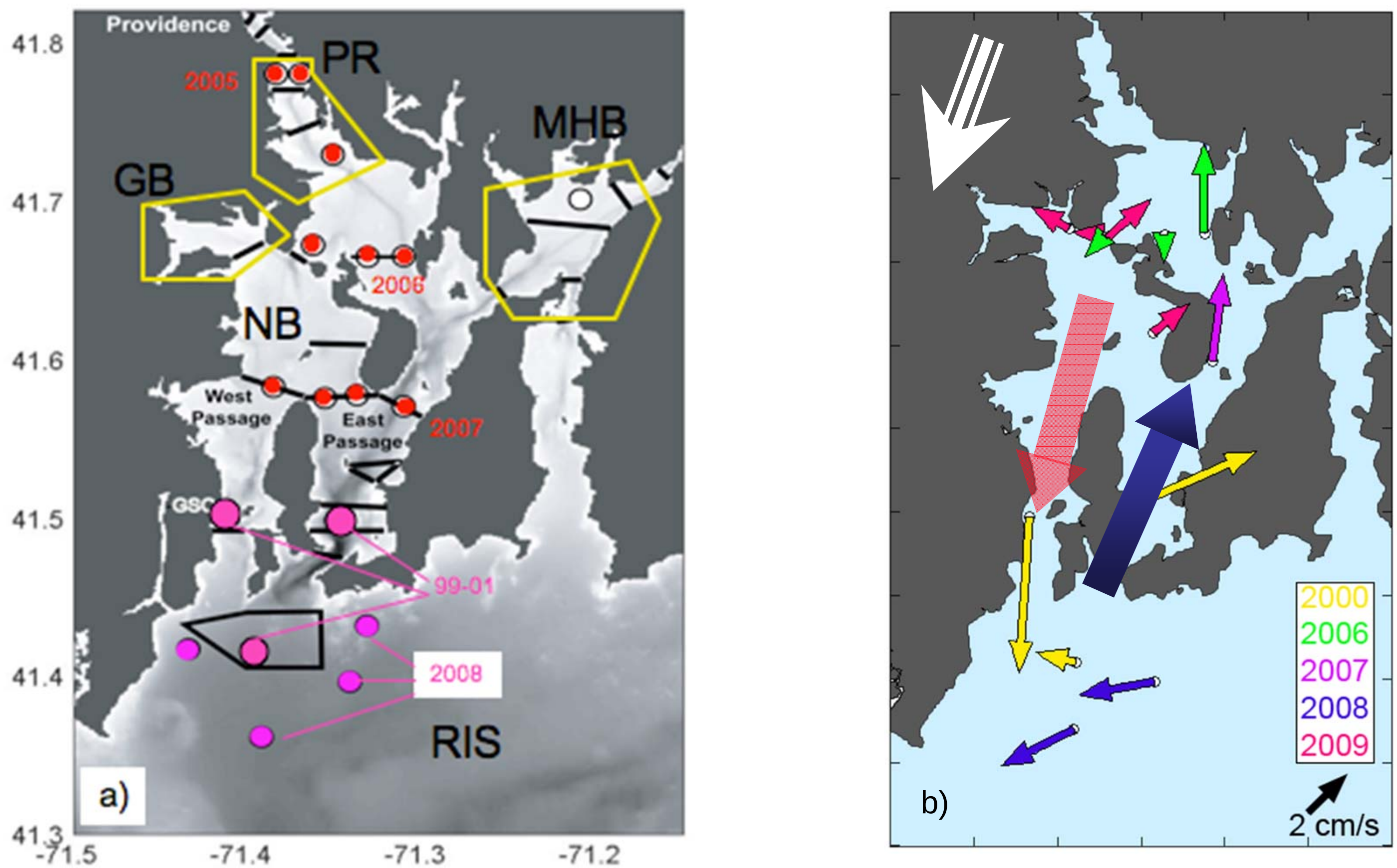




Data summary:

long-shore flow outside mouth

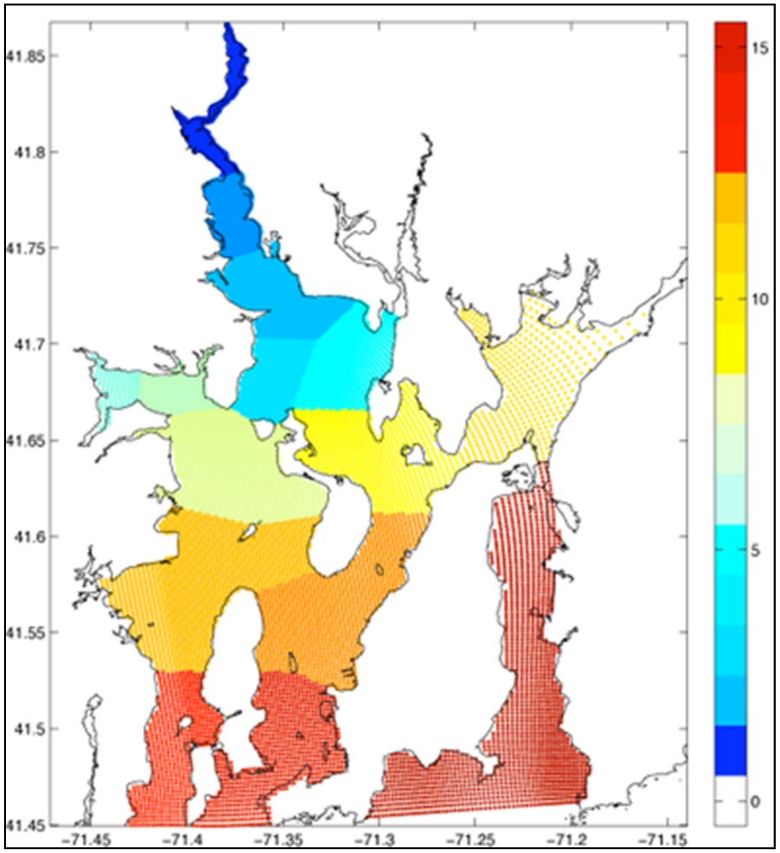
counterclockwise residual flow between passages

bay-wide flushing after northward winds shift to southward

Two Recent Data-Model Projects

1. NOAA-CHRP (Coastal Hypoxia Research Program)
   EcoGEM Hybrid Narraganett Bay model (Vaudrey, Kremer, Ullman & others)

   ROMS dye exchanges drive simplified ecosystem box model
   State variables: phyto., nitrogen, phos., benthic carbon, and oxygen



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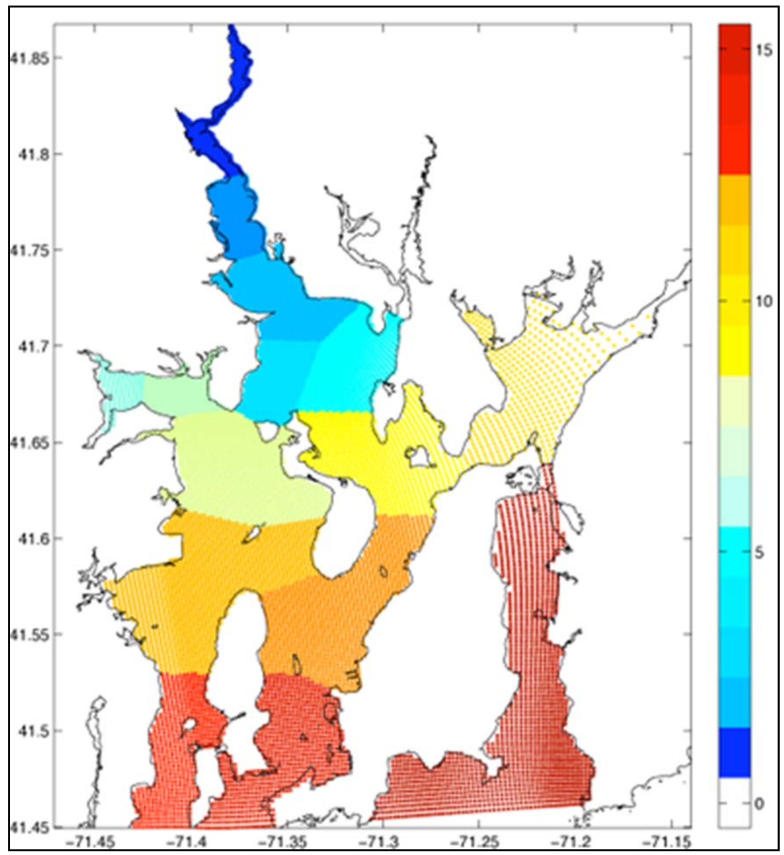
   ROMS dye exchanges drive simplified ecosystem box model
   State variables: phyto., nitrogen, phos., benthic carbon, and oxygen

30 eco-boxes

ROMS moves/mixes 30 dyes

Dye exchanges averaged to 30 eco-boxes

2006 Full year simulation



Two Recent Data-Model Projects

1. NOAA-CHRP (Coastal Hypoxia Res. Prog.)

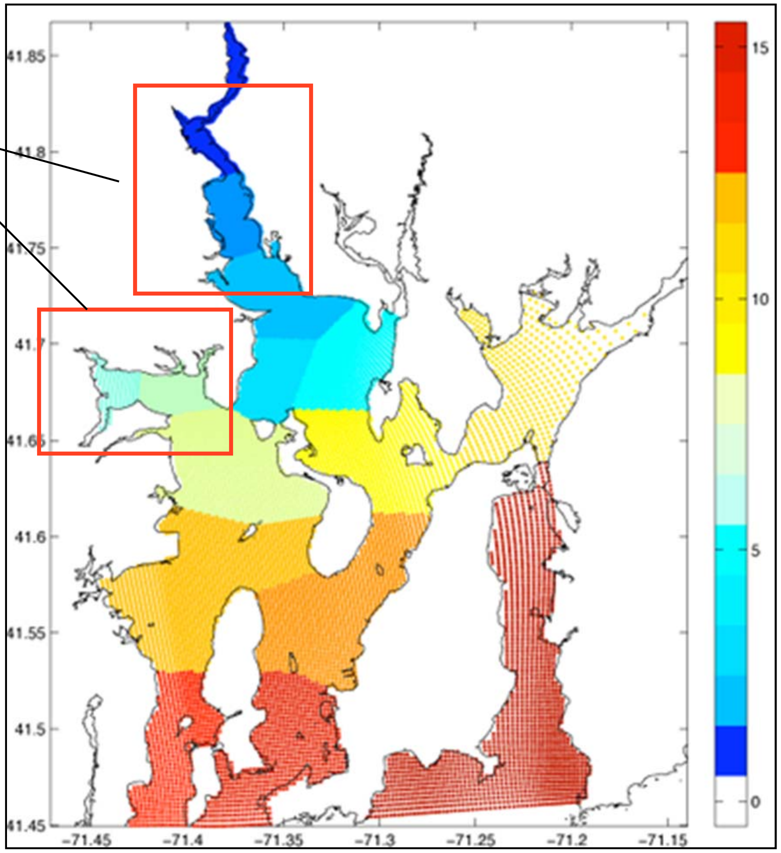
2. **Urban Impacted Systems (RISG, NBC)**

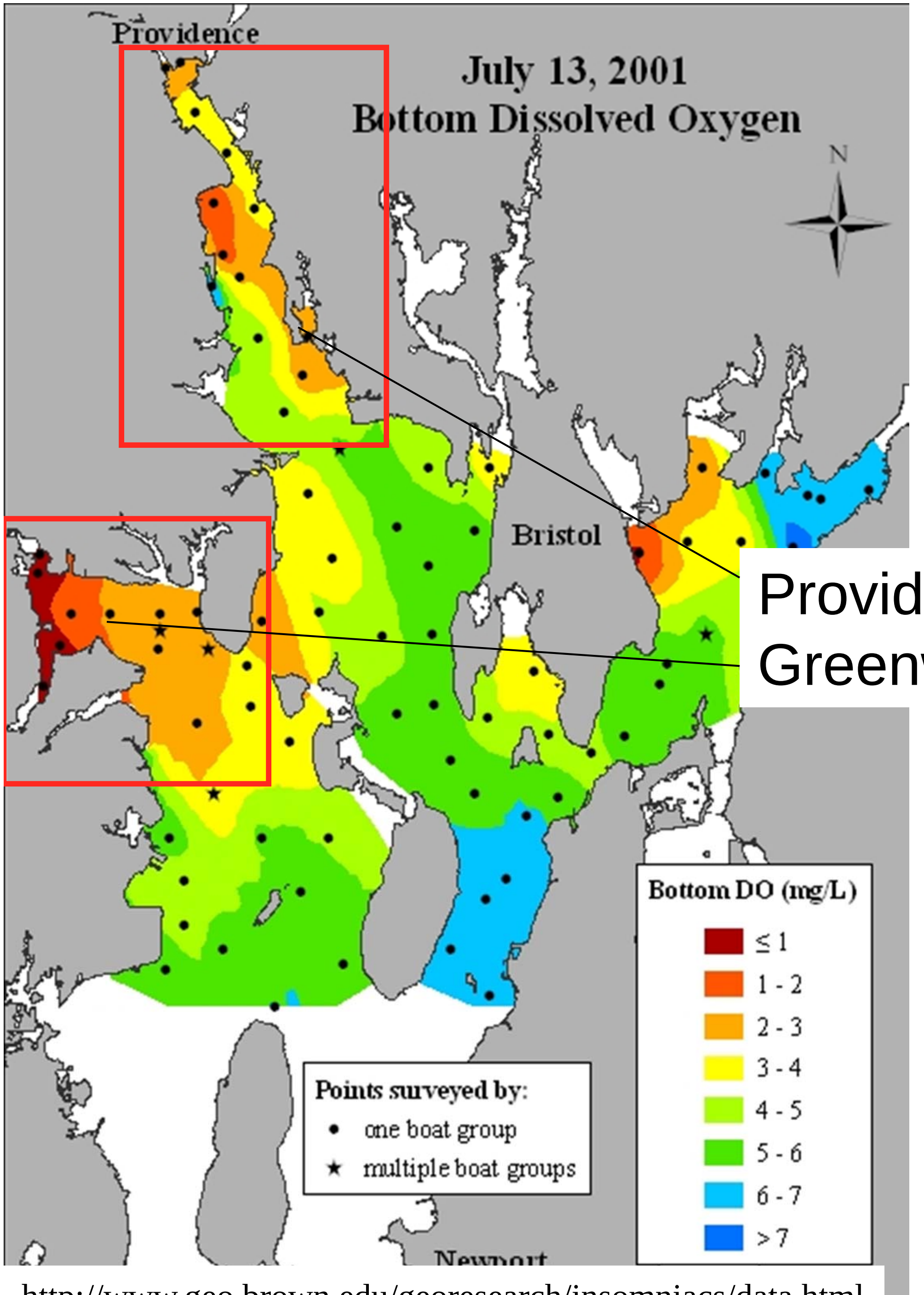
Circulation and chemical transport in most impacted regions of upper Narragansett Bay:

a) Providence River

b) Greenwich Bay

Hypothesis: Flushing is crucial in controlling water quality in chronic hypoxic regions of the Bay

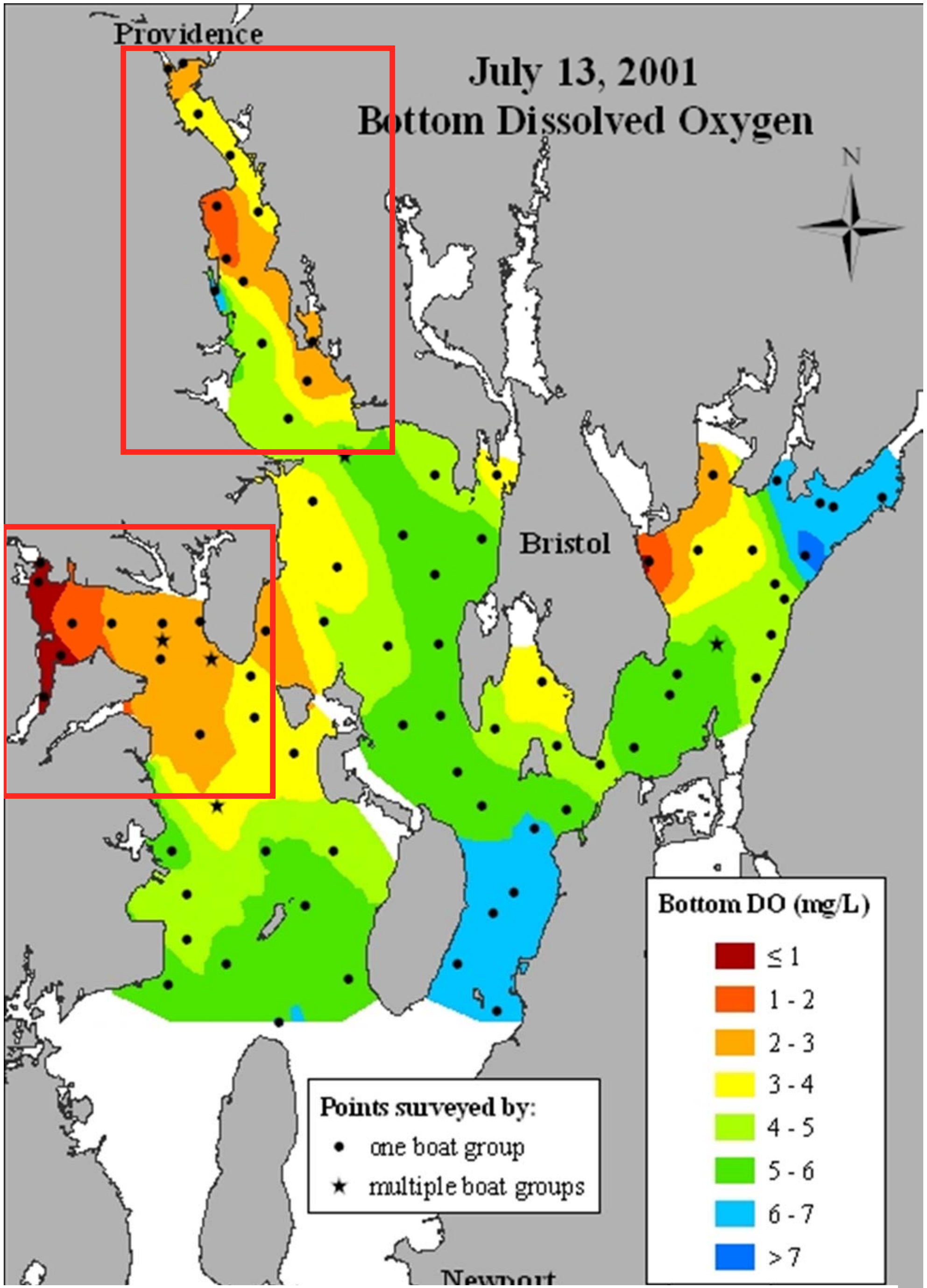




http://www.geo.brown.edu/georesearch/insomniacs/data.html

2001

Providence River & Greenwich Bay: Chronic hypoxia



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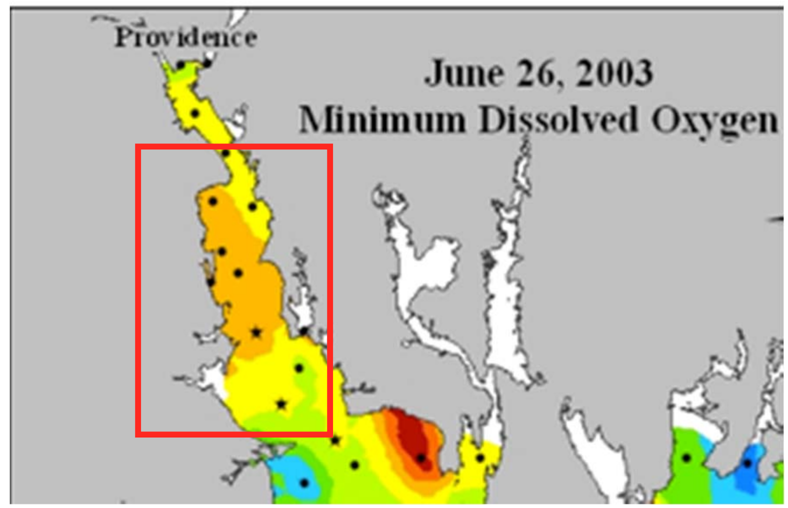
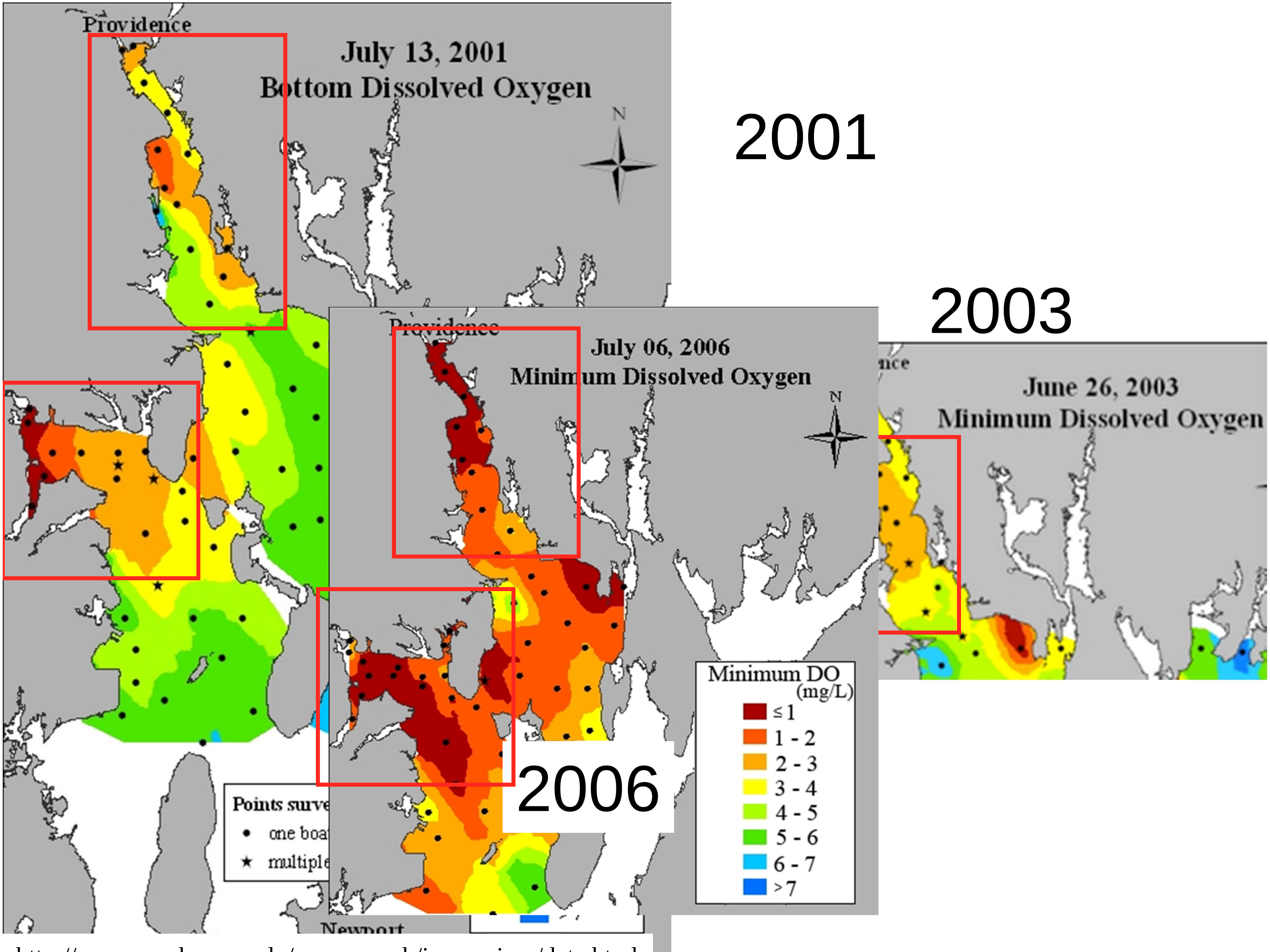
2003





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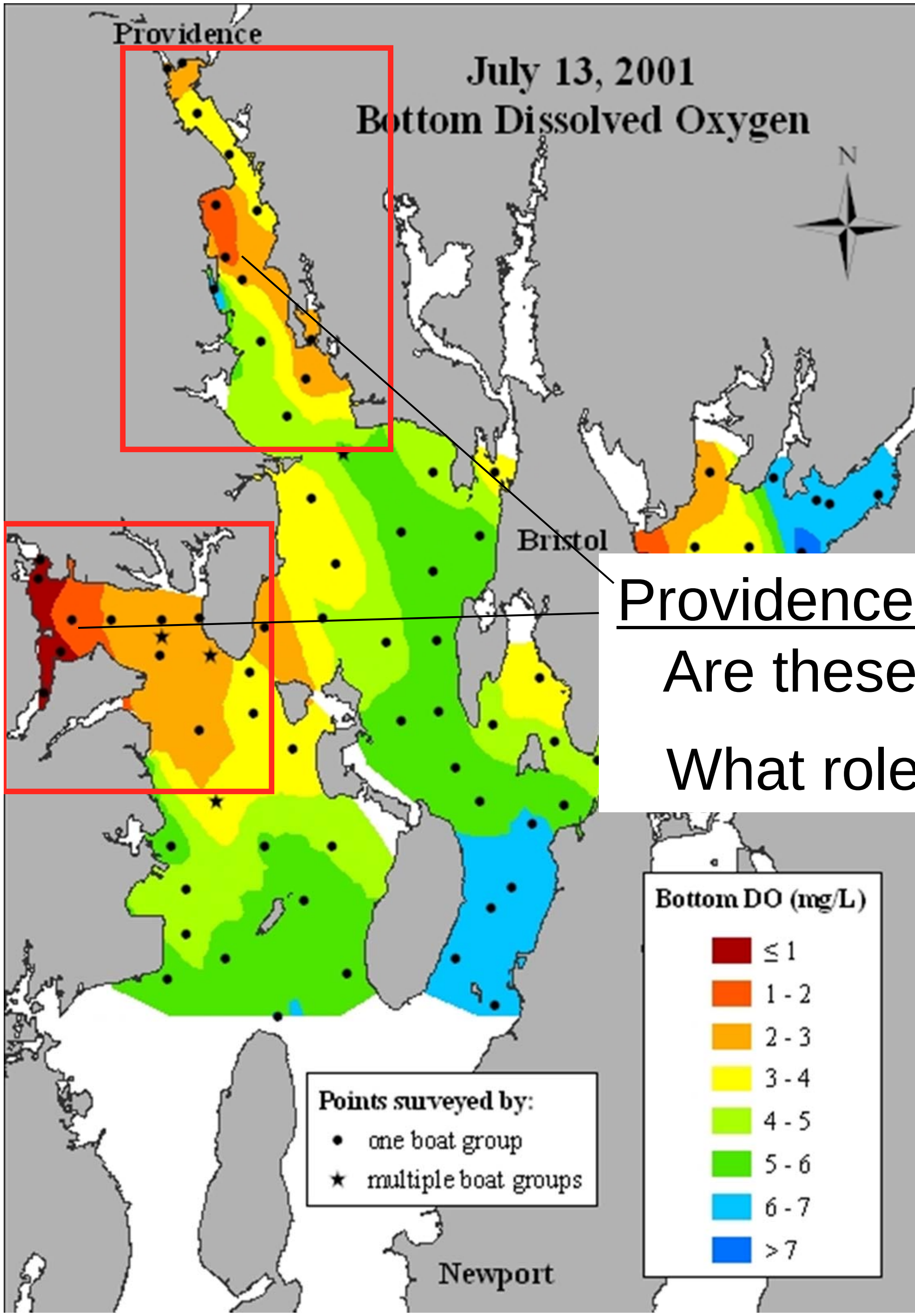


2001

Providence River & Greenwich Bay:

Are these low oxygen nucleation zones?

What role does flushing play?

Talk Outline:

Focus on the Providence River *(Greenwich Bay equally interesting, C. Balt PhD Thesis)*

Early ideas on flow, flushing & chemical transport in the Providence River

Advances in our understanding of flow & flushing

Advances in our understanding of chemical transport

Talk Outline:

Focus on the Providence River *(Greenwich Bay equally interesting, C. Balt PhD Thesis)*

Early ideas on flow, flushing & chemical transport in the Providence River

Advances in our understanding of flow & flushing

Advances in our understanding of chemical transport

Discussion Points:

Strategies for mitigating bad water nucleation zones

Improved flushing

Release strategies

Modifying chronic chemical transport pathways

What's so special about the Providence River?

Mapview of Estuary

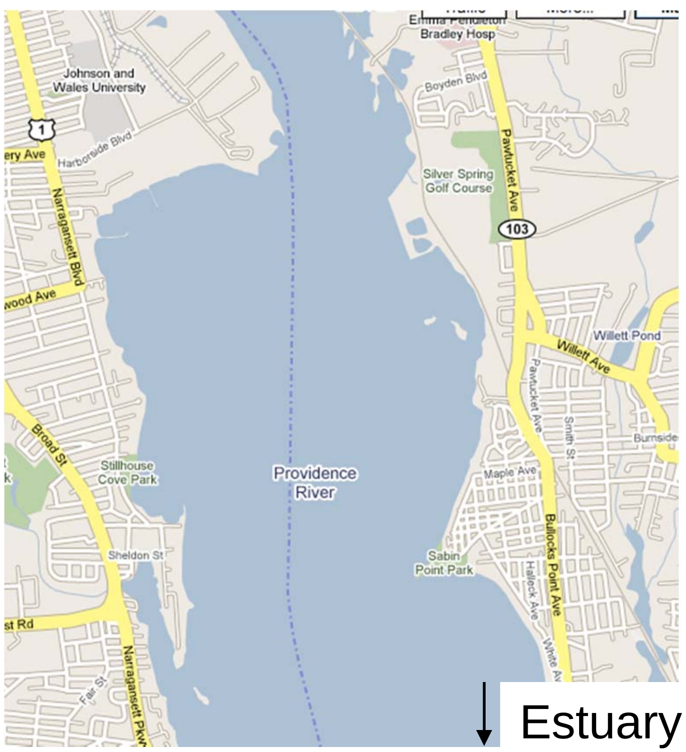
1. Deep Shipping Channel (~50')

2. Broad-Shallow Edgewood Shoals (~10')

Early flushing estimates for the Providence River:

Estuary head

runoff



Estuary mouth

Fraction of (Fresh) Water Method

$$\text{Flushing time} \sim \frac{\text{Volume } (m^3)}{\text{Runoff } (m^3 / t)}$$

Early flushing estimates for the Providence River:

Estuary head

runoff

Estuary mouth

Fraction of (Fresh) Water Method

$$\text{Flushing time} \sim \frac{\text{Volume } (m^3)}{\text{Runoff } (m^3 / t)}$$

Key Assumption: Complete mixing

Fraction of Fresh Water / Box Model: (Asselin & Spaulding, 1993)

Flushing Time ~ 1 / Runoff

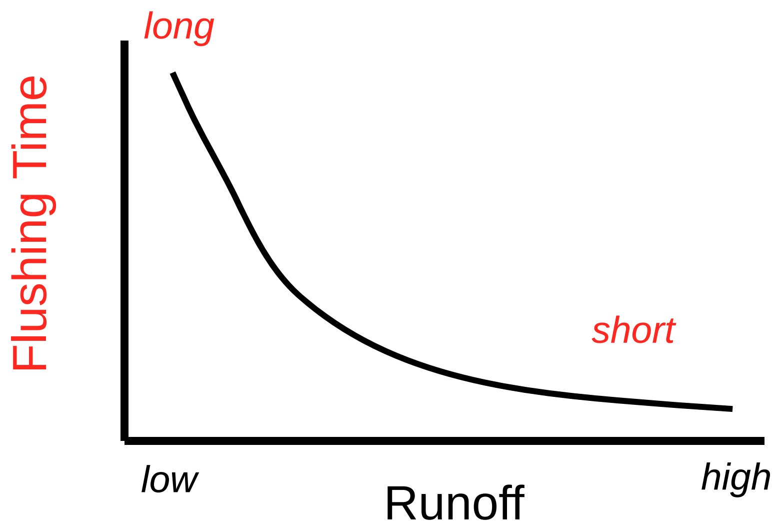
	Runoff (CMS)	Flushing time (days)
High	90	0.8
Low	5	6

Fraction of Fresh Water / Box Model: (Asselin & Spaulding, 1993)

Flushing Time ~ 1 / Runoff

	Runoff (CMS)	Flushing time (days)
High	90	0.8
Low	5	6
Average	42	2.5

Box Models: Increase runoff = faster flushing



Are results consistent with computational hydrodynamic models?

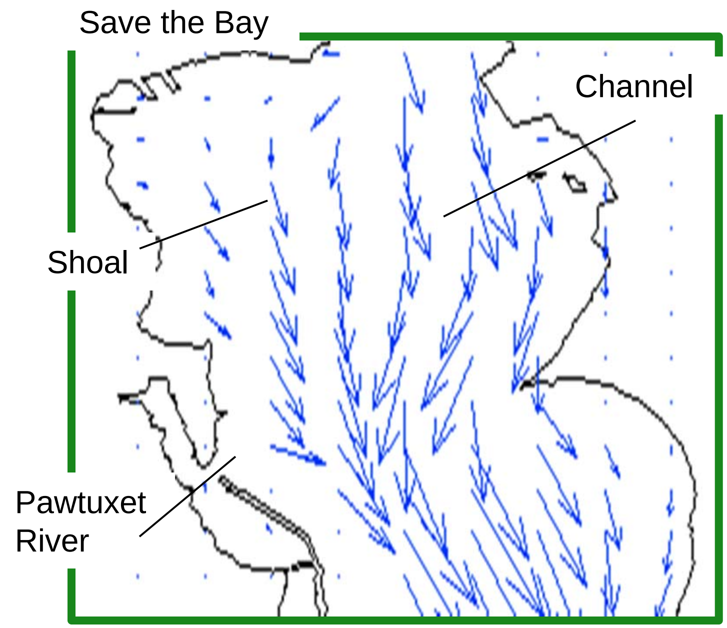
Early ROMS: Vertically-integrated Flow in Providence River

Bergondo, 2004

Grid (box sizes) in river > 100m

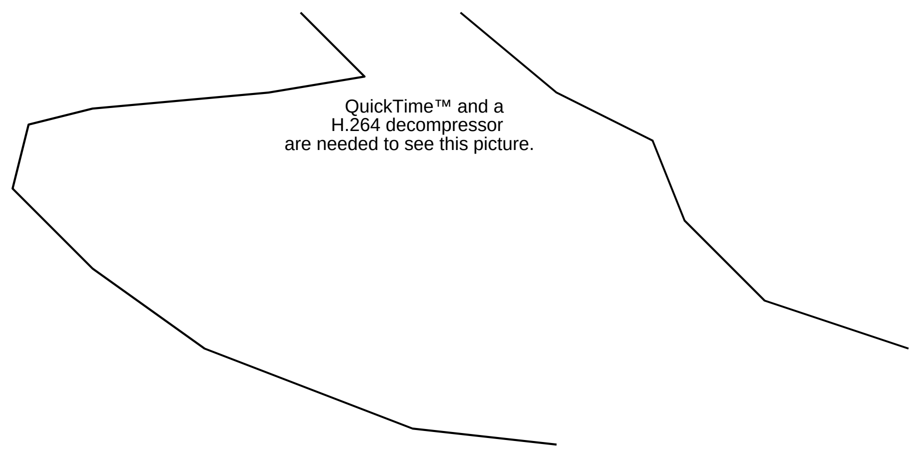
Edgewood Shoal energetic outflow/inflow

Shoal-channel flows in-phase



Movie of flow vectors in upper Providence River (LaSota,2008)

(Coarse-grid ROMS)



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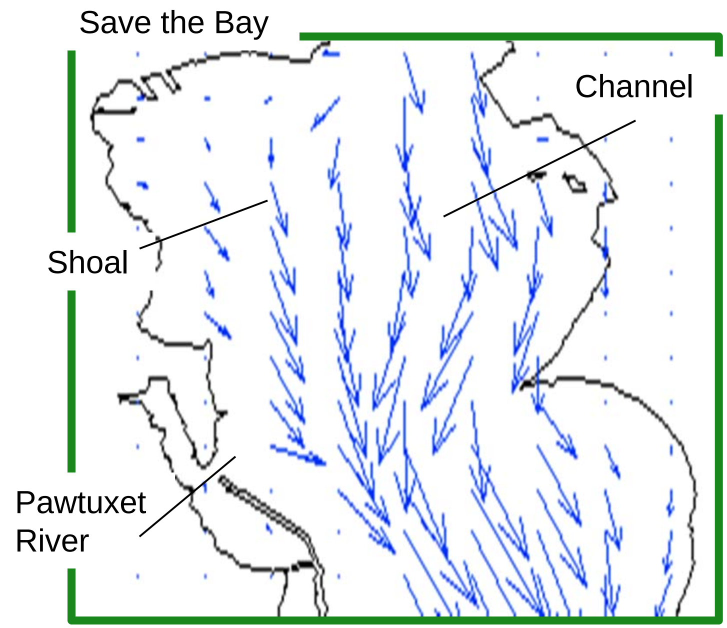
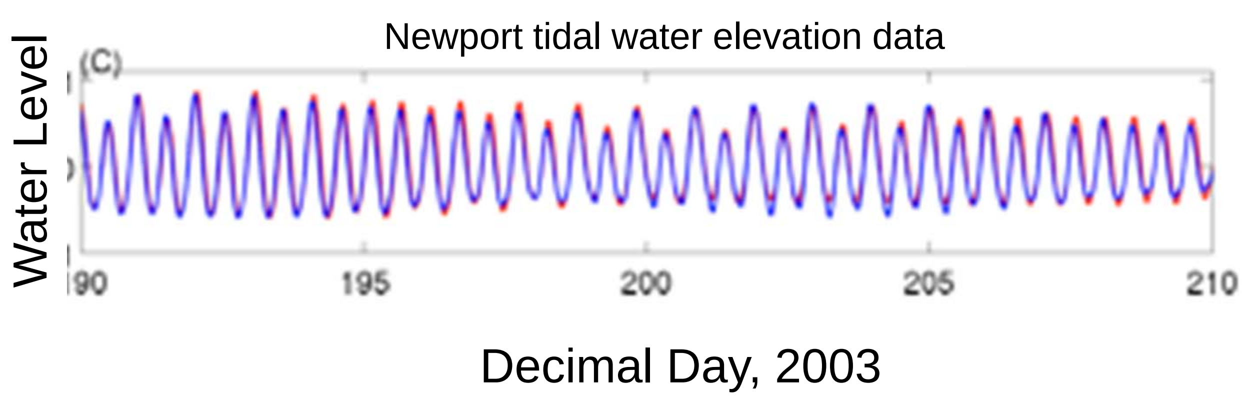


Do models match data?

Data (Red)
vs
Model (Blue)

Skill = .98

(1 = excellent)



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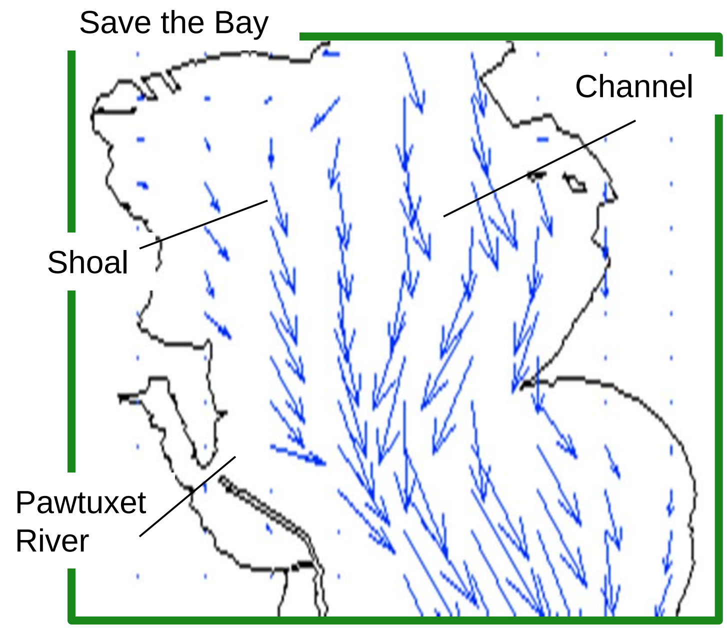

Models compare well to instantaneous (tidal) data records.

Model predictions for flushing efficiency?

Early ROMS: Vertically integrated Flow in Providence River

Bergondo, 2004

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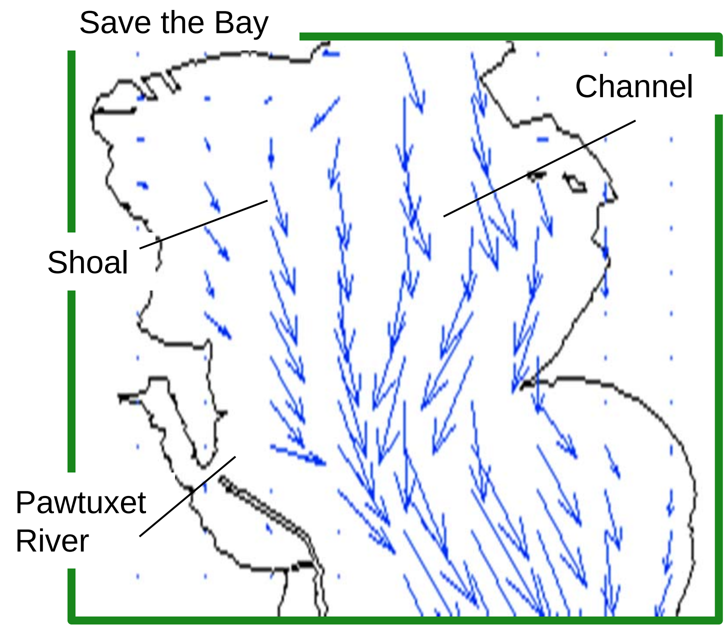
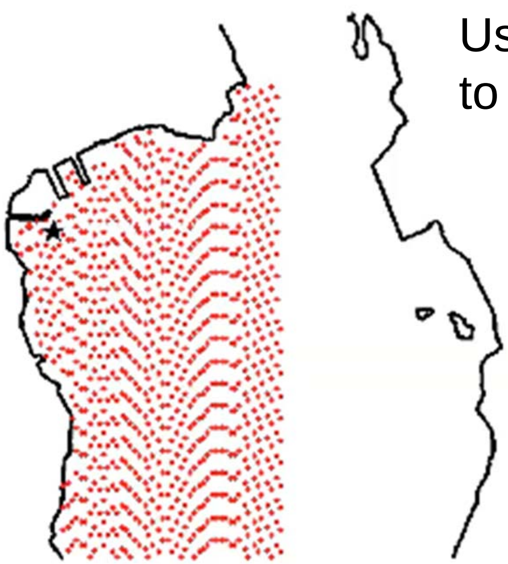
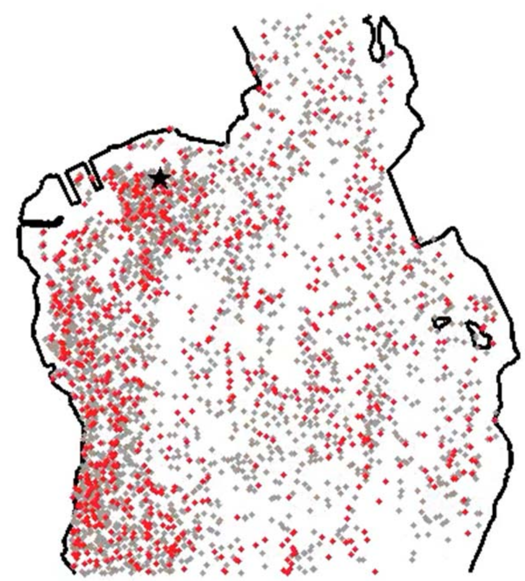
Edgewood Shoal energetic outflow



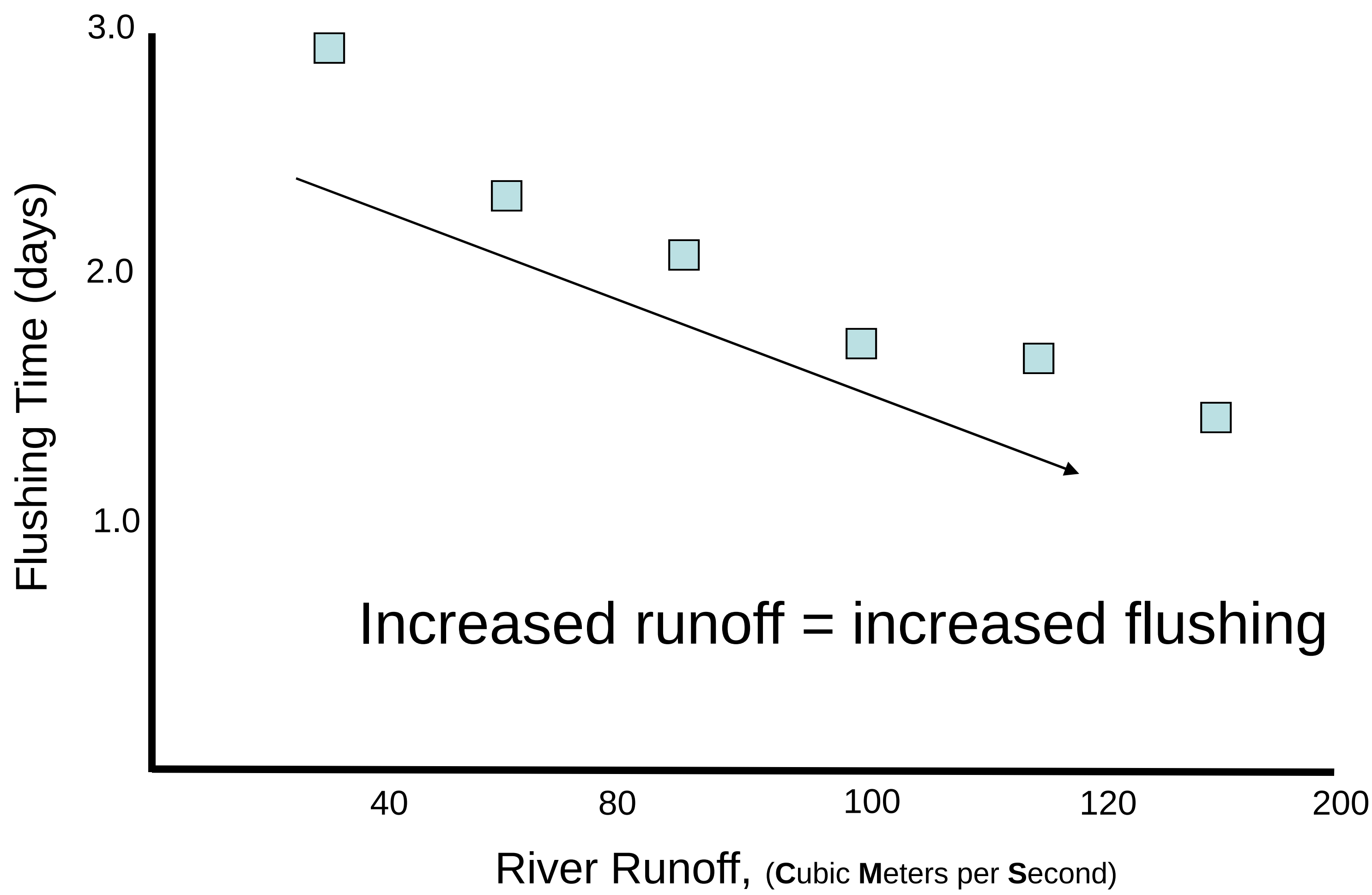
Use passive tracers in ROMS
to calculate flushing efficiency





ROMS Float-derived Flushing Times for Providence River

Bergondo PhD Thesis (2004)



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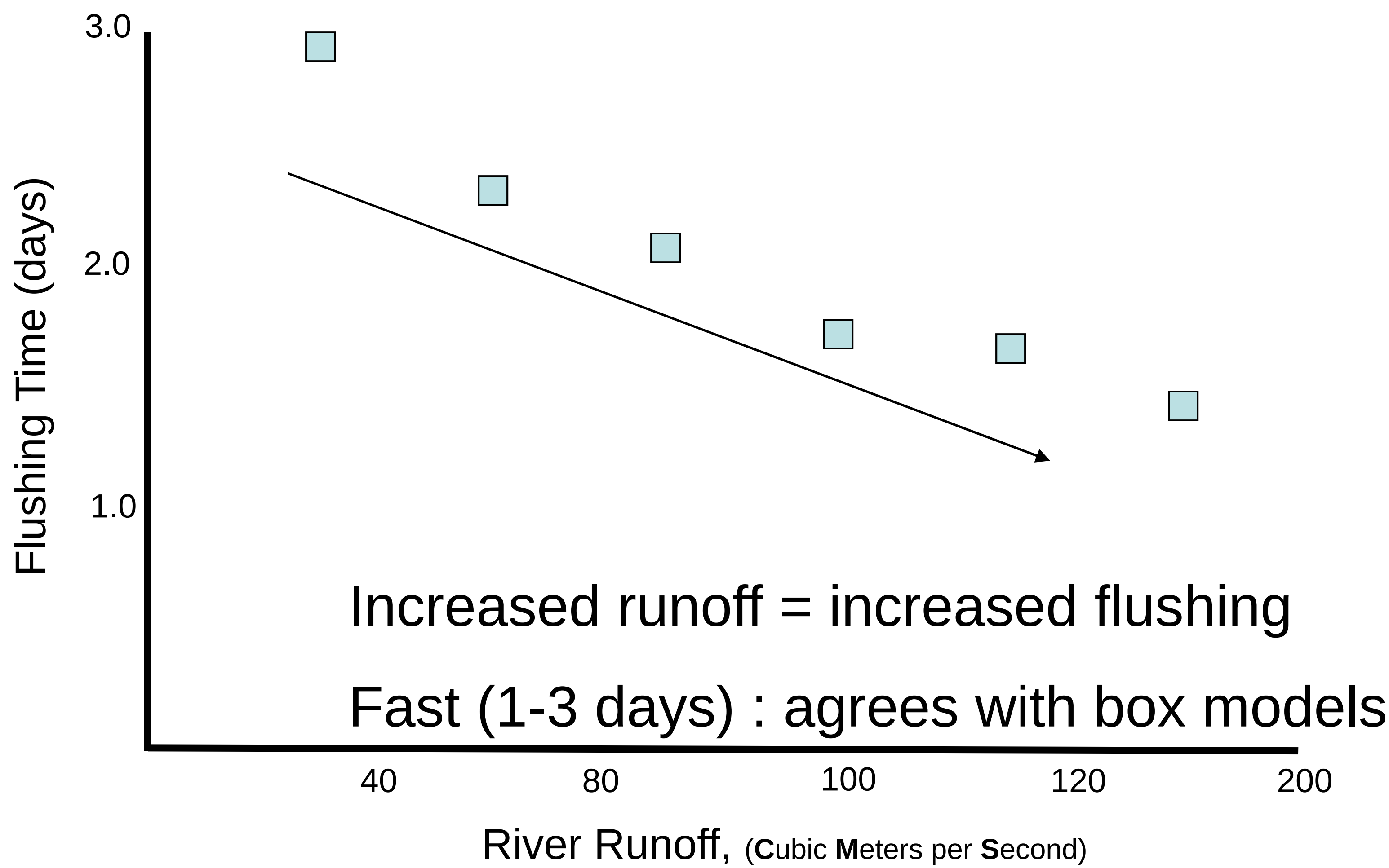
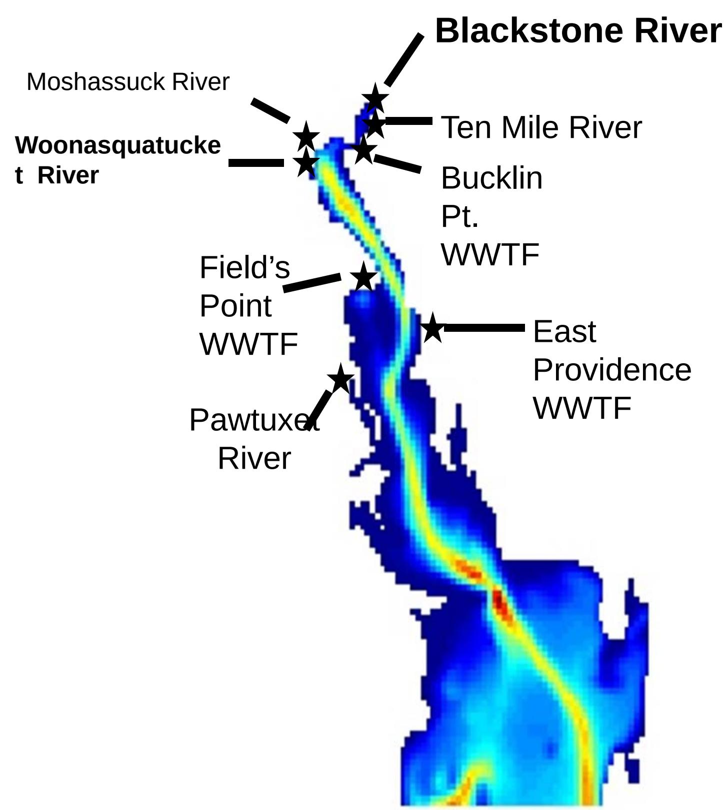


ROMS Detective Work:
Which nutrient sources feed chronic hypoxic zones?

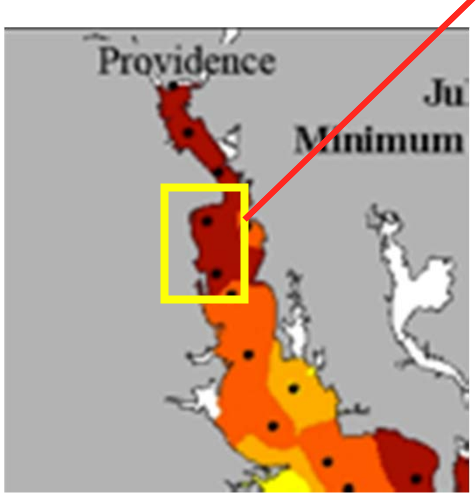
Method: Tag all rivers and WWTFs with separate dyes.

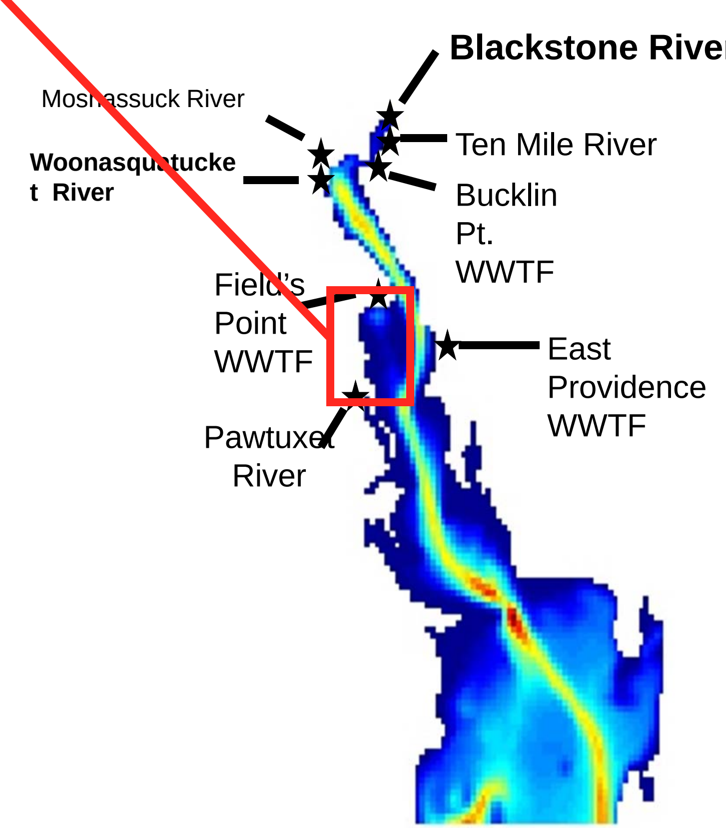


(LaSota MS Thesis 2010)

ROMS Detective Work:
Which nutrient sources feed chronic zones?

Example of ROMS as a forensic tool:
Track which dyes feed Edgewood Shoals

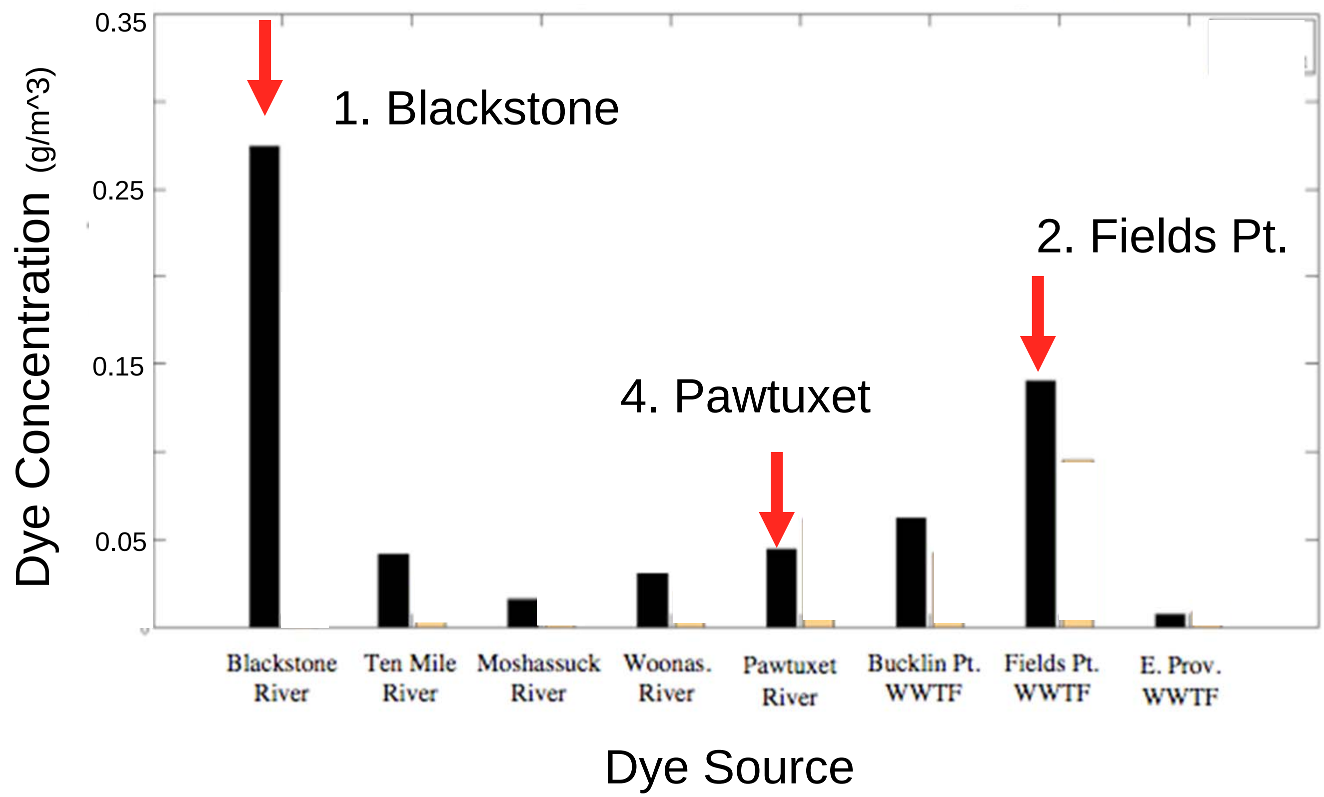




(LaSota MS Thesis 2010)

ROMS Run with
Average Runoff/Tide
Conditions:

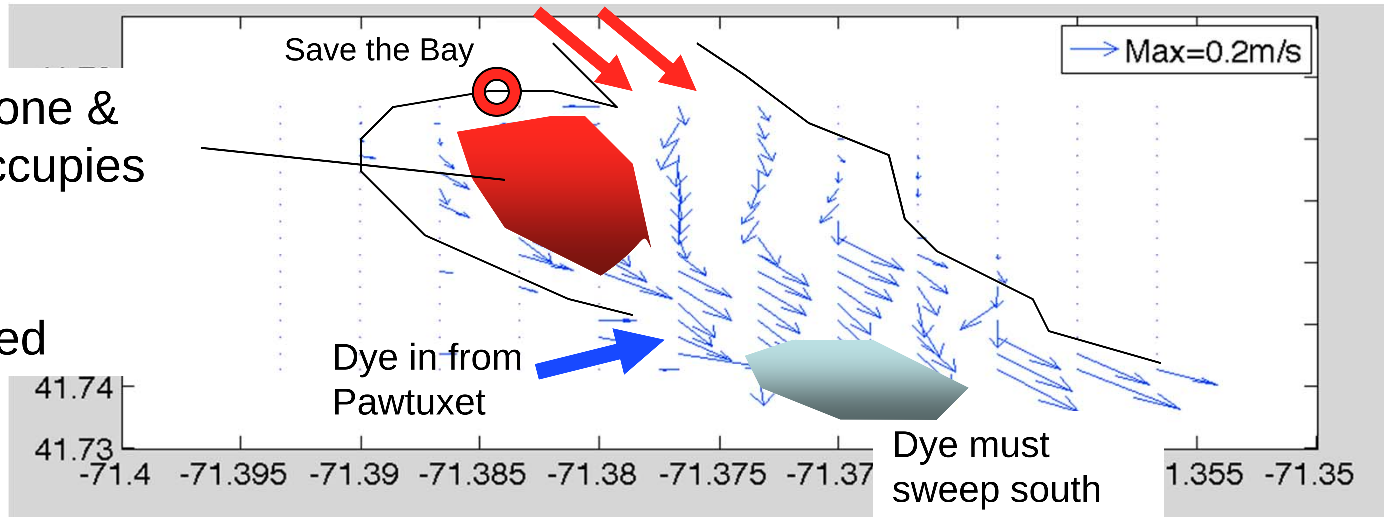
Calculate % of each dye source on Edgewood Shoals



Dye (nutrient sources) Accumulation vs. Flow

Dye in from Blackstone & Fields Pt. WWTF occupies shoals.

Region is well-flushed



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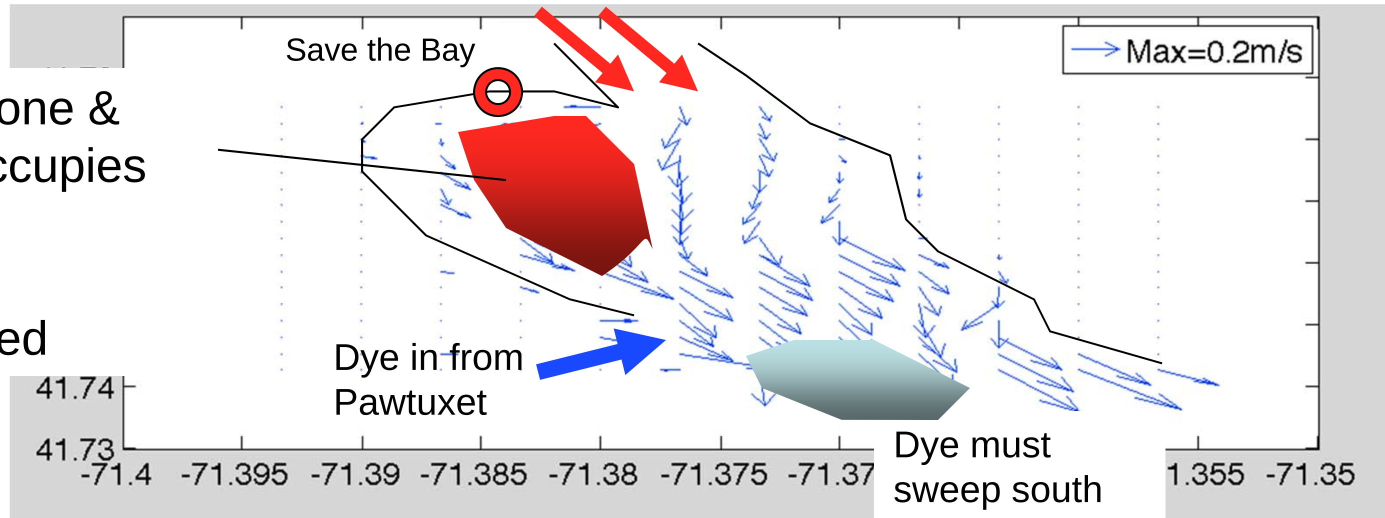


ROMS good match with data

ROMS predict fast flushing (agree with box models)

ROMS predict dye sources for shoals from north

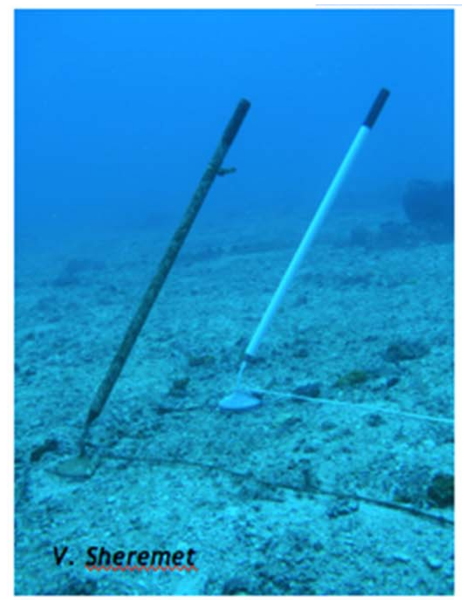
Data & Improved Models Paint a Different Picture

1st: Tilt Current Meters in Providence River

Improved Spatial & Time Information

2009 (3 months)
2010 (6 months..**flood**)

Bathymetric Map: Providence River - Edgewood



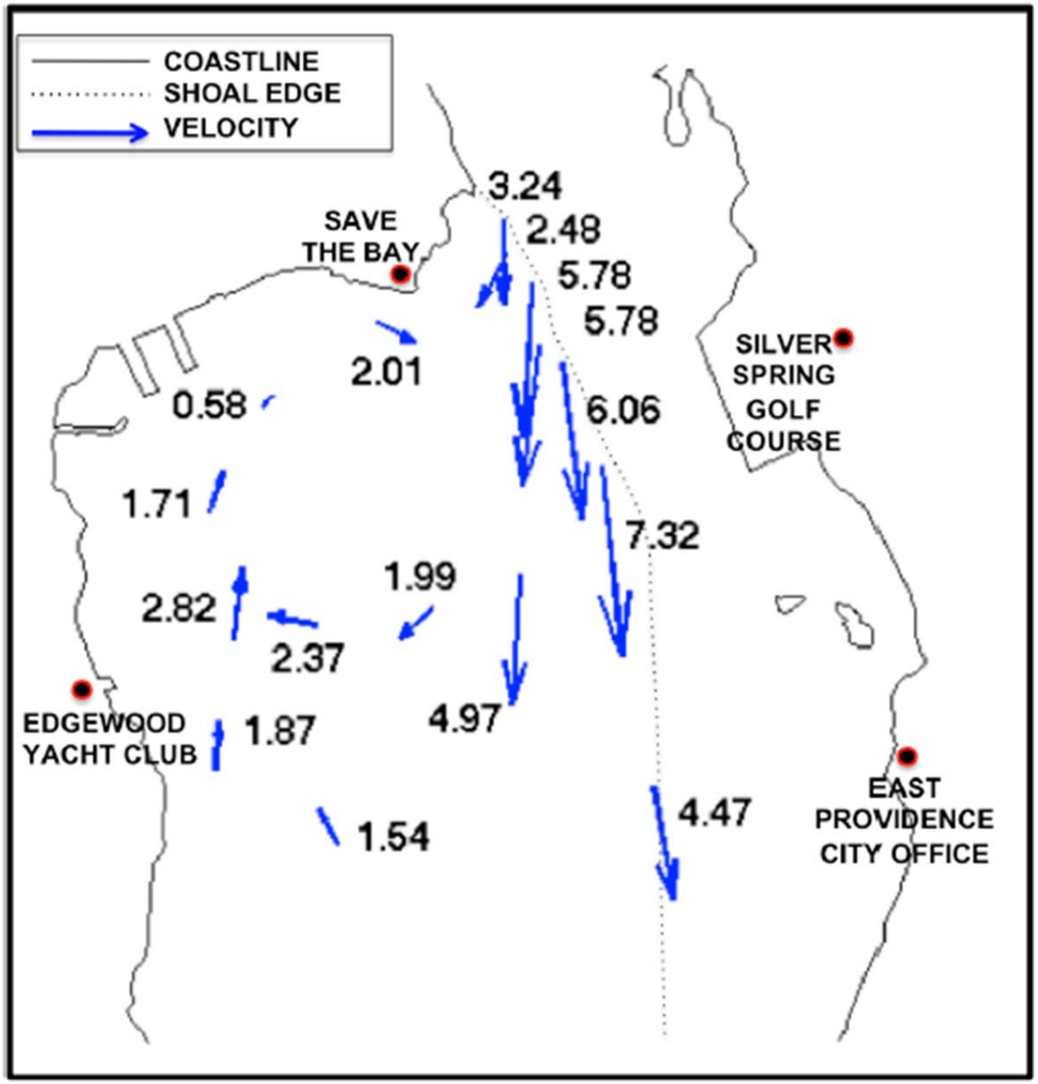
Providence River Data example: Stable retention gyre

Each arrow is current meter site

Deployment averaged vectors

Winter-Spring, 2010

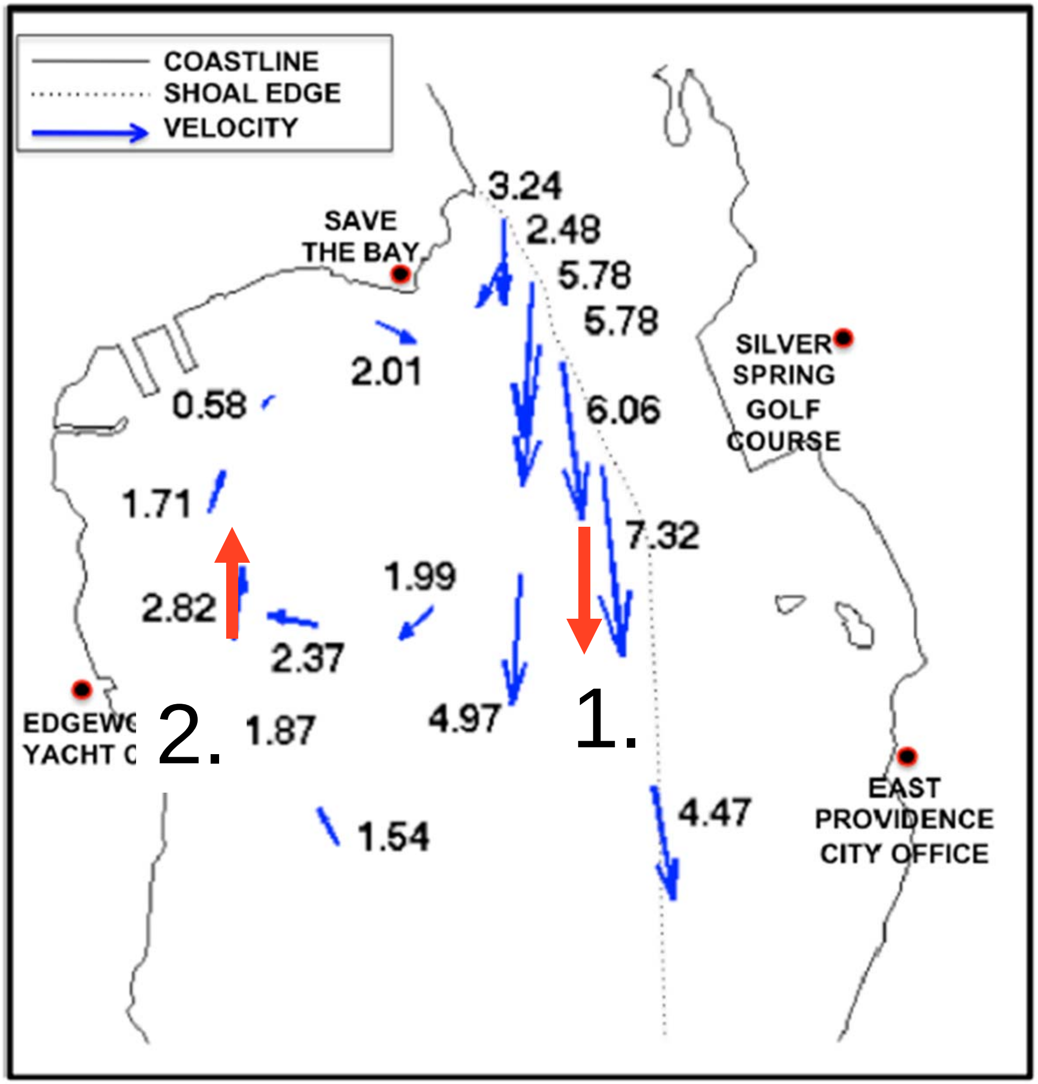
Flow rates in cm/s.



Providence River Data example: How stable?

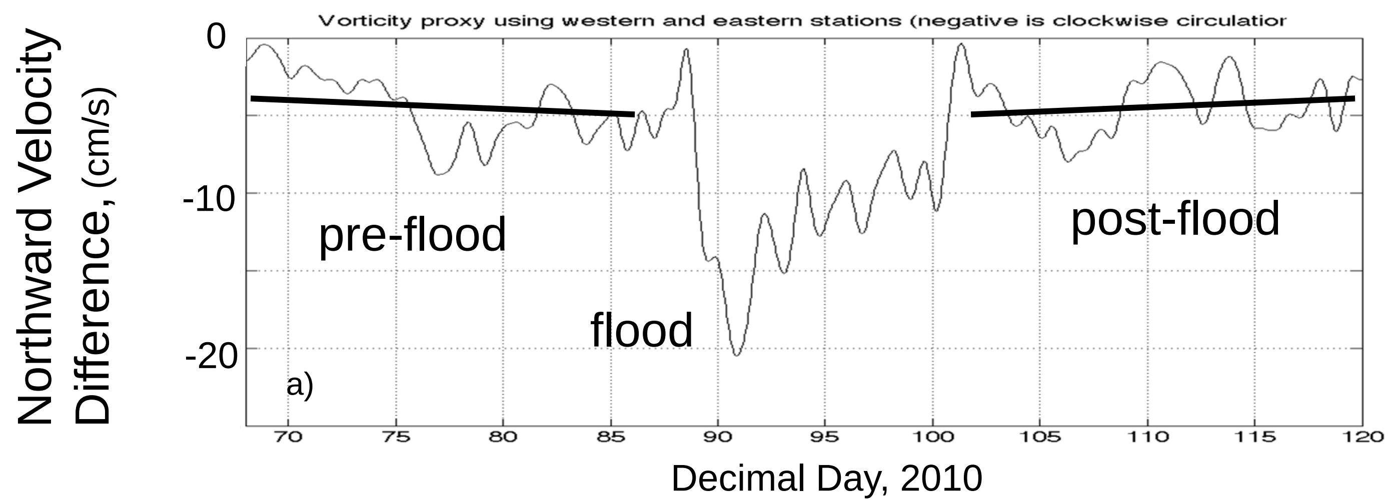
Time variations in gyre:

North residual current
Site 1 - Site 2

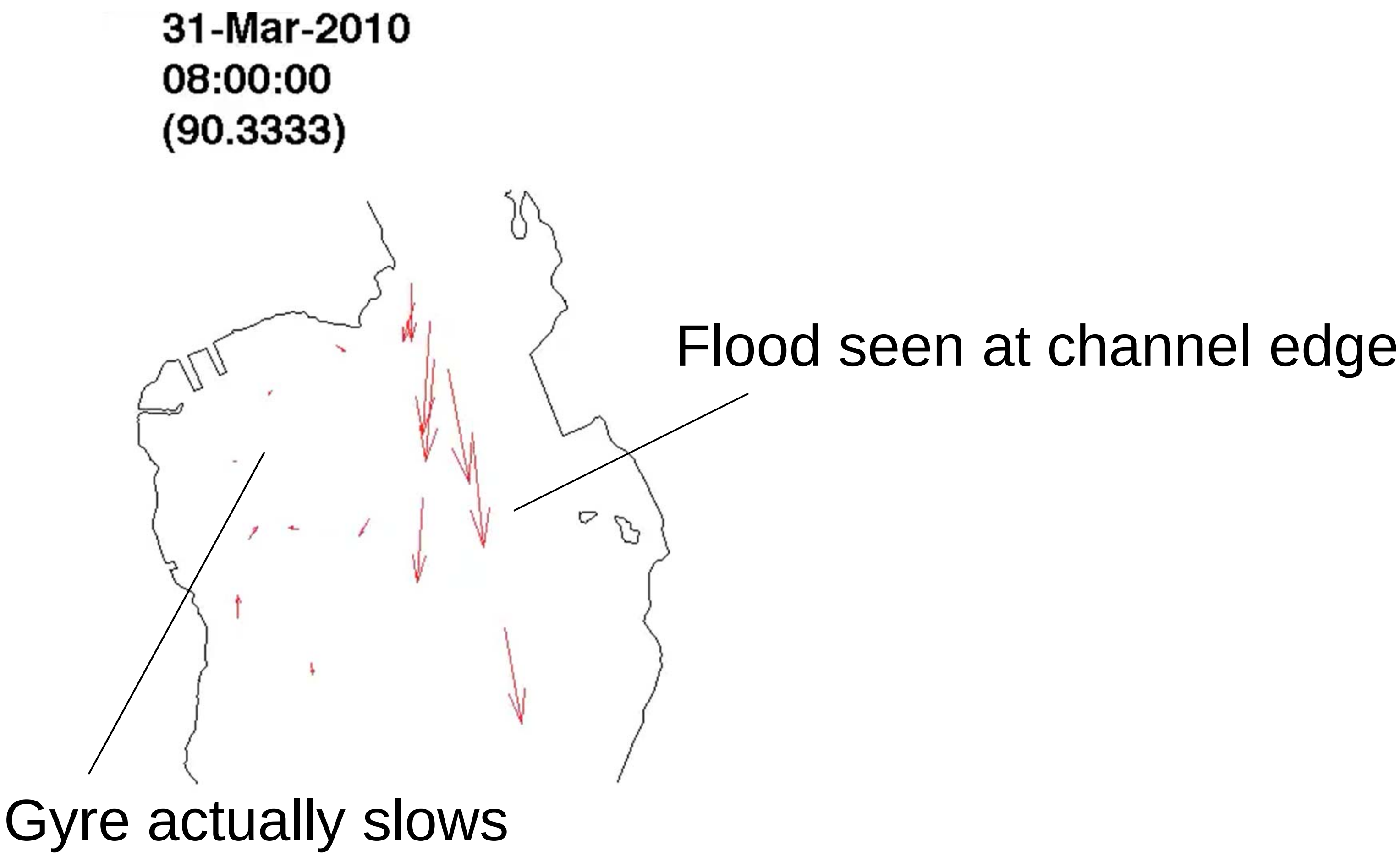


Gyre constantly spins

Northward flow in western arm of Edgewood gyre did not feel the Great March 2010 Flood



Edgewood Shoals flow does not increase during flood



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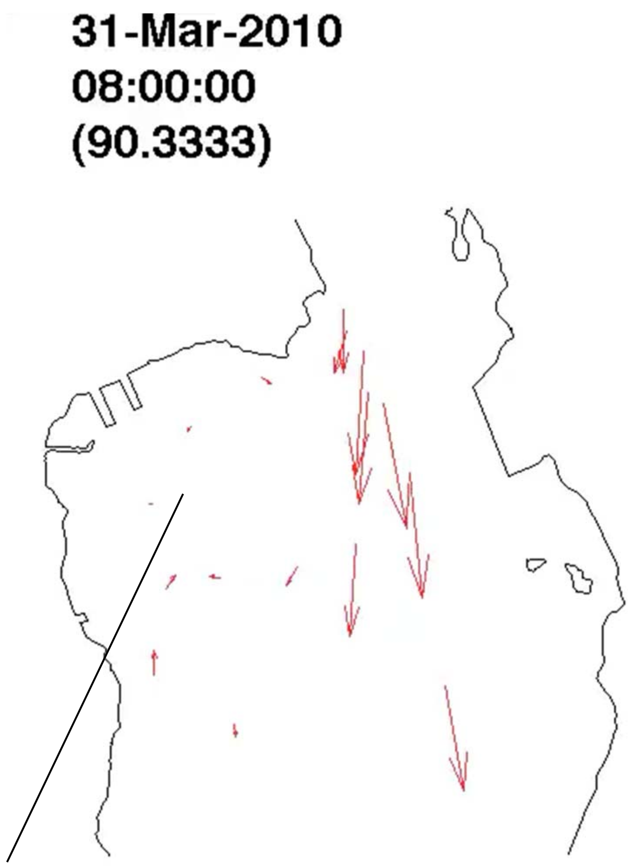
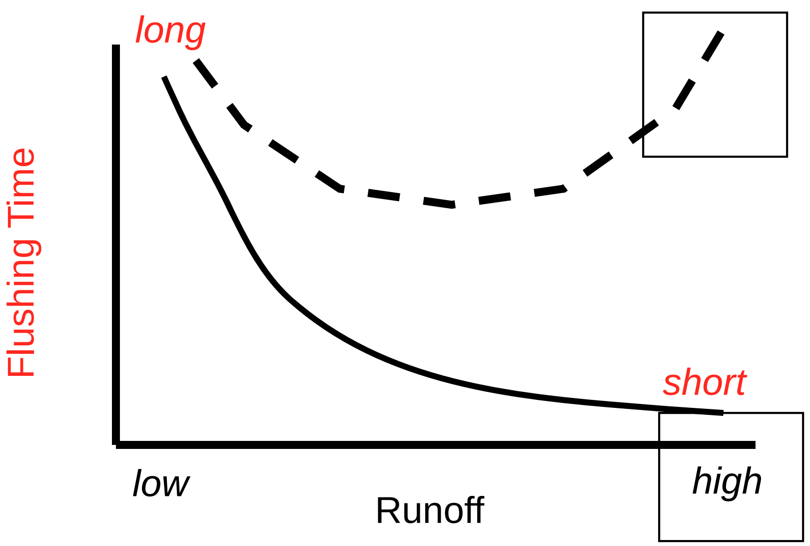


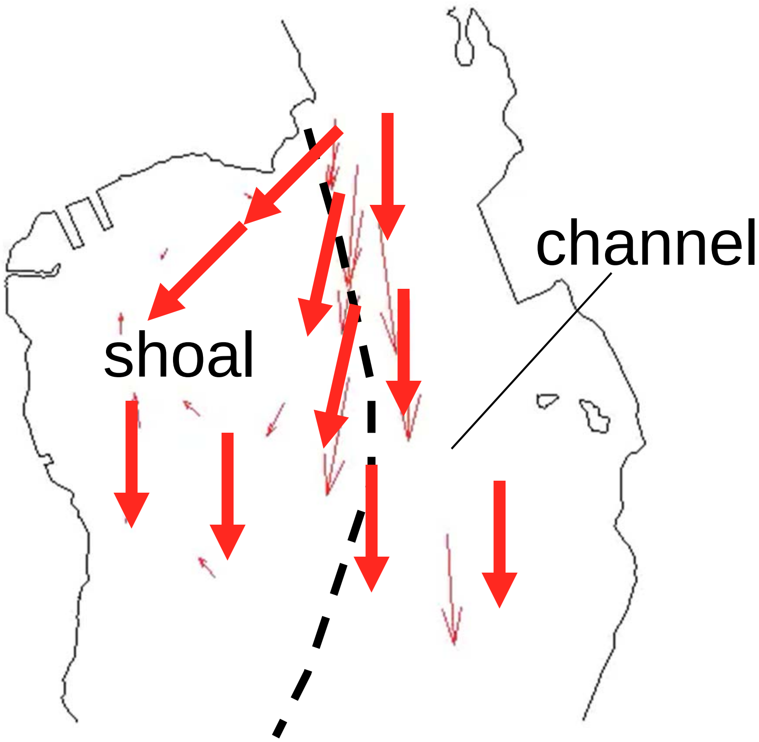
Flow energy doesn't increase with flood runoff

Behavior different from box models & coarse ROMS models



Box models & coarse ROMS predict:

Flood is high runoff, expect fast flush!



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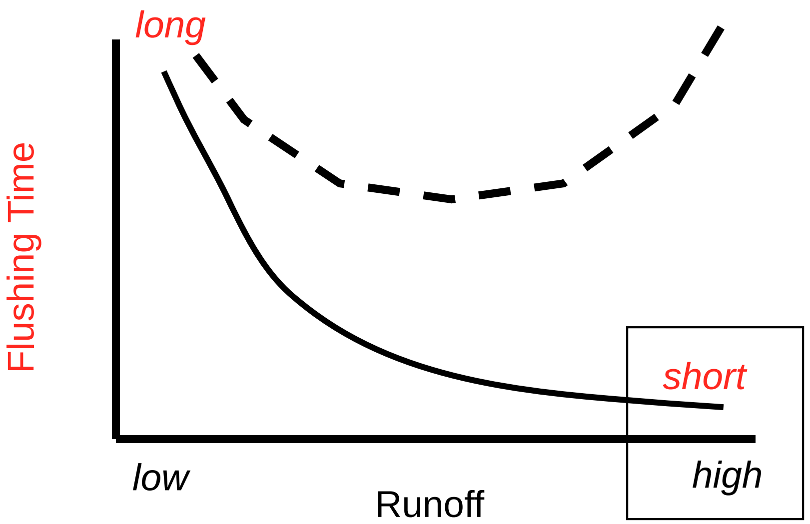
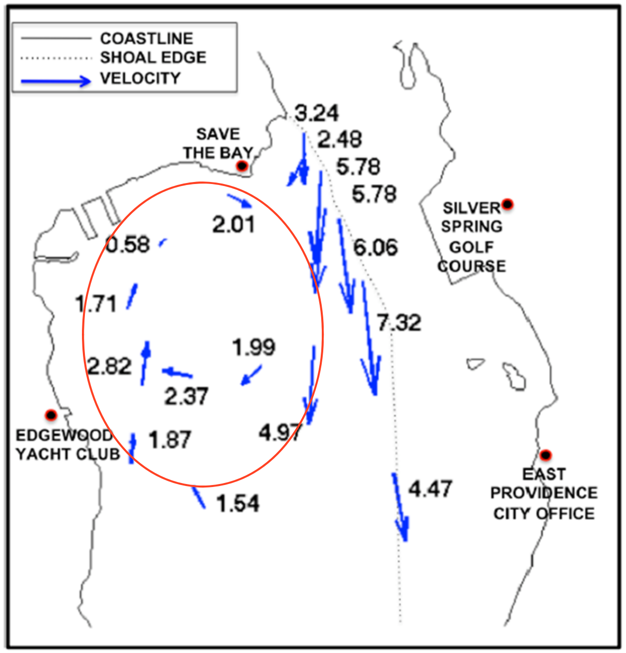




RISG, NOAA-CHRP & NBC Supported Improvements in Data > ROMS

1) Data show flow on Edgewood Shoals moving in gyre.

2) Based on rates/length scales, ~3 days for one bottom water circuit

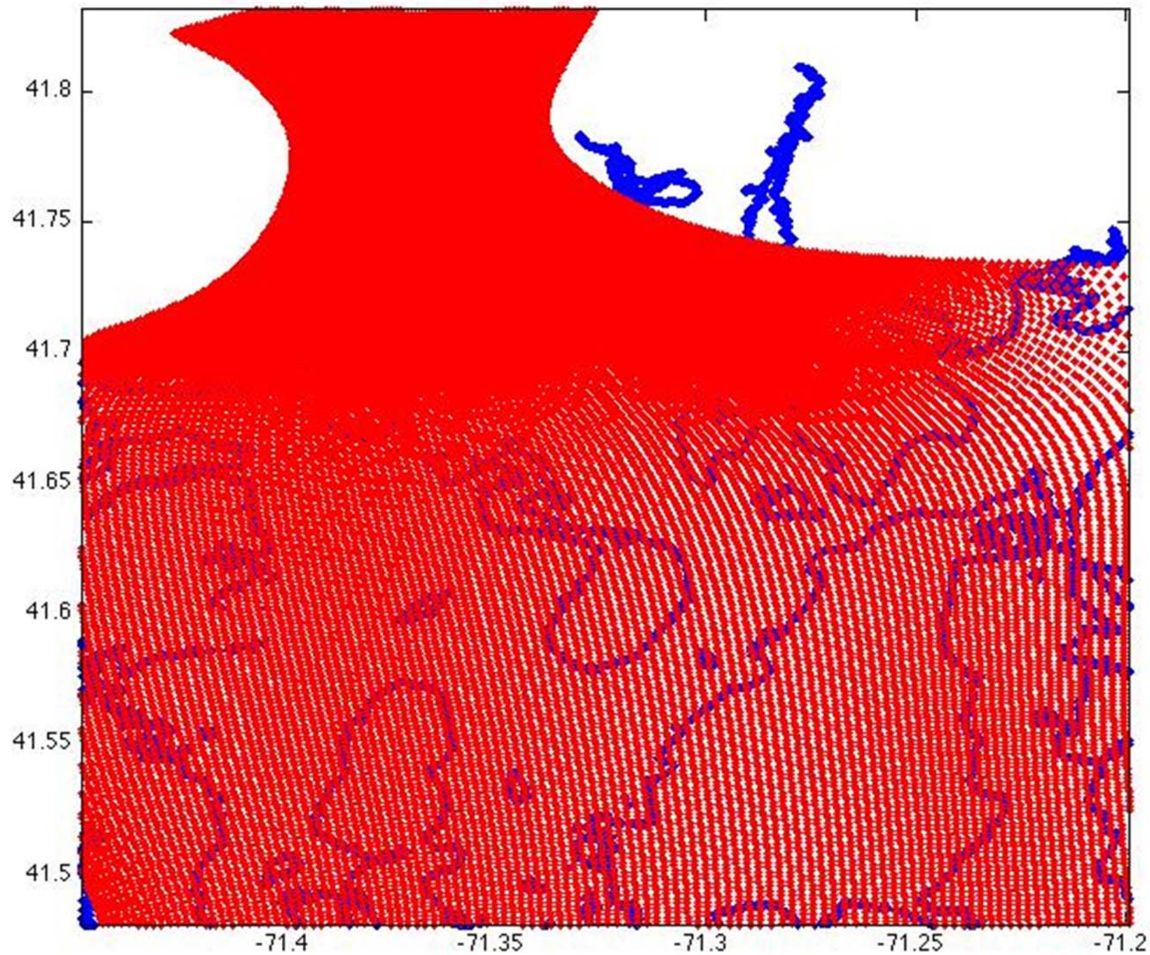
3) Data sets lead to improved ROMS

good data-model match in residual flow
dyes & tracers predict 7-10 day flushing time for gyre bottom water
forensic dye study predicts chemical transport from south is key

Improved ROMS simulates gyre & Predicts slow flush of gyre

Higher Resolution ROMS Grid: Smaller grid boxes in north

Finer grid

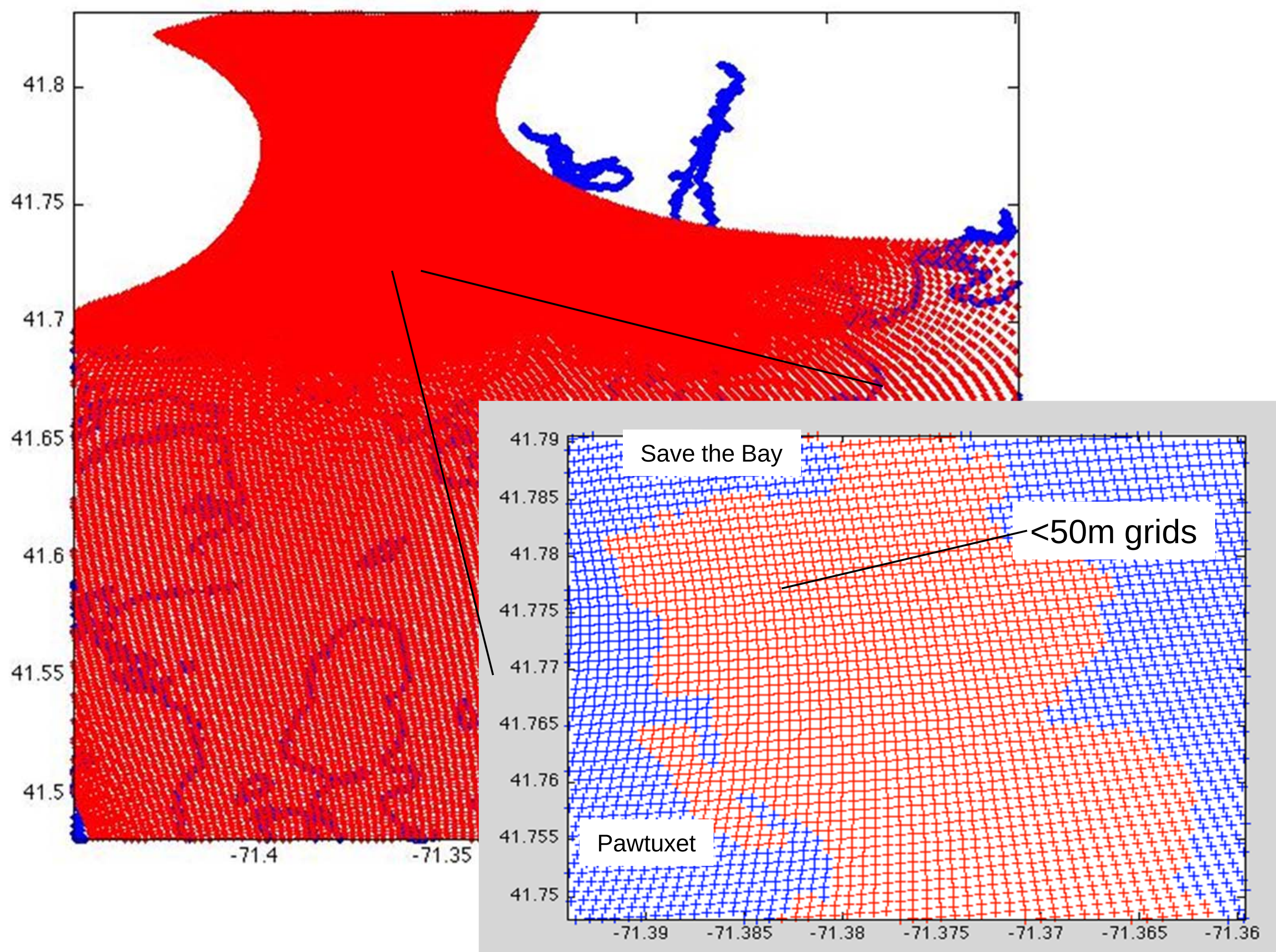


Coarser grid

Higher Resolution ROMS Grid: Smaller grid boxes in north

Sub-50m grid boxes in Providence River

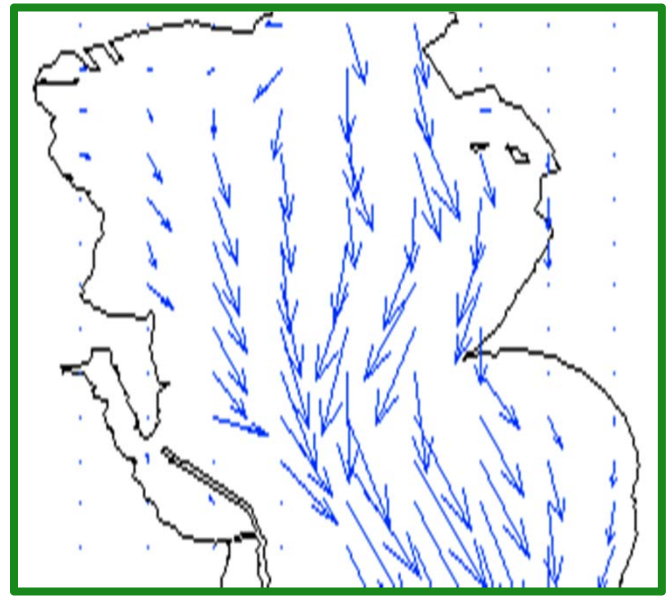
Finer grid



Coarser grid

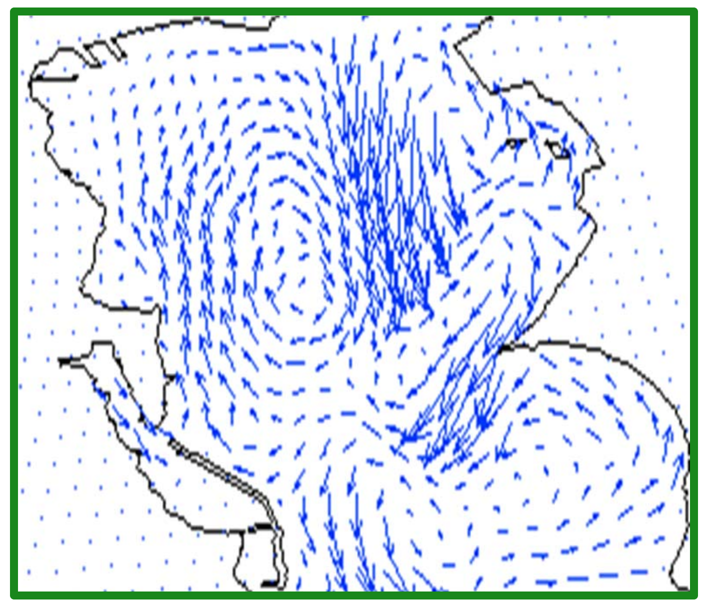
1st Generation ROMS

Flow on shoal same as in channel



Finer Grid ROMS:

Simulates tidal and residual character of gyre

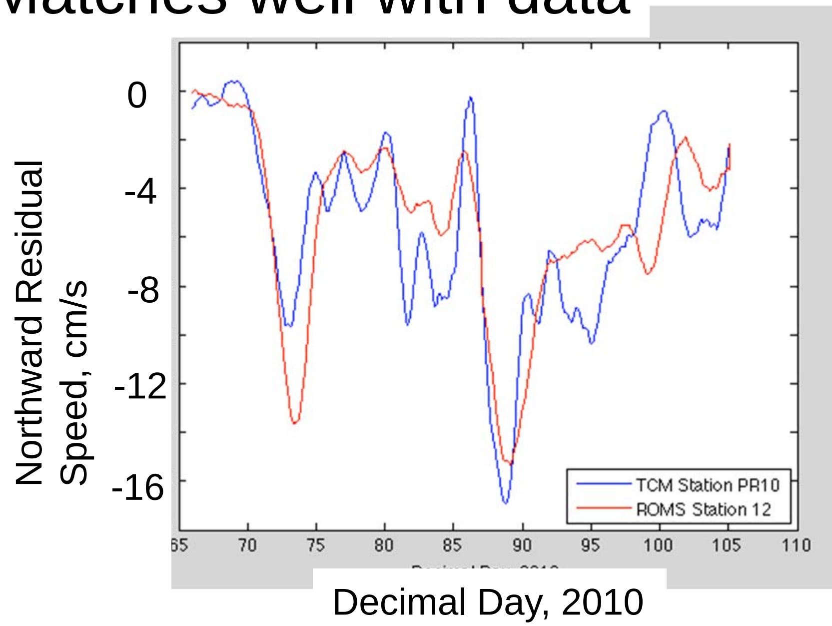


Finer grid ROMS simulates gyre: Matches well with data

Comparison of residual flows at shoal-channel edge:

ROMS (red) vs. Data (blue)

Model skill parameter >0.9
(1 is perfect match)



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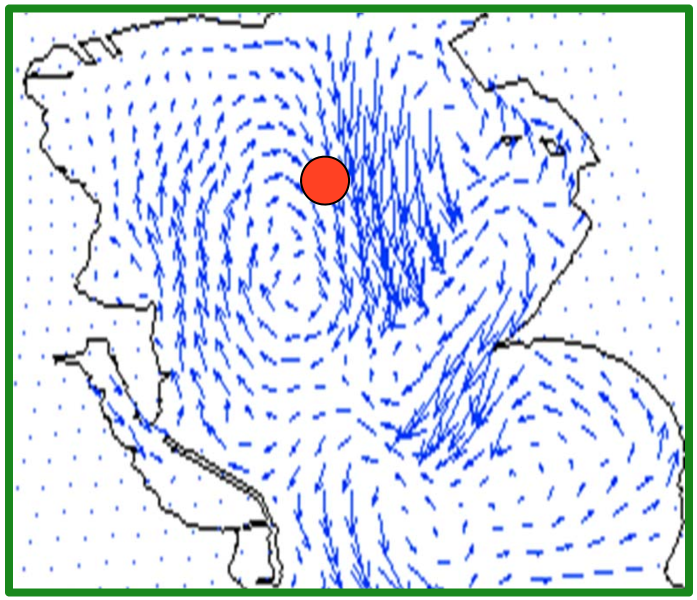

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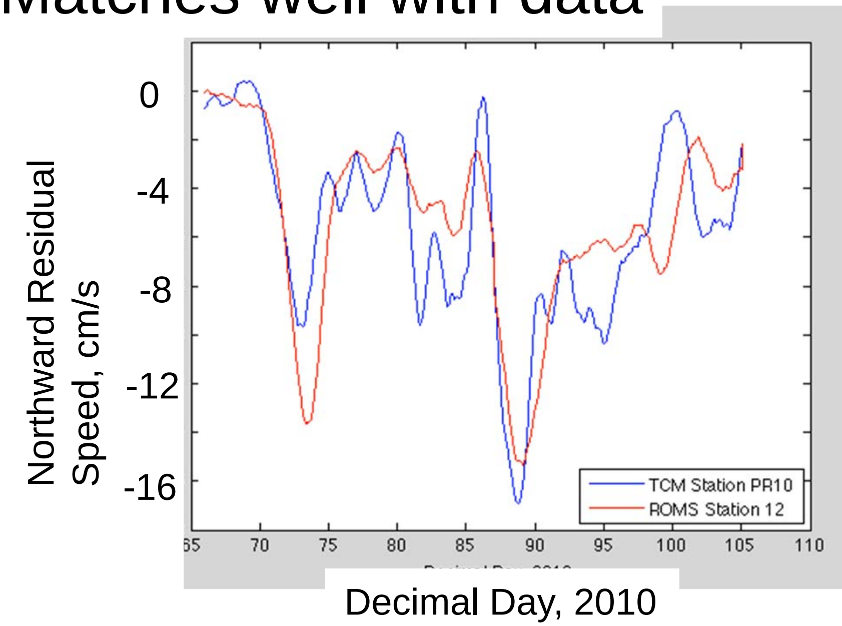

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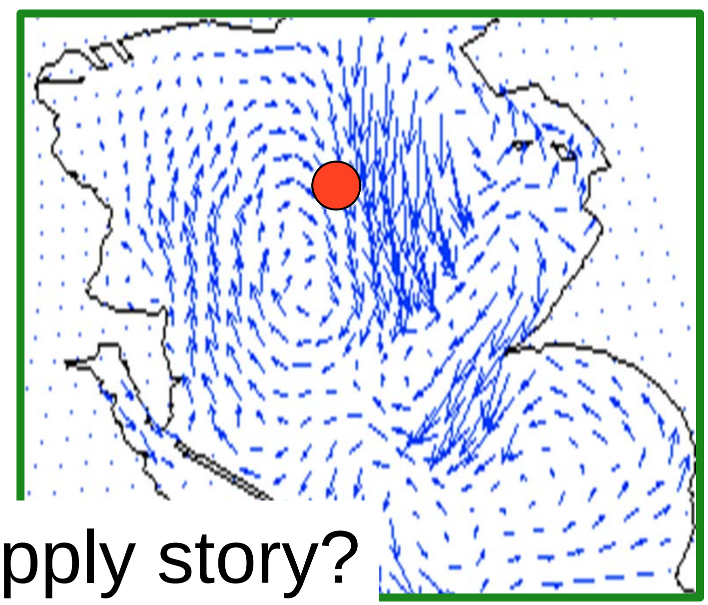


Flushing & nutrient supply story?

Quantifying Flushing:

1. Dyes
2. Passive tracers (2010 Summer conditions)

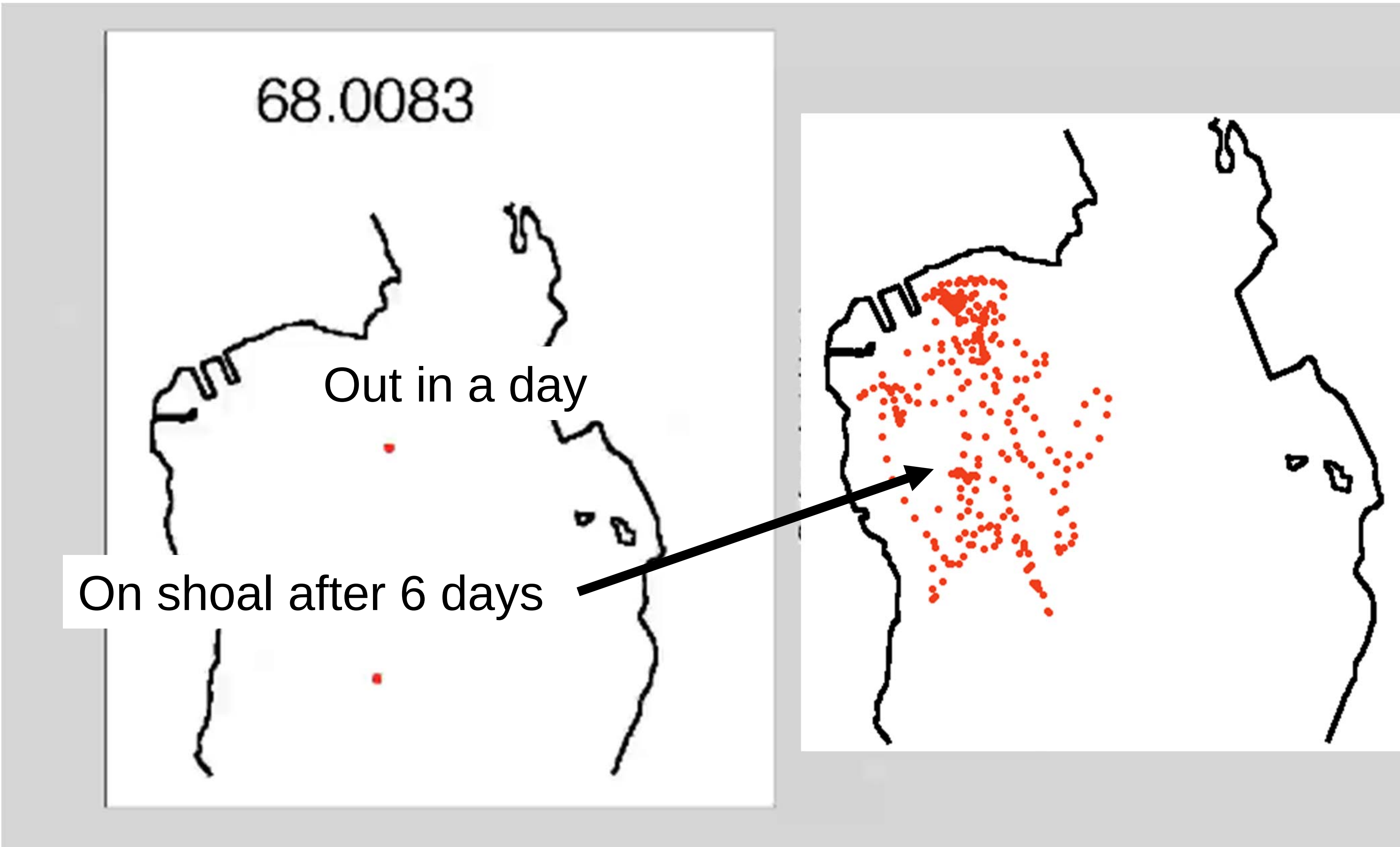
QuickTime™ and a
H.264 decompressor
are needed to see this picture.

Movie: Track Channel vs Shoal Bottom Floats (2010 conditions)

QuickTime™ and a
H.264 decompressor
are needed to see this picture.

Shoal bottom water floats can take 6-10 days to exit …..

just the shoal



Box models & Coarse ROMS Predict Time to Flush Whole Providence River

Flushing Time ~ 1 / Runoff

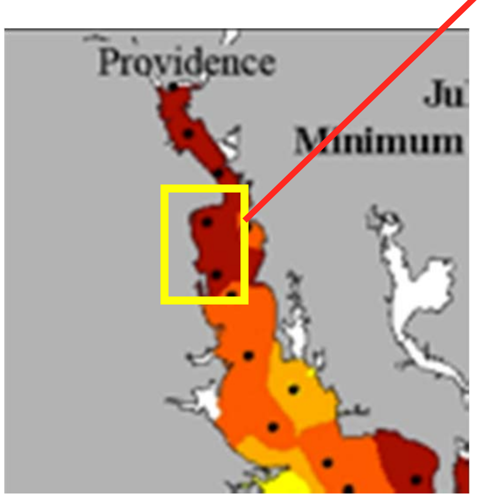
	Runoff (CMS)	Flushing time (days)
High	90	0.8
Low	5	6
Average	42	2.5

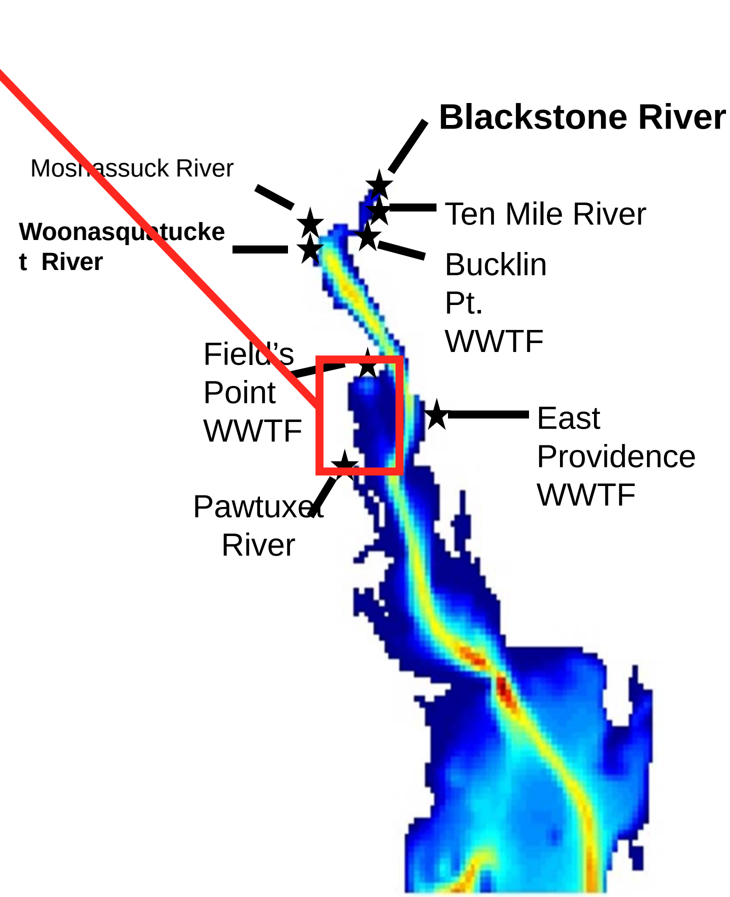
High Resolution ROMS Edgewood Shoals bottom water flushing time

40-50	6-10 days

Using improved, gyre-resolving ROMS, which nutrient sources feed Edgewood Shoals?

Track which dyes feed Edgewood Shoals





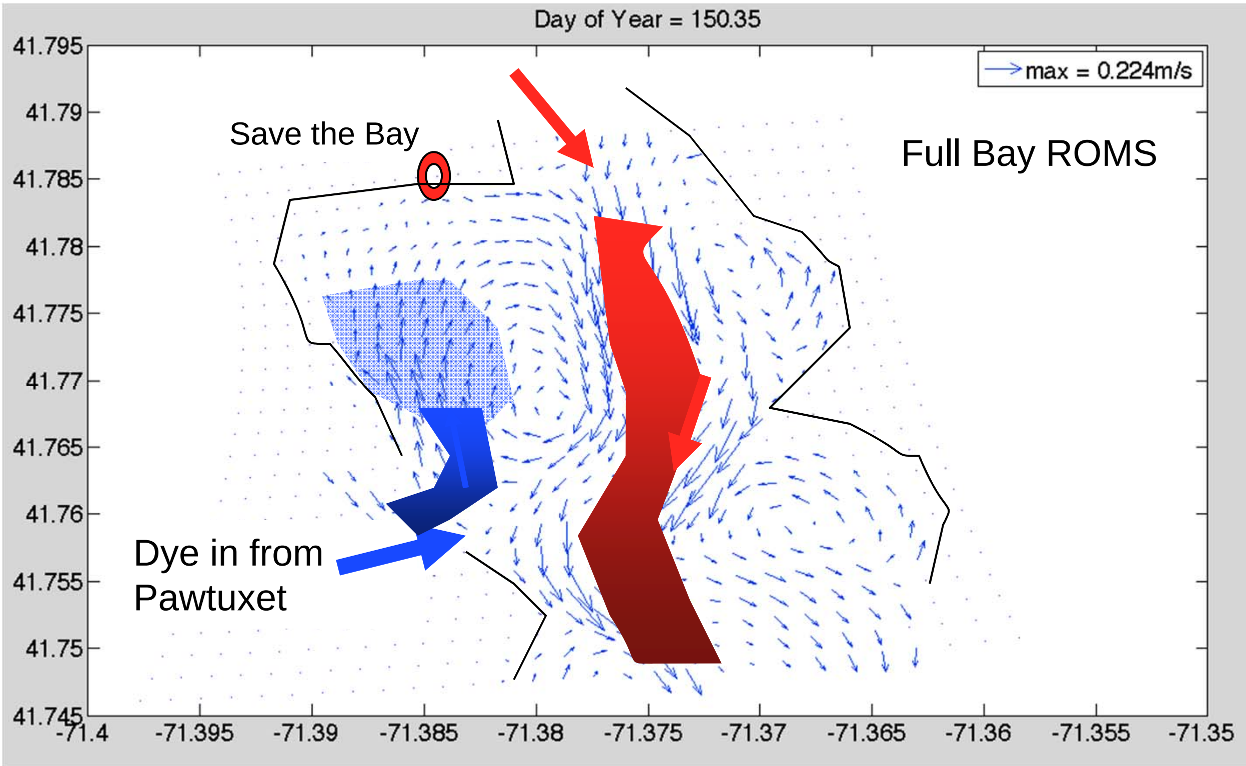
(LaSota MS Thesis 2010)

Using improved, gyre-resolving ROMS, which nutrient sources feed Edgewood Shoals?

Source of dye (nutrients) to Edgewood from Pawtuxet (from south)

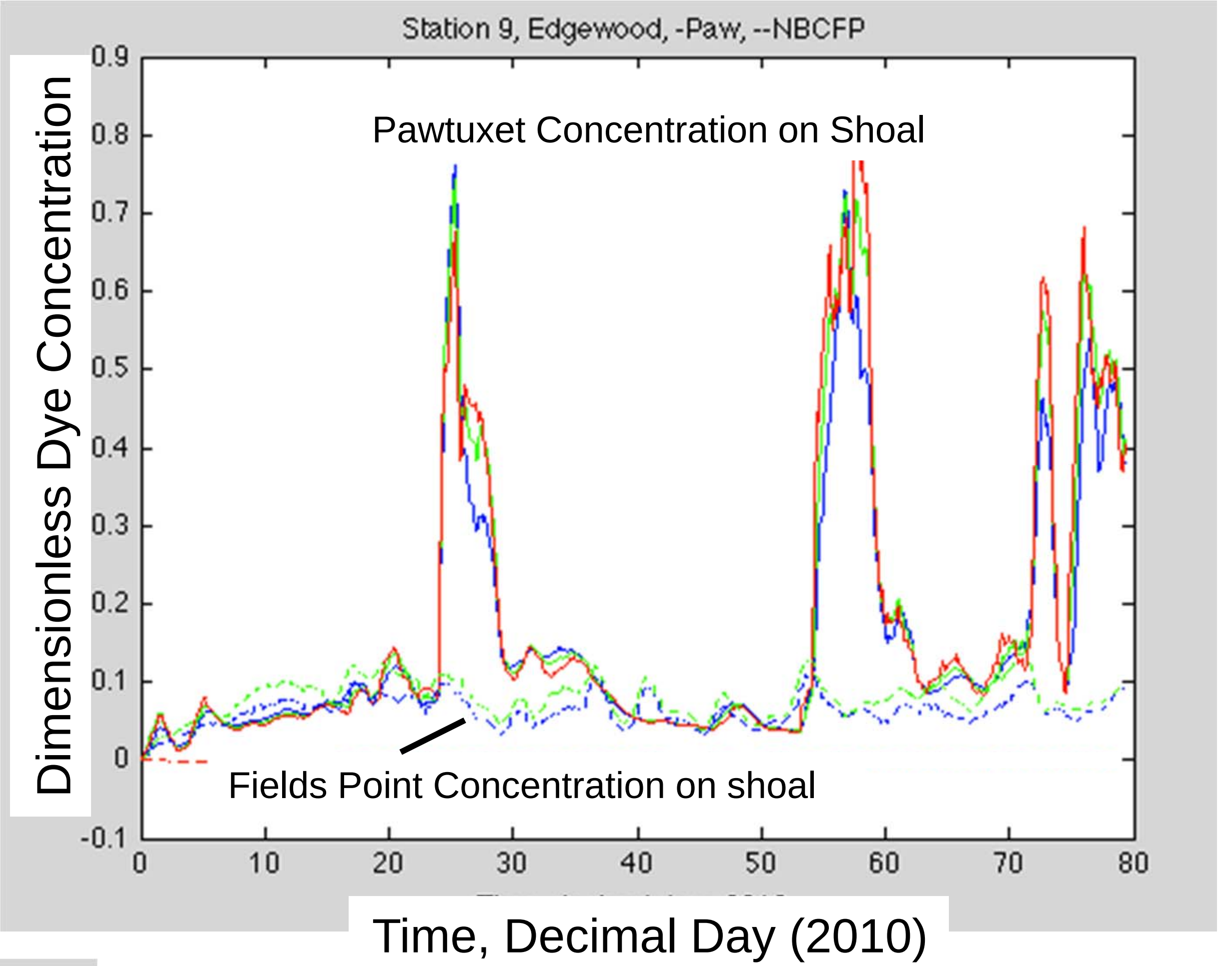
Dye in bottom water retained for 6-10 days

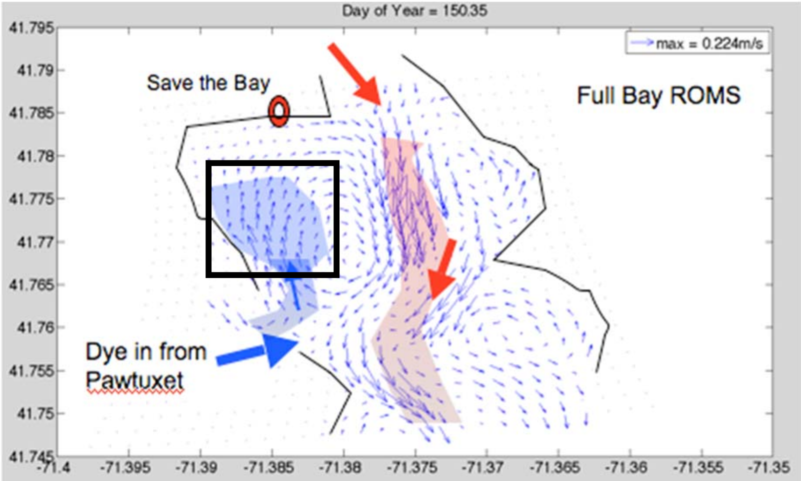
Dyes from the north tend to folow channel



ROMS Prediction:

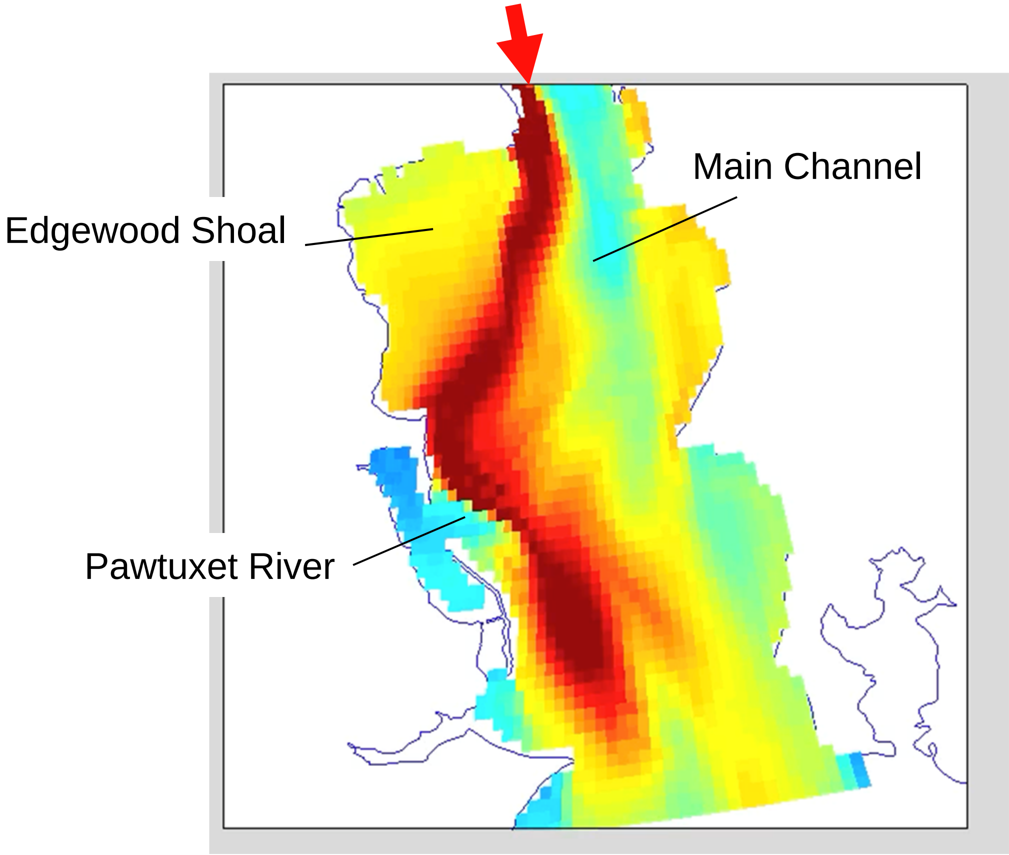
Pawtuxet bigger player in Shoal dye concentrations





Dye Tagging Fields Point outflow during Summer 2010 ROMS simulation

Average Concentration in upper half of water column



Hugs western channel edge (match with ADCP data)

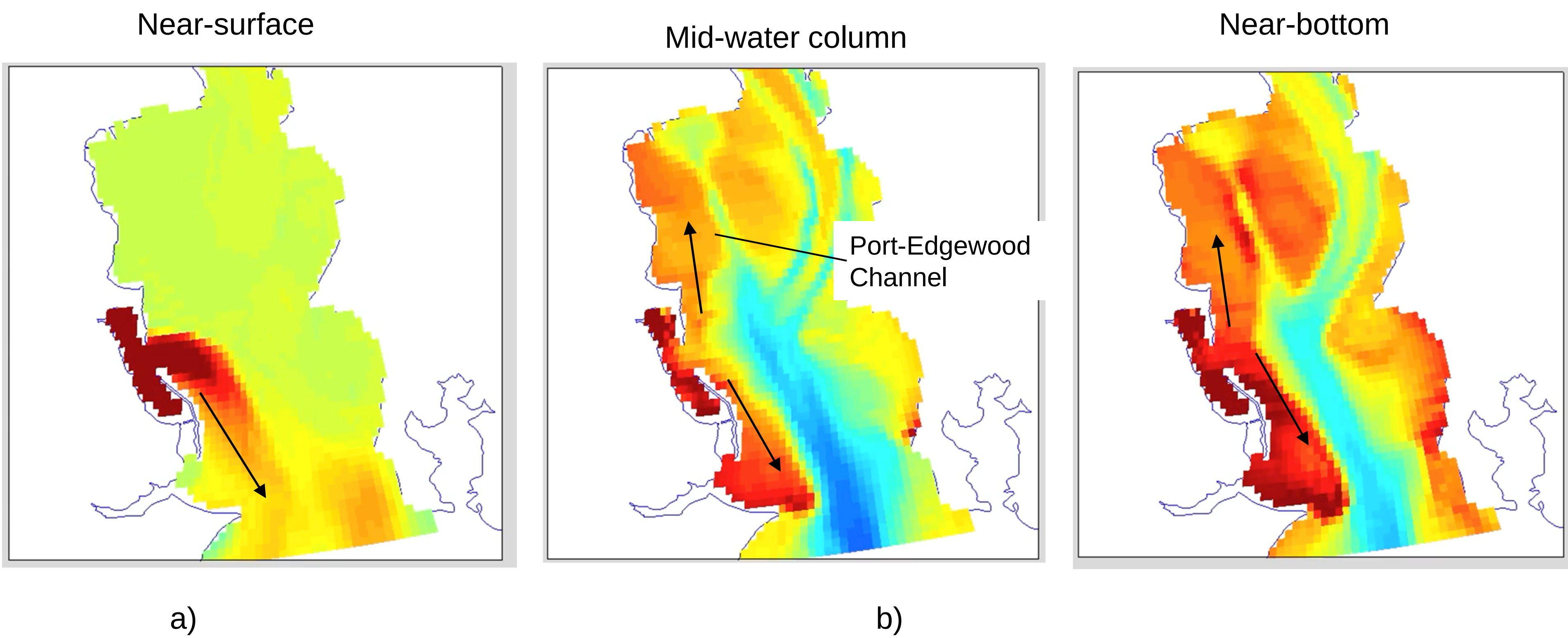
Impacts western shore at Pawtuxet mouth

Disperses southward

Pawtuxet Dye Dispersion:

Surface plume entrains southward

Mid & Bottom plume entrains northward



Red Color : Concentration = 0.6

Fields Pt. Dye: Near-surface (red = 0.05)

QuickTime™ and a
H.264 decompressor
are needed to see this picture.

Pawtuxet Dye: Near-bottom (red = 0.15)

QuickTime™ and a
H.264 decompressor
are needed to see this picture.

Blackstone River dye: Near-surface (red = 0.2)

QuickTime™ and a
H.264 decompressor
are needed to see this picture.

Conclusions:

RISG, NOAA & NBC funding has provided a decade of spatially-temporally detailed hydrographic data in all sections of Narragansett Bay

Better data > better models > better process-level understanding

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Case Study: Edgewood Shoals, Chronic Low DO

- Stable gyre
-Bi-modal flushing (not simple box model)
- Predicted POOR flushing of shoal bottom water
- Nutrient sources from South important

Conclusions:

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Case Study: Edgewood Shoals, Chronic Low DO

- Stable gyre
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- Predicted POOR flushing of shoal bottom water
- Nutrient sources from South important

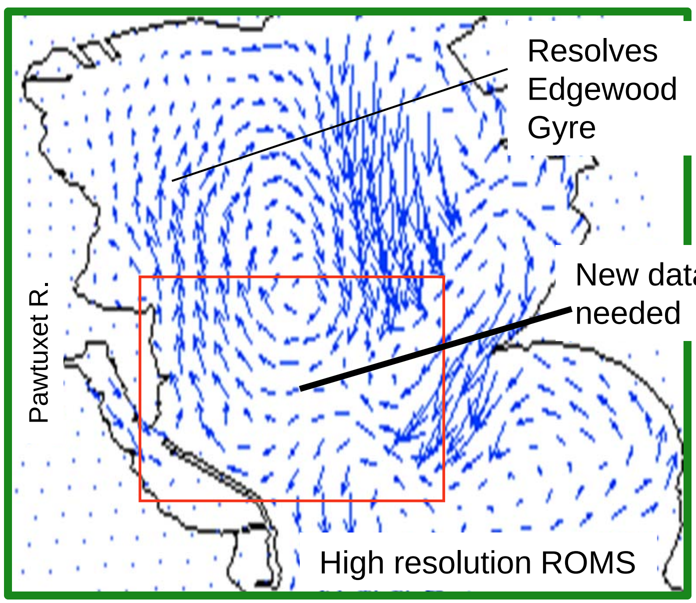
Data/ROMS input to water quality strategy

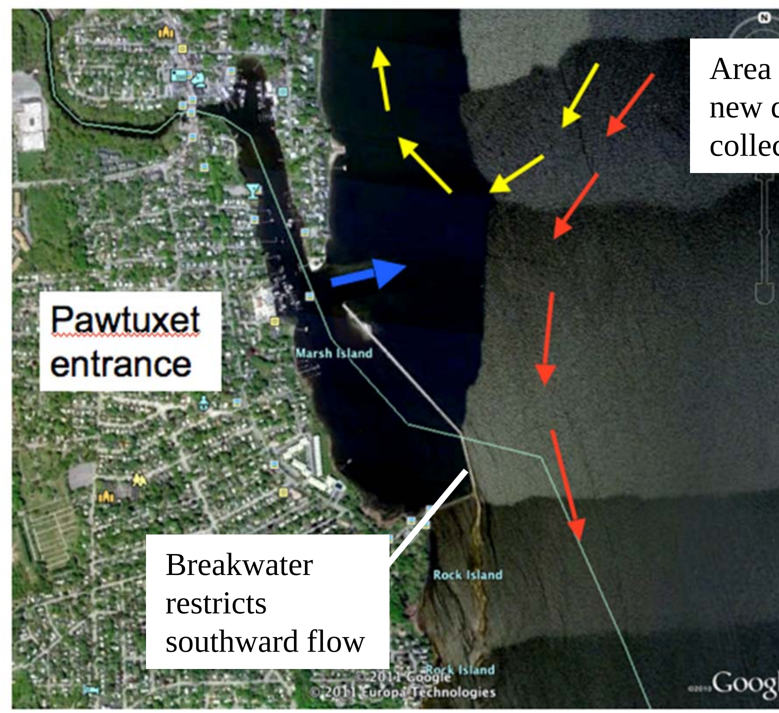
- Engineering solution to break gyre
- Mitigate Pawtuxet R. (geometry of source, nutrient concentration of source)

Processes operating at mouth of Pawtuxet River are predicted by ROMS to be important.

Pawtuxet dye entrained northward into gyre
Fields Pt , Blackstone & northern dyes impact western shore here
Role of Port Edgewood Channel in chemical transport & flushing

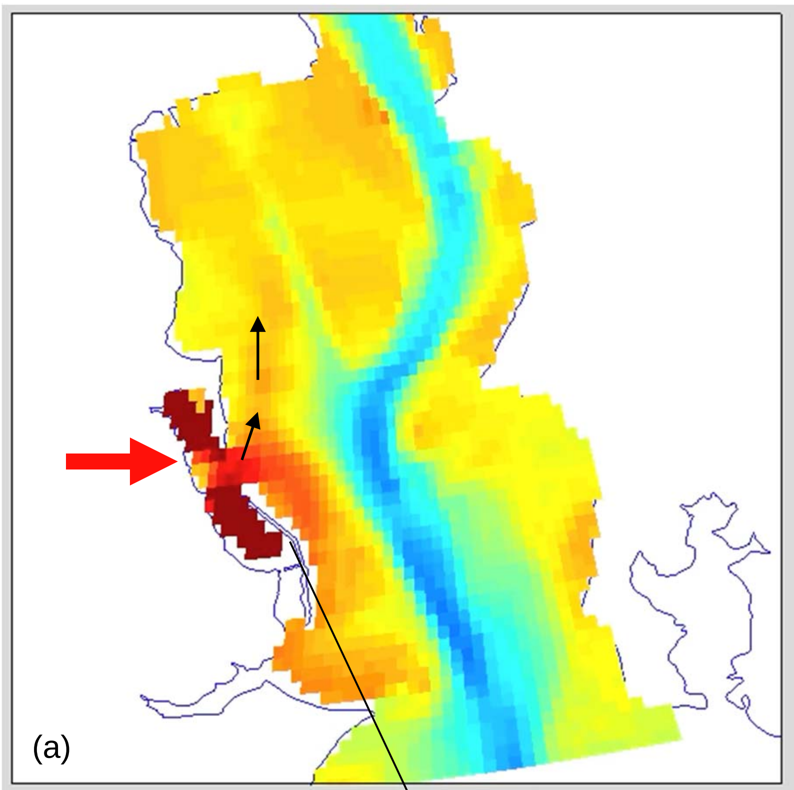
We are data challenged in this area





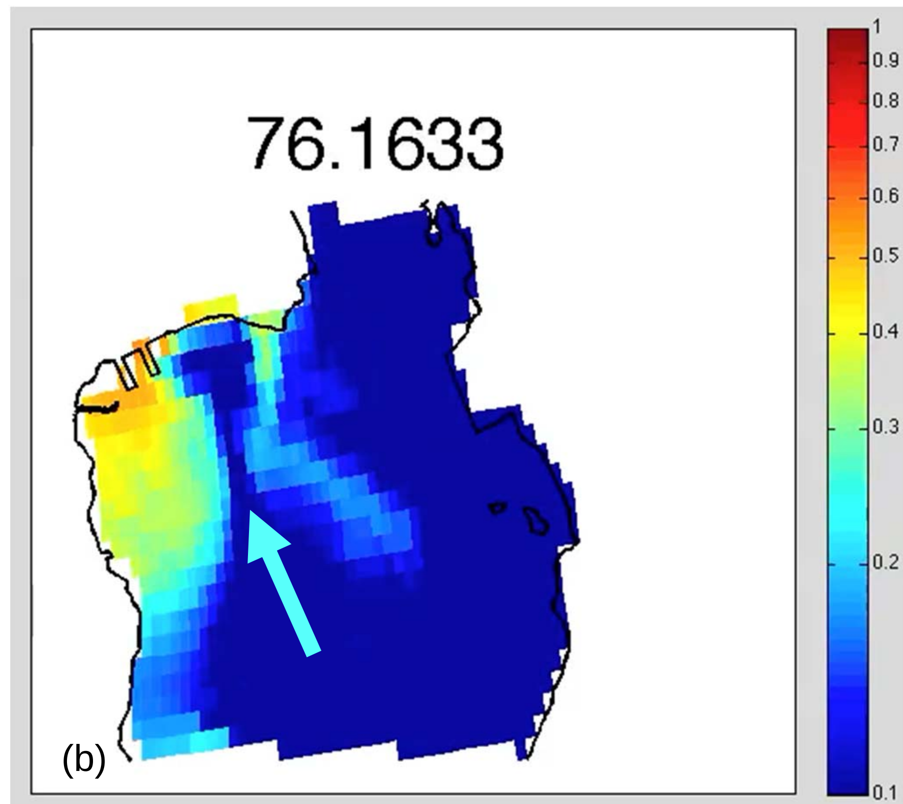
ROMS Testing of Potential Changes to Limit Chronic Retention / Hypoxia

Pawtuxet breakwater enhances northward Pawtuxet dye transport



Remove breakwater

Port Edgewood Channel enhances flushing



Dredge Port Edgewood Channel

Dye lower half of Edgewood Shoal water column

Low runoff = Weak gyre

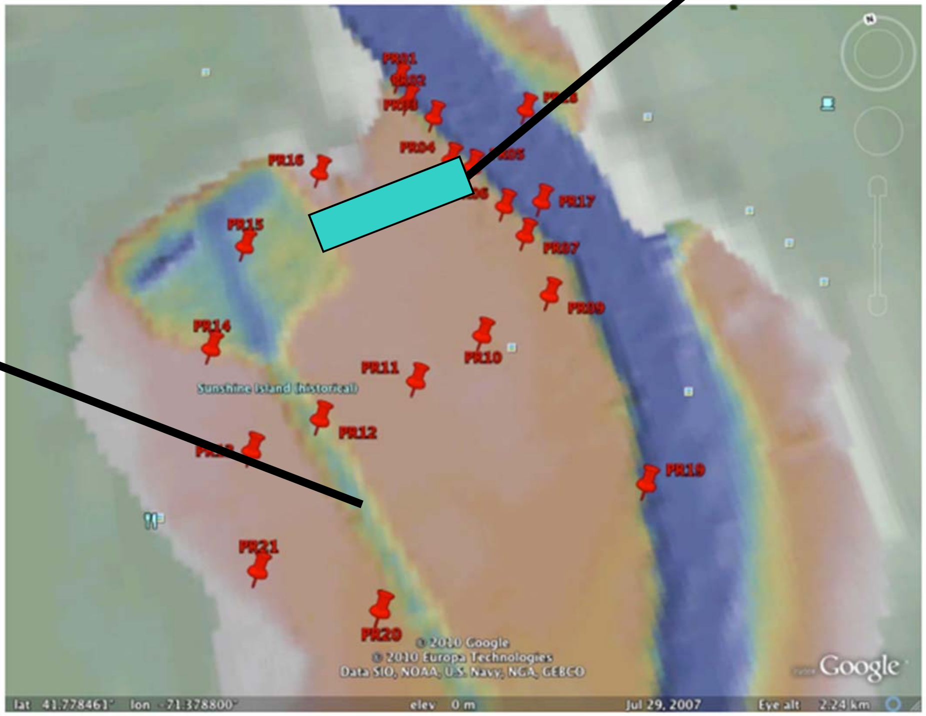
Spring tide = Stronger flow up Port Edgewood Channel

QuickTime™ and a
H.264 decompressor
are needed to see this picture.

ROMS dredging scenarios to improve flushing

2. Dredge a connection

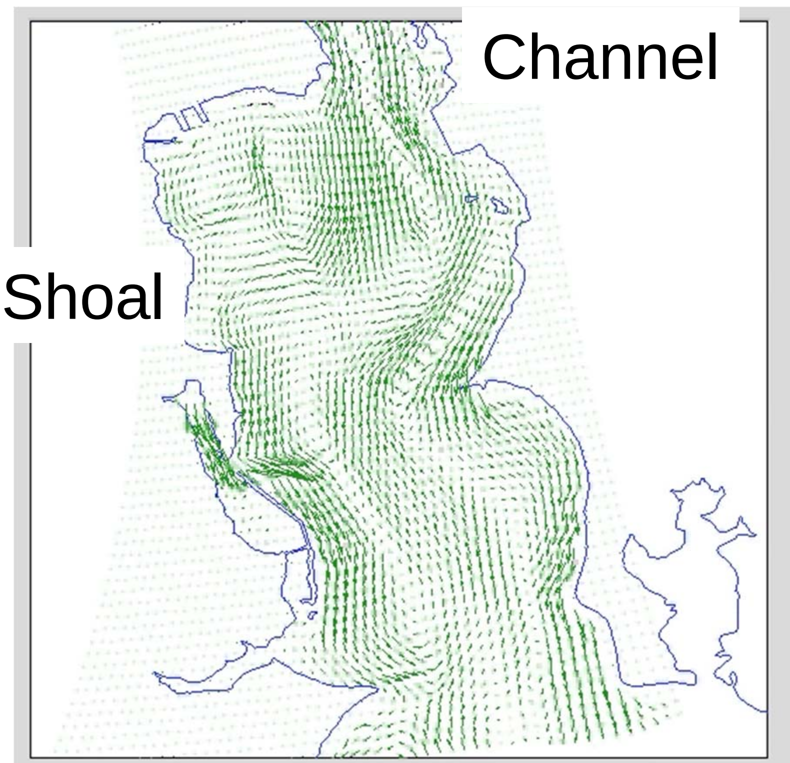
1. Dredge Port Edgewood channel



Multiple Modeling Methods: Flushing of Urban Hotspots

Providence River Example

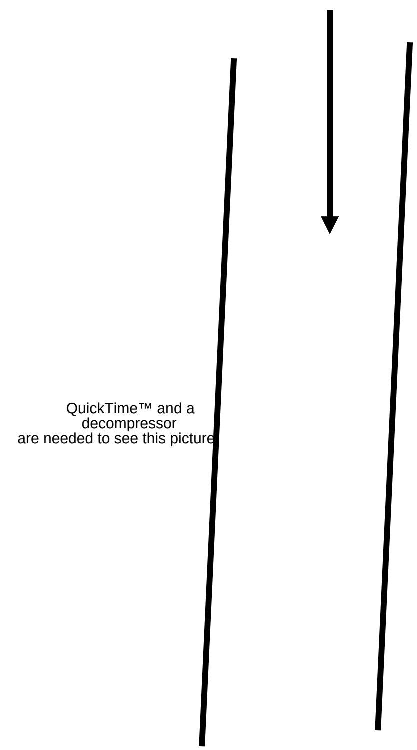
1) ROMS Model:
3-D Flows



2) GFD Lab Model
3-D Flows

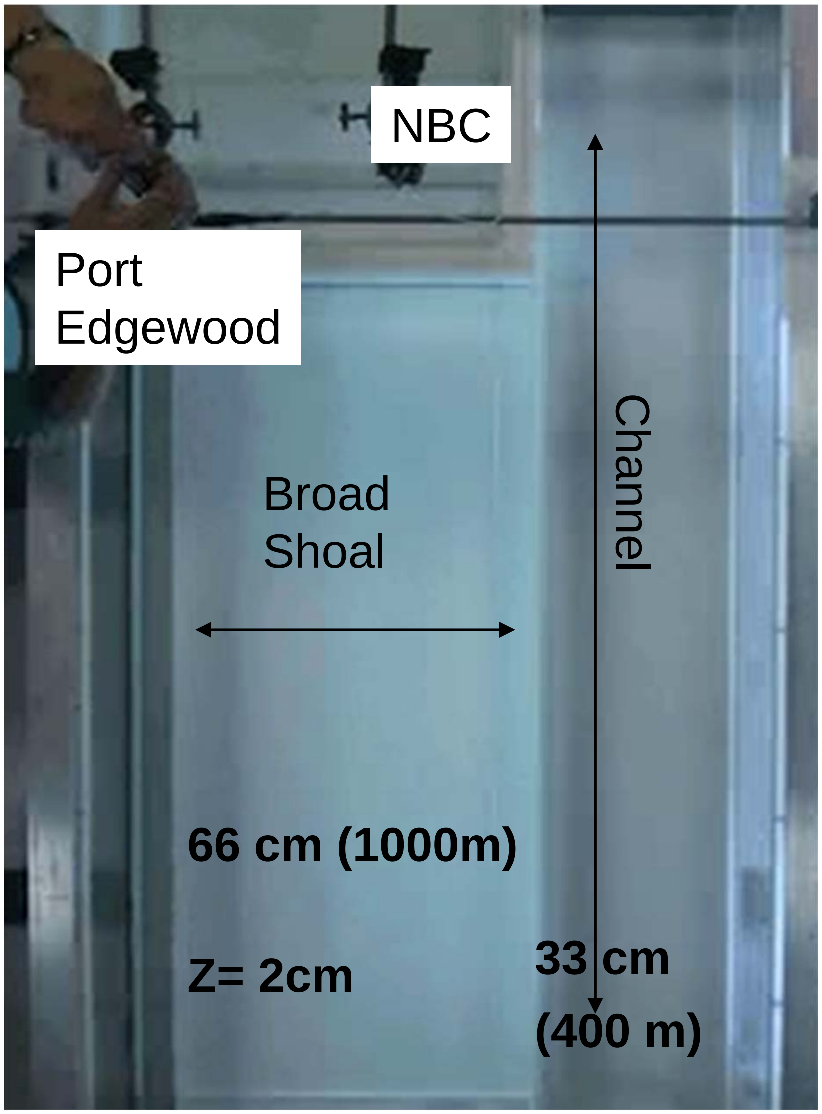
Channel

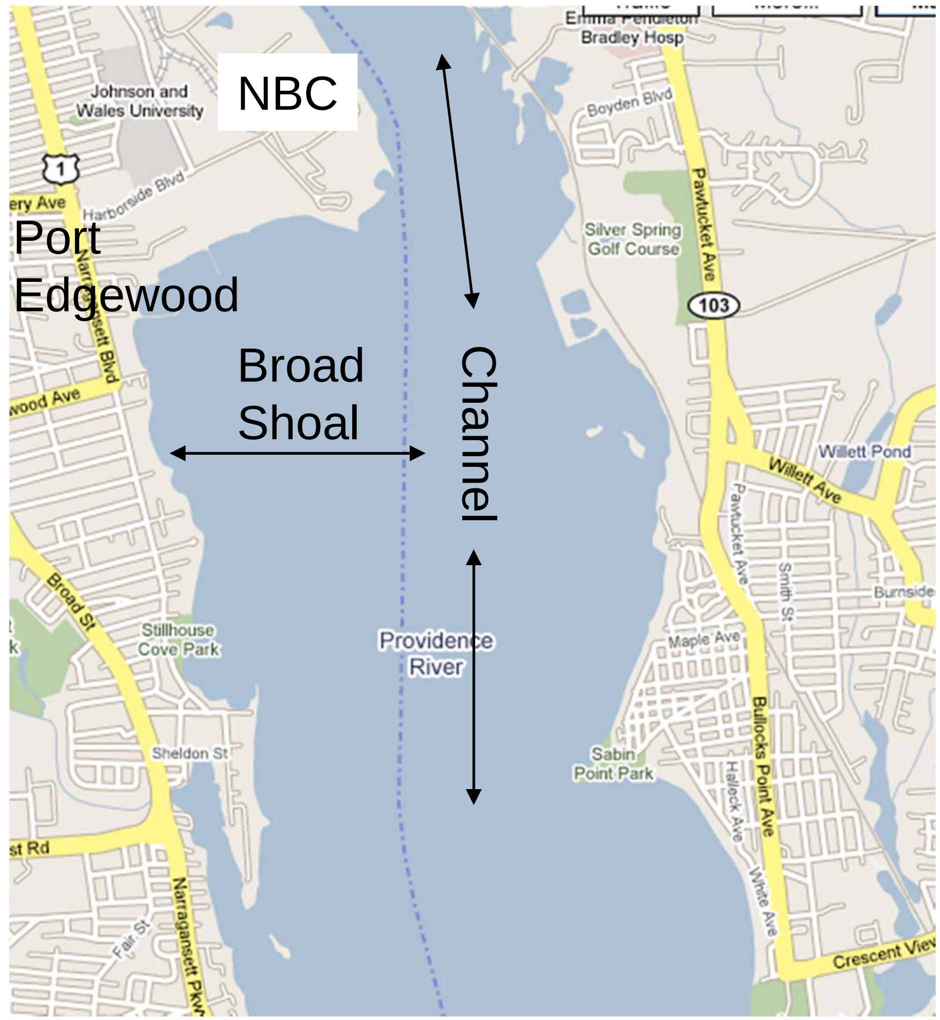
Shoal

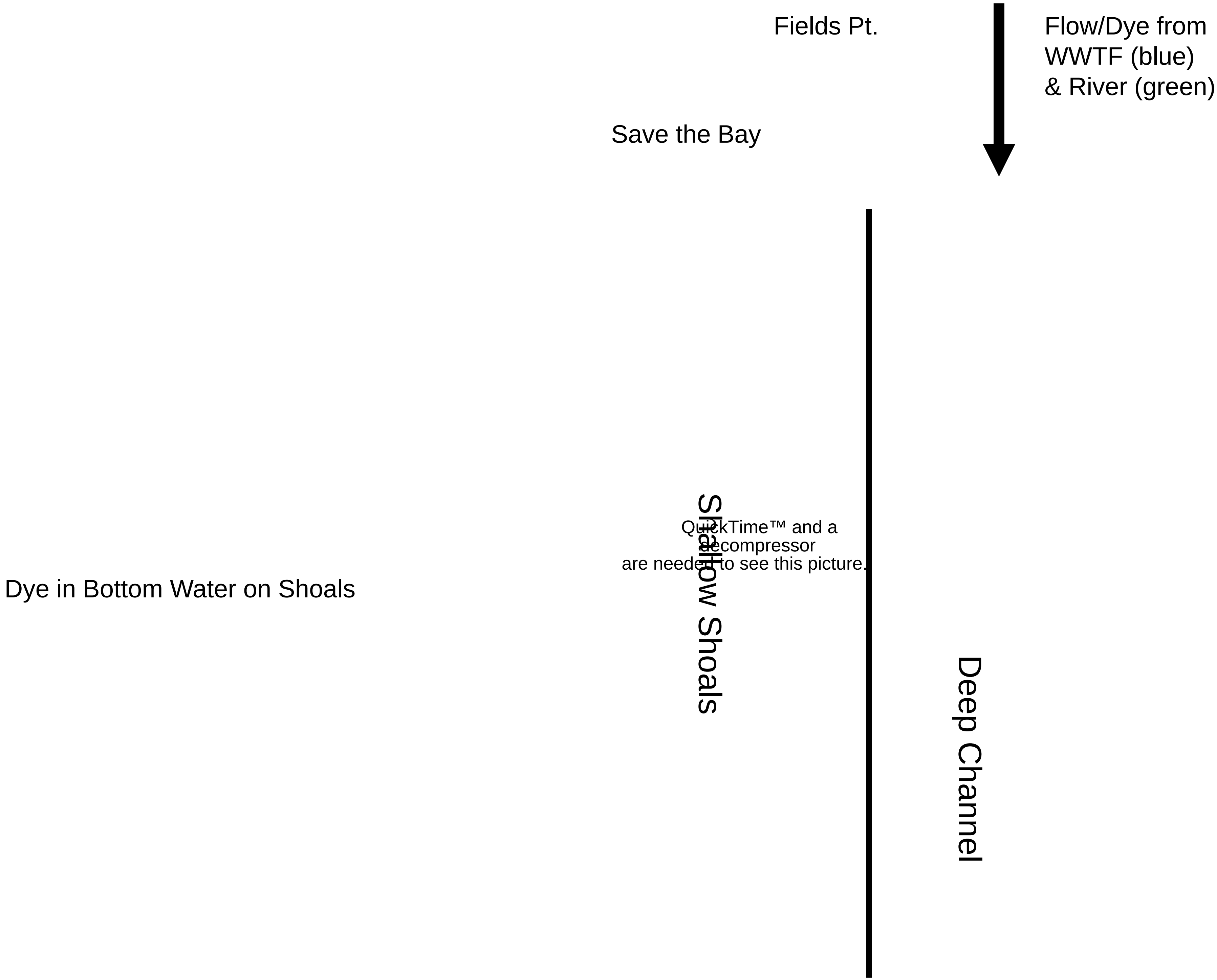


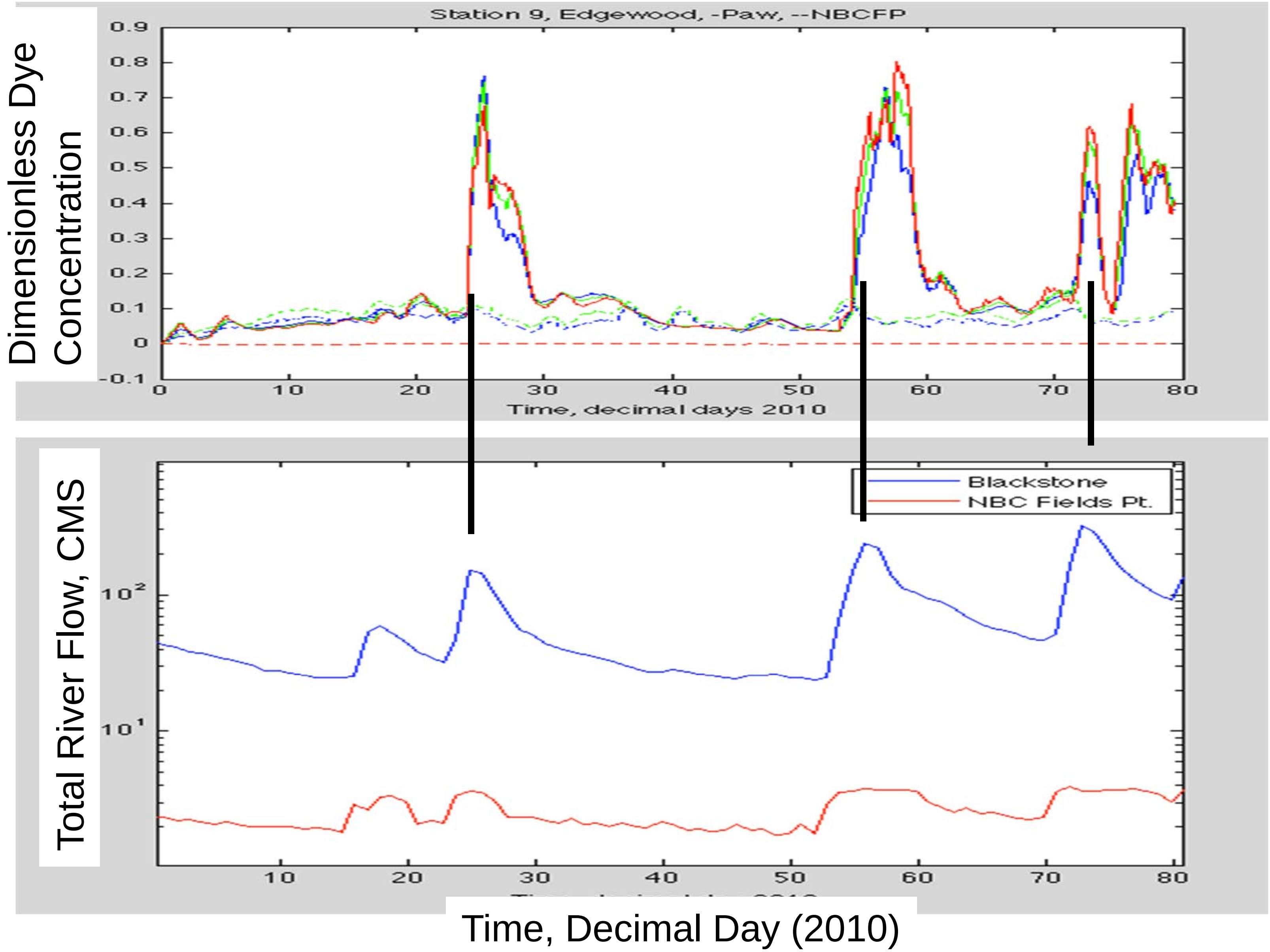
1. ROMS shows gyre & 2. TCM Data show gyre:

3. Scaled Lab Model of the Providence River reveals small-scale physics of gyre






Fields Pt.
Flow/Dye from
WWTF (blue)
& River (green)
Save the Bay
QuickTime™ and a
decompressor
are needed to see this picture.
Shallow Shoals
Deep Channel
Dye in Bottom Water on Shoals



2010 Pawtuxet pulses: Correlate with runoff

Conditions for Prov. River model runs

Average River flow (m3/s):
Blackstone - 22.1
Ten Mile - 3.1
Moshassuck - 1.1
Woonasquatucket - 2.1
Pawtuxet - 10

Average effluent flow (m3/s):
Field's Pt. - 2.17
Bucklin Pt. - 1.09 E.
Providence - 0.24

Average DYE concentration (mg/L):
Blackstone - 1.98
Ten Mile - 2.02
Moshassuck - 1.93
Woonasquatucket - 1.82
Pawtuxet - 2.63
Field's Point - 8
Bucklin Point - 8
E. Providence 8

Winds (mph):
Low NE - 0.5
Average NE - 8.4
High NE - 25.4
Low SW - 0.4
Average SW - 7.1
High SW - 18.5

Convert to real concentrations

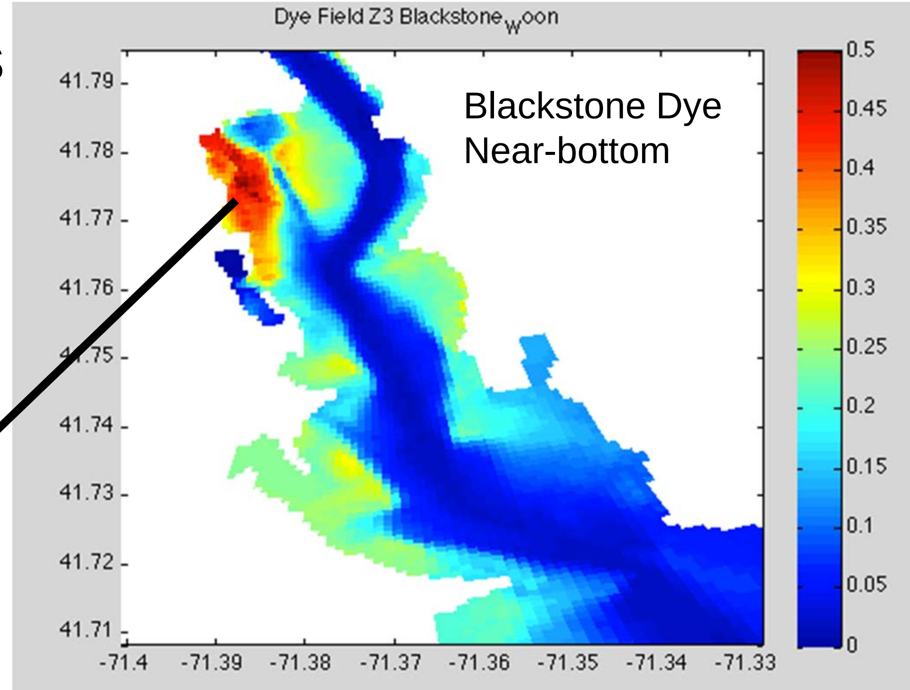
$$C = C^* \, Csrc$$

Mg/l — From ROMS — Mg/l From rivers

Blackstone:

Max Shoal Concentration

~ 0.5 x 2 mg/l = 1.0 mg/l

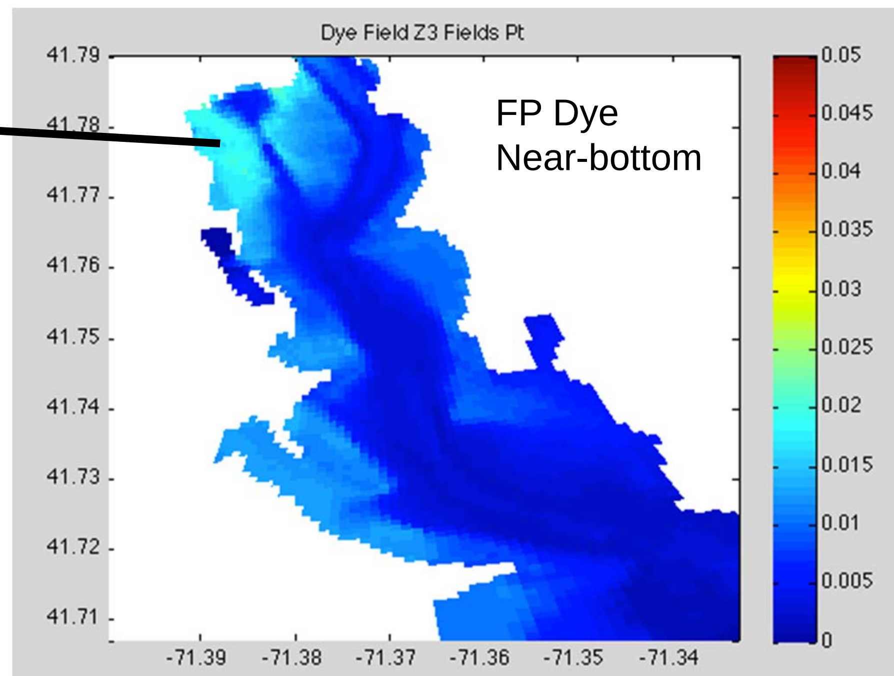


C*

Fields Pt:

Max Shoal Concentration

~ .02 x 10mg/l = 0.2 mg/l



C*

Pawtuxet:

Max Shoal Concentration

~ 2.6 mg/l x 0.6 ~ 1.6 mg/l

QuickTime™ and a
H.264 decompressor
are needed to see this picture.

Quantifying Flushing:

1. Dyes
2. Passive tracers (shown here for summer 2010)

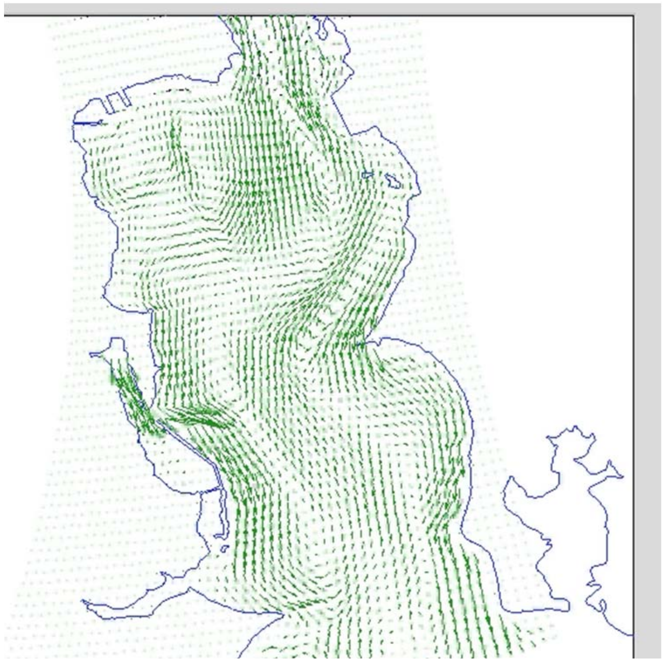
QuickTime™ and a
H.264 decompressor
are needed to see this picture.

Multiple Modeling Methods: Flushing of Urban Hotspots

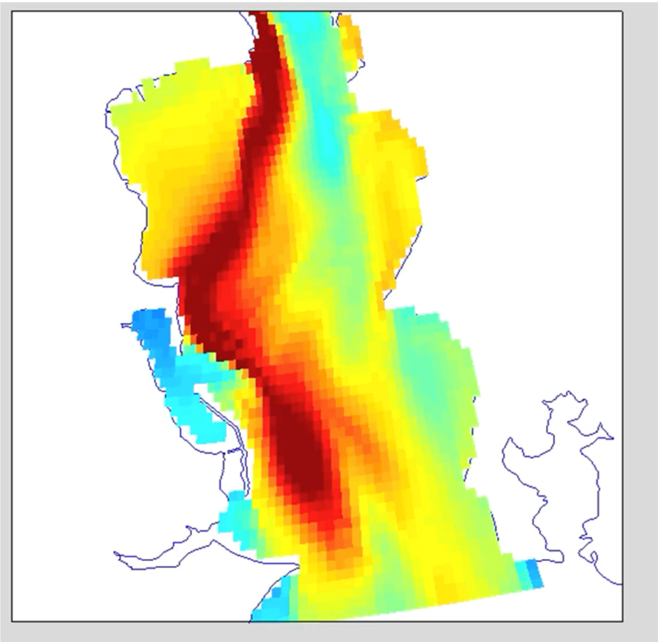
Providence River Example

Use Dyes and Lagrangian tracers to map chemical transport

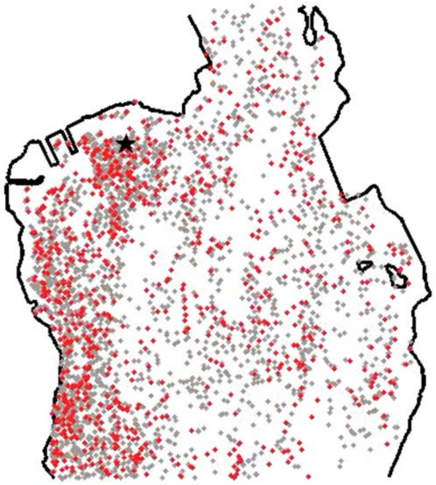
3-D Flows
Providence River



3-D Dye Transport
(Fields Pt WWTF)



Tracking
Biogeochemical
Tracers



Narragansett Bay ROMS Models

I. Build a reliable tool for simulating estuarine physics: circulation, flushing, transport

II. Further understanding of fundamental estuarine physical processes

III. Advance models to serve as foundation for ecosystem management