Circulation & Chemical Transport in Upper Narragansett Bay

Water Quality

Circulation
- Tides
- Winds
- Runoff
- Density
Hypothesis: Water quality controlled by lack of flushing from key regions
Theme of today's talk: The “scientific” cycle

Scientific Truth

Models

data

time

Data
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)

Regional Ocean Modeling System (ROMS): 3D Hydrodynamic-transport

Scientific Truth

Hydrographic Data:
Currents, Salinity, Temp.
Advances in ROMS model & data sets have led to better predictive tools for RI waters & understanding of Bay processes.

**Hydrographic Data**
- Acoustic Doppler Current Profilers (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

ROMS Hydrodynamic Computer Model

Spatially extensive:
2) RIS-Bay ROMS
4) New England Shelf - Bay ROMS

1. Upper Bay Bergondo-ROMS
3) High resolution Bay ROMS Model (RED)

99-01
2006
2007
2008
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*
Two Recent Data-Model Projects

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

   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
Providence River & Greenwich Bay: Chronic hypoxia

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

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Early flushing estimates for the Providence River:

Fraction of (Fresh) Water Method

\[
\text{Flushing time} \sim \frac{\text{Volume (m}^3\text{)}}{\text{Runoff (m}^3/\text{t)}}
\]
Early flushing estimates for the Providence River:

Fraction of (Fresh) Water Method

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

Key Assumption: Complete mixing
Fraction of Fresh Water / Box Model: (Asselin & Spaulding, 1993)

Flushing Time $\sim \frac{1}{\text{Runoff}}$

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<th>Runoff (CMS)</th>
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Fraction of Fresh Water / Box Model: (Asselin & Spaulding, 1993)

**Flushing Time ~ 1 / Runoff**

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<td>Average</td>
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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)
Early ROMS: Vertically integrated Flow in Providence River

Bergondo, 2004

Grid (box sizes) in river > 100m

Edgewood Shoal energetic outflow

Do models match data?

Data (Red) vs Model (Blue)

Skill = .98
(1 = excellent)

Newport tidal water elevation data

Decimal Day, 2003
Early ROMS: Vertically integrated Flow in Providence River

Bergondo, 2004

Grid (box sizes) in river > 100m

Edgewood Shoal energetic outflow

Models compare well to instantaneous (tidal) data records.

Model predictions for flushing efficiency?
Early ROMS: Vertically integrated Flow in Providence River

Bergondo, 2004

Grid (box sizes) in river > 100m

Edgewood Shoal energetic outflow

Use passive tracers in ROMS to calculate flushing efficiency
ROMS Float-derived Flushing Times for Providence River


Increased runoff = increased flushing
ROMS Float-derived Flushing Times for Providence River


Increased runoff = increased flushing

Fast (1-3 days) : agrees with box models
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

<table>
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<tr>
<th>Dye Source</th>
<th>Dye Concentration (g/m^3)</th>
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<td>2. Fields Pt.</td>
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<td>4. Pawtuxet</td>
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Dye (nutrient sources) Accumulation vs. Flow

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

Region is well-flushed

Dye must sweep south

Save the Bay
Dye (nutrient sources) Accumulation vs. Flow

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

Region is well-flushed

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

Flood seen at channel edge

Gyre actually slows

31-Mar-2010
08:00:00
(90.3333)
Edgewood Shoals flow does not increase during flood

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!

Behavior different from box models & coarse ROMS models
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
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Sub-50m grid boxes in Providence River.
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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Flushing & nutrient supply story?
Quantifying Flushing:

1. Dyes
2. Passive tracers (2010 Summer conditions)
Movie: Track Channel vs Shoal Bottom Floats (2010 conditions)
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

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<tr>
<td>High Resolution ROMS Edgewood Shoals bottom water flushing time</td>
<td></td>
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<tr>
<td>40-50</td>
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<td>6-10 days</td>
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Using improved, gyre-resolving ROMS, which nutrient sources feed Edgewood Shoals?

Track which dyes feed Edgewood Shoals

(\textit{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 follow 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)
Pawtuxet Dye: Near-bottom  (red = 0.15)
Blackstone River dye: Near-surface  (red = 0.2)
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
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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

Port Edgewood Channel enhances flushing

(a) Remove breakwater

(b) Dredge Port Edgewood Channel
Dye lower half of Edgewood Shoal water column

Low runoff = Weak gyre
Spring tide = Stronger flow up Port Edgewood Channel
1. Dredge Port Edgewood channel

2. Dredge a connection

ROMS dredging scenarios to improve flushing
Multiple Modeling Methods: Flushing of Urban Hotspots

Providence River Example

1) ROMS Model: 3-D Flows

2) GFD Lab Model: 3-D Flows
1. ROMS shows gyre & 2. TCM Data show gyre:

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

\[ C = C^* \cdot C_{src} \]

Mg/l From ROMS Mg/l From rivers

**Blackstone:**
Max Shoal Concentration
\[ \sim 0.5 \times 2 \text{ mg/l} = 1.0 \text{ mg/l} \]

**Fields Pt:**
Max Shoal Concentration
\[ \sim 0.02 \times 10 \text{ mg/l} = 0.2 \text{ mg/l} \]

**Pawtuxet:**
Max Shoal Concentration
\[ \sim 2.6 \text{ mg/l} \times 0.6 \sim 1.6 \text{ mg/l} \]
QuickTime™ and a H.264 decompressor are needed to see this picture.
Quantifying Flushing:
1. Dyes
2. Passive tracers  (shown here for summer 2010)
Multiple Modeling Methods: Flushing of Urban Hotspots

Providence River Example

Use Dyes and Lagrangian tracers to map chemical transport
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