Hydrologic, geologic, and geochemical effects on nutrient fluxes to Indian River Bay: Evidence from measurements at Holts Landing State Park

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Scott Andres, Delaware Geological Survey
Kevin Kroeger, Leonard Konikow, USGS
David Krantz, Joel Banaszak, University of Toledo
John Bratton, NOAA
Submarine Groundwater Discharge (SGD)
Fresh Discharge to bays
48-59%
Total Recharge

Russoniello et al., in prep
**Question:** How does geology affect nutrient fluxes from groundwater to Indian River Bay?

→ Geology: Fine-grained infill over paleovalley features

- Groundwater fluxes – fresh and saline
- Groundwater salinity distributions
- Groundwater nutrient distributions...reactions?
Question: How does geology affect nutrient fluxes from groundwater to Indian River Bay?

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Geophysics (CHIRP, Resistivity)
Geological, hydrological, geochemical field investigation

- Holts Landing as representative study site
GEOPHYSICAL CHARACTERIZATION

Resistivity: groundwater salinity
CHIRP seismic: geologic features
Geological Characterization: Offshore chirp seismic profiling
Seismic and Resistivity Tracklines – Holts Landing
Seismic and Resistivity Tracklines – Holts Landing
Geological control of Salinity Distributions
Geological control of Salinity Distributions

David Krantz and Joel Banaszak
Continuous Resistivity Profiling

- Tow single current electrode and array of receivers
- Saline water $\rightarrow$ low $\Omega$, fresh water $\rightarrow$ high $\Omega$
Seismic and **Resistivity** Tracklines – Holts Landing
Subsurface Salinity Distribution:
Classical Conceptual Model:
Indian River Bay Conceptual Model:
Indian River Bay Conceptual Model:

- **Shore-Parallel**
  - Low-K Paleovalley Fill
  - High-K Paleochannel

- **Patch**
  - Fresh
  - Mixing Zone
  - Saline
Fresh Groundwater Discharge Mode:

- Diffuse Discharge
- Focused Discharge
HYDROLOGIC CHARACTERIZATION

Seepage Meters: Groundwater discharge
Groundwater salinity: deep and shallow
Measurements: wells, SGD, salinity
Submarine Groundwater Discharge (SGD) Measurements

Seepage Meters
SGD Measurements
SGD Flux

Flux [cm/d]

1
20
140

700+ measurements...

Russoniello et al., in prep
SGD Salinity

Average ~9% Fresh Discharge

Diffuse Discharge <50% Fresh

Focused Discharge >75% Fresh

Percent Fresh
- 0-5%
- 6-10%
- 11-25%
- 26-75%
- 76-100%

Magnitude Only
SGD Salinity

Focused Fresh Discharge
SGD Salinity

Diffuse Fresh Discharge
SGD Salinity

Diffuse Fresh Discharge
Offshore Multi-level Wells (DGS Team)
GEOCHEMICAL CHARACTERIZATION

Field Parameters (Salinity, pH, DO, ORP)
Nutrients (NO$_3$, NH$_4$, PO$_4$, Si)
Dissolved gases (N$_2$, Ar)
Nutrients and Field Parameters
Nutrients and Field Parameters
Nutrients and Field Parameters
Nitrate [uM]

Fresh wells (<0.5 ppt)
Nitrate [μM]

Shallowest Port

- Offshore Multi-level Well
- Offshore Multi-level Samplers
- Offshore Monitoring Well
- Onshore Monitoring Well
Nitrate

\[ \text{uM} \]

Shallowest Port

28  25  10  32  0  50  26  200

15  306

Focused Discharge

\(~200\ \text{uM nitrate}\)
Nitrate

[5 uM]

Shallowest

Port

[28 25 10 32 50 26 200 15 -306 126 -224 80 436 5]

Diffuse Discharge (longer flowpaths) <50 uM nitrate

High Nitrate

Mixing Zone

Low Nitrate?
Indian River Bay Conceptual Model:
Indian River Bay Conceptual Model:
Indian River Bay Conceptual Model:

Saline Exchange → Ammonium Release

Decomposing Organics (High Ammonium)

Fresh

Mixing Zone

Saline
Nutrients tied to flowpaths...
beginning smaller-scale variable-density modeling:

Fernandez et al., *in prep*
Nutrients tied to flowpaths... beginning smaller-scale variable-density modeling:

SEAWAT Model

Shore-perpendicular shoreline

V.E= 30

Fernandez et al., in prep
**Summary: Indian River Bay, embayment scale**

- Geologic features (paleochannels and paleovalley fill) affect:
  - Flowpaths
  - Salinity distributions
  - Fresh groundwater discharge patterns, rates

- Flowpaths likely affect nitrogen transformations, fluxes
  - Mode of SGD may determine nitrate concentrations (longer flowpaths, mixing transform \([\text{NO}_3^-]\)?)
  - Gases evidence of denitrification along flowpaths – work in progress...
  - ~ High ammonium (and low nitrate) in saline porewater

*Next... Flowpath geochemistry ➔ Transformations Smaller-scale modeling*
Implications?

⇒ Role of heterogeneity in reducing (or not) nutrient fluxes

⇒ Importance of hydrogeology and geology in estimating fluxes (not just groundwater ‘endmember’ multiplied by fresh SGD)

⇒ Potential role of humans in changing this...i.e. dredging, upland management and land-use changes
Thank You!

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Scott Andres, Delaware Geological Survey
David Krantz, University of Toledo
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Andrew Musetto, UD Undergraduate Student
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Deon Knights, UD Undergraduate Student
Nutrients tied to flowpaths...
beginning smaller-scale variable-density modeling:

SEAWAT
Summary

- Seismic, Resistivity → Low-permeability paleochannel infill causes offshore freshwater plume, mixing zone
- Seepage meters, Shallow porewater salinity → Diffuse fresh SGD occurs around edge of paleochannel infill
- Focused fresh SGD occurs at locations away from paleochannel features
- Nitrate high onshore, decreases offshore beneath infill.
- ~ High ammonium (and low nitrate) in saline porewater
- Seasonal, Tidal fluctuations small, perhaps greater near surface?
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Next... Flowpath geochemistry → Transformations
Smaller-scale modeling
Nitrate

concentration (μmol/L)

salinity ‰

Multilevel wells
Monitoring Wells
Ammonium

concentration (μmol/L)
salinity ‰

(1.5, 478)

Multilevel Wells
Monitoring wells
Evidence of Denitrification?
→ Dissolved Gases

\[ \text{Ar (\mu M)} \]

\[ \text{N2 (\mu M)} \]

- **ASW 0 salinity**
- **ASW 29 salinity**
- **1 to 3 salinity, shore parallel CMT3,4,5**
- **29 salinity, CMT1**
- **1 to 2 salinity CMT2,6,7,8**
- **4 to 9 salinity CMT2,6,7,8**
- **14 to 15 salinity CMT2,6,7,8**
- **18 to 19 salinity CMT2,6,7,8**
- **21 to 25 salinity CMT2,6,7,8**
- **ASW salinity 0**
- **ASW + excess air at 12 C**
- **ASW salinity 29**
Evidence of Denitrification? → Dissolved Gases

Expected Groundwater Equilibrium with atmosphere

K. Kroeger
Average ~9% Fresh Discharge

Diffuse Discharge <10% Fresh

Focused Discharge >75% Fresh

SGD Salinity
SGD Salinity

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