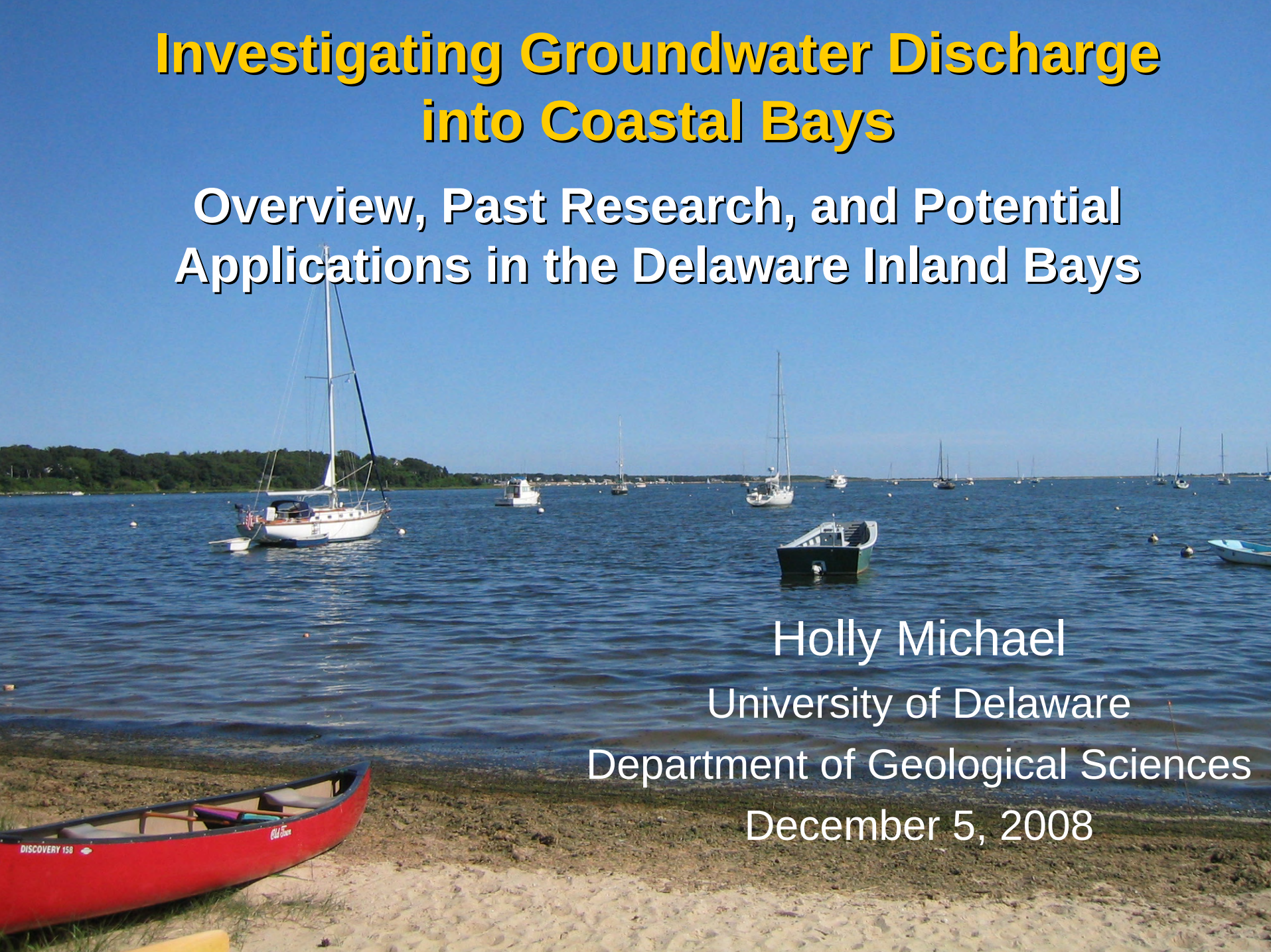
Investigating Groundwater Discharge into Coastal Bays

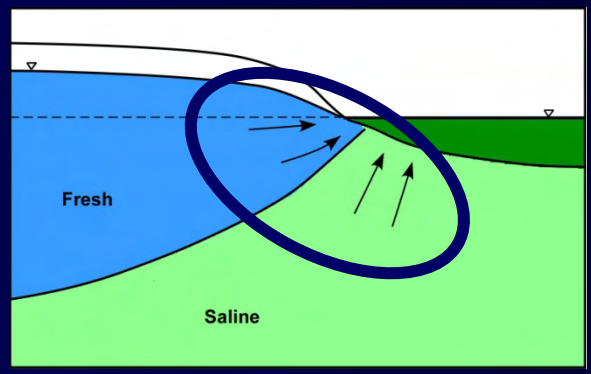
Overview, Past Research, and Potential Applications in the Delaware Inland Bays



Holly Michael
University of Delaware
Department of Geological Sciences
December 5, 2008

This talk…

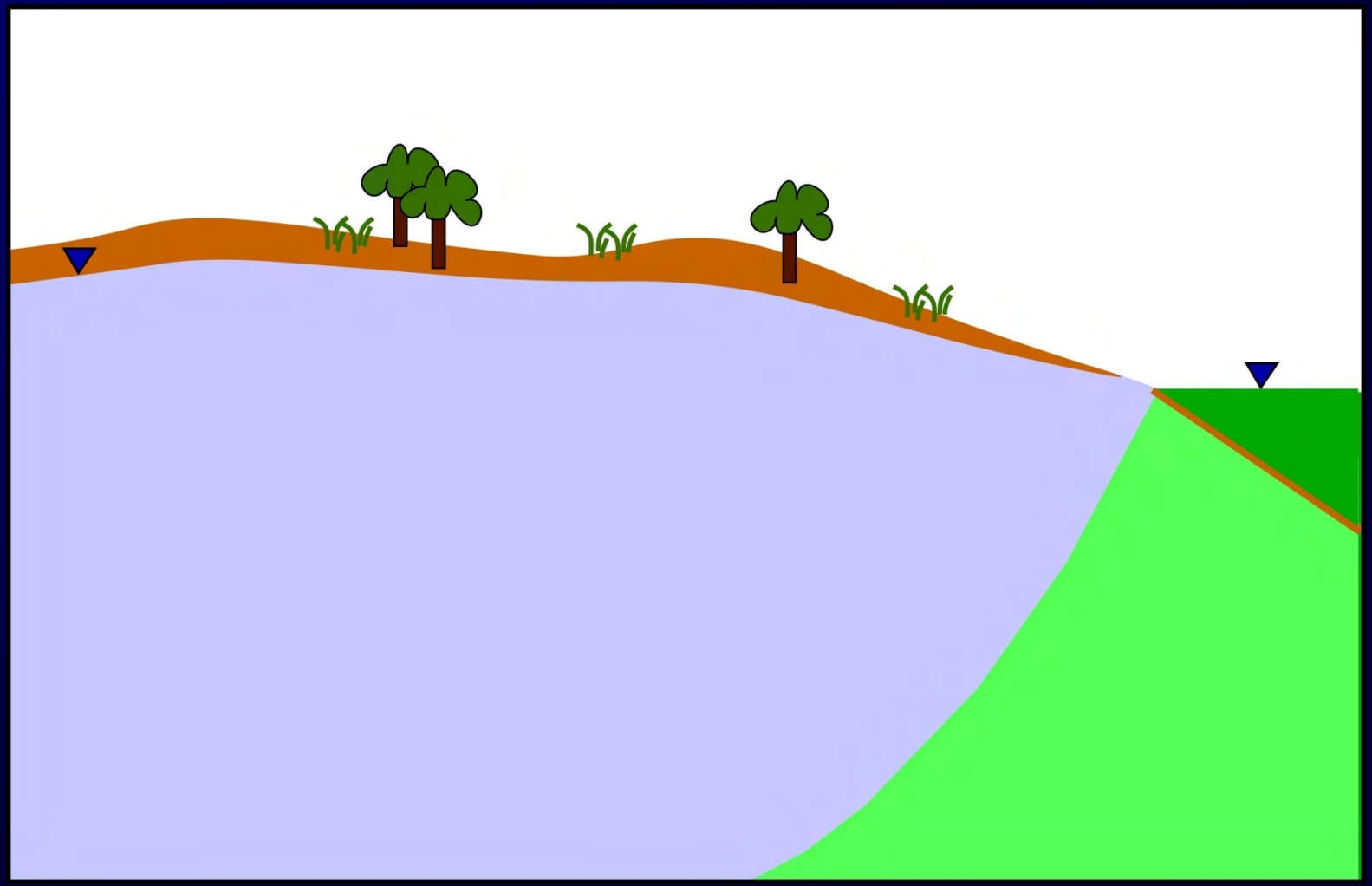
- Overview of coastal groundwater dynamics



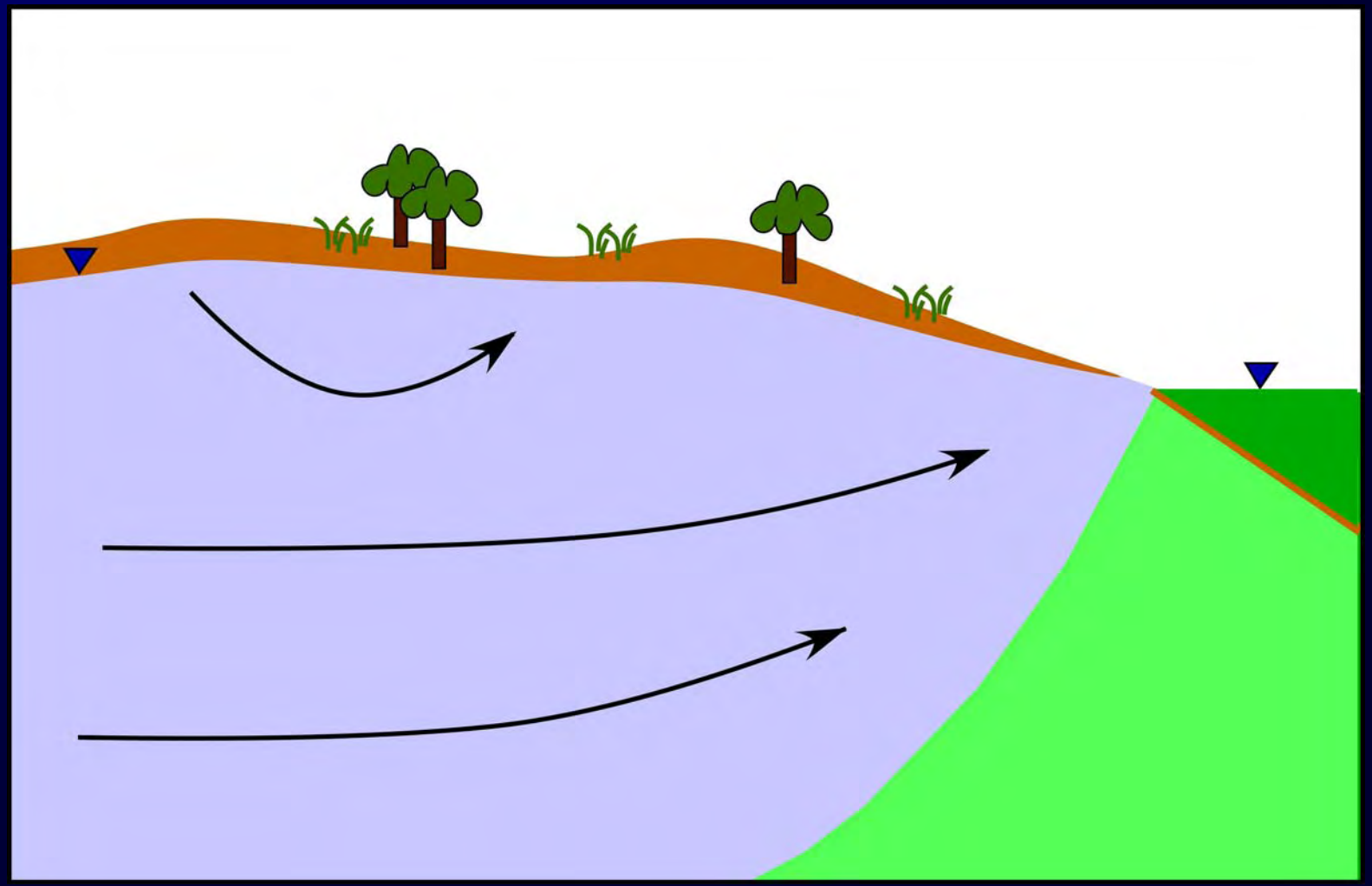
- Brief look at work on Cape Cod

- Background on previous Indian River Bay work and ideas for future research in the Inland Bays

Coastal Groundwater:



Fresh Groundwater Flow to the Coast:



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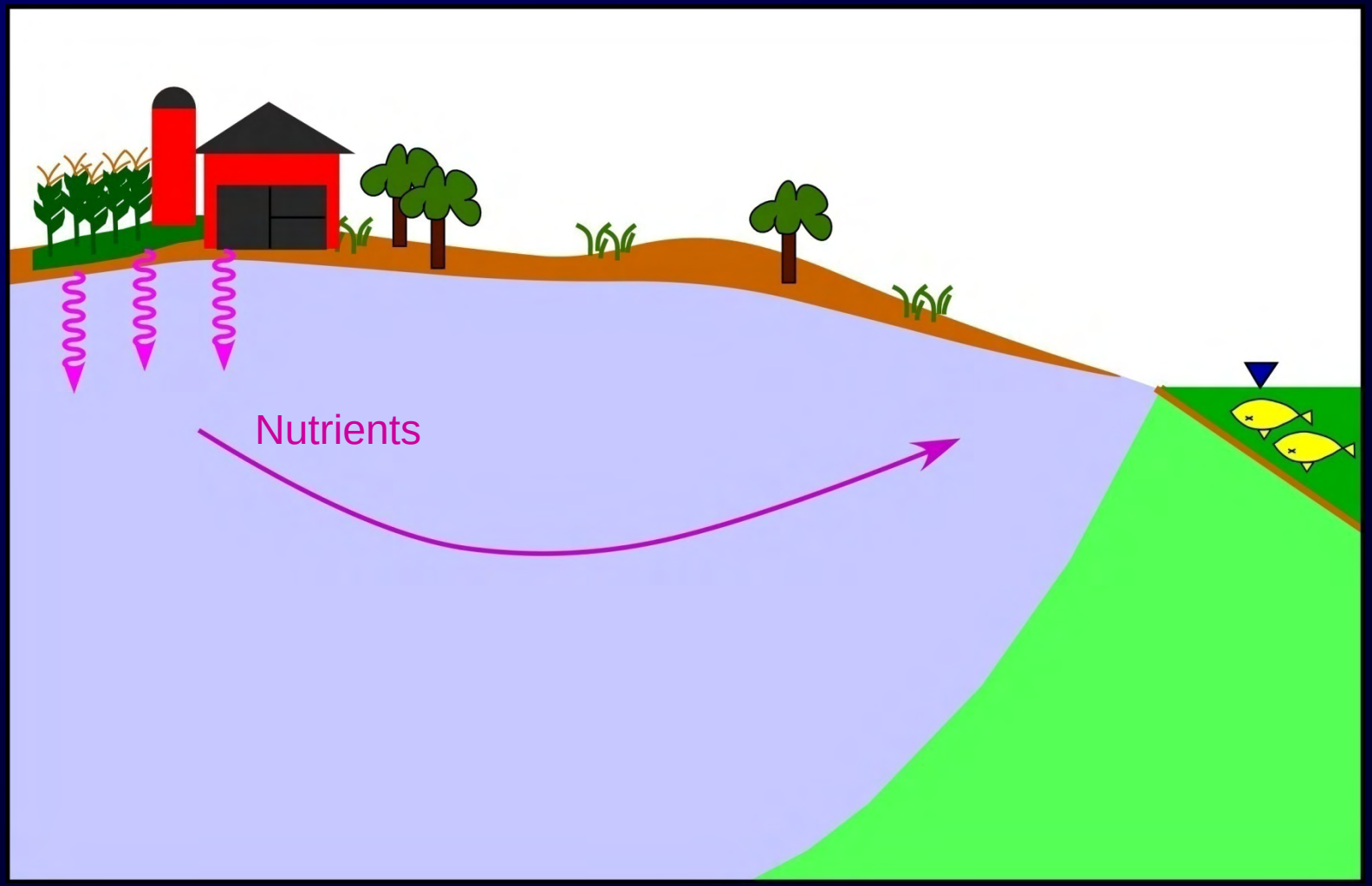
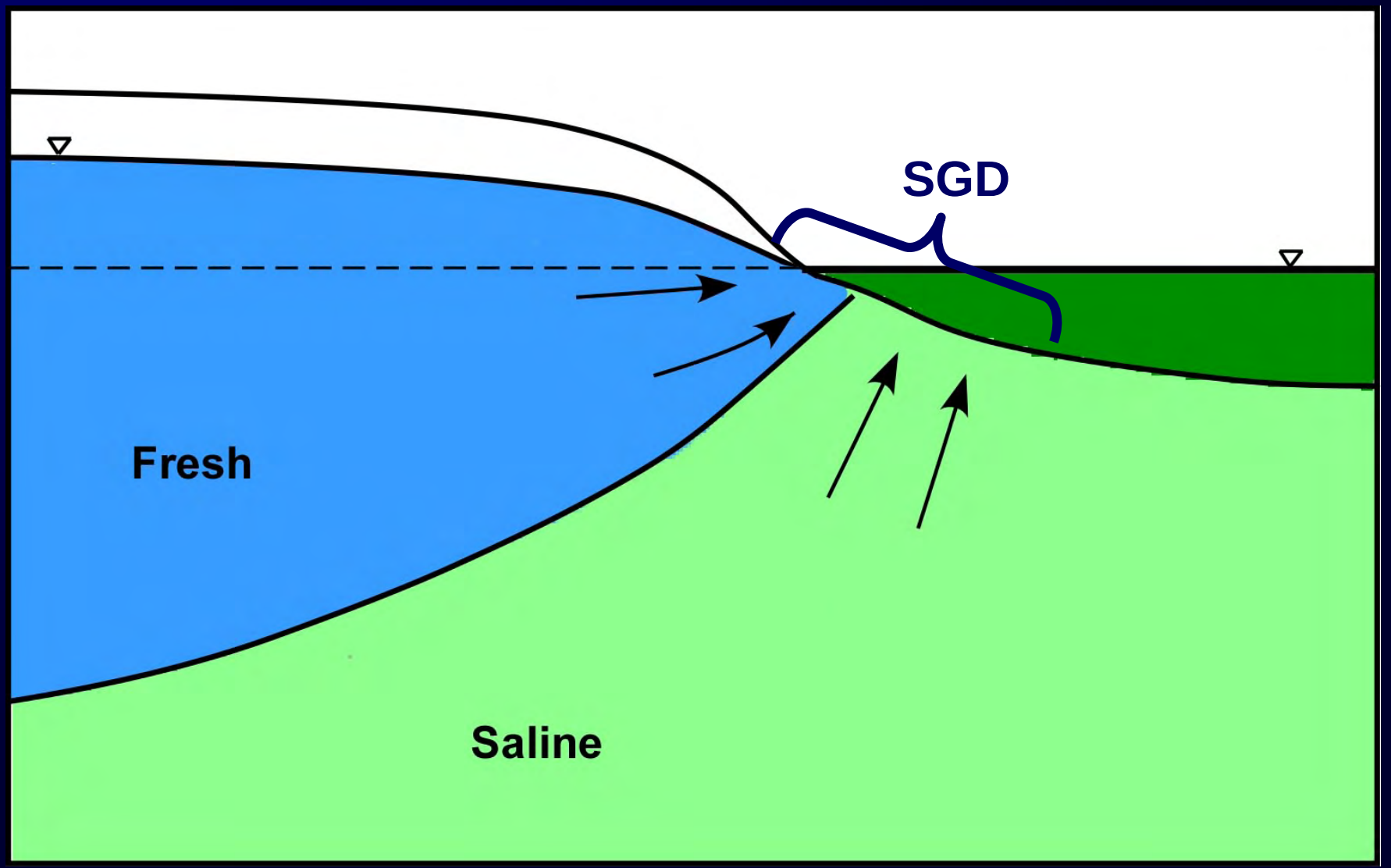
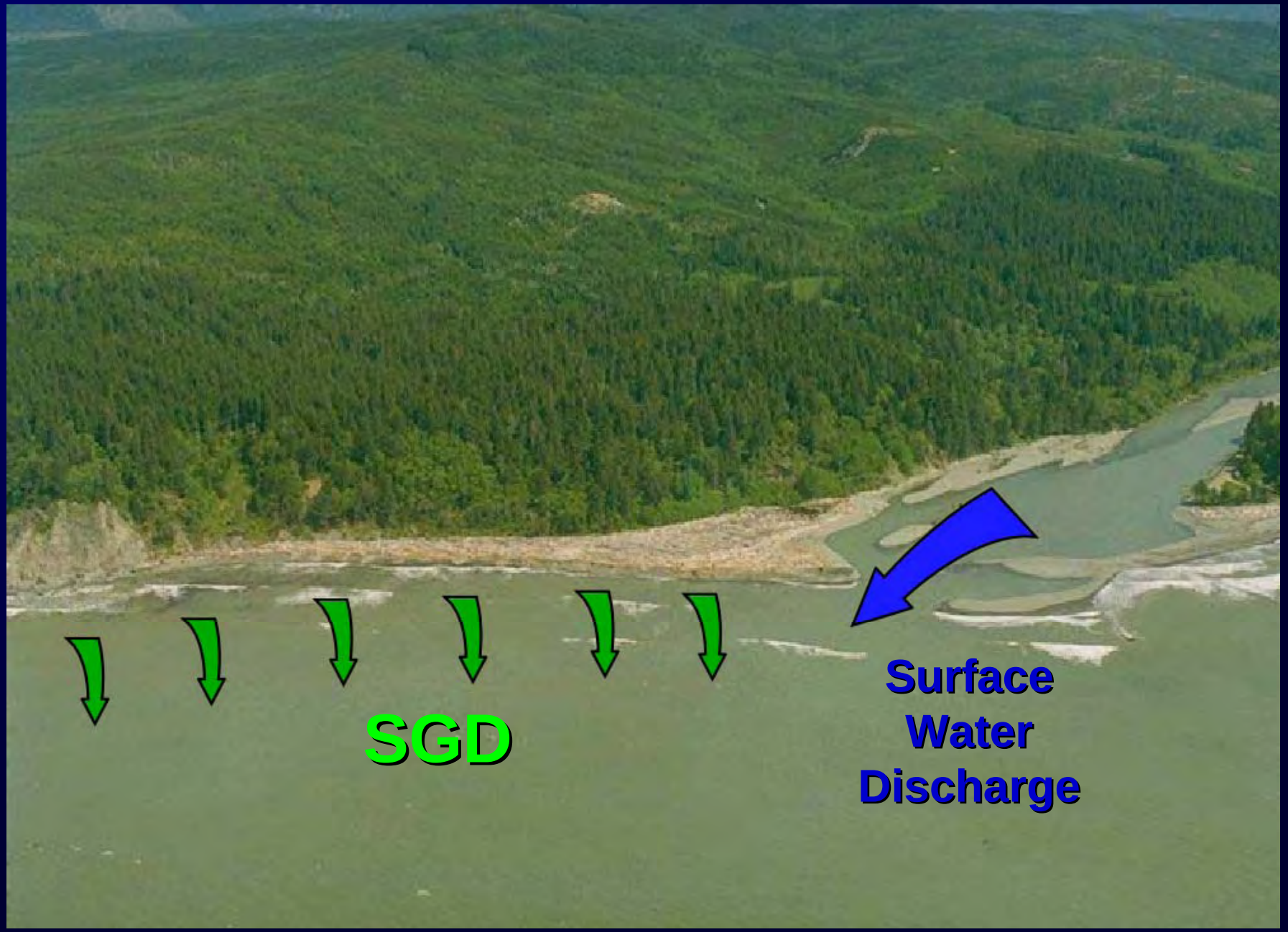


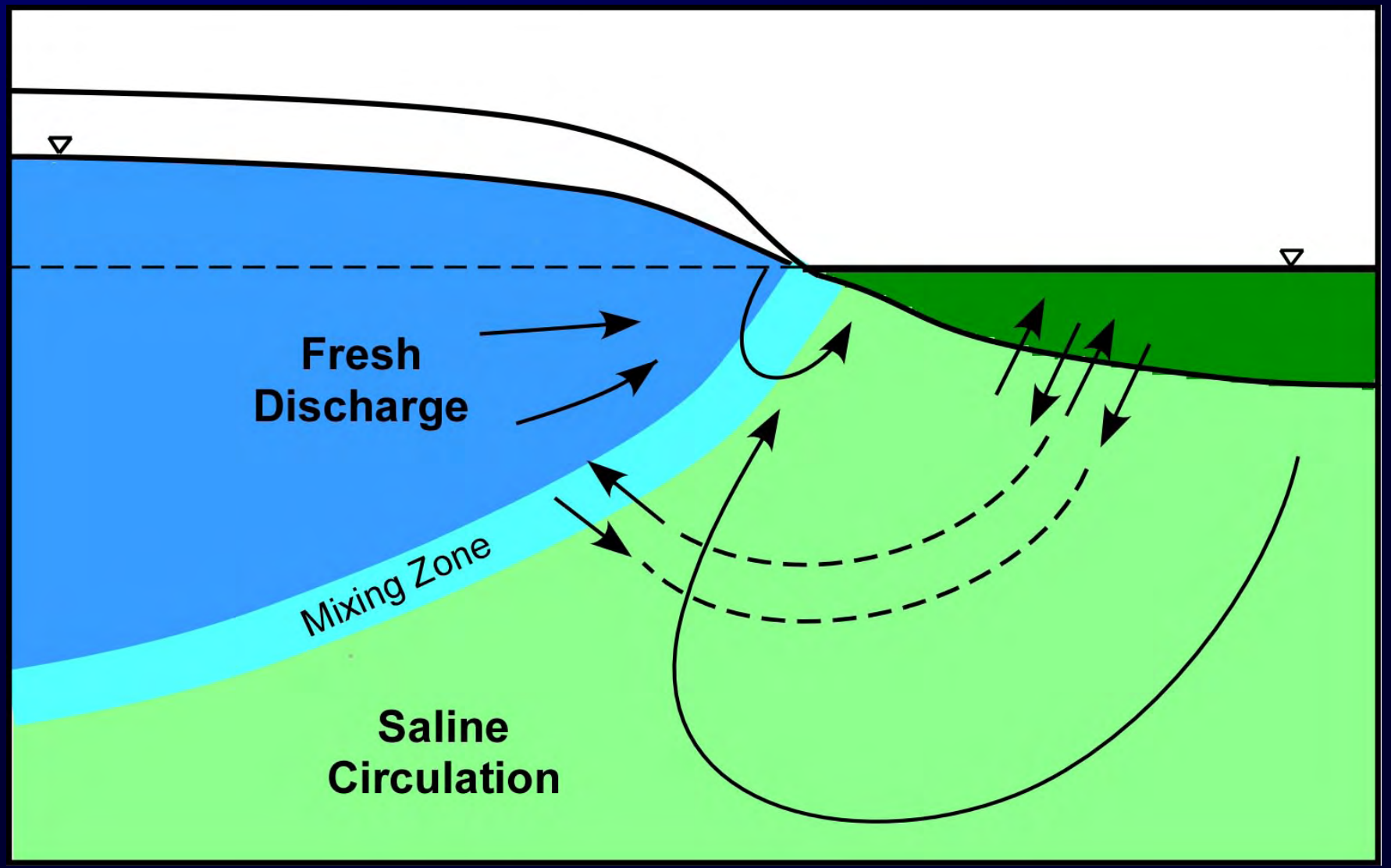
Implications for ecosystems

Submarine Groundwater Discharge (SGD):




SGD
Surface
Water
Discharge

Driving Mechanisms of SGD

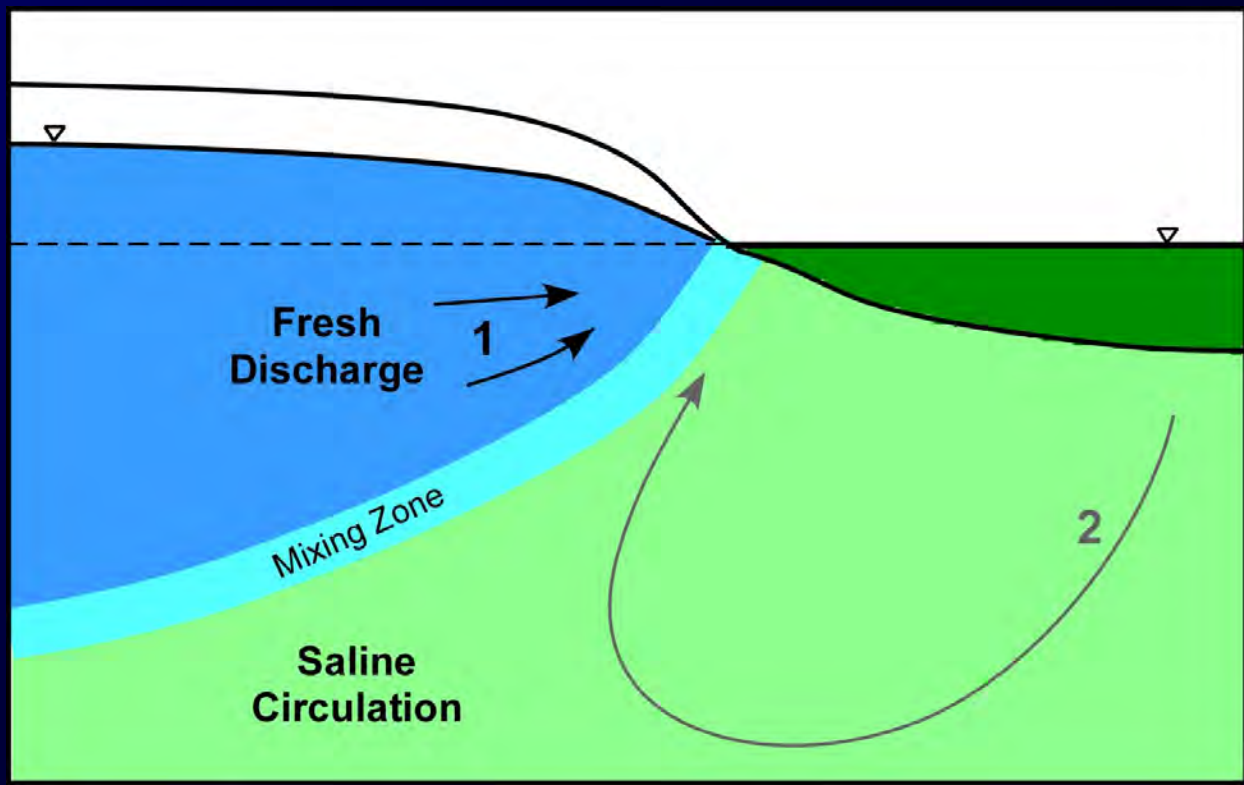


Driving Mechanisms of SGD

Steady Forcing

1 – Freshwater discharge

2 – Density-driven circulation



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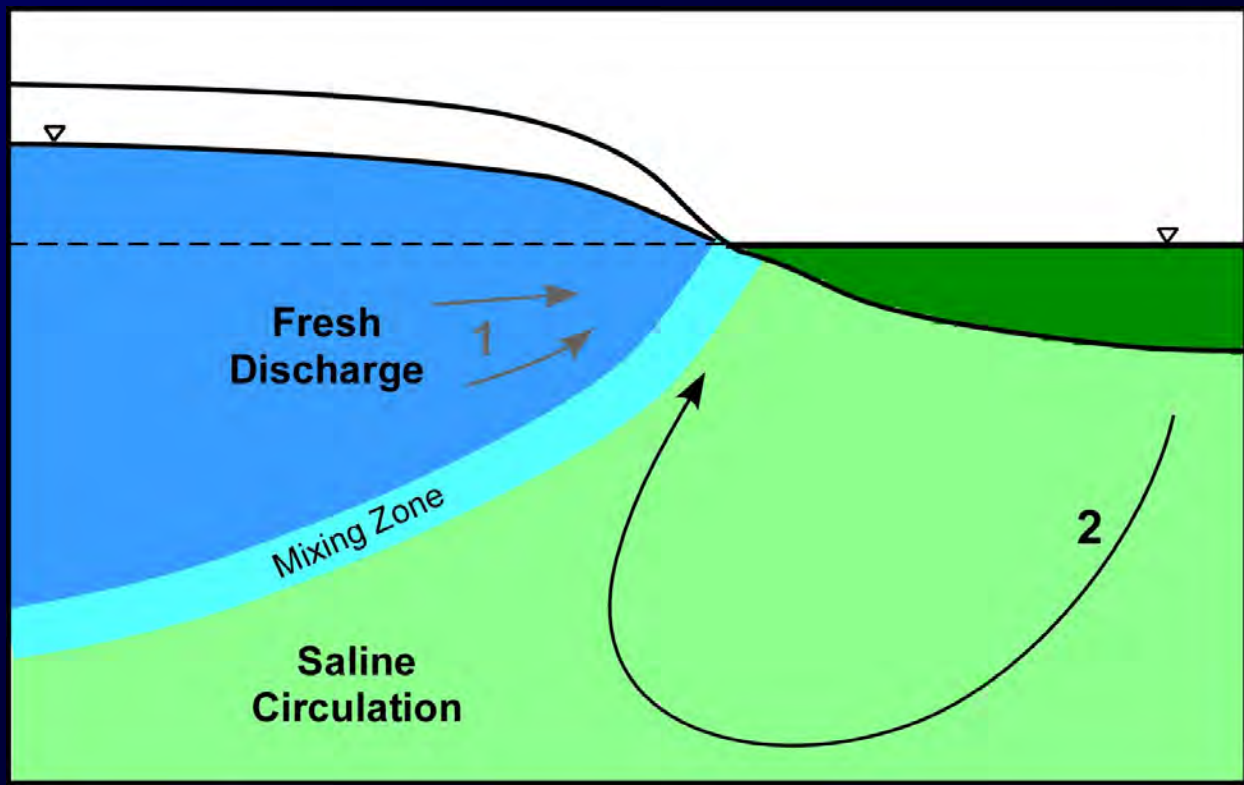


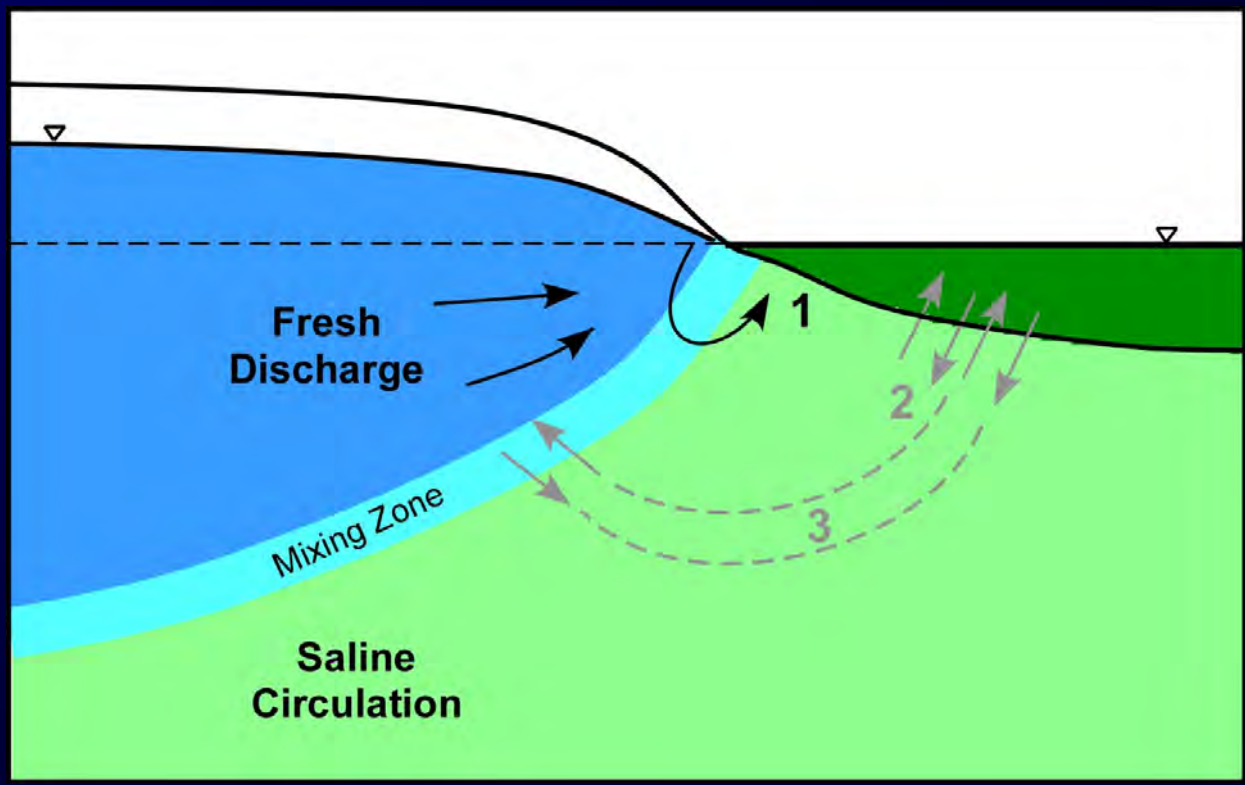
Driving Mechanisms of SGD

Transient Forcing

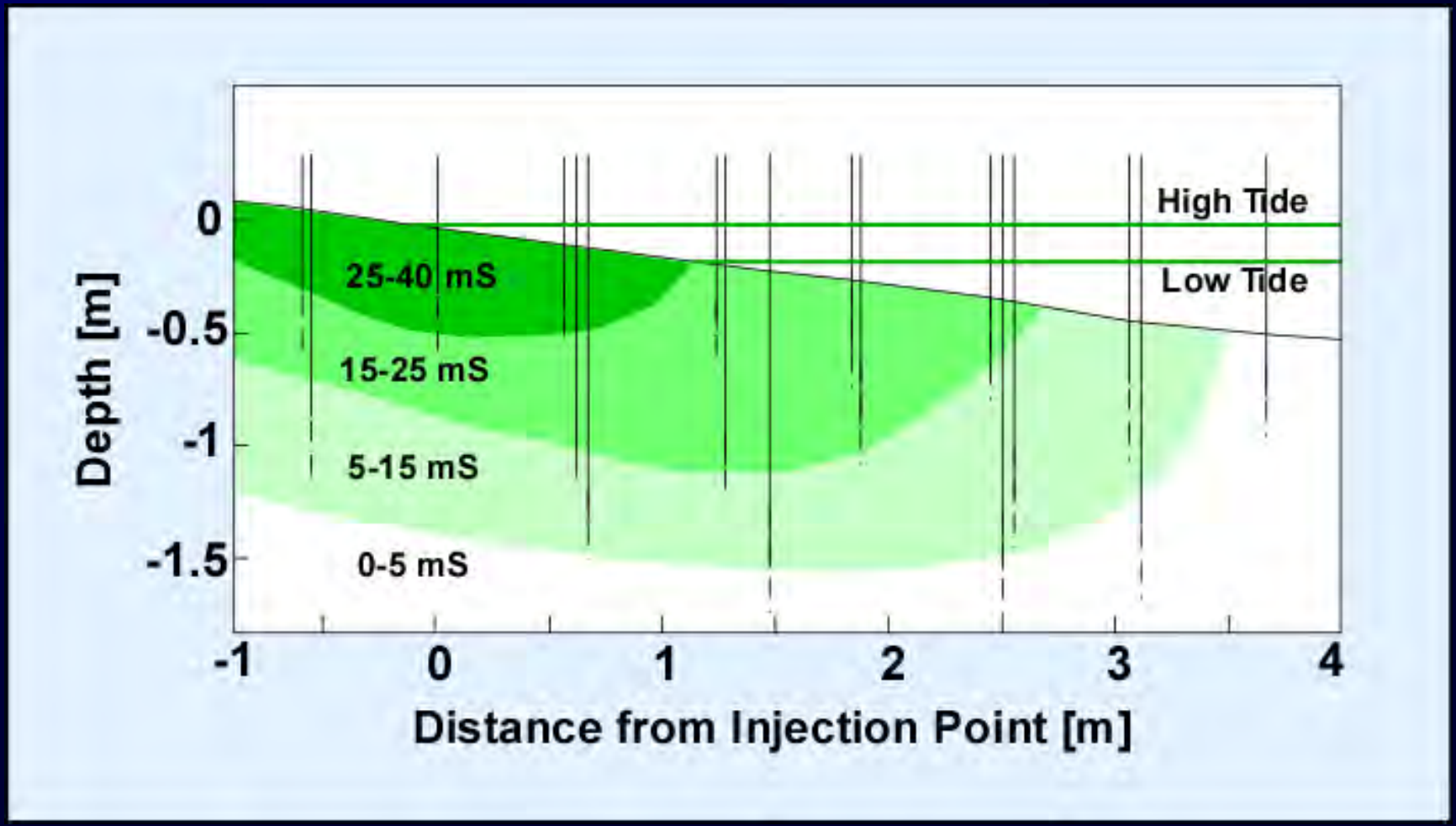
1 – Nearshore: tides and waves

2 – Offshore: waves and tides

3 – Seasonal forcing



Sodium Bromide Tracer Test: Initial Salinity Profile



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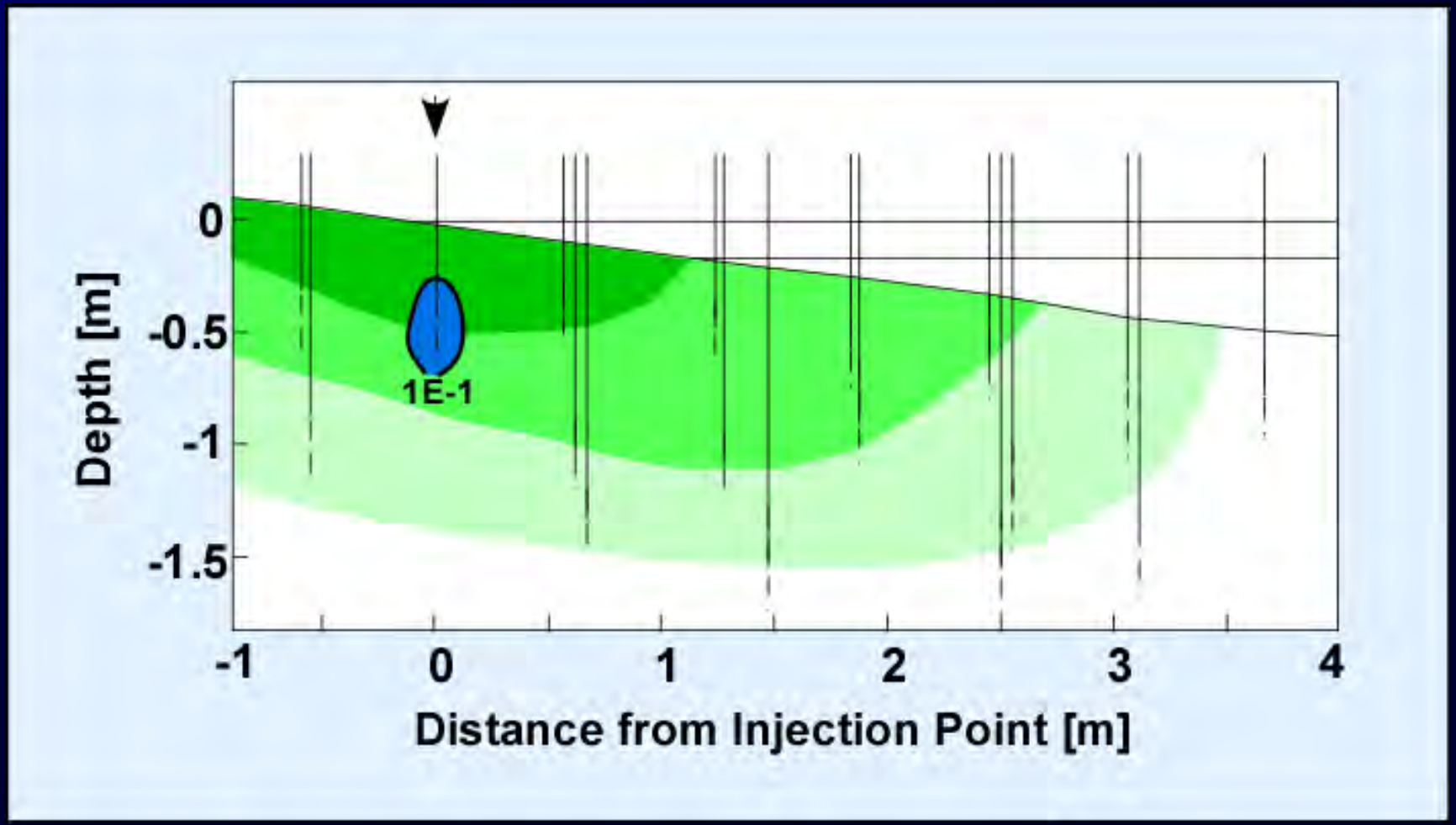

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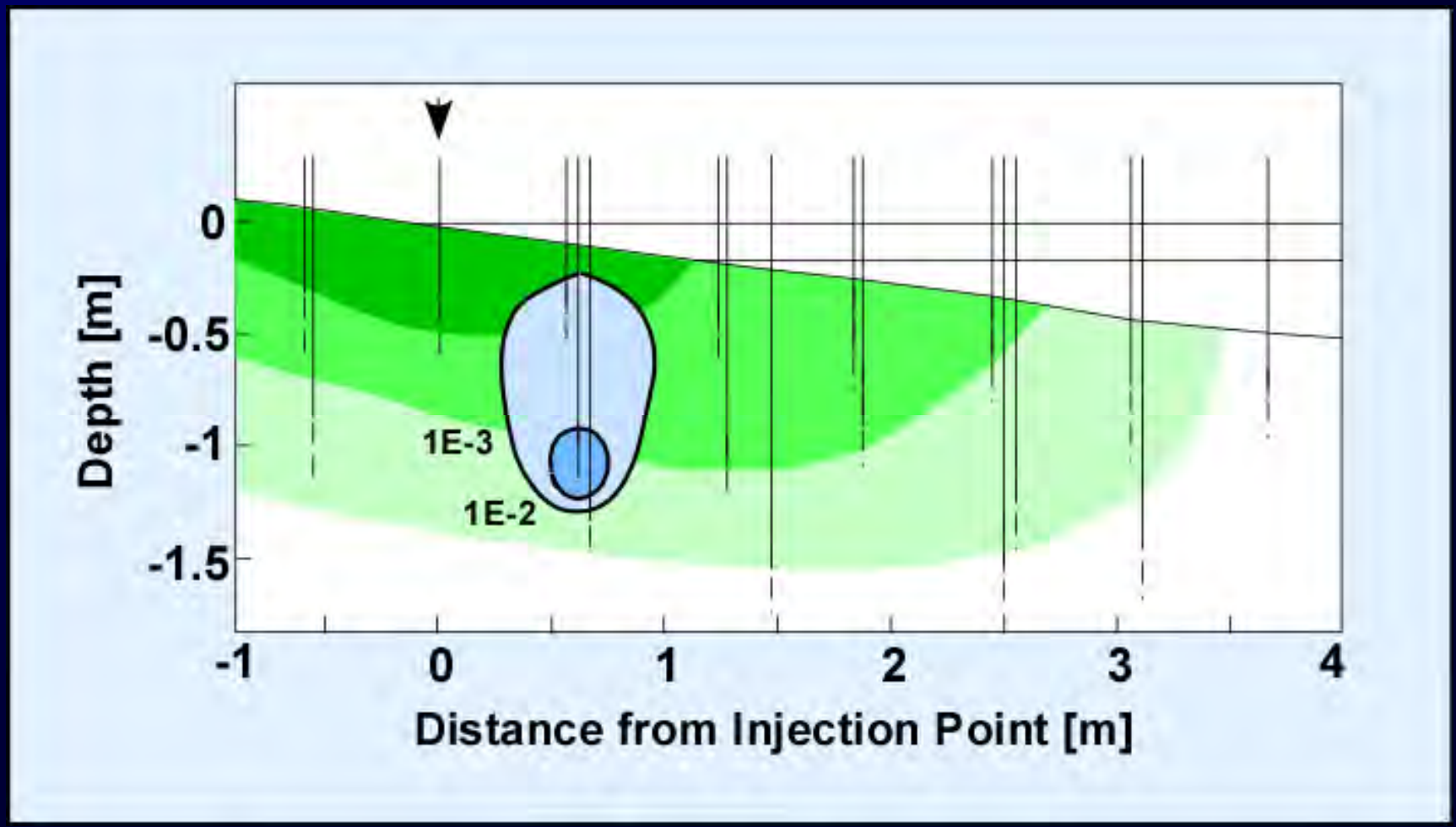

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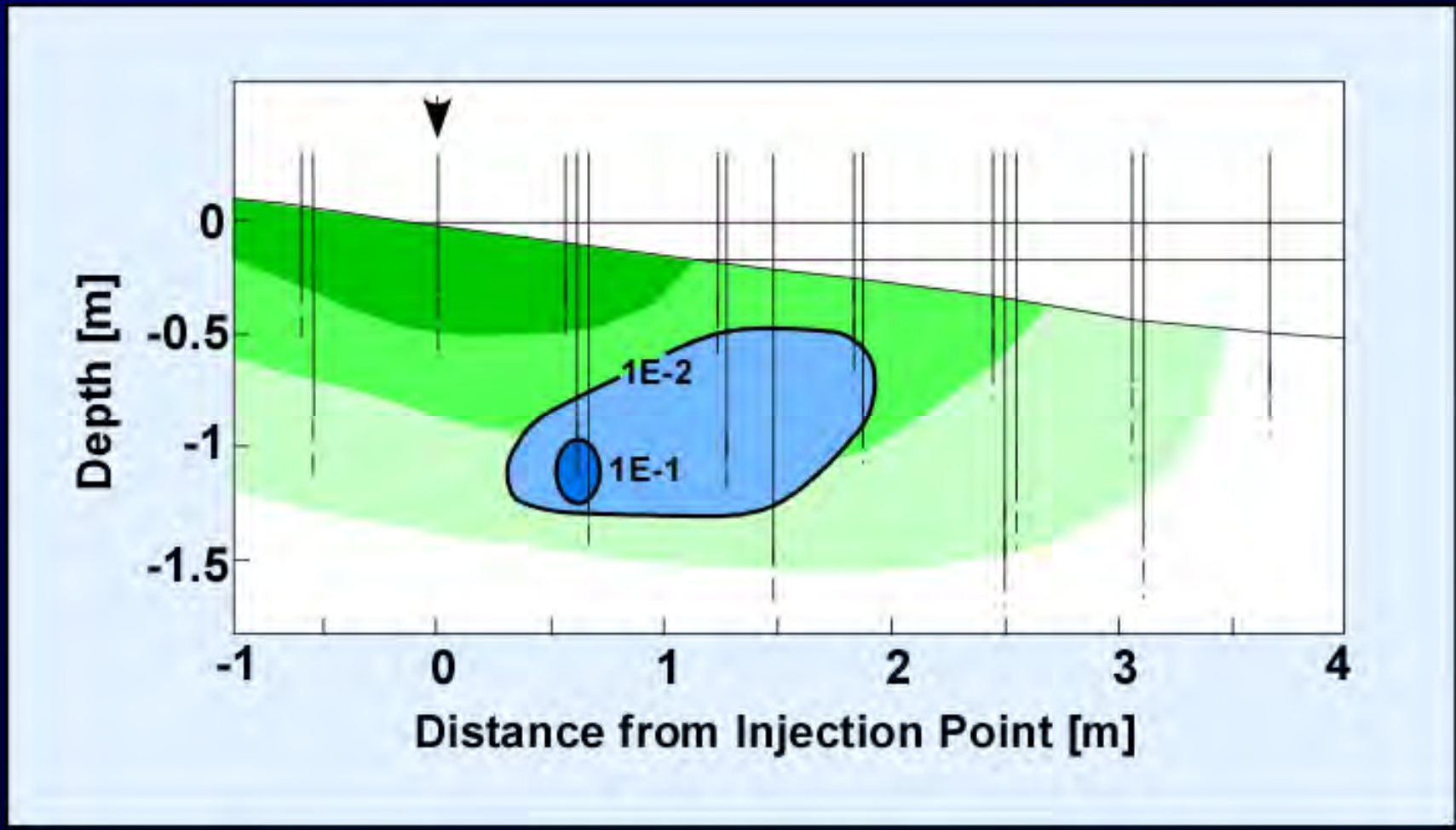

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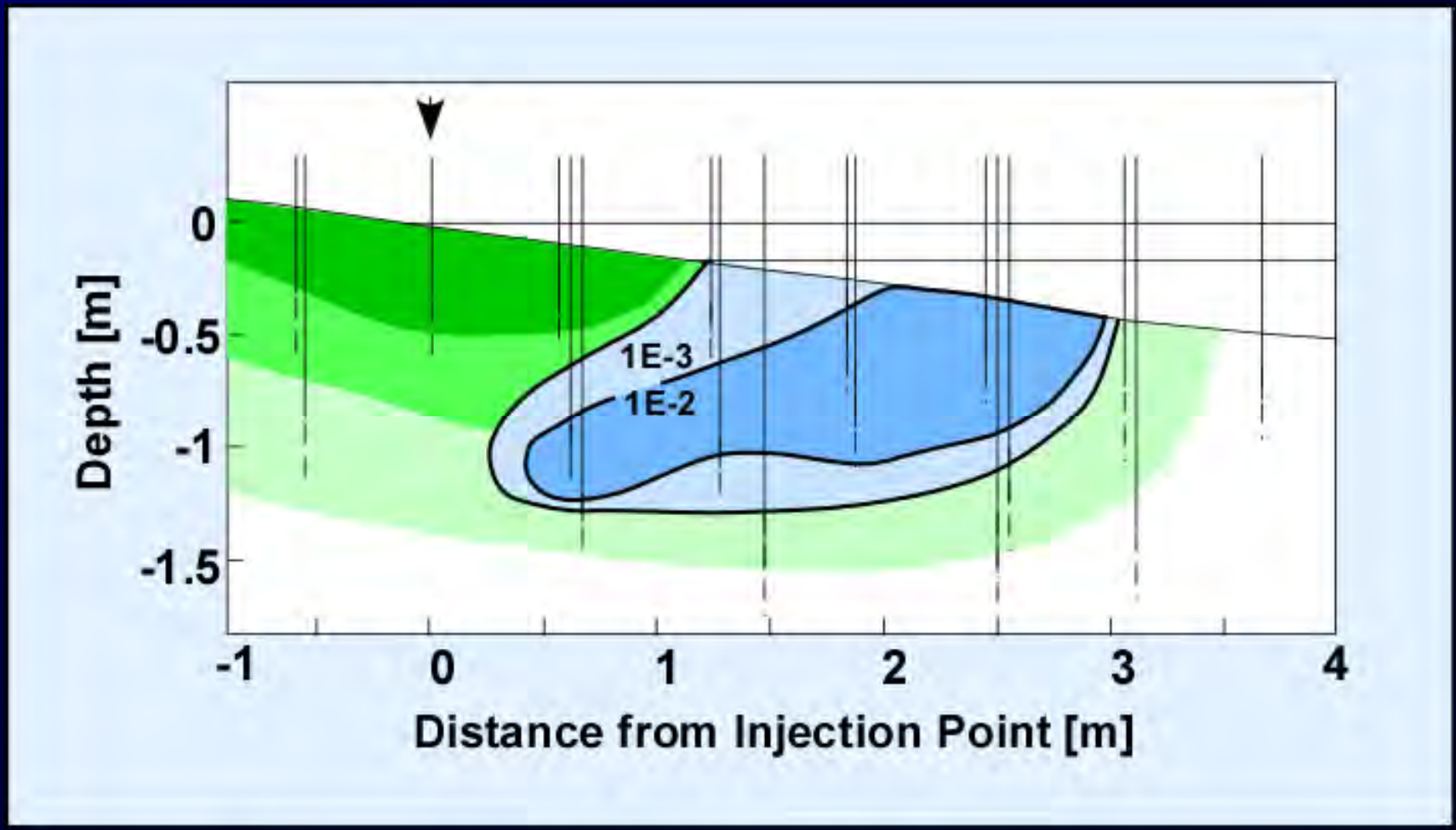

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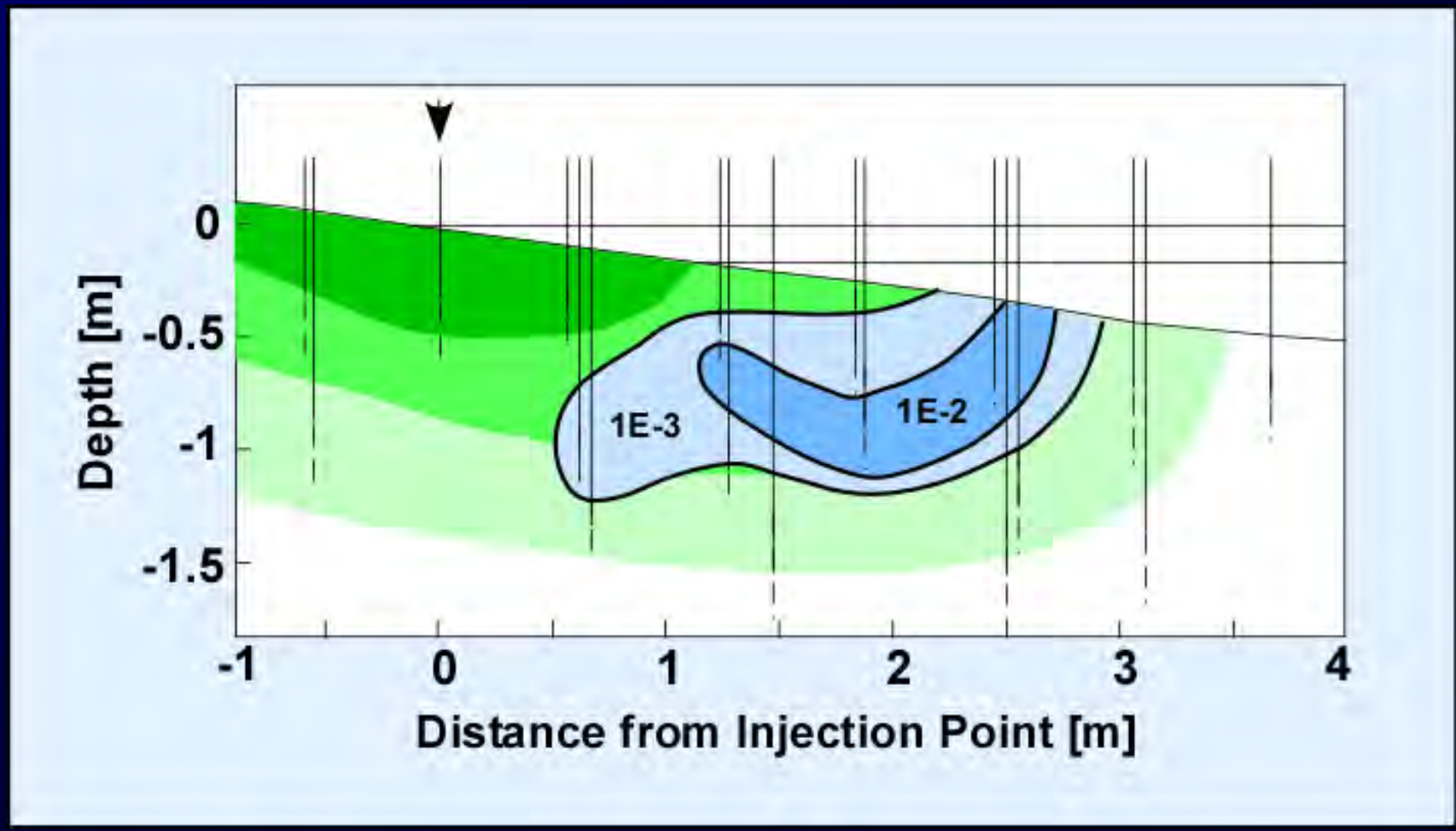

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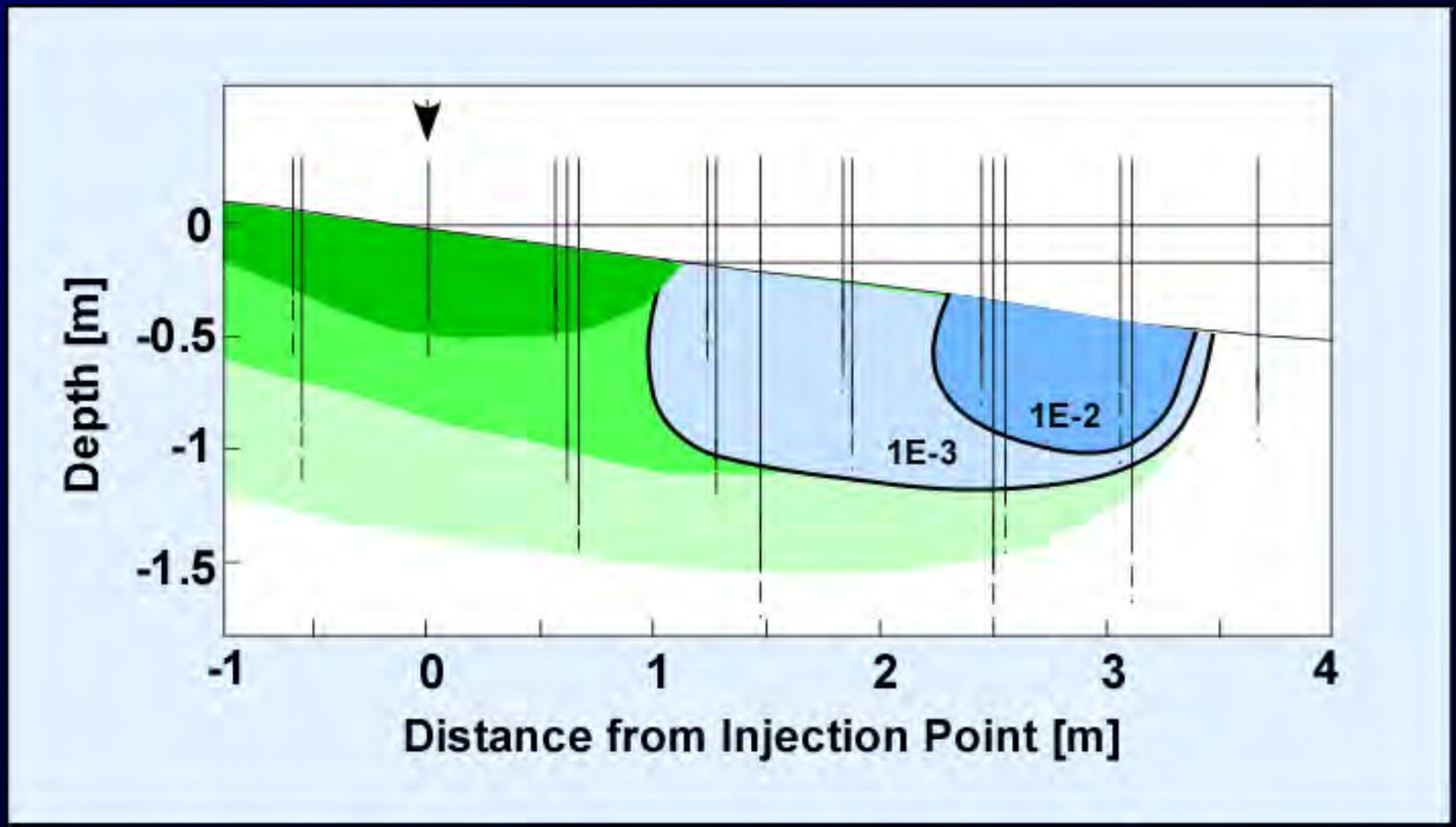

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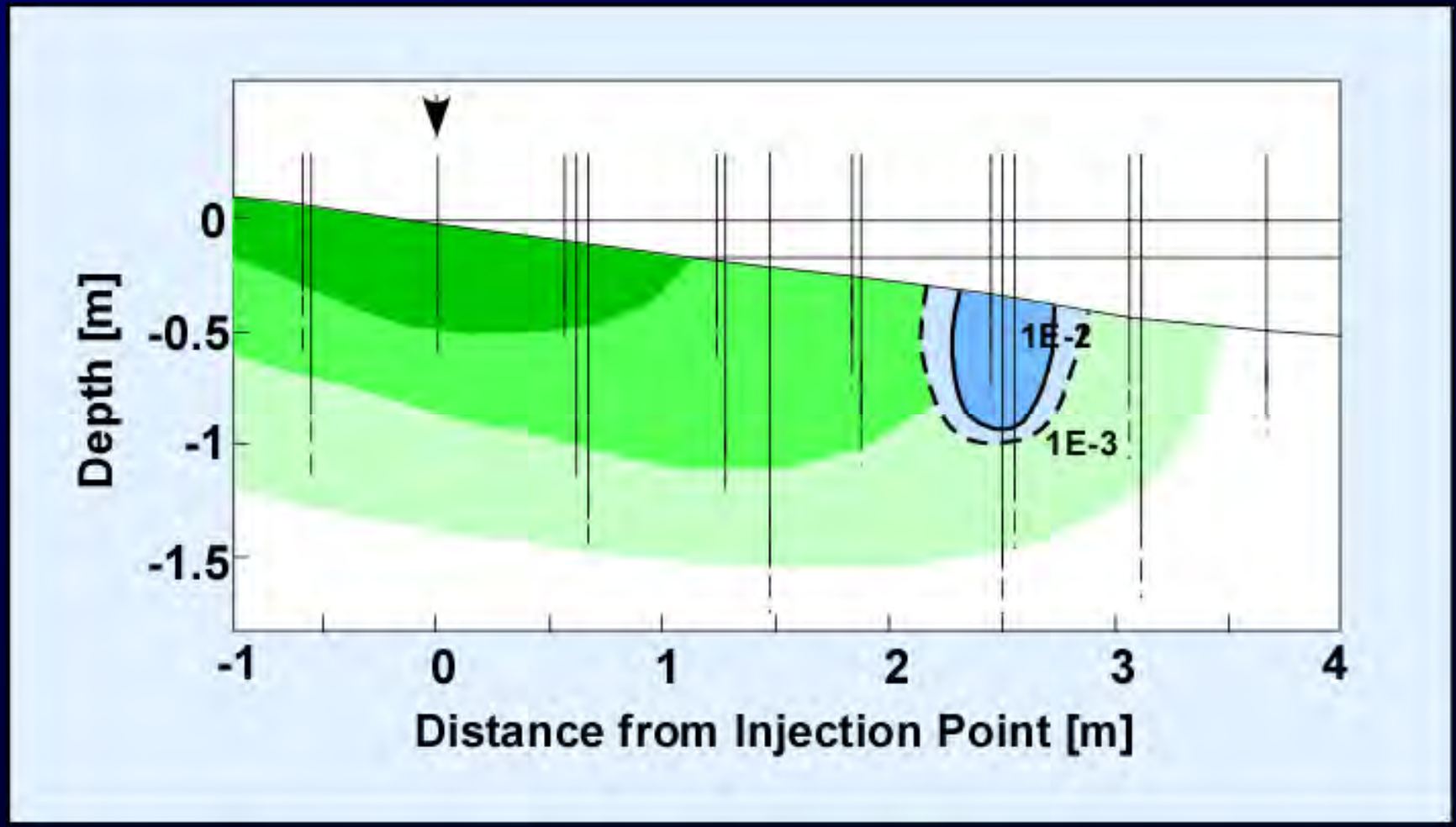

Driving Mechanisms of SGD

Transient Forcing

1 – Nearshore: tides and waves

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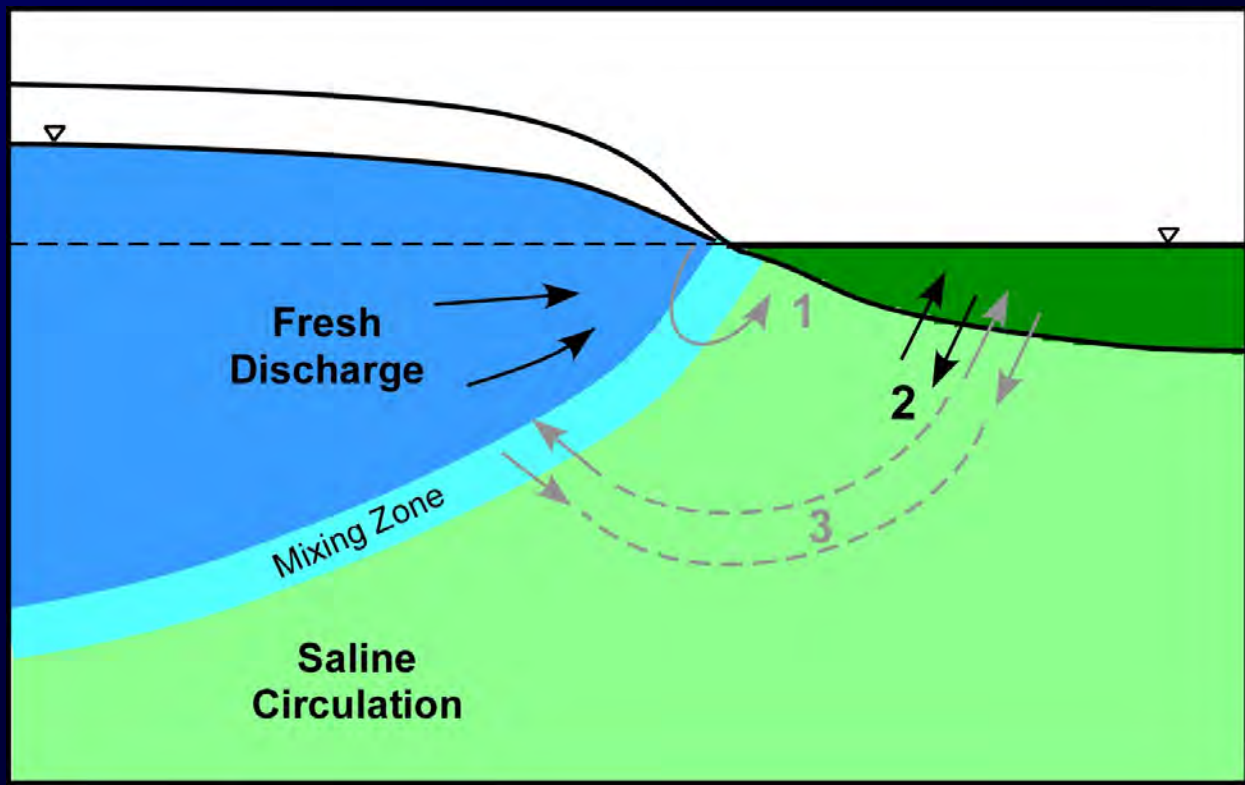
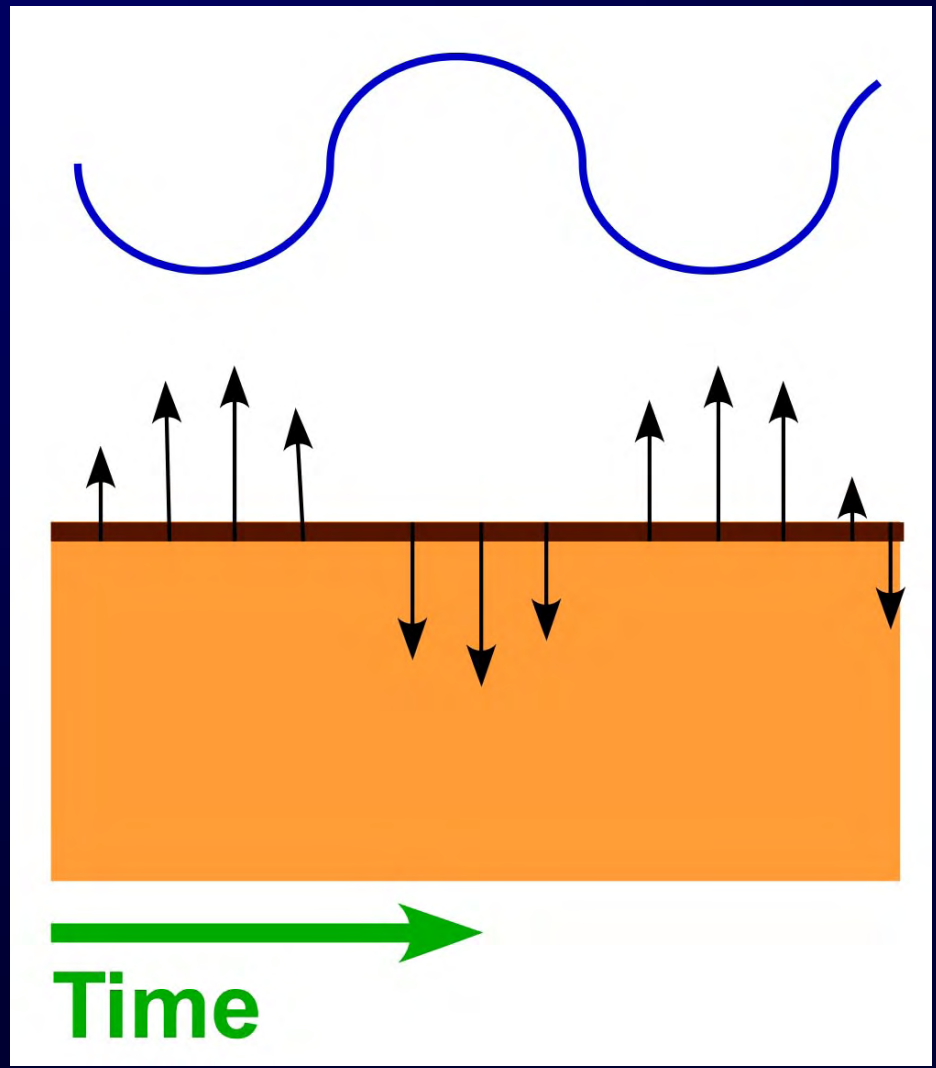
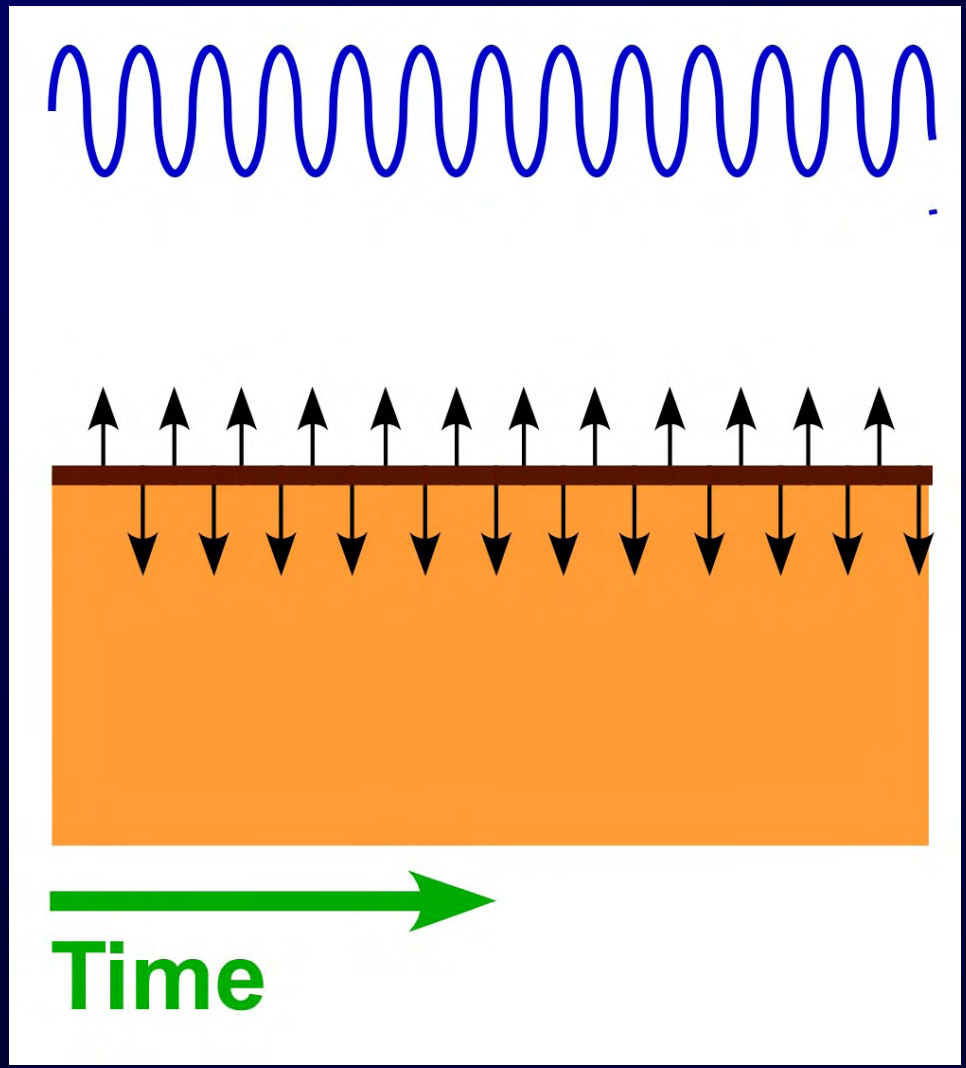


Offshore: tides



Offshore: tides, waves



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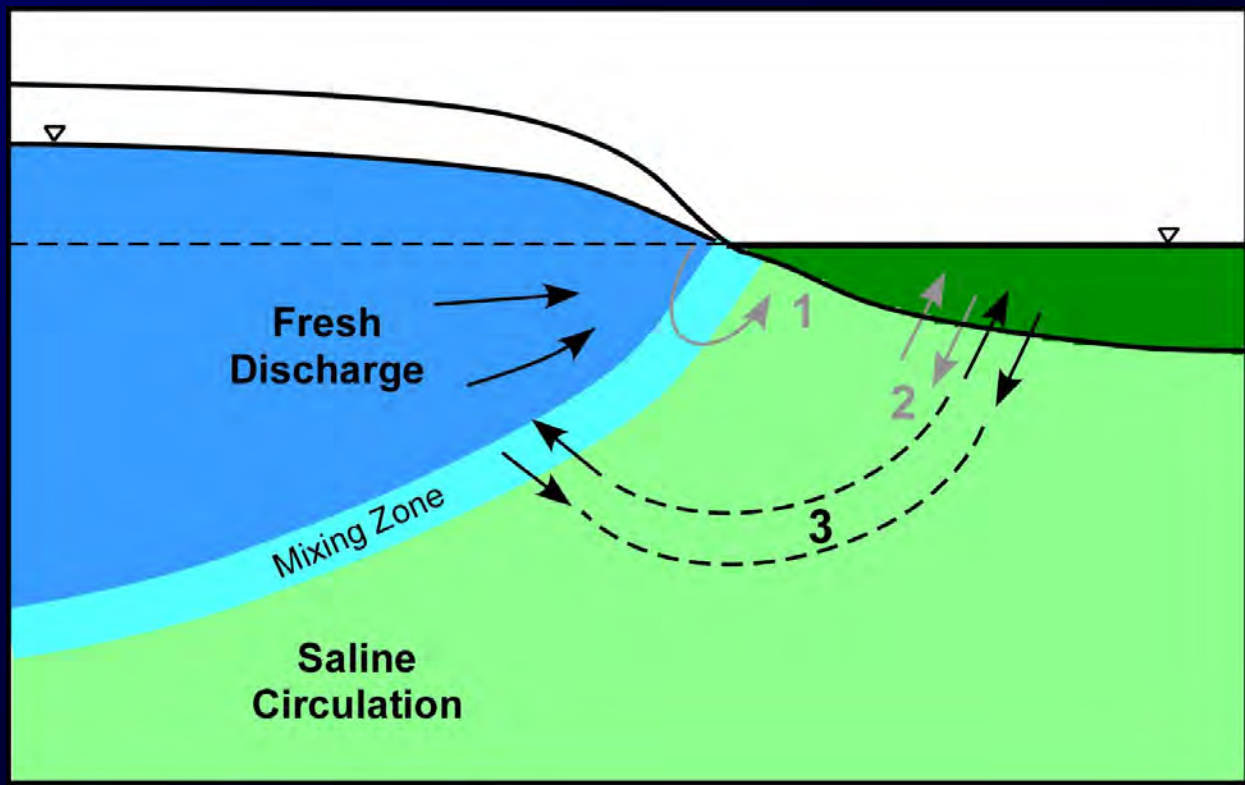
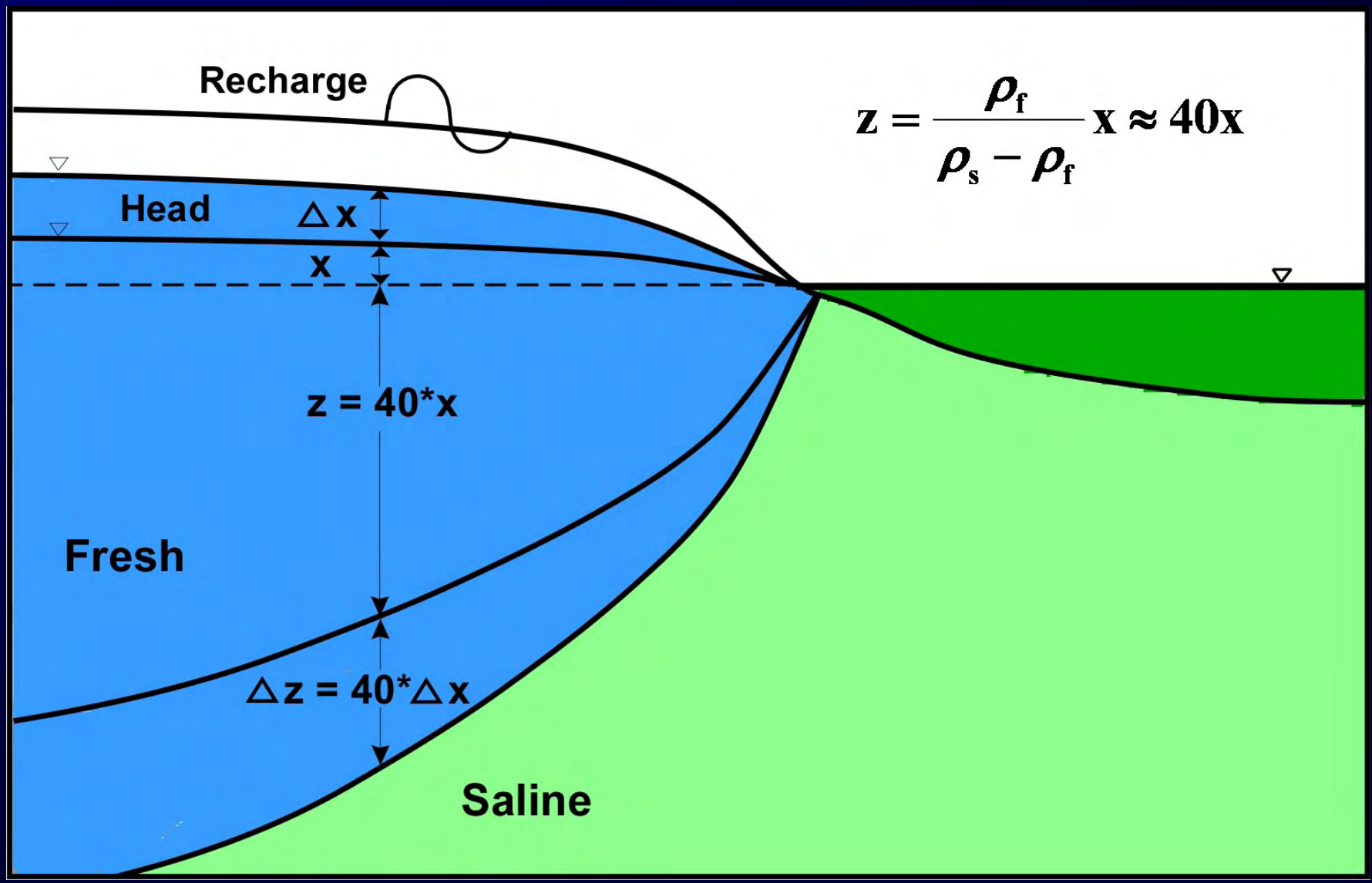
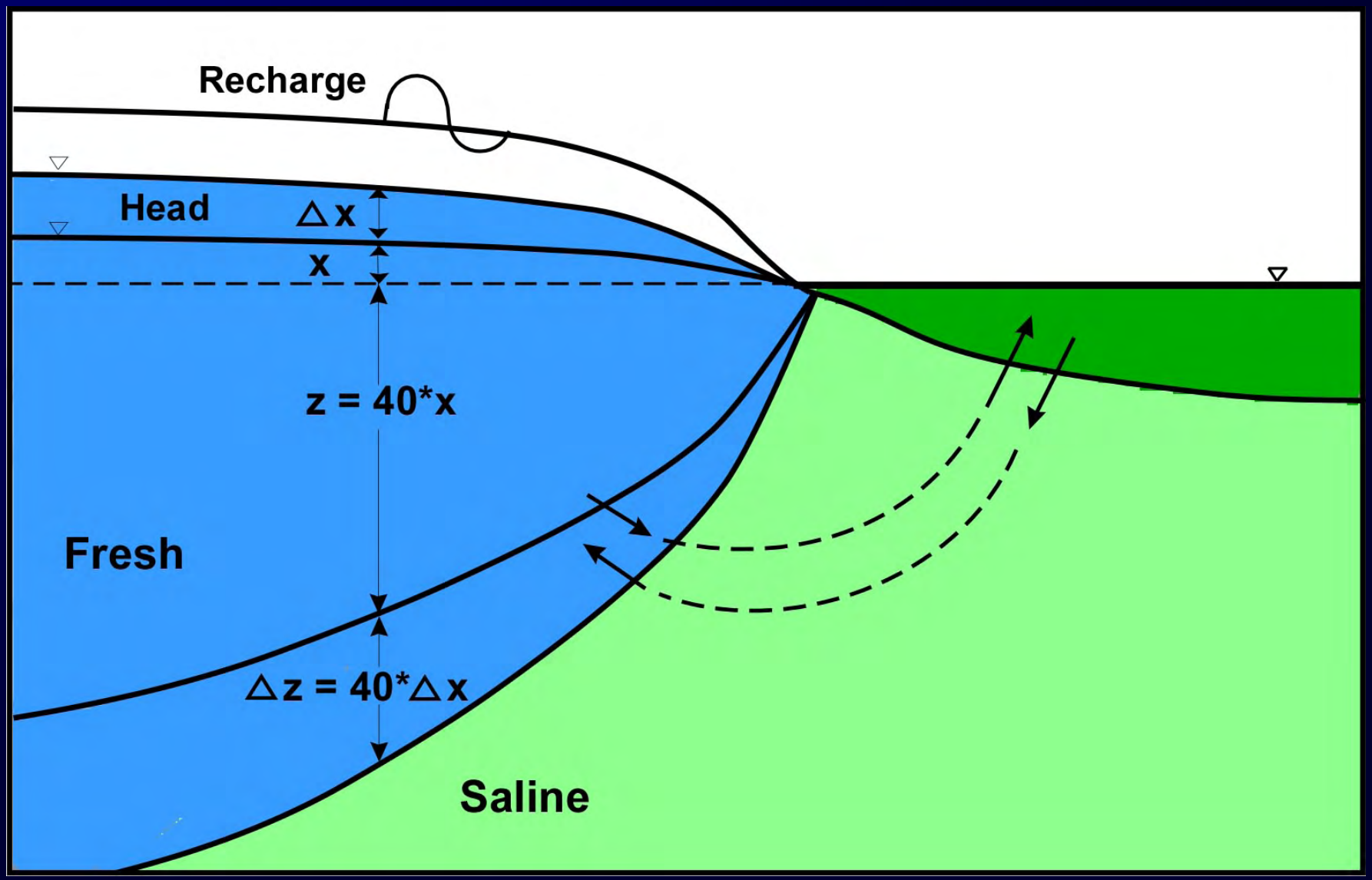



Recharge
$z = \frac{\rho_f}{\rho_s - \rho_f} x \approx 40x$
Head
△x
x
z = 40*x
Fresh
△z = 40*△x
Saline


Recharge
Head
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Tools for Measuring/Estimating SGD

In the field:

- Seepage Meters (direct)
- Hydraulic Gradients (indirect)
- Tracers (very indirect)

Modeling:

- 2D, 3D numerical models
- Variable-density

Seepage Meters

Seepage Meters

Hydraulic Head Gradients (Piezometers)

Tools for Measuring/Estimating SGD

In the field:

- Seepage Meters (direct)
- Hydraulic Gradients (indirect)
- Tracers (very indirect)

Modeling:

- 2D, 3D numerical models
- Variable-density

Modeling

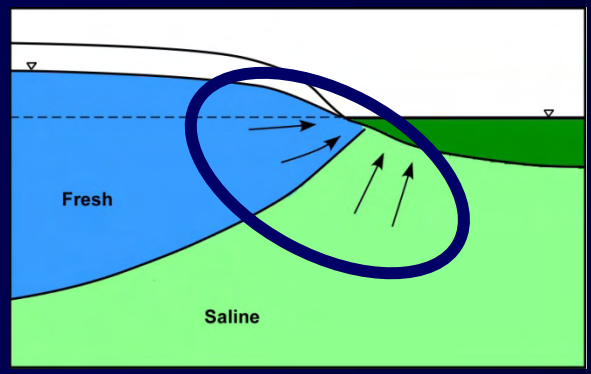
- Simulate groundwater flow and solute transport
  - Based on governing equations (physics)

A TOOL for understanding systems

- Different features/conceptual models → *controls*
  (what determines groundwater discharge rates?)
- Simulation → *answers to questions*
  (what are estimated groundwater discharge rates?)
- Variation of parameters → *sensitivity*
  (how sure are we of the estimates?)

This talk…

- Overview of coastal groundwater dynamics

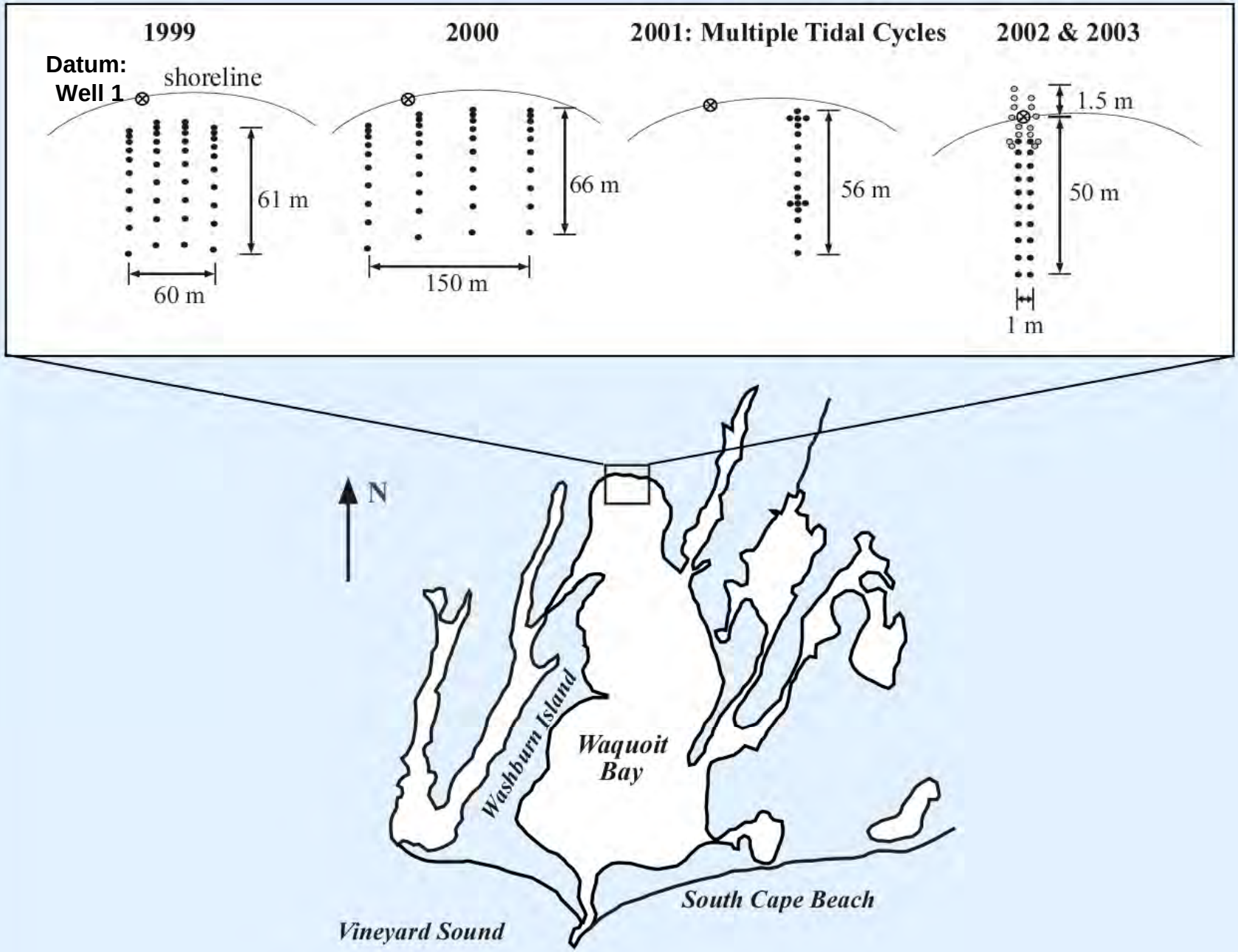


- Brief look at work on Cape Cod

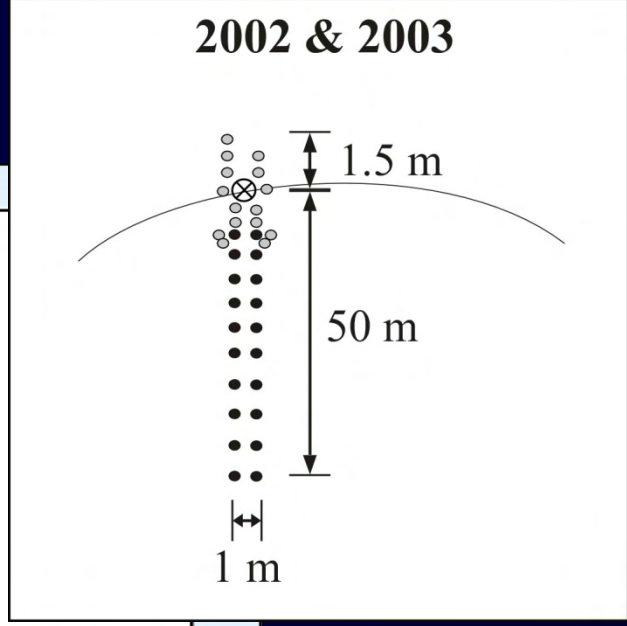
- Background on previous Indian River Bay work and ideas for future research in the Inland Bays

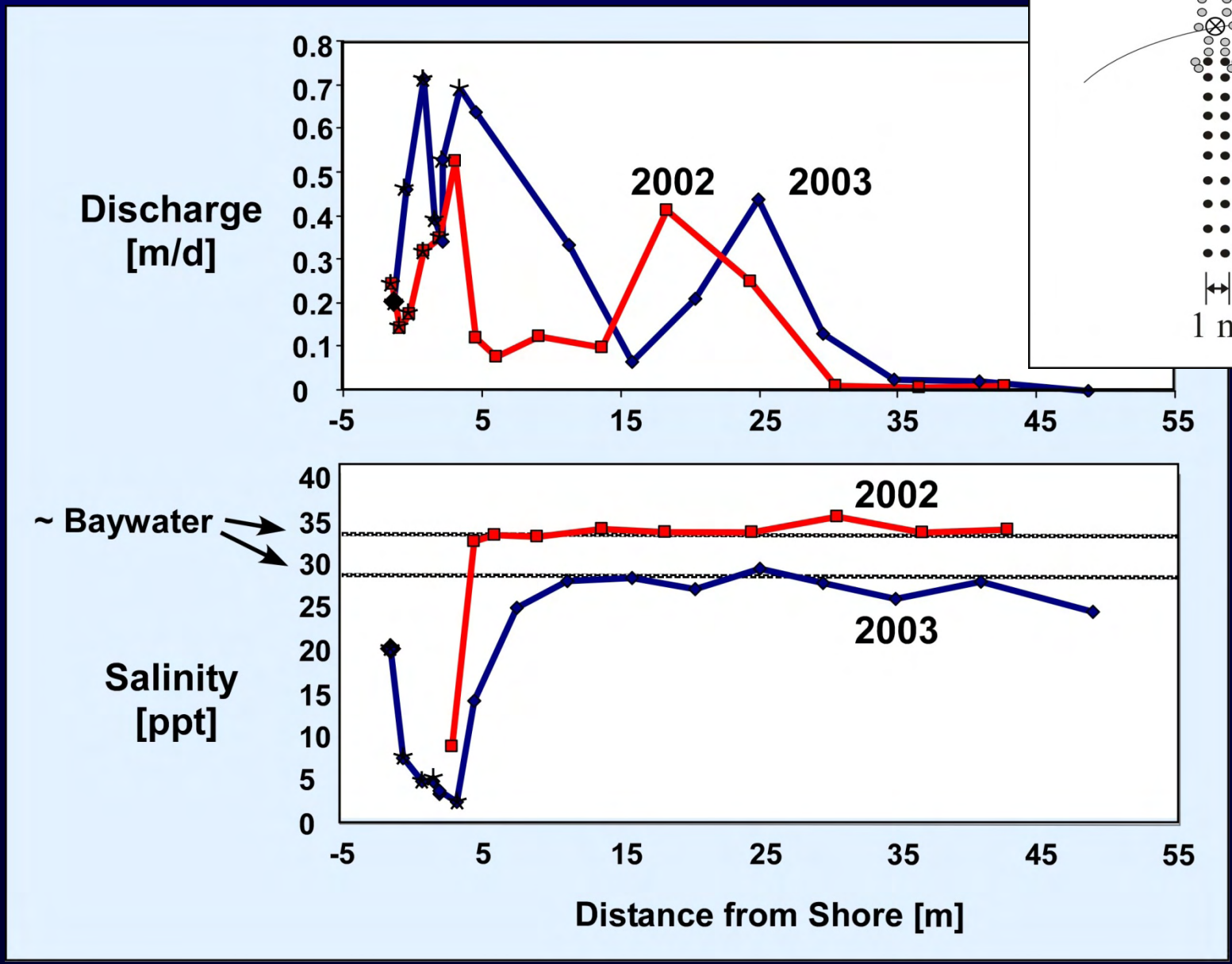
Waquoit Bay, MA

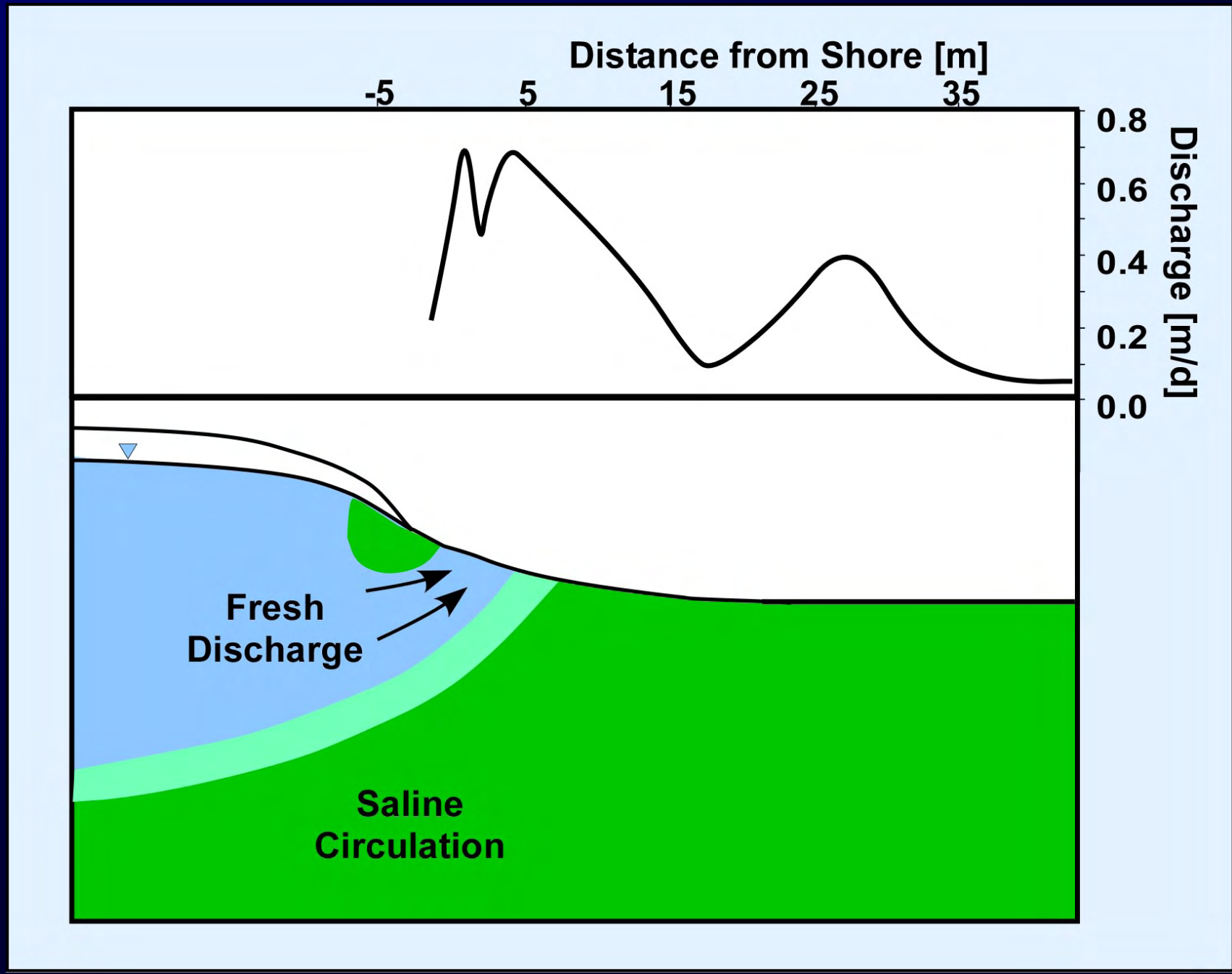
Image from Google Earth: www.earth.google.com

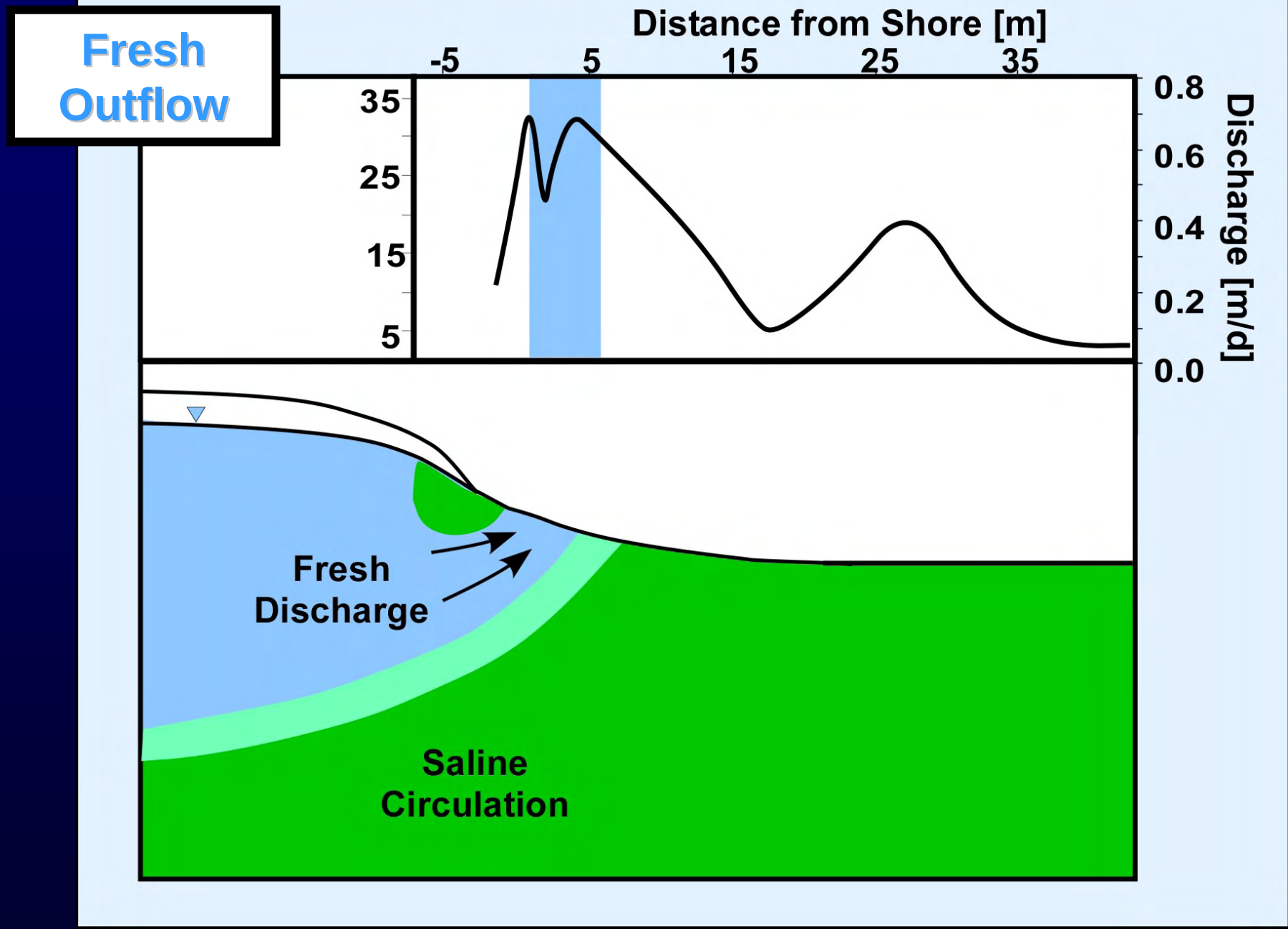

1999
2000
2001: Multiple Tidal Cycles
2002 & 2003
Datum:
Well 1
shoreline
61 m
60 m
66 m
150 m
56 m
1.5 m
50 m
1 m
N
Washburn Island
Waquoit
Bay
South Cape Beach
Vineyard Sound

Seepage Meter Transect Results:

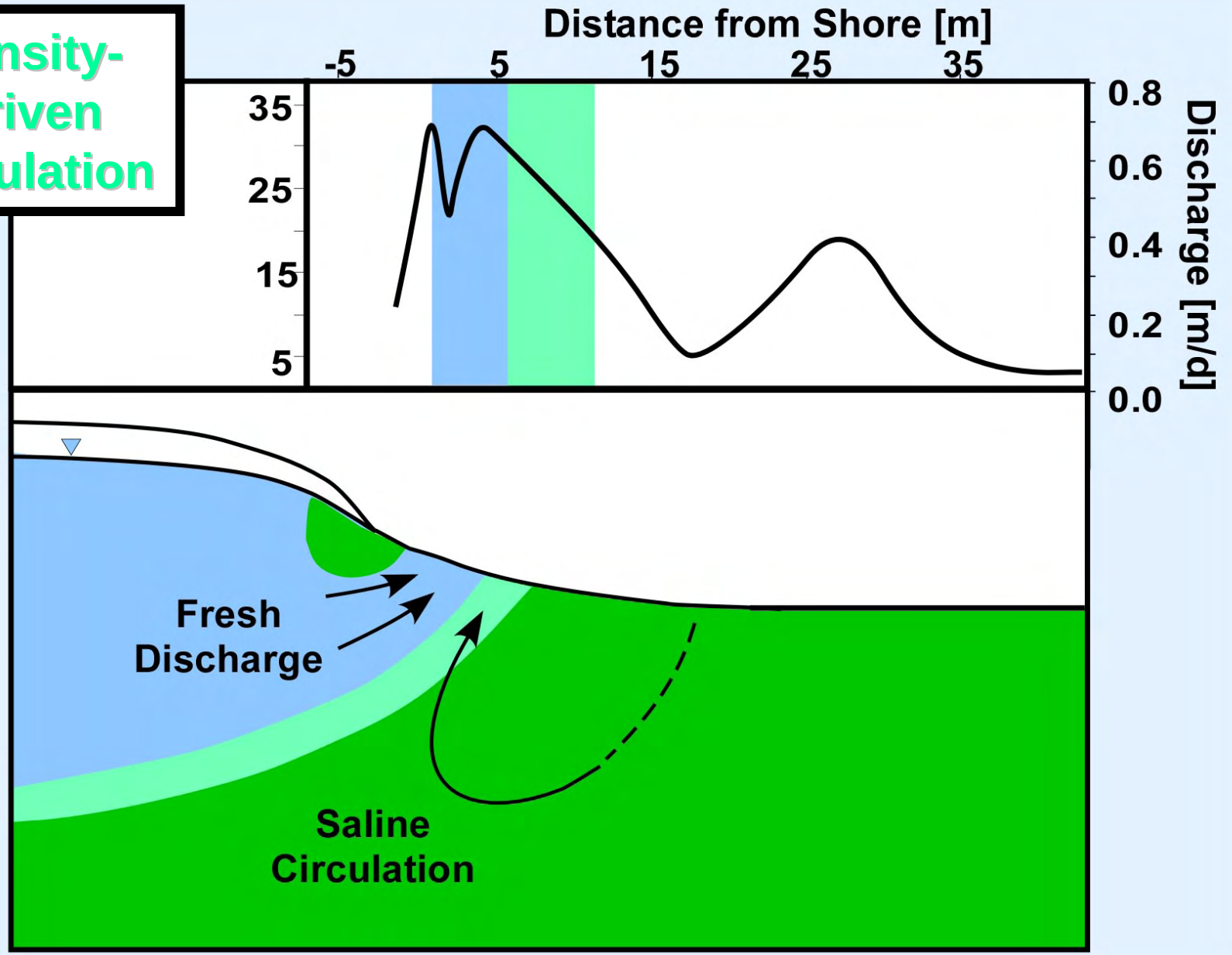




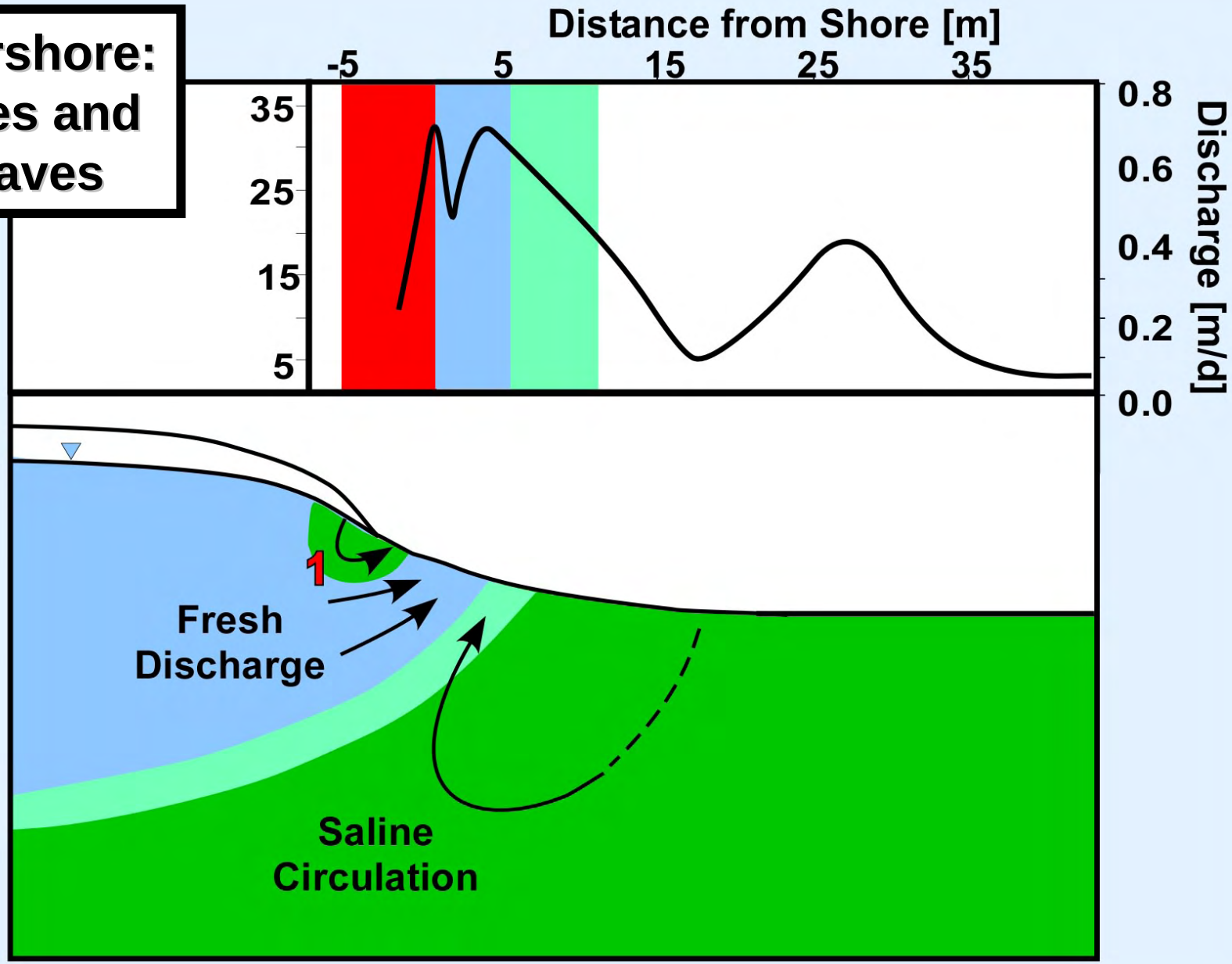

Distance from Shore [m]
-5
5
15
25
35
0.8
0.6
0.4
0.2
0.0
Discharge [m/d]
Fresh
Discharge
Saline
Circulation


Fresh Outflow
Distance from Shore [m]
-5
5
15
25
35
35
25
15
5
0.8
0.6
0.4
0.2
0.0
Discharge [m/d]
Fresh Discharge
Saline Circulation

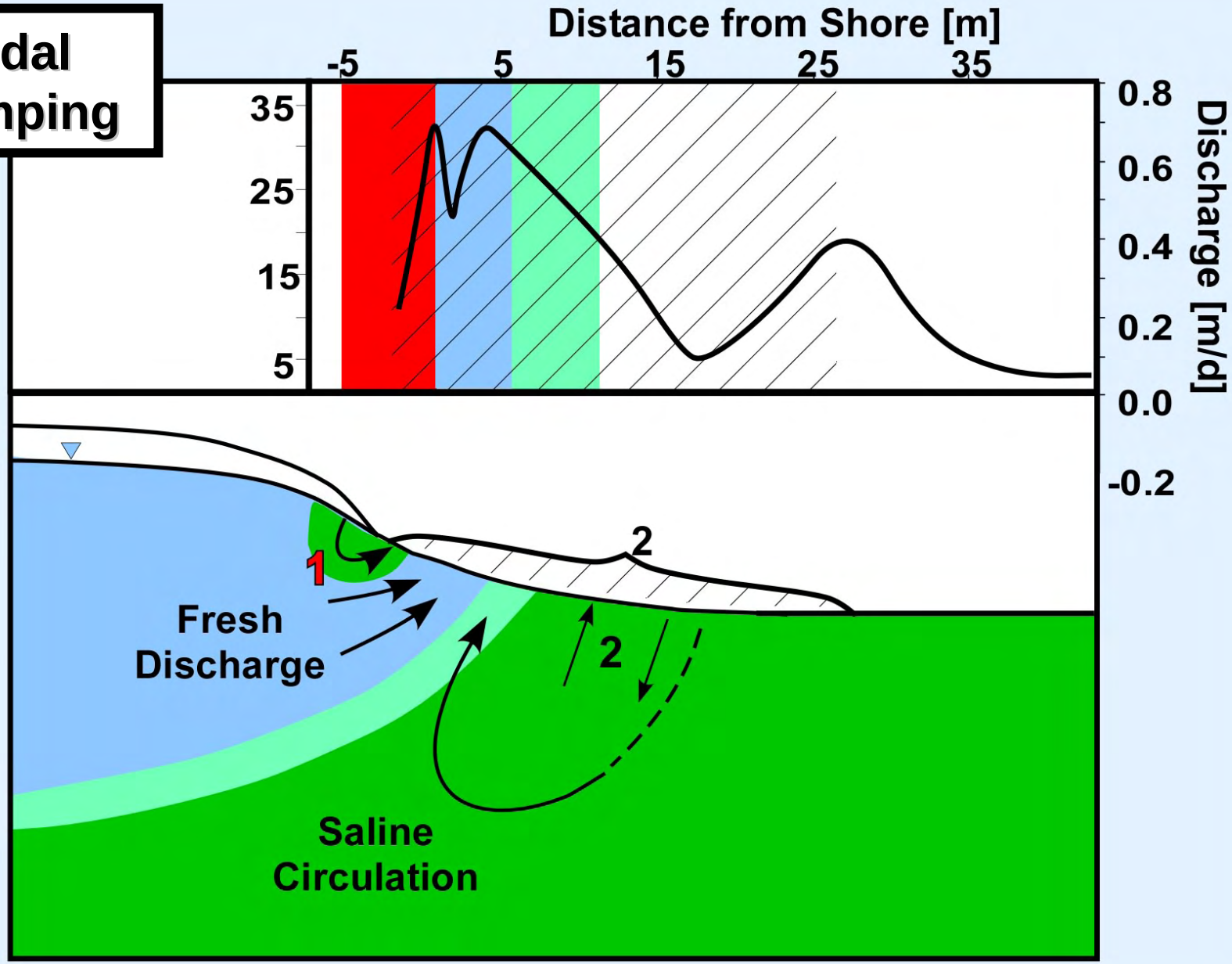
Density-Driven Circulation



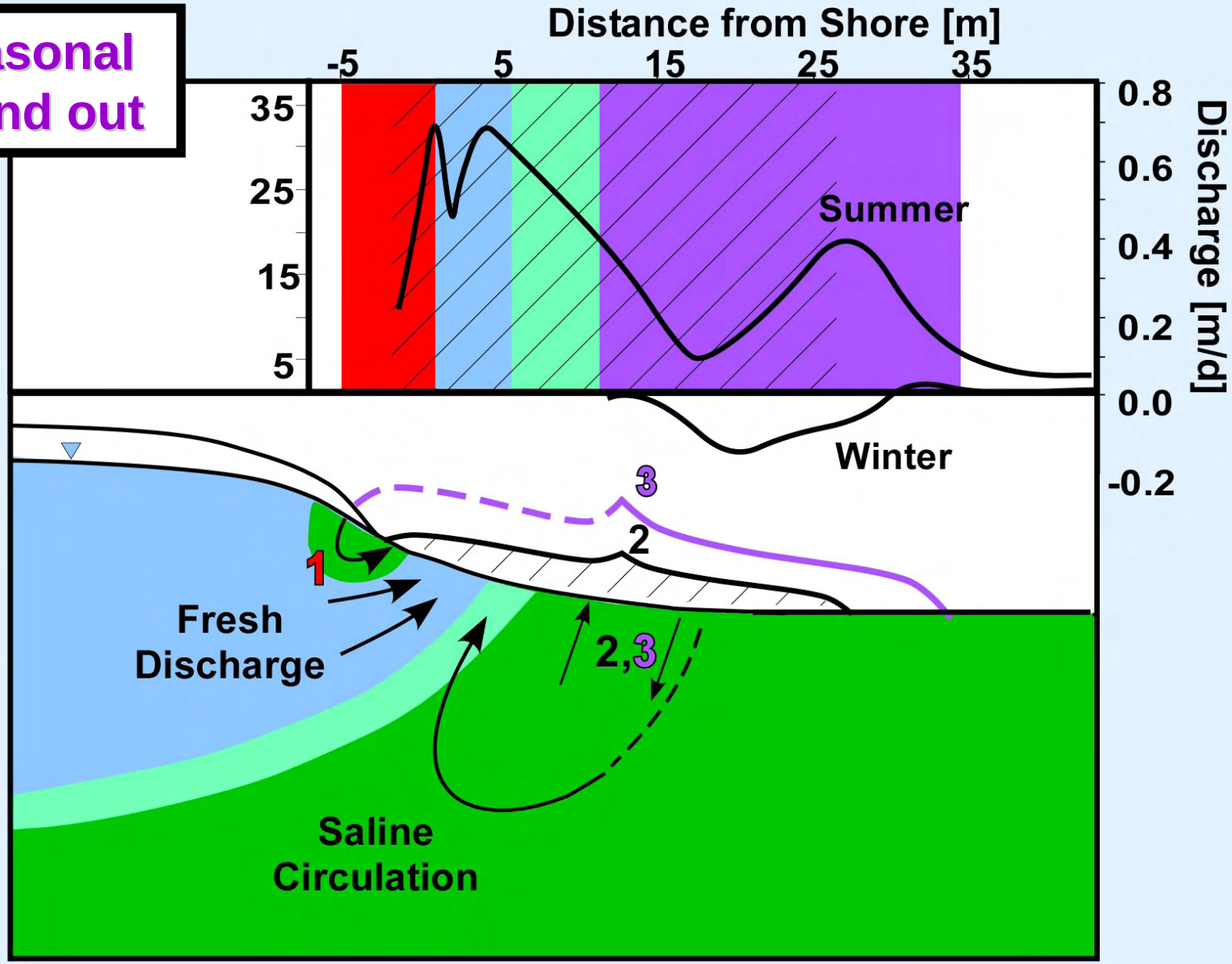
Nearshore: Tides and Waves

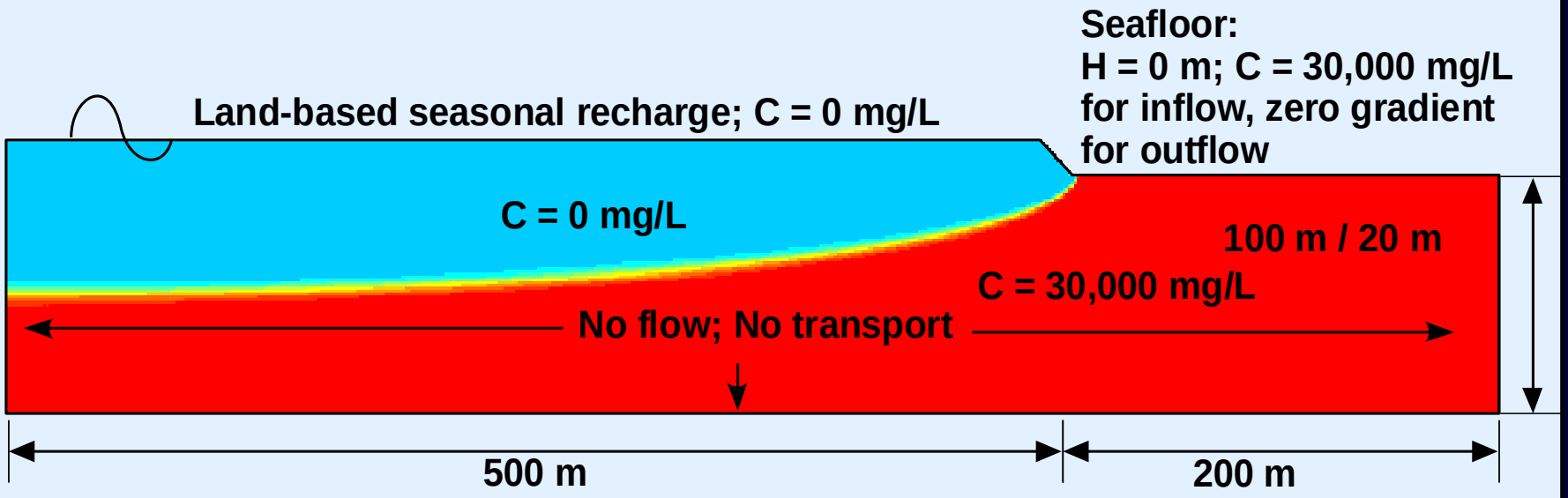


Tidal Pumping



Seasonal in and out

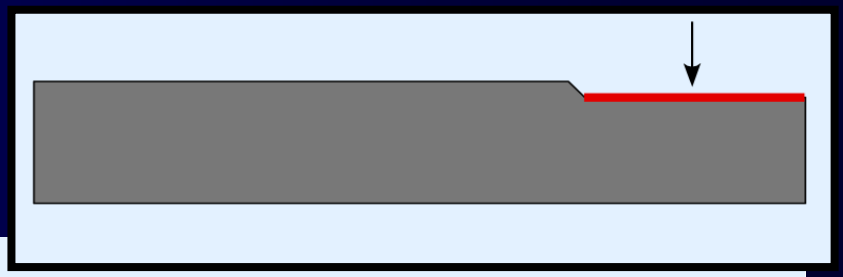


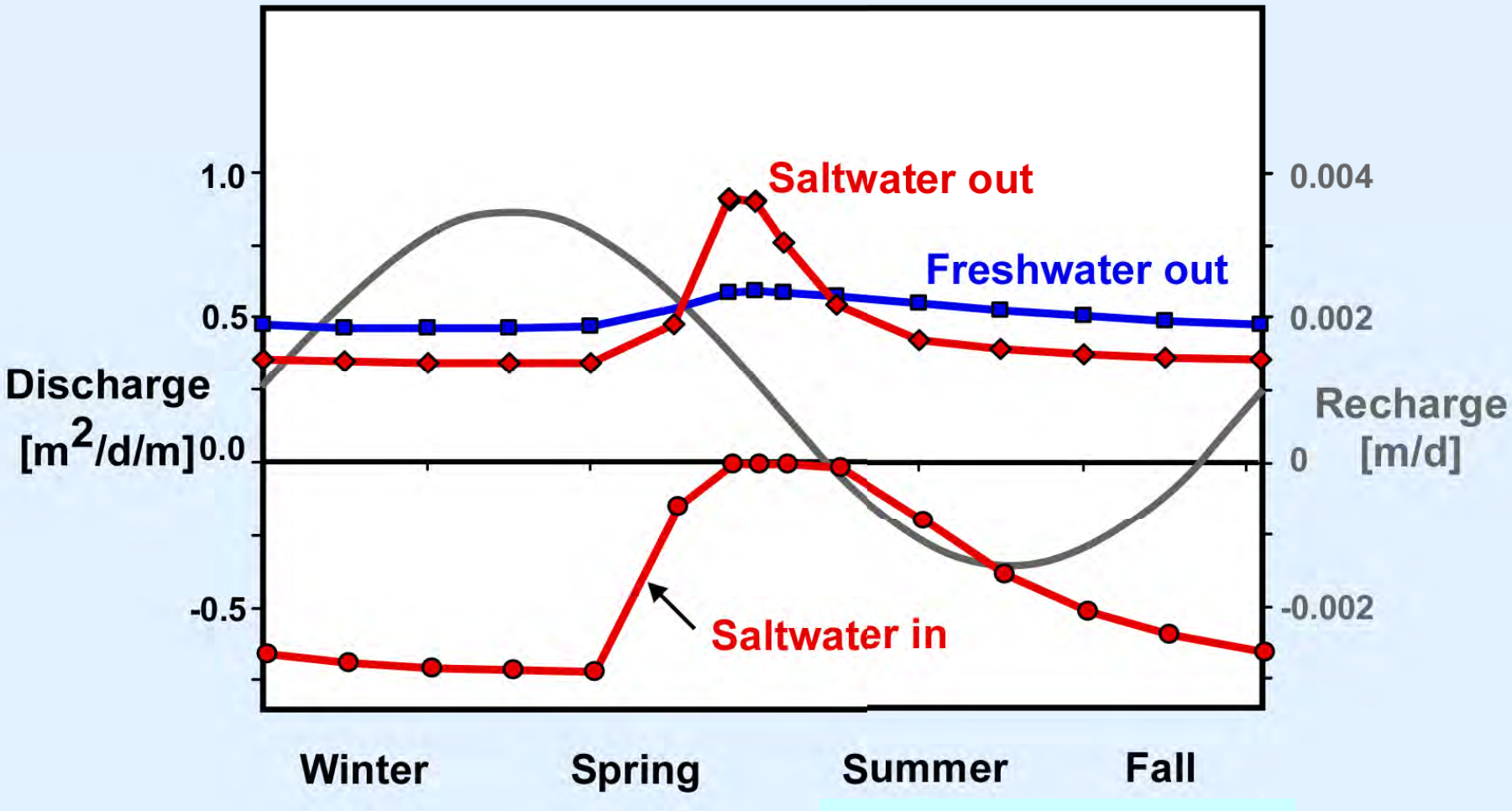


Numerical Model

- 2D
- Simulates groundwater flow and salt transport

Seafloor Groundwater Discharge (Modeled)





From Waquoit Bay…

- Different forcing mechanisms move water of different origins (terrestrial, marine) and at different flow rates
- We are able to quantify flow rates and zones using field measurements and modeling

We also Know…

- Different types of discharging water may have different levels and types of dissolved nutrients (high vs. low, bioavailable vs. non-bioavailable)

→ Identifying types and rates of SGD could help estimate nutrient loads

→ Potential application to Inland Bays

This talk…

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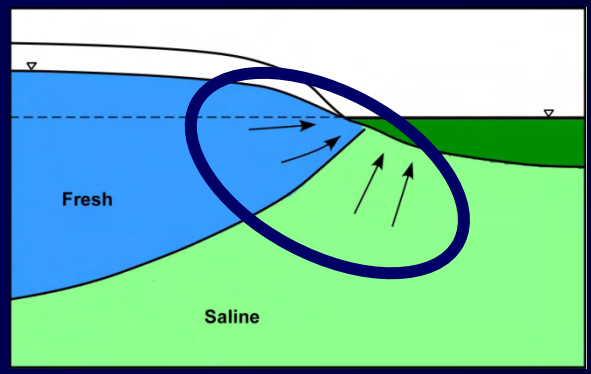

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Prior Related Work in Indian River Bay:

(DGS, DNREC, USGS, UD, etc…)

Onshore and Offshore…

Geology

- Characterization of Columbia Aquifer
- Identification of paleovalleys

Hydrogeology

- Characterization of hydraulic properties
- Estimation of fresh groundwater flow

Geochemistry

- Salinity distribution
- Nutrients
- Ages

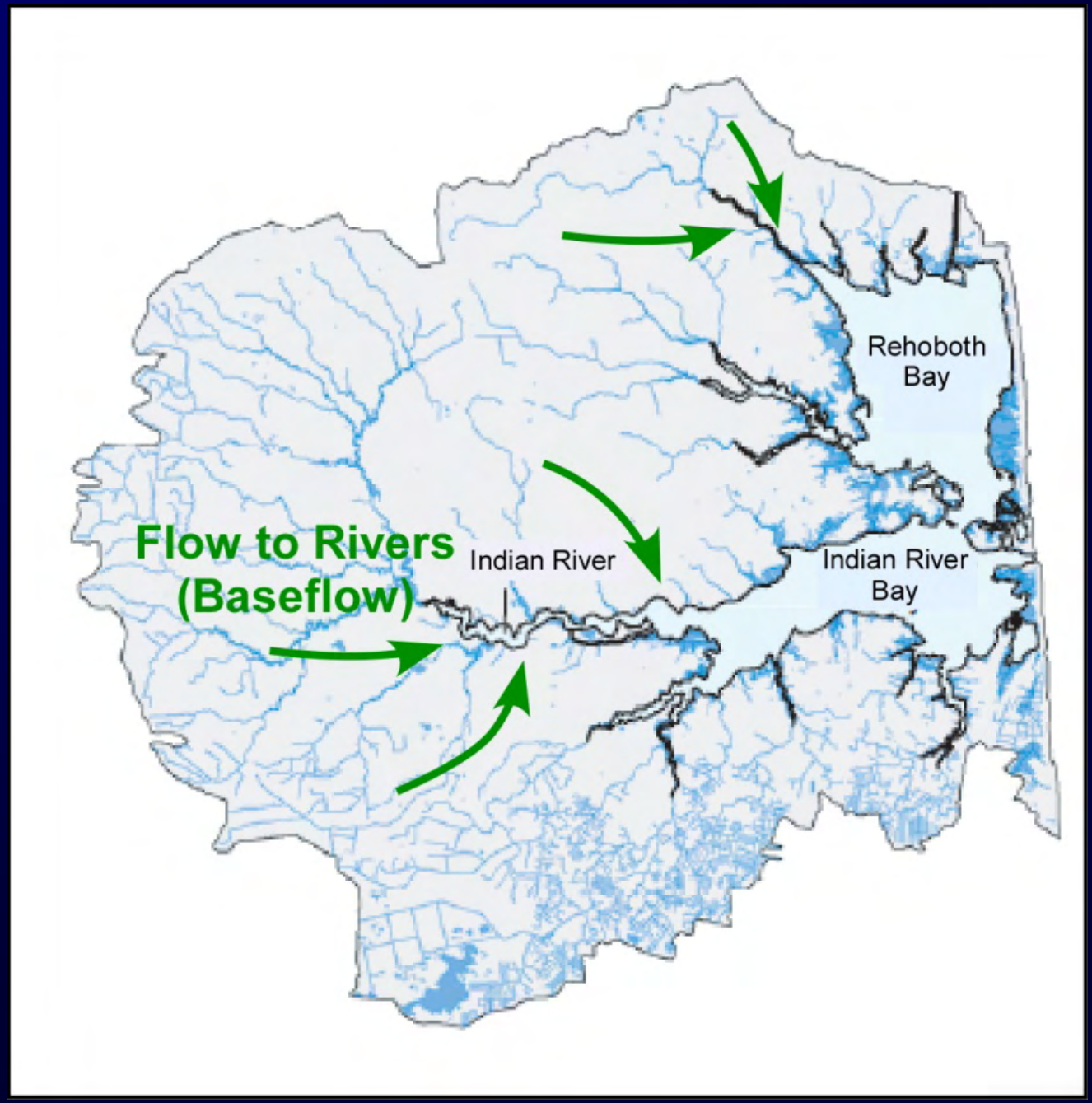
Prior Related Work in Indian River Bay:

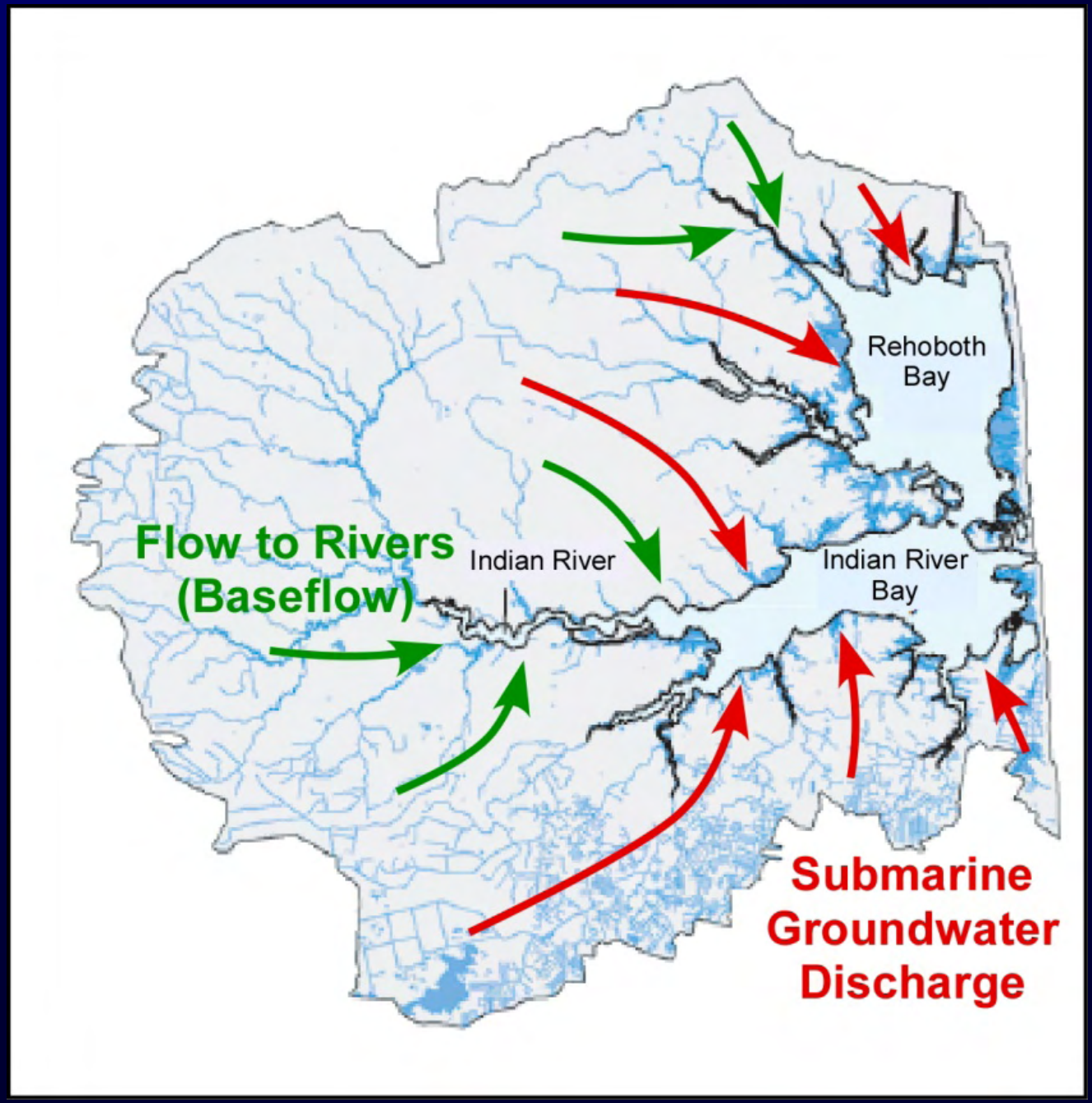
(DGS, DNREC, USGS, UD, etc…)

Onshore and Offshore…

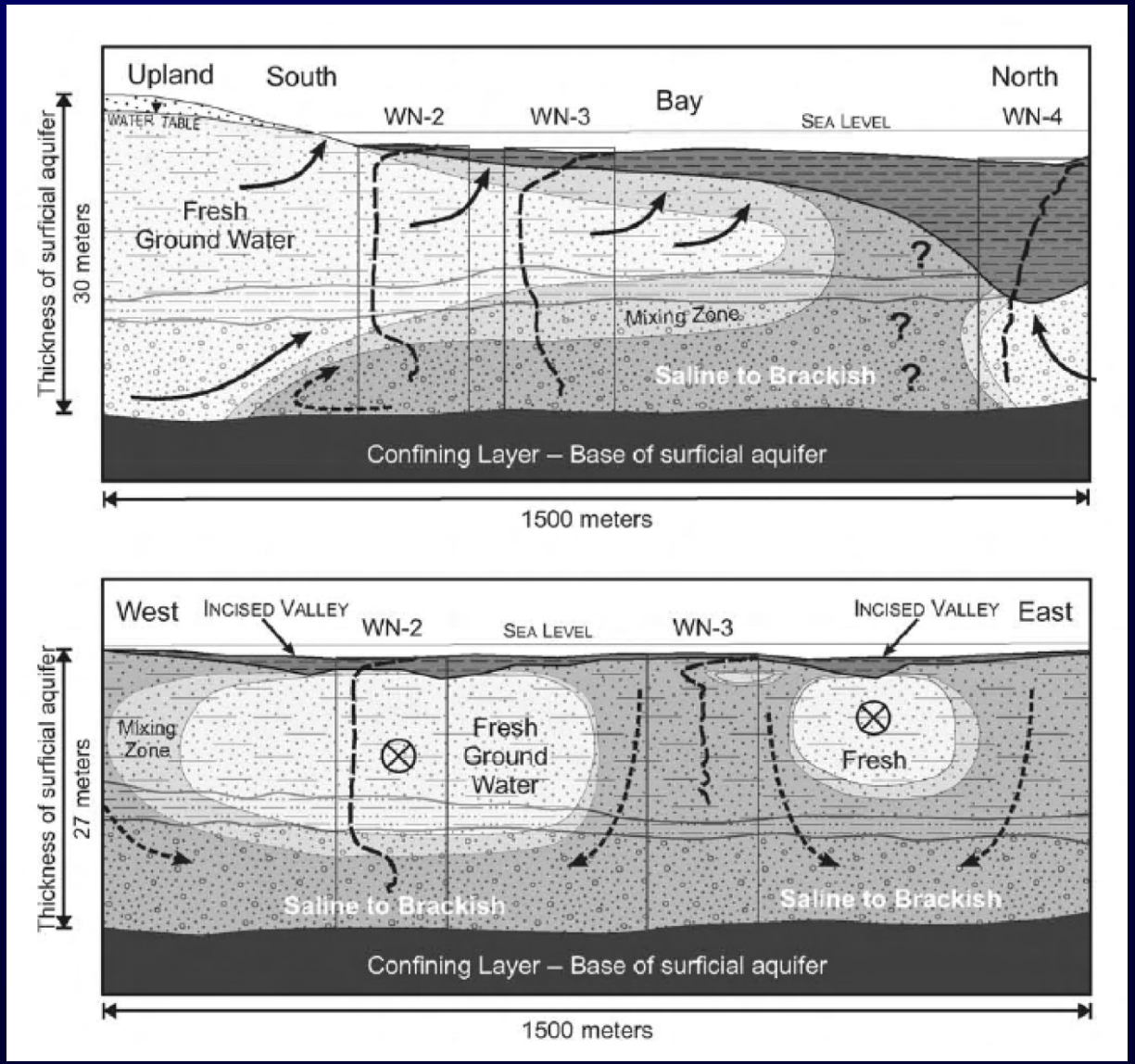
- Valuable basis for understanding the system
- Reveals complexities previously not understood
- Essential framework for future research on hydrogeology and nutrient loading to the bays

Mckenna, Andres, and Lepp, 2007

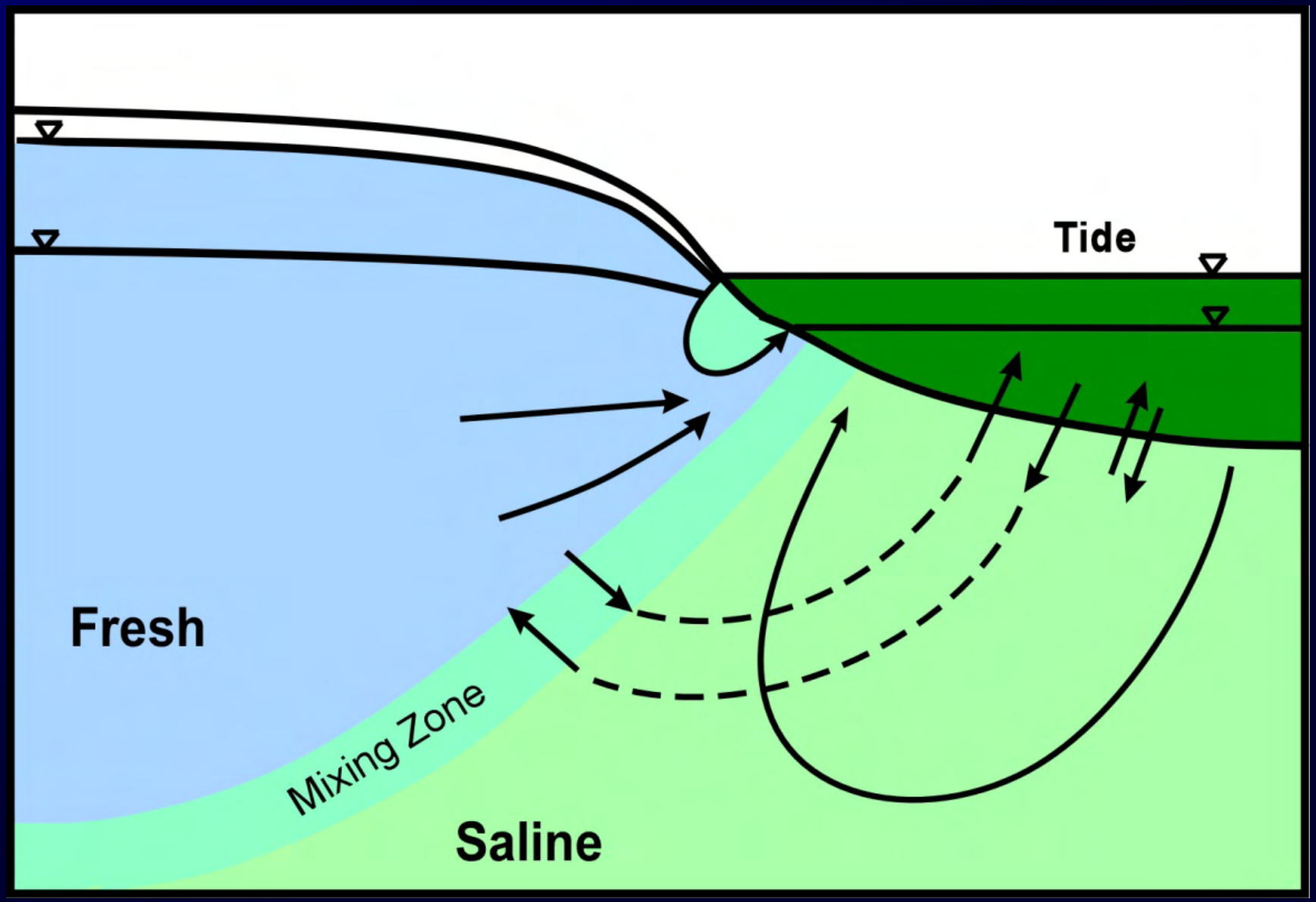

Rehoboth
Bay
Flow to Rivers
(Baseflow)
Indian River
Indian River
Bay


Rehoboth
Bay
Flow to Rivers
(Baseflow)
Indian River
Indian River
Bay
Submarine
Groundwater
Discharge

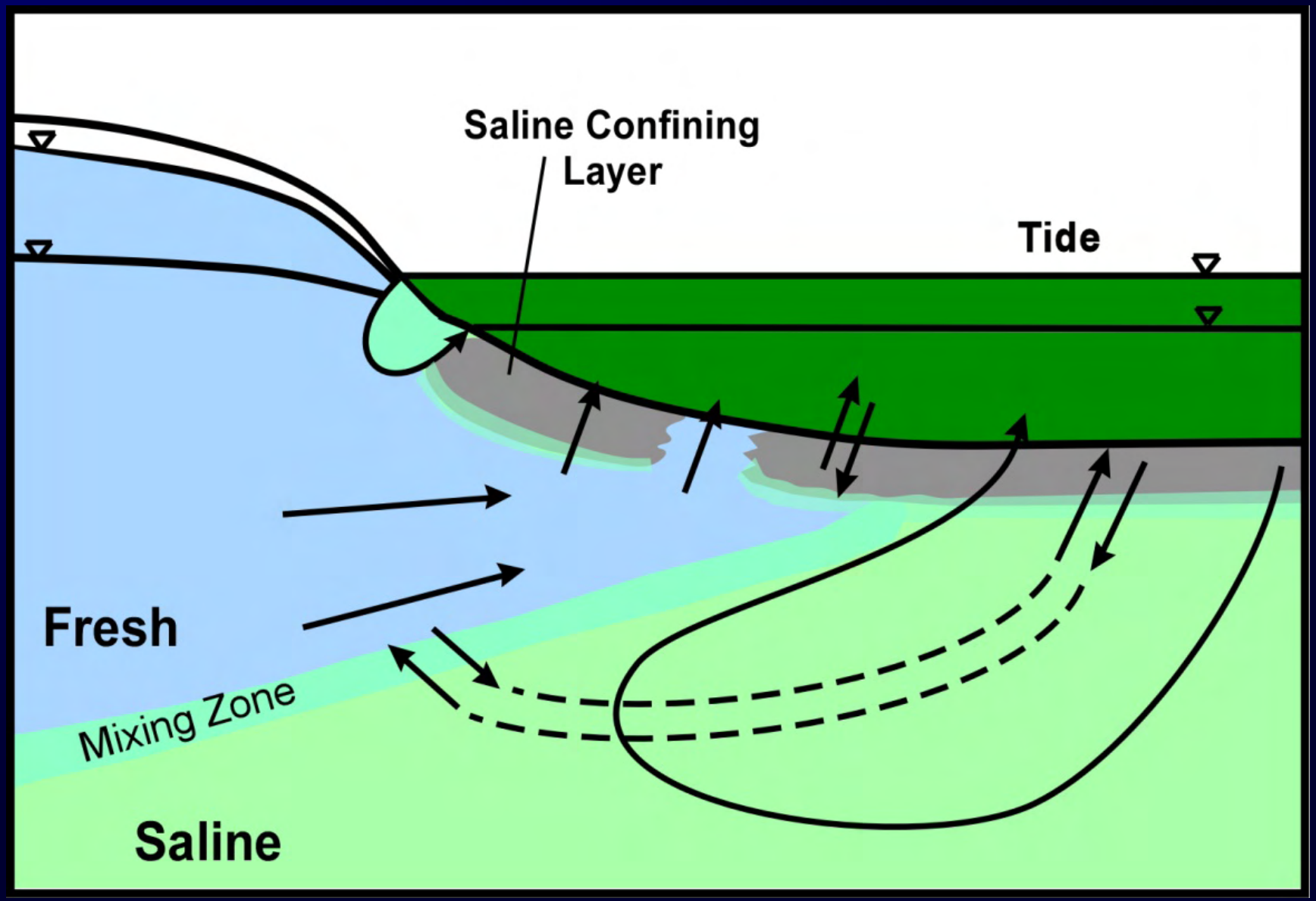
Krantz et al., 2004



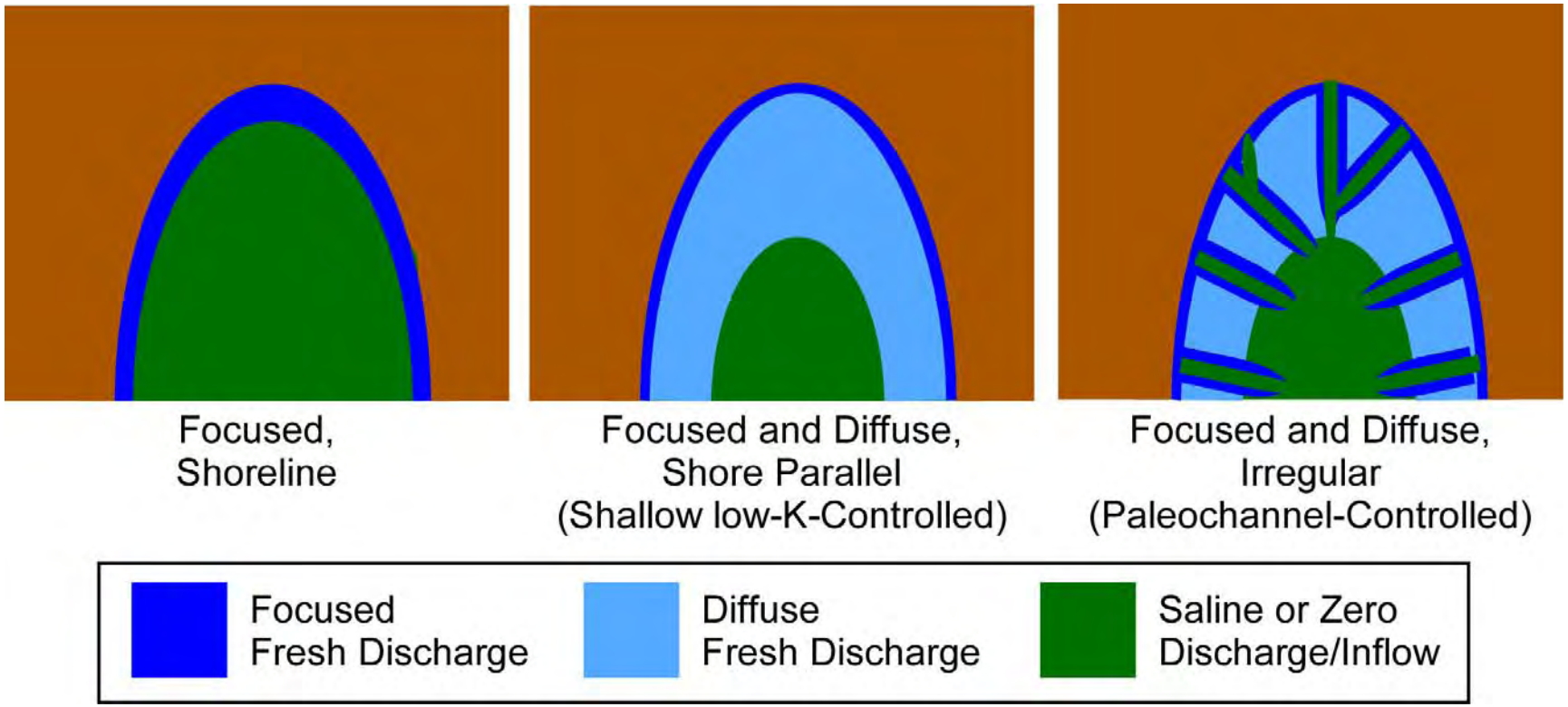
Classical Conceptualization:



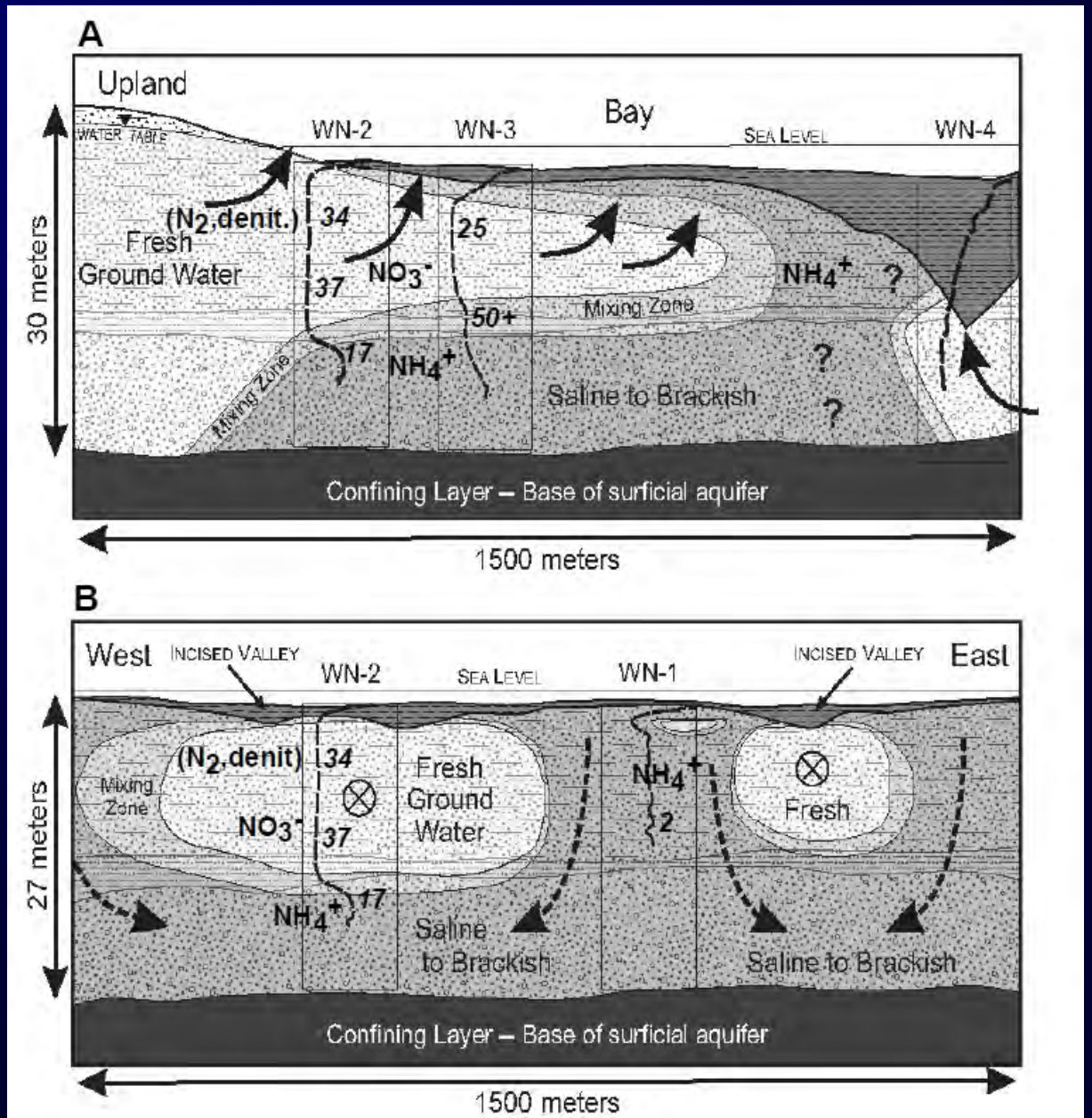
Indian River Bay Conceptualization:



Discharge Modes:



Böhlke and Krantz, 2003



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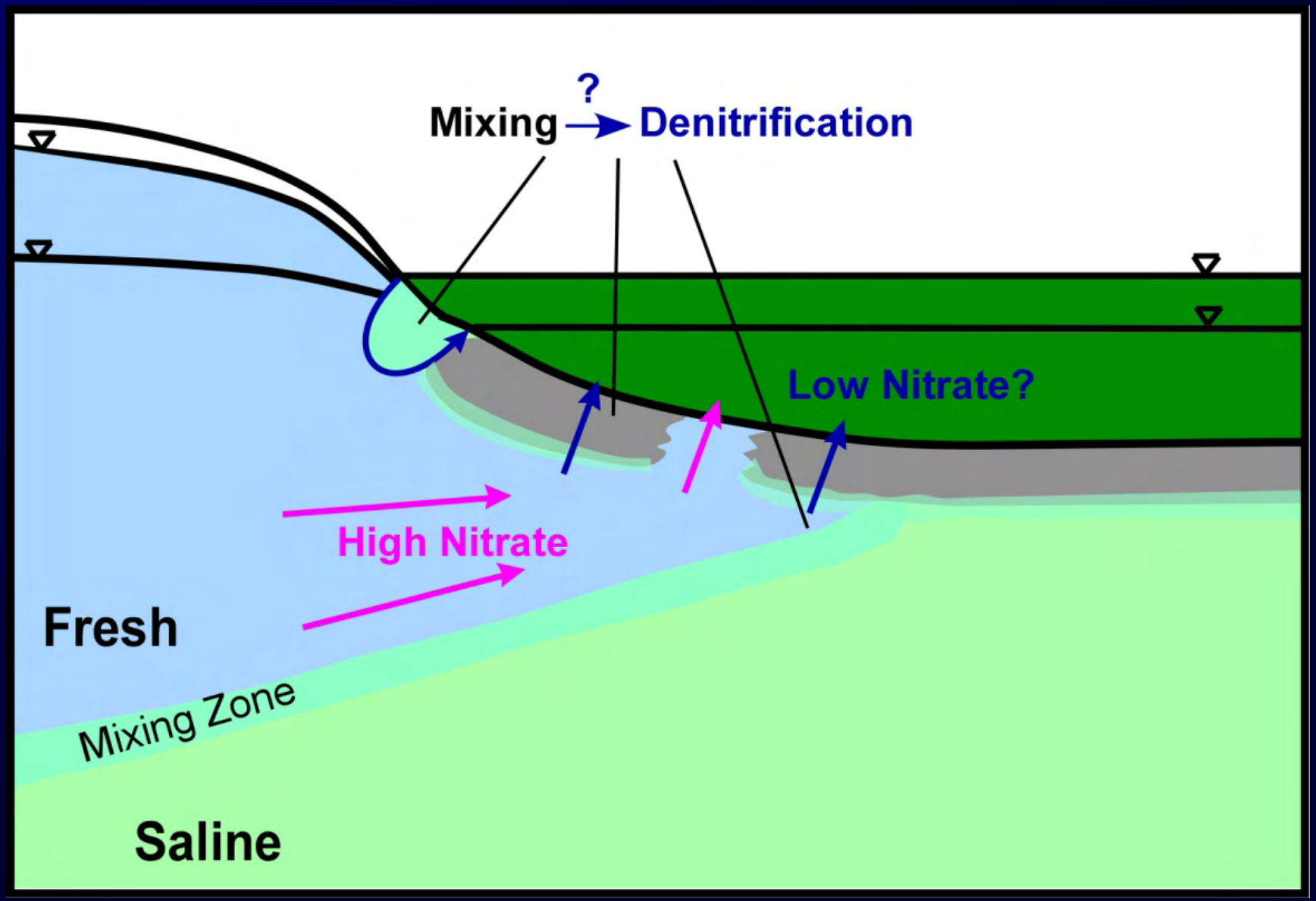

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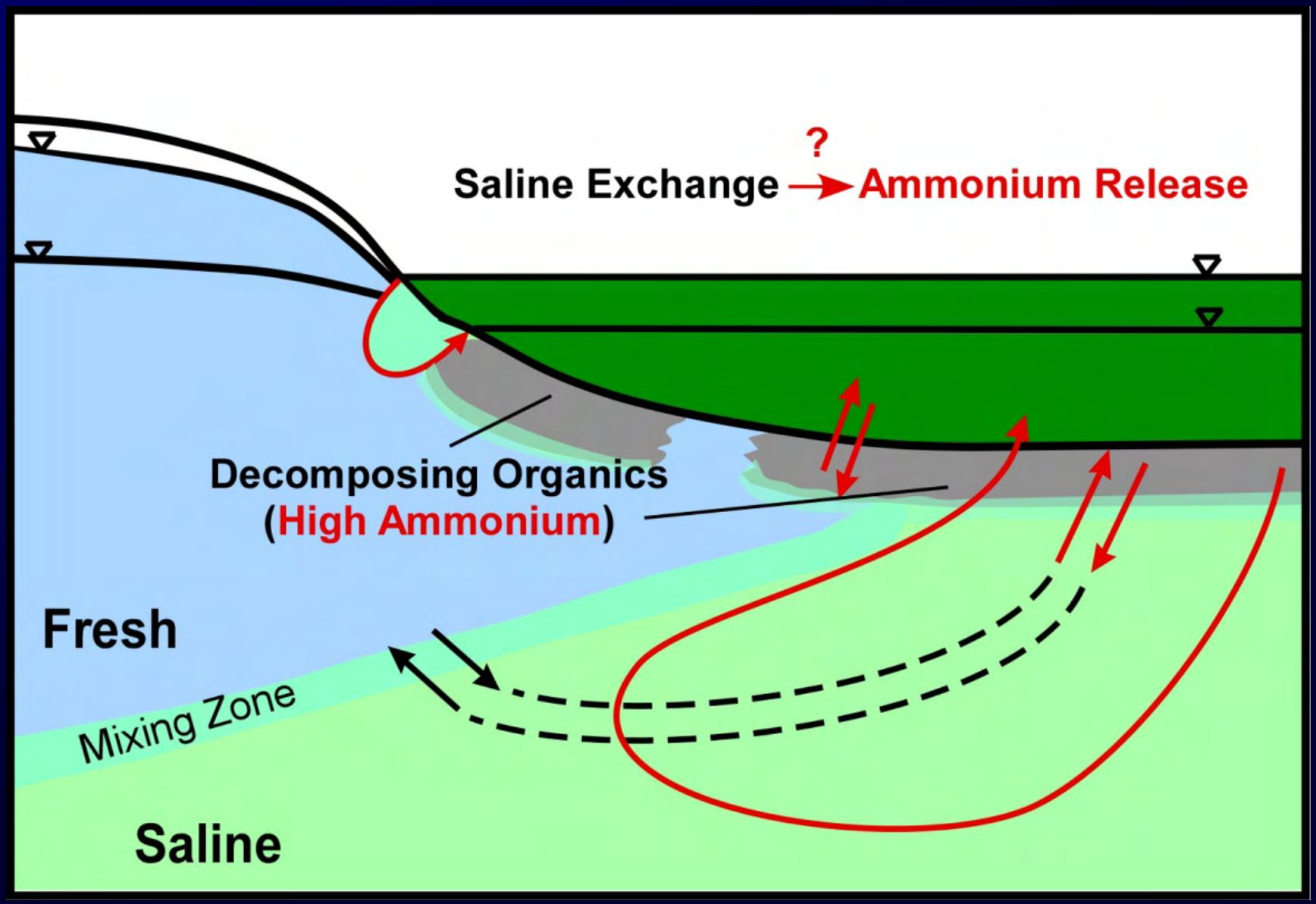

To Investigate these Ideas:

Field Work:

- Further hydrogeologic investigation
- SGD measurements on the bayfloor
- Geochemical sampling and analyses

Modeling:

- Large 3D model of watershed and bays
- Smaller models of individual mechanisms

❖ **Estimate fluxes of fresh and saline groundwater, and associated nutrient species**

Results May:

- Improve understanding of coastal groundwater systems
- Aid in development of more effective management schemes
- Help to identify practices that may exacerbate nutrient loading
- Improve the health of bay ecosystems!

Thank You!

CONTACT INFORMATION:

Holly Michael (University of Delaware): hmichael@udel.edu