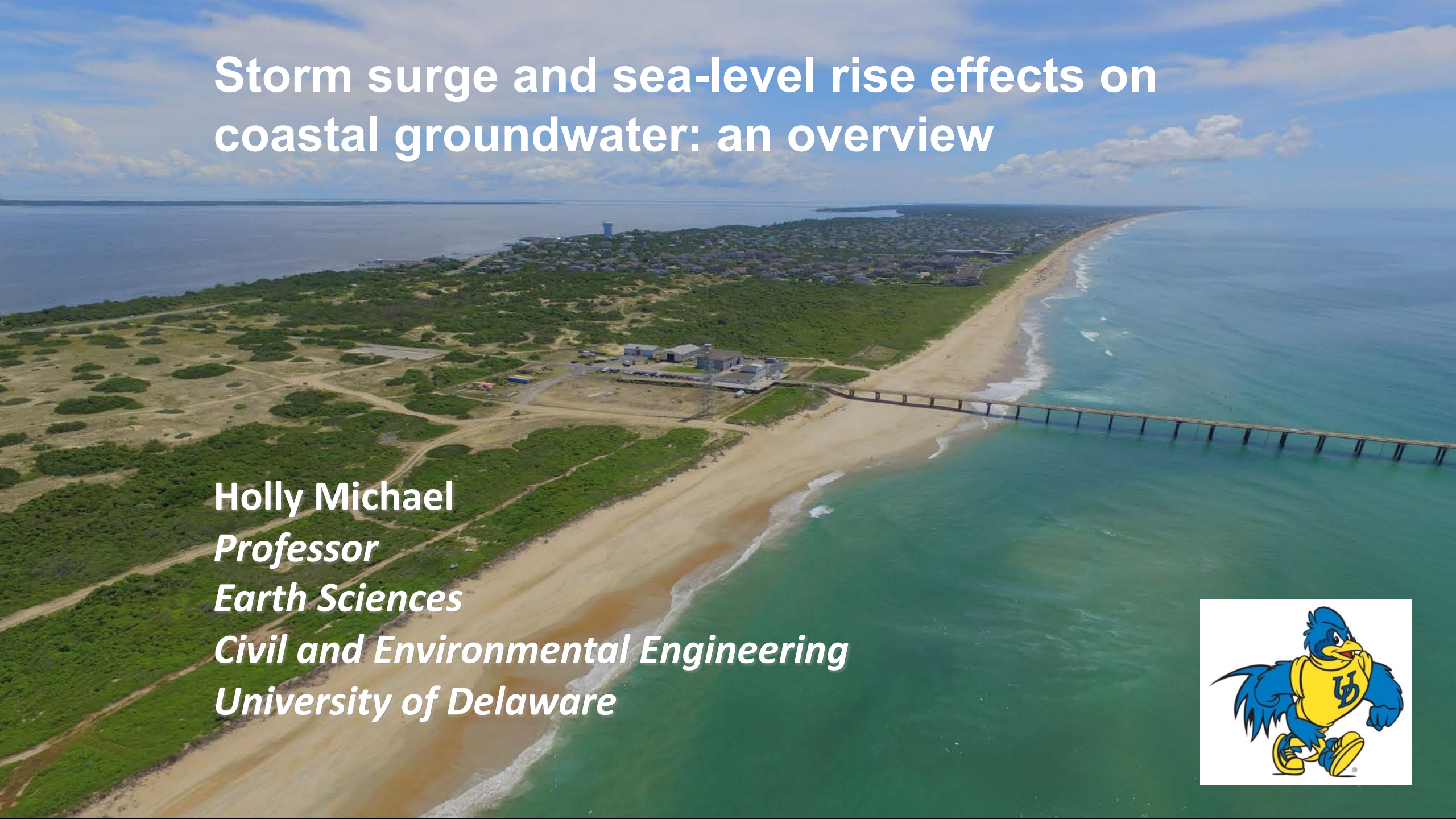
Storm surge and sea-level rise effects on coastal groundwater: an overview



Holly Michael
Professor
Earth Sciences
Civil and Environmental Engineering
University of Delaware

Contributors:

Rachel Housego, Anner Paldor & Chelsea Peters, UD Postdocs

Mary Hingst, Ryan Frederiks, UD Graduate Students

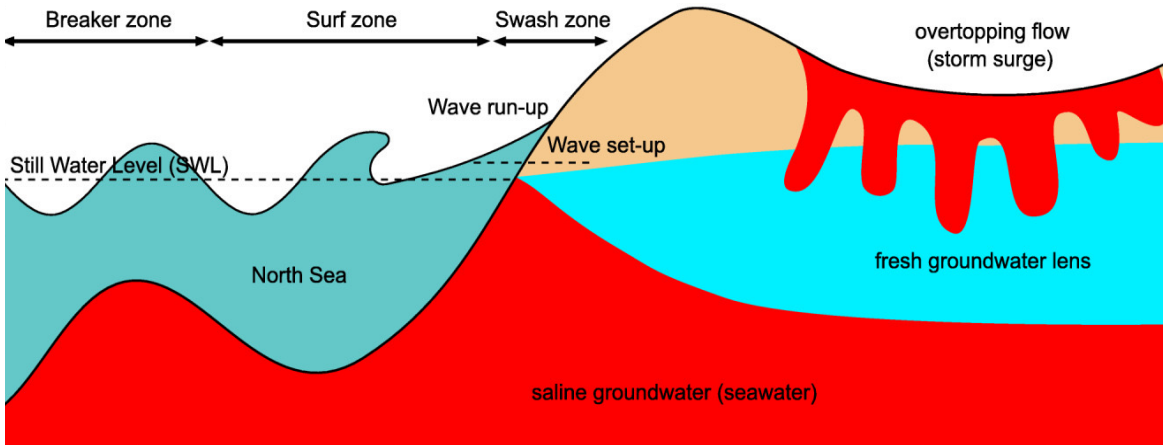
Scott Andres and Rachel McQuiggan, Delaware Geological Survey

Groundwater and Climate Change

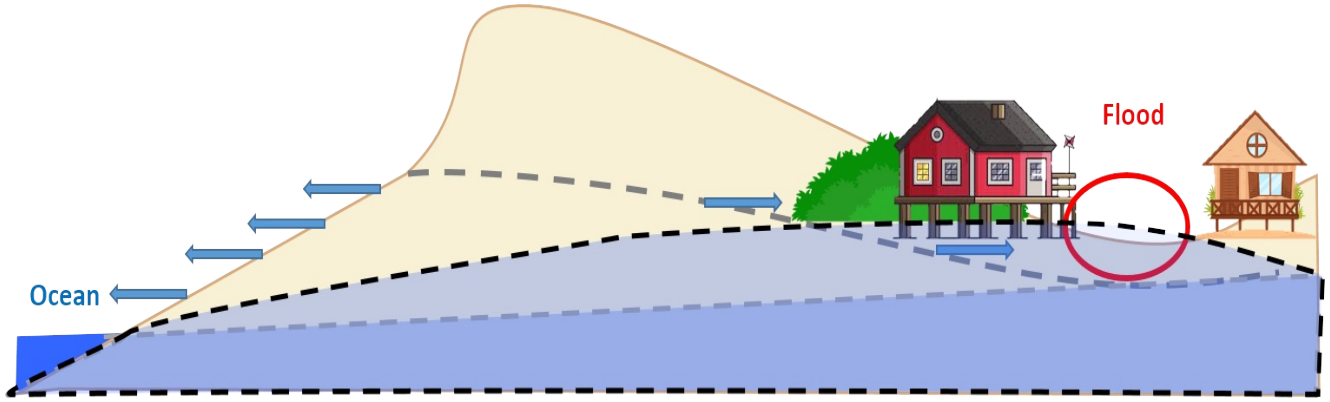
Lake Cachuma near Santa Barbara, California, in 2015
SCIENCE/SCOTT LONDON/ALAMY LIVE NEWS

→ Groundwater mitigates water resource variability in the face of climate change

Salinization

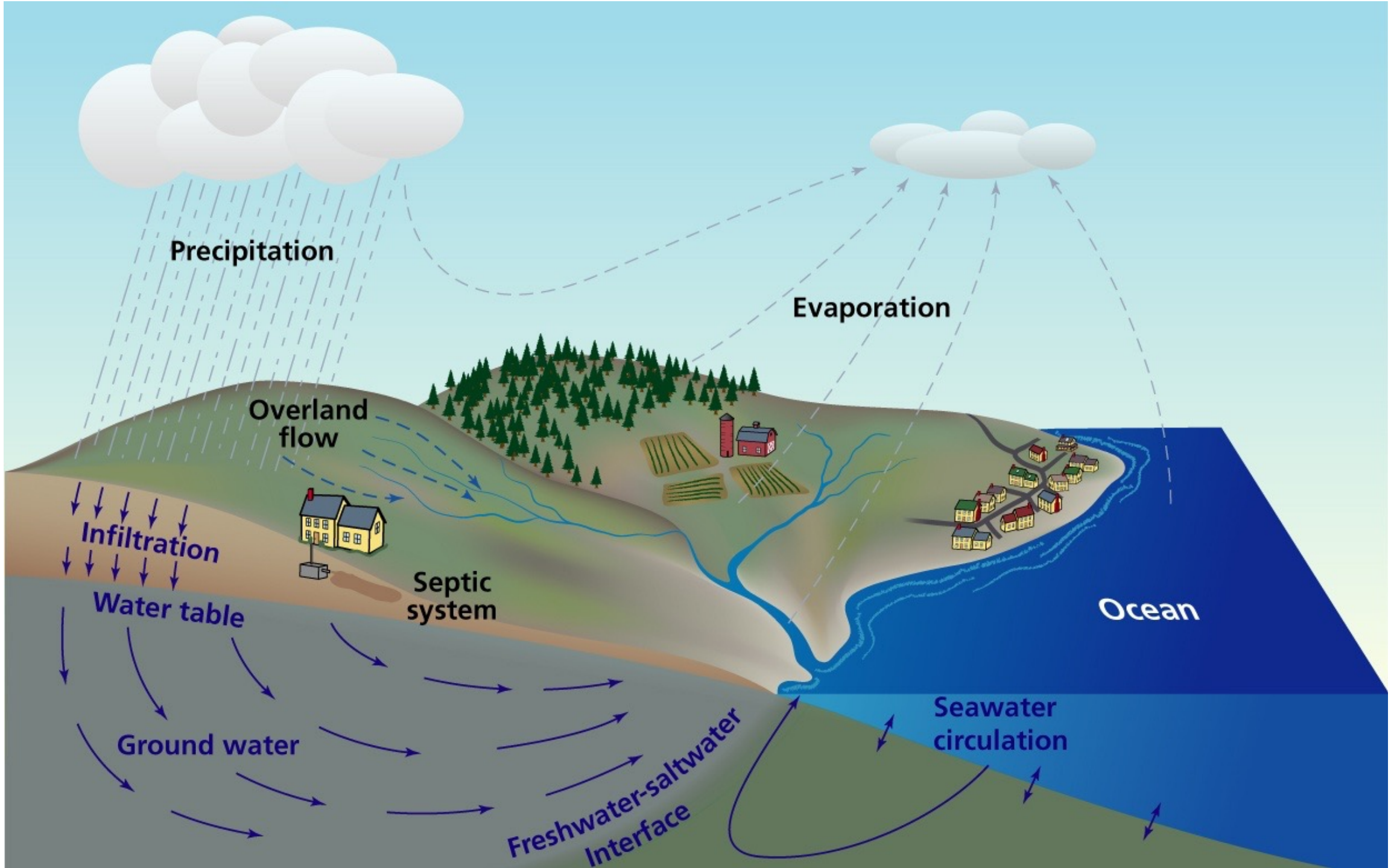


Rising water tables leading to *groundwater flooding*



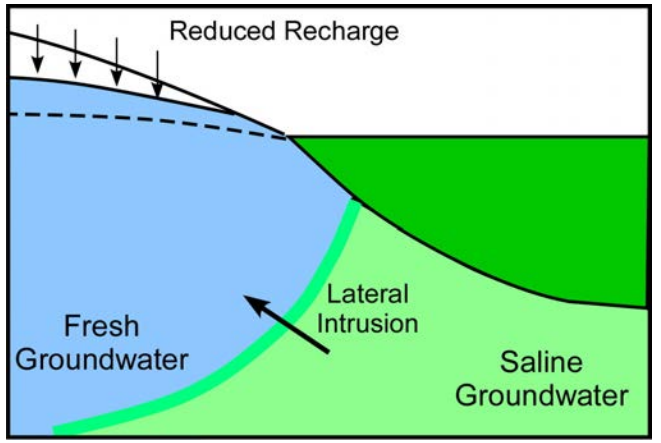
Water Resources Research, Volume: 53, Issue: 8, Pages: 6487-6509, 2017, DOI: (10.1002/2016WR020339)

R. Housego

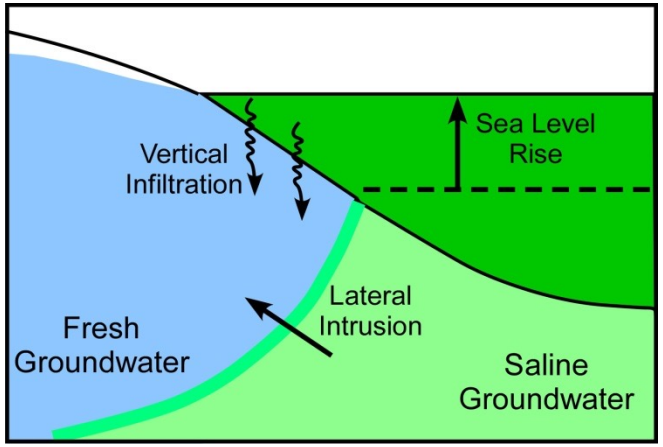

Precipitation
Evaporation
Overland flow
Infiltration
Water table
Septic system
Ocean
Ground water
Seawater circulation
Freshwater-saltwater Interface

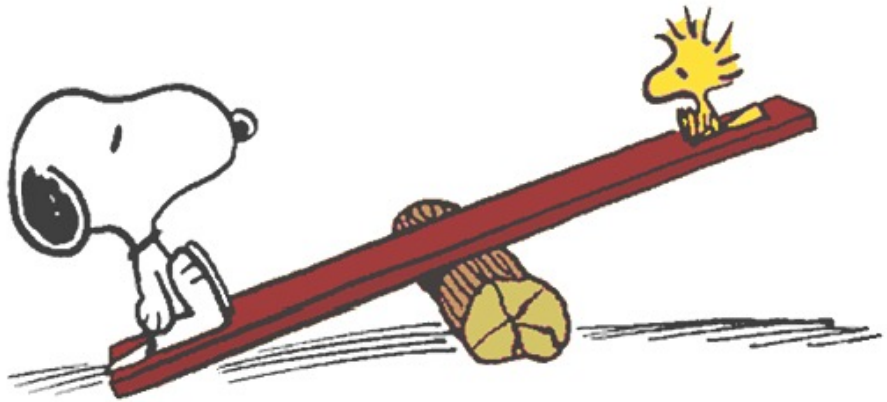
Mechanisms of Groundwater Salinization:

Recharge reduction and pumping – *Lateral Intrusion (SLOW)*



Sea-level rise – *Lateral and Vertical Intrusion (SLOW*





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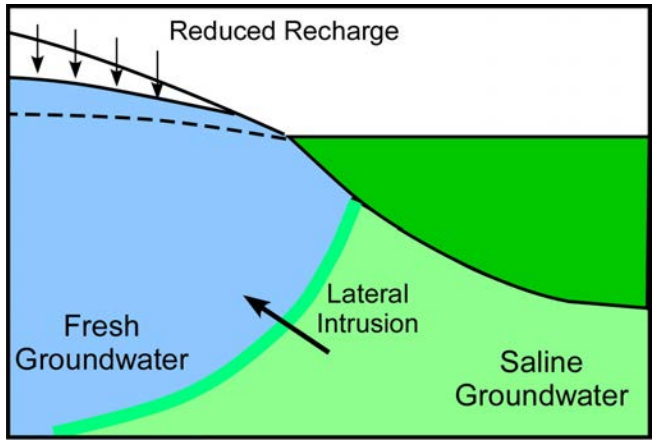

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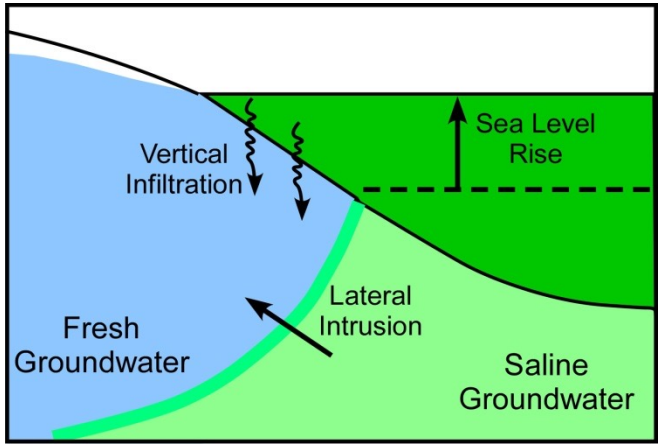
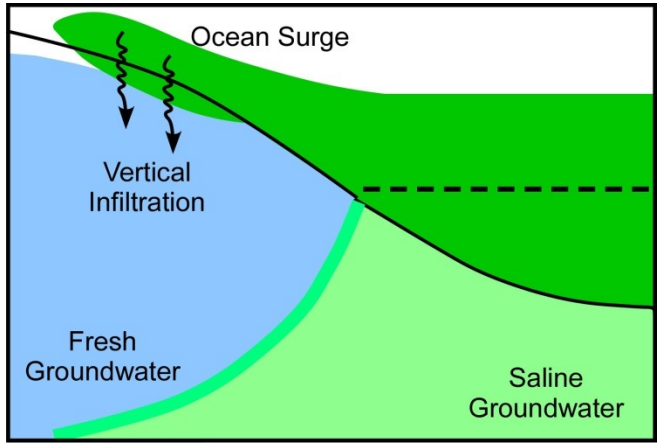


Ocean surge and flooding– *Vertical Intrusion (FAST)*



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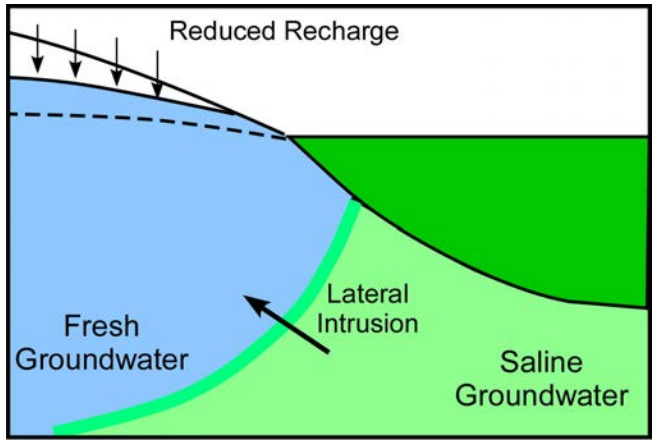
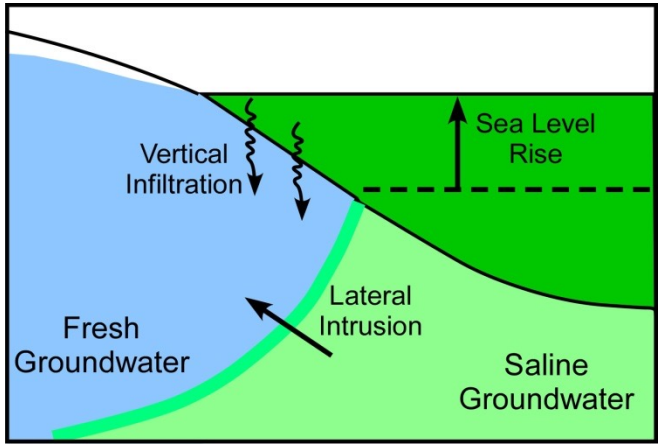


Only ~1% seawater ruins a freshwater resource!

And damages freshwater ecosystems (crops, trees…)

Sea-level rise –
Lateral and Vertical Intrusion
(SLOW



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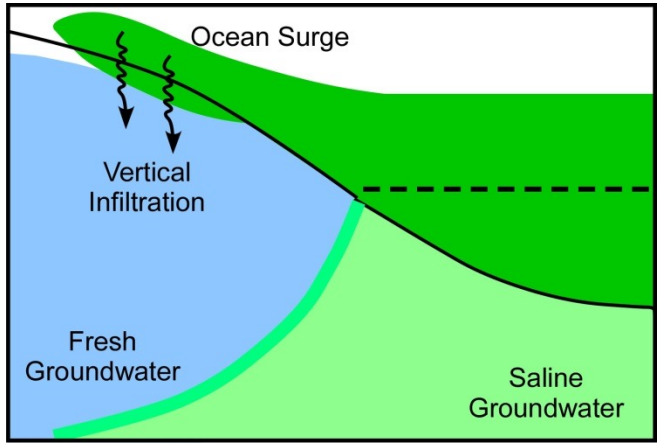
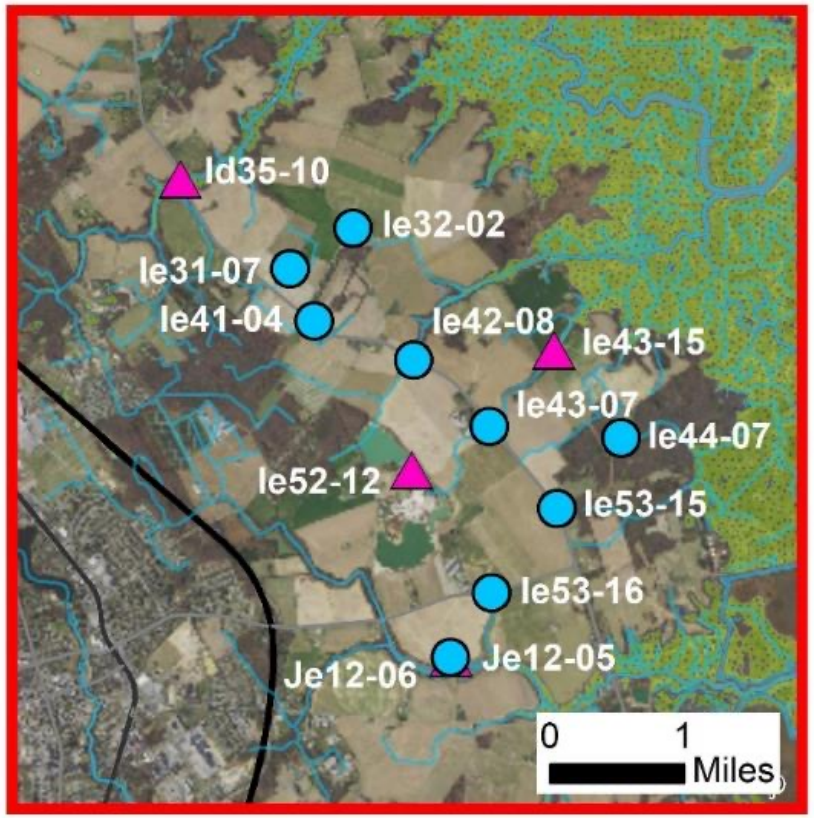


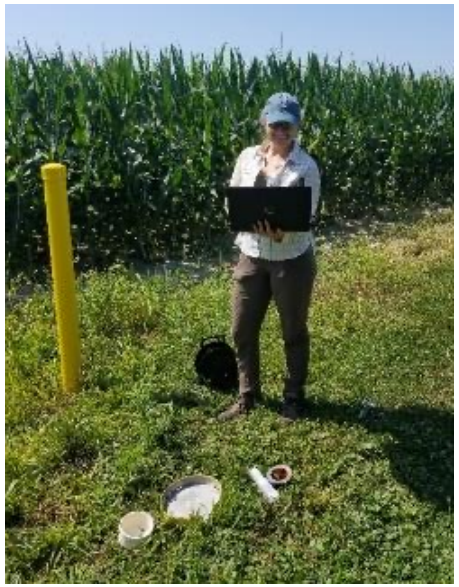
Example: Salinization in Greater Dover, Delaware

Slow and fast processes leading to groundwater salinization

40 Active Monitoring Locations

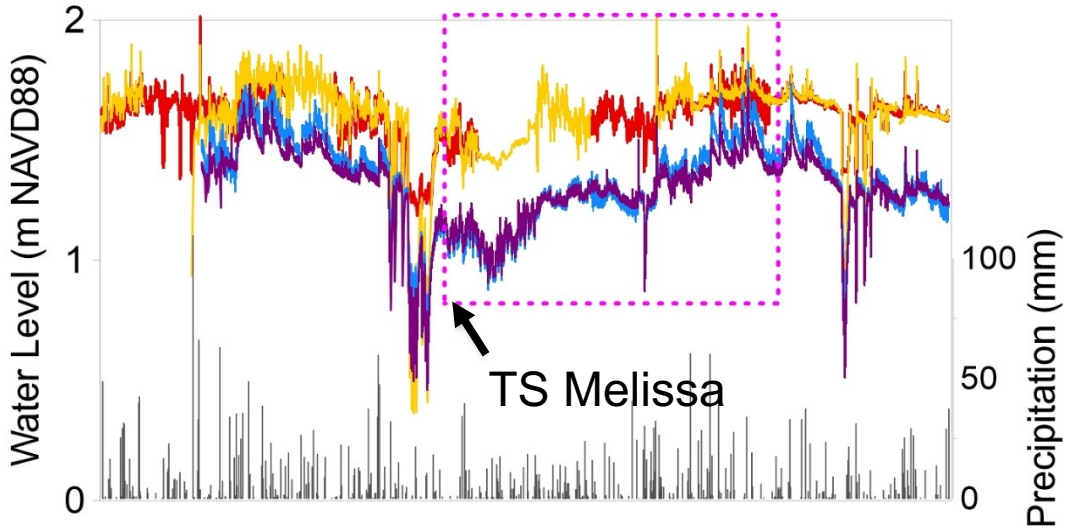
- Deep and shallow wells
- Streams
- Marshes
- Irrigation ponds

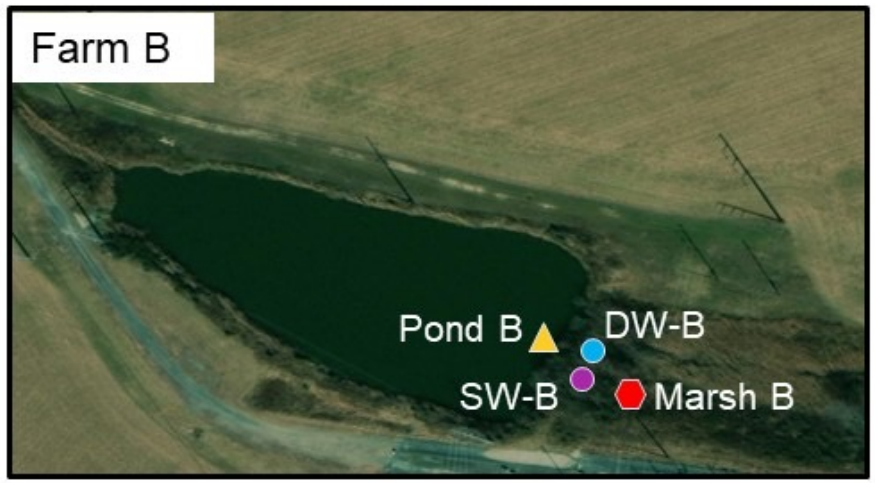


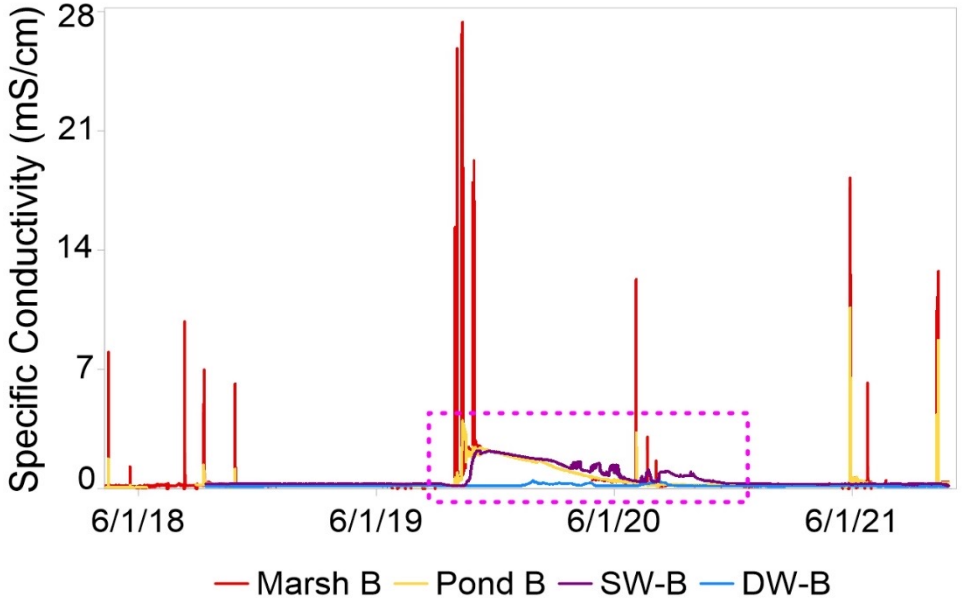


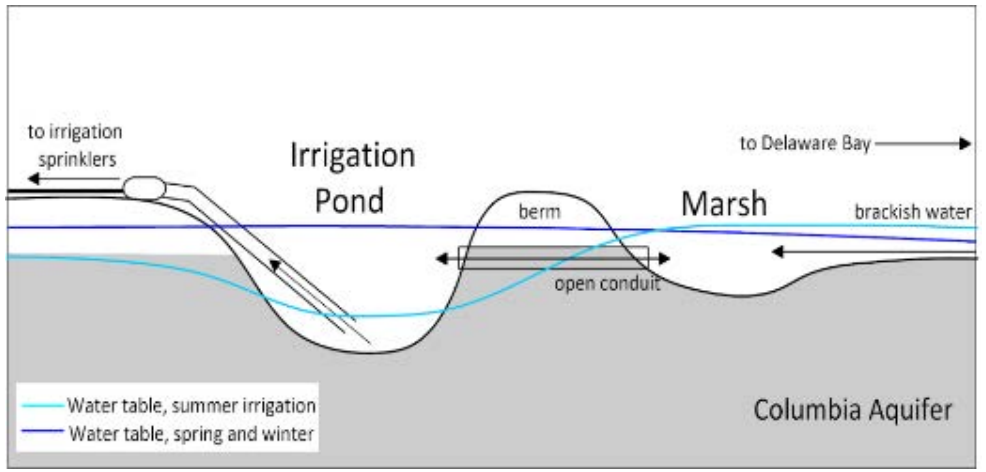
Salinization in Greater Dover, Delaware

Example Data – Tropical Storm Melissa salinizes surface water, groundwater

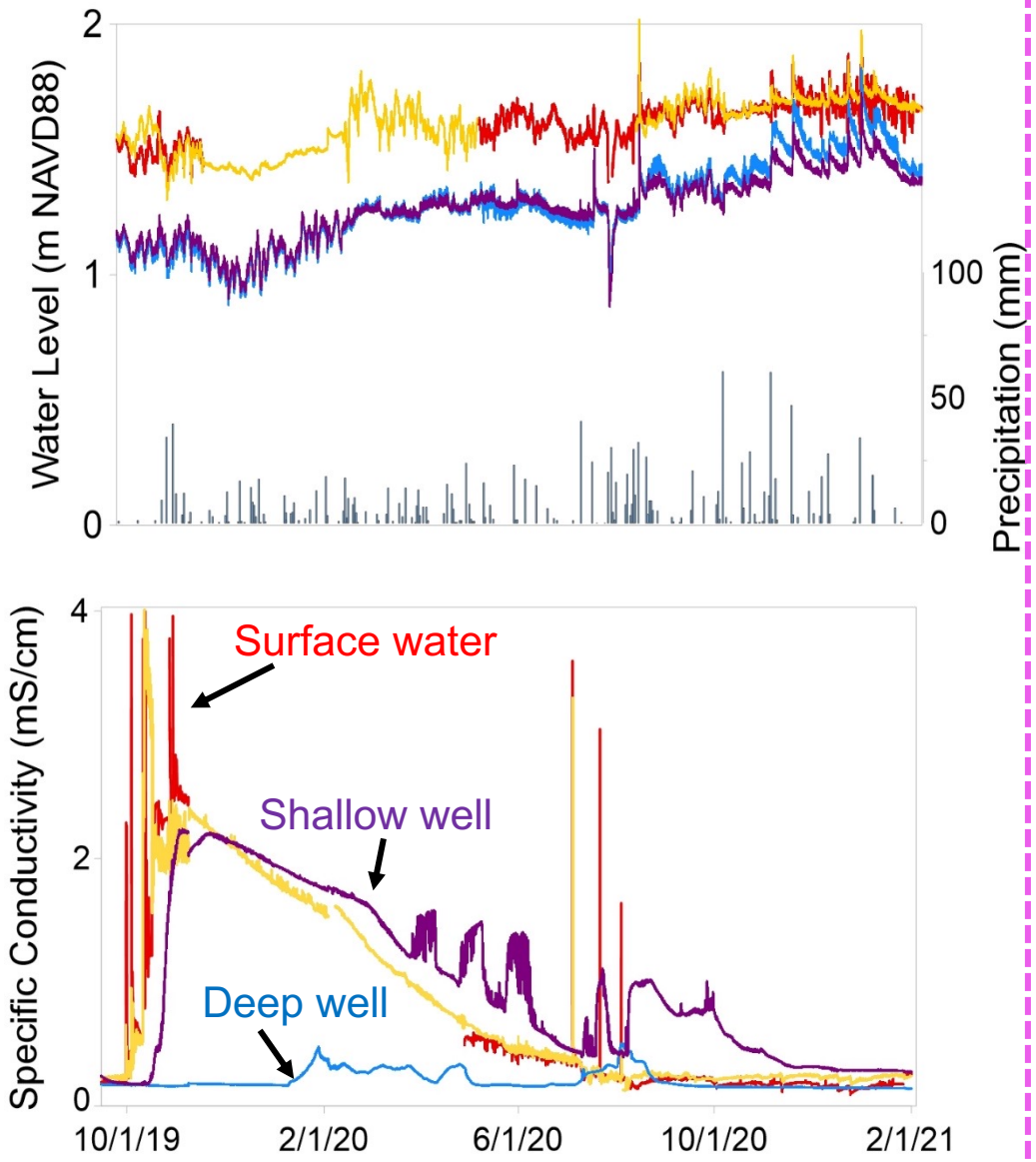








Farm B marsh, pond, shallow well, deep well



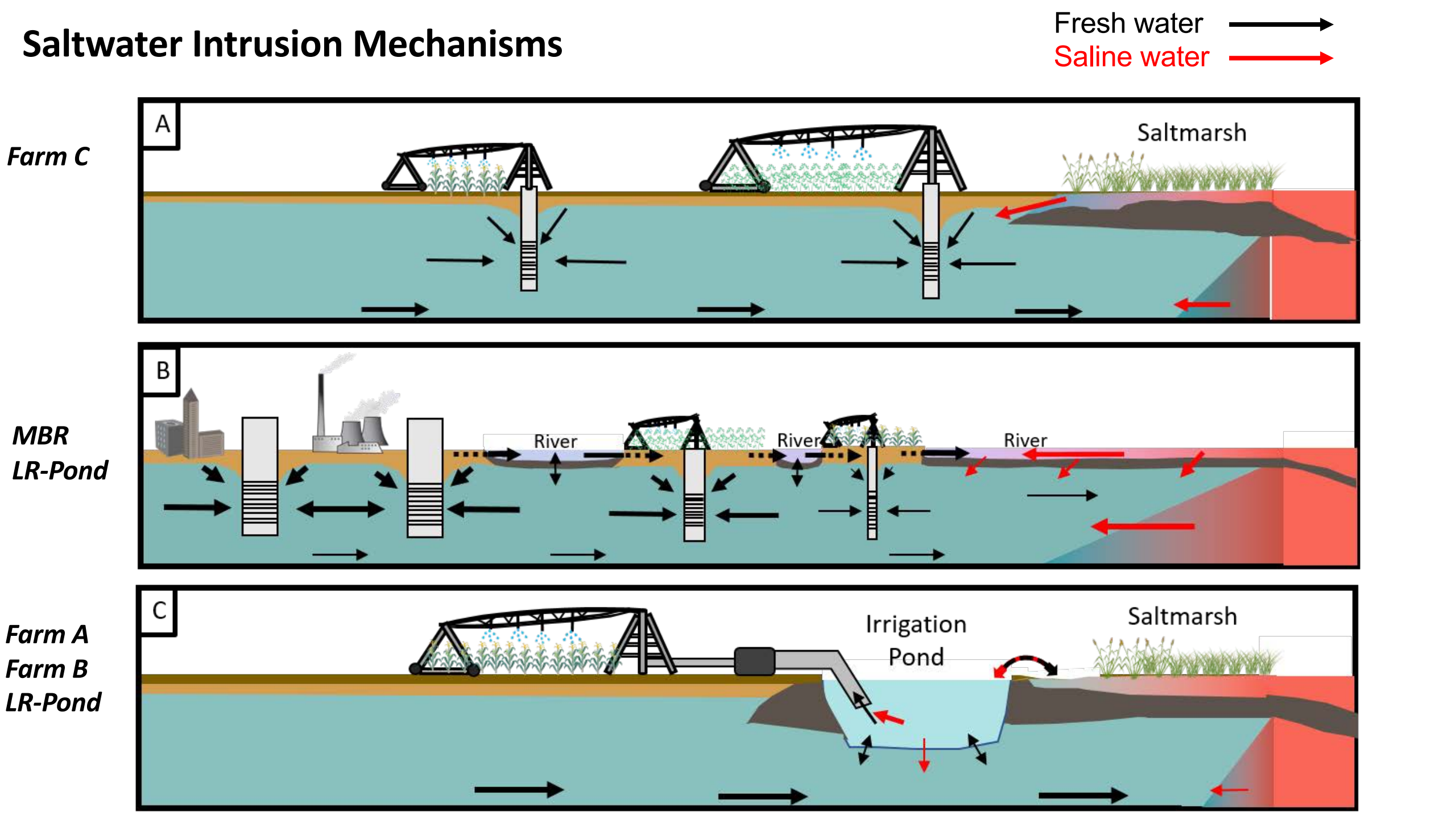
→ ***Tropical Storm Melissa caused a spike in salinity in the marsh and pond***

→ ***Salinity in the shallow well spiked after 2 weeks***

→ ***Salinity in the deep well rose after a few months and did not recover for almost a year***

Fast salinization → Slow recovery

Saltwater Intrusion Mechanisms



Farm C

MBR
LR-Pond

Farm A
Farm B
LR-Pond

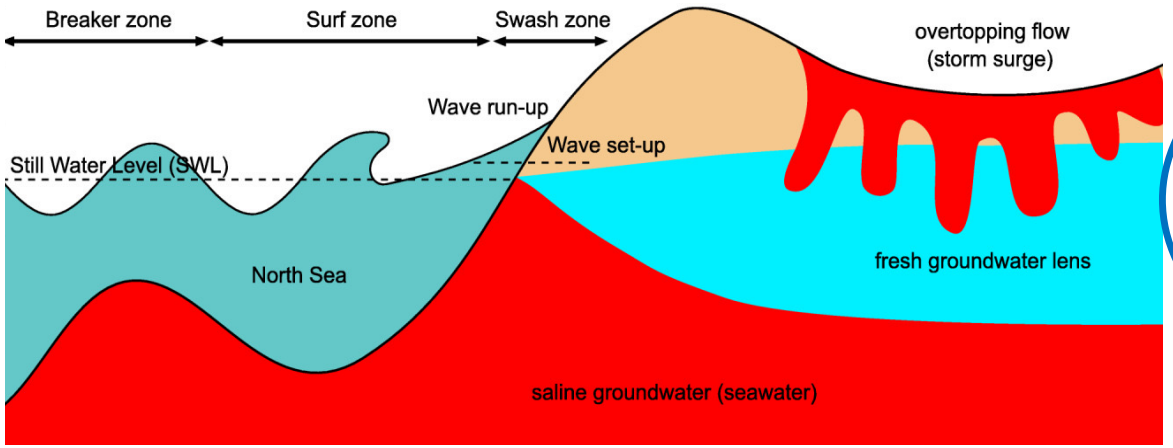
Groundwater and Climate Change

Lake Cachuma near Santa Barbara, California, in 2015
SCIENCE/SCOTT LONDON/ALAMY LIVE NEWS

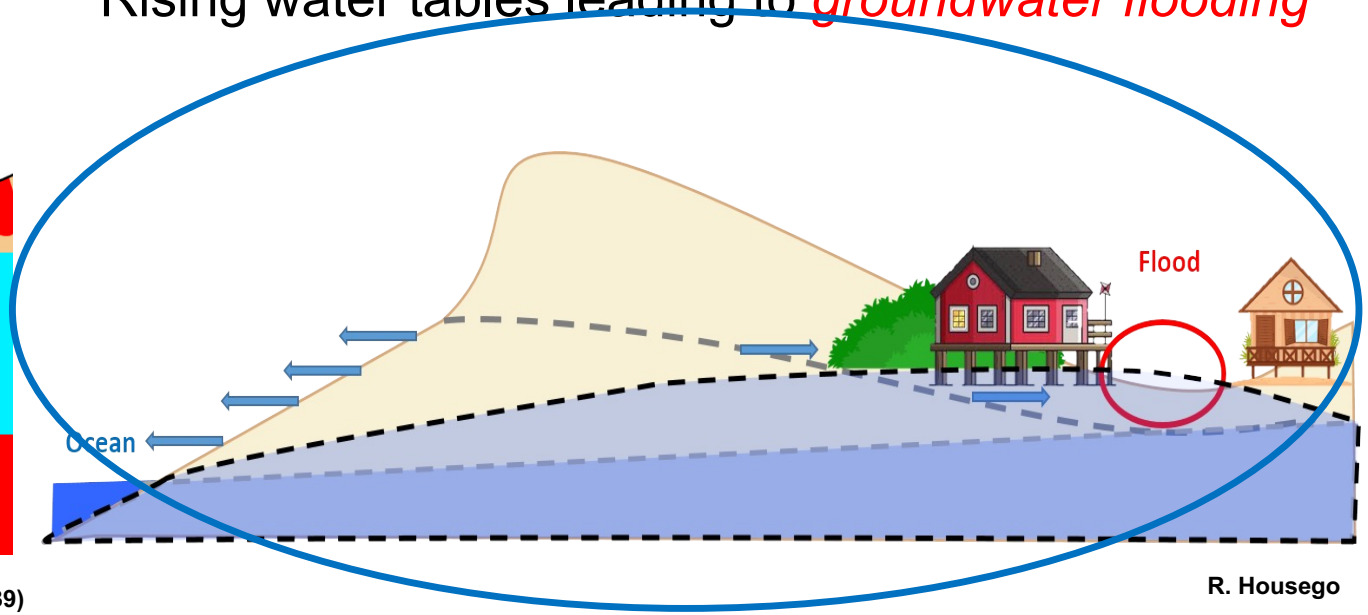
→ Groundwater mitigates water resource variability in the face of climate change

→ Two main effects of climate change on coastal groundwater:

Salinization



Rising water tables leading to *groundwater flooding*



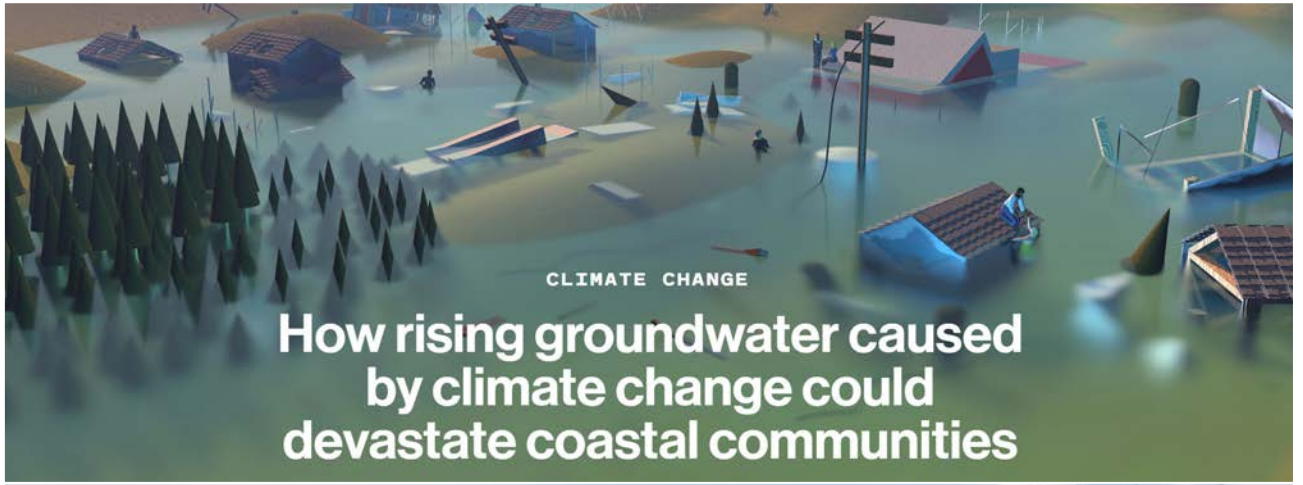
R. Housego

Water Resources Research, Volume: 53, Issue: 8, Pages: 6487-6509, 2017, DOI: (10.1002/2016WR020339)

Groundwater flooding: A hazard from below

MIT Technology Review

- Incidents of flooding are increasing across the U.S. East Coast (NOAA 2020).
- Coastal groundwater can contribute to flooding



Credit: Rachel Housego

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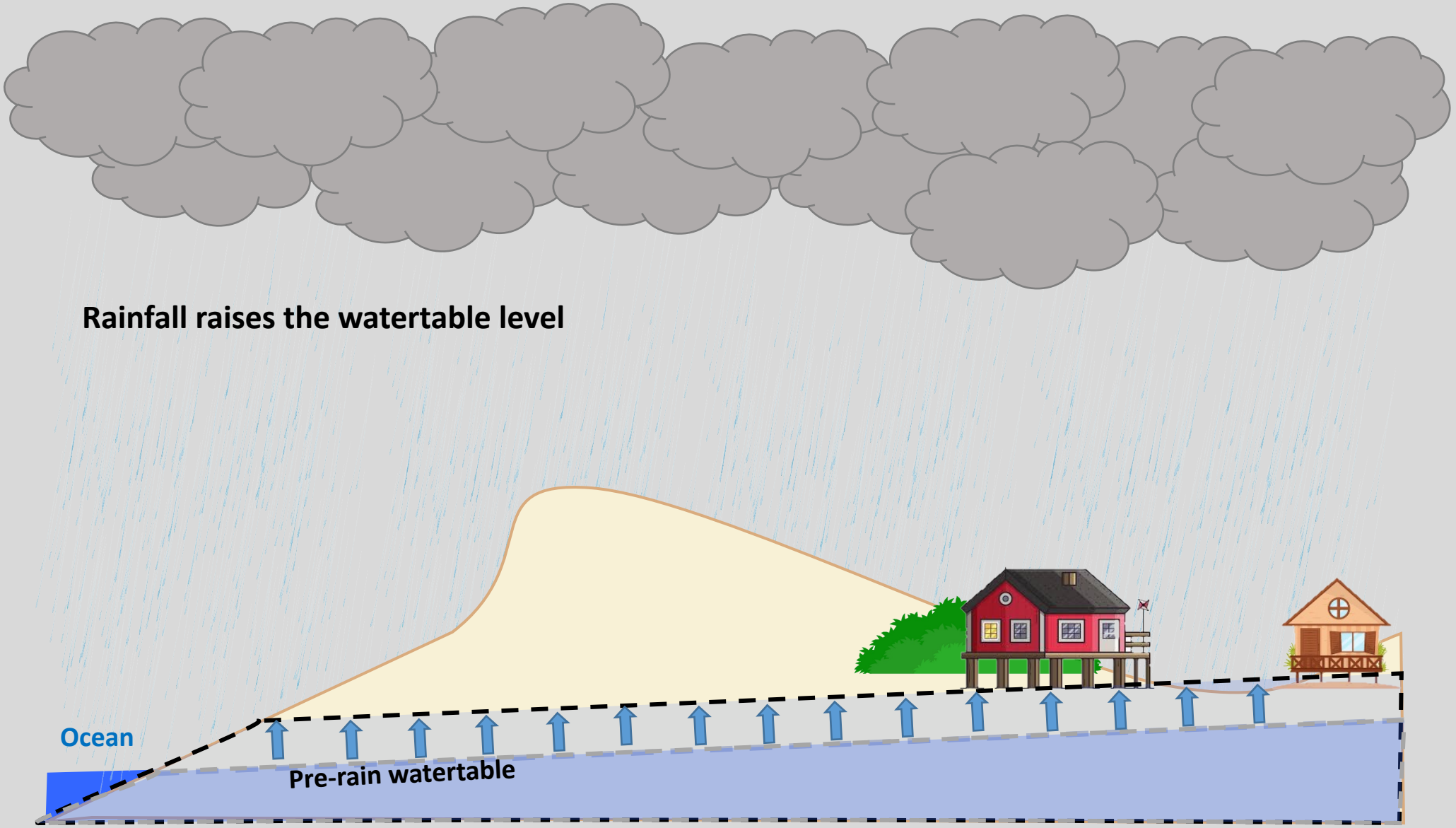
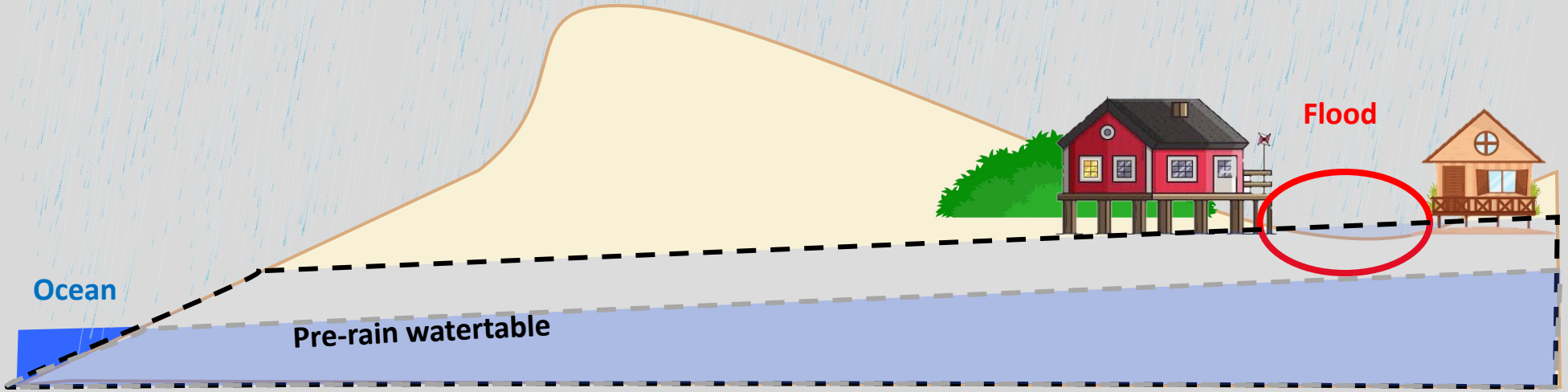
From the land side:



Credit: Rachel Housego

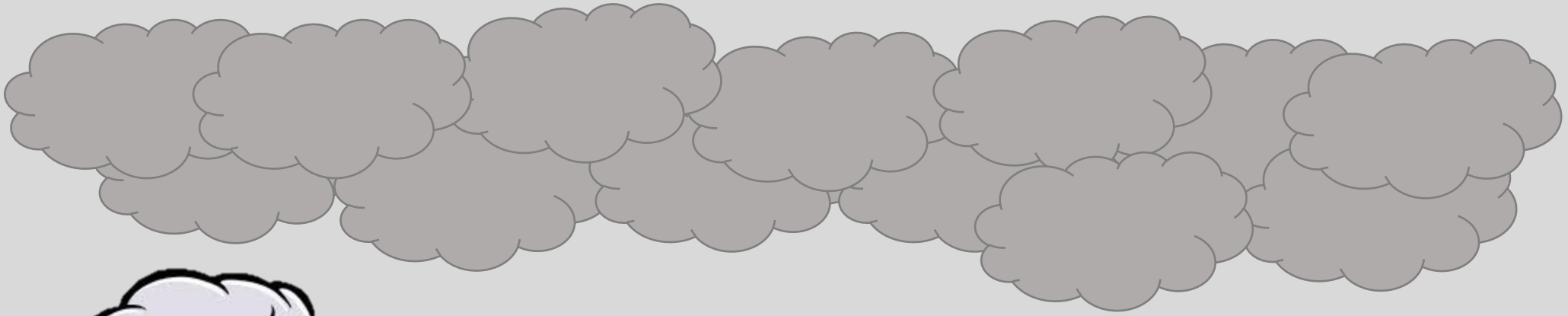
From the land side:

Rainfall raises the watertable level
Flooding occurs when the water table exceeds the land surface.

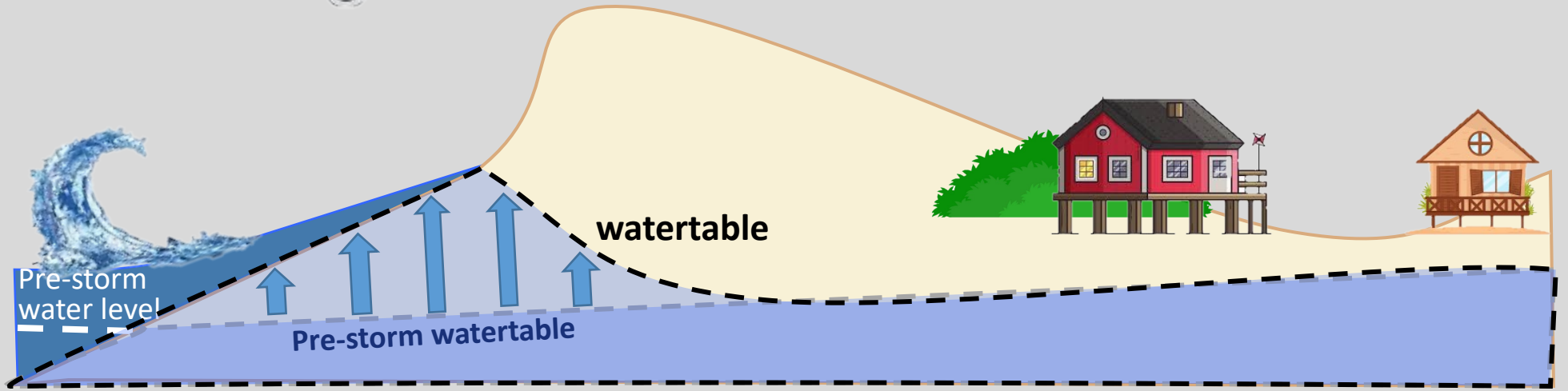


Credit: Rachel Housego

From the sea side:



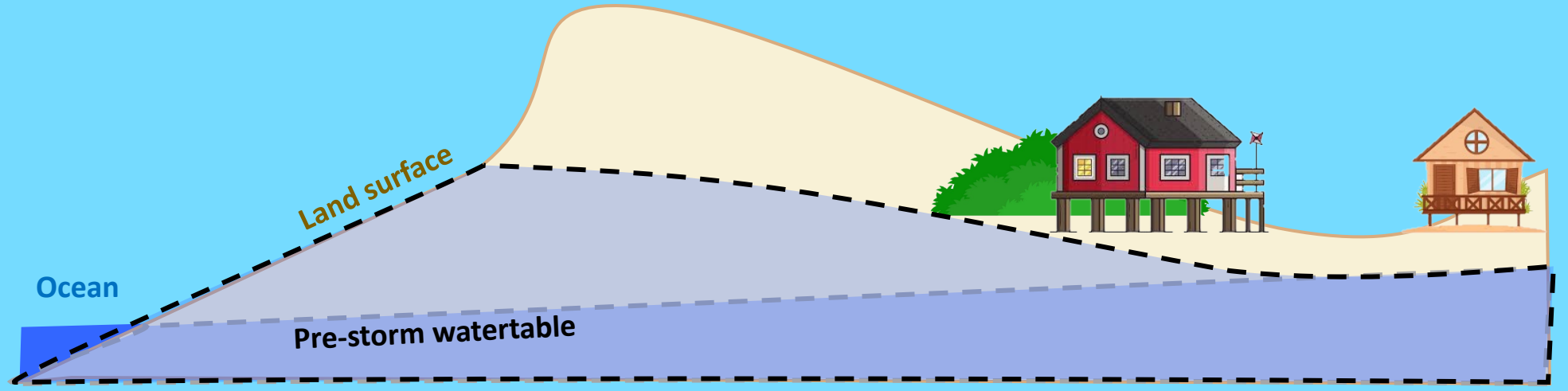
Wind, waves, and low pressures increase the water level at the coast, and seawater infiltrates along the beach and dune.



Credit: Rachel Housego

From the sea side:

After the storm the ocean water level recedes but the water table remains elevated

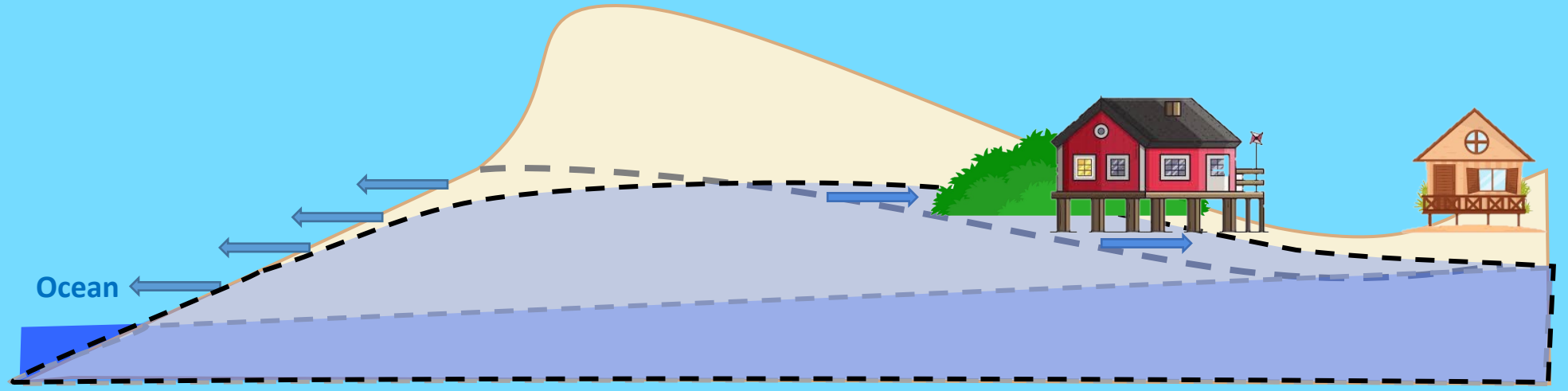


Credit: Rachel Housego

From the sea side:

Groundwater discharges through the beach face, lowering the groundwater level near the shore

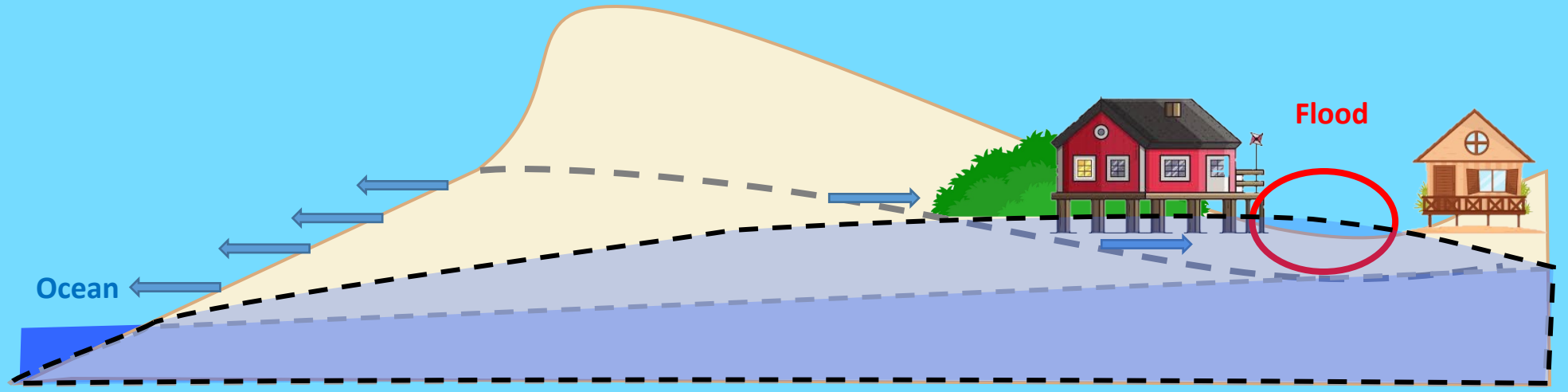
Water also flows inland through the ground, and “bulge” moves inland.



Credit: Rachel Housego

From the sea side:

Flooding occurs when the land surface is exceeded by the groundwater level.



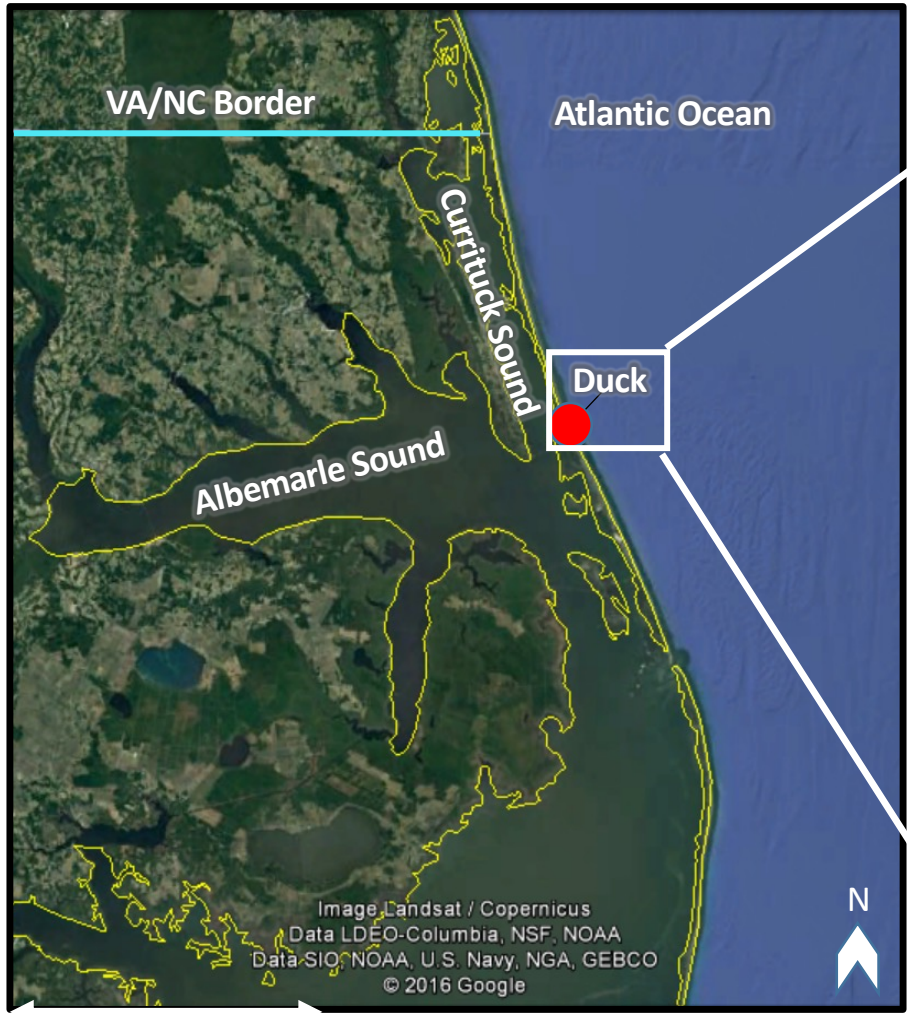
Credit: Rachel Housego

Case Study: Outer Banks, NC

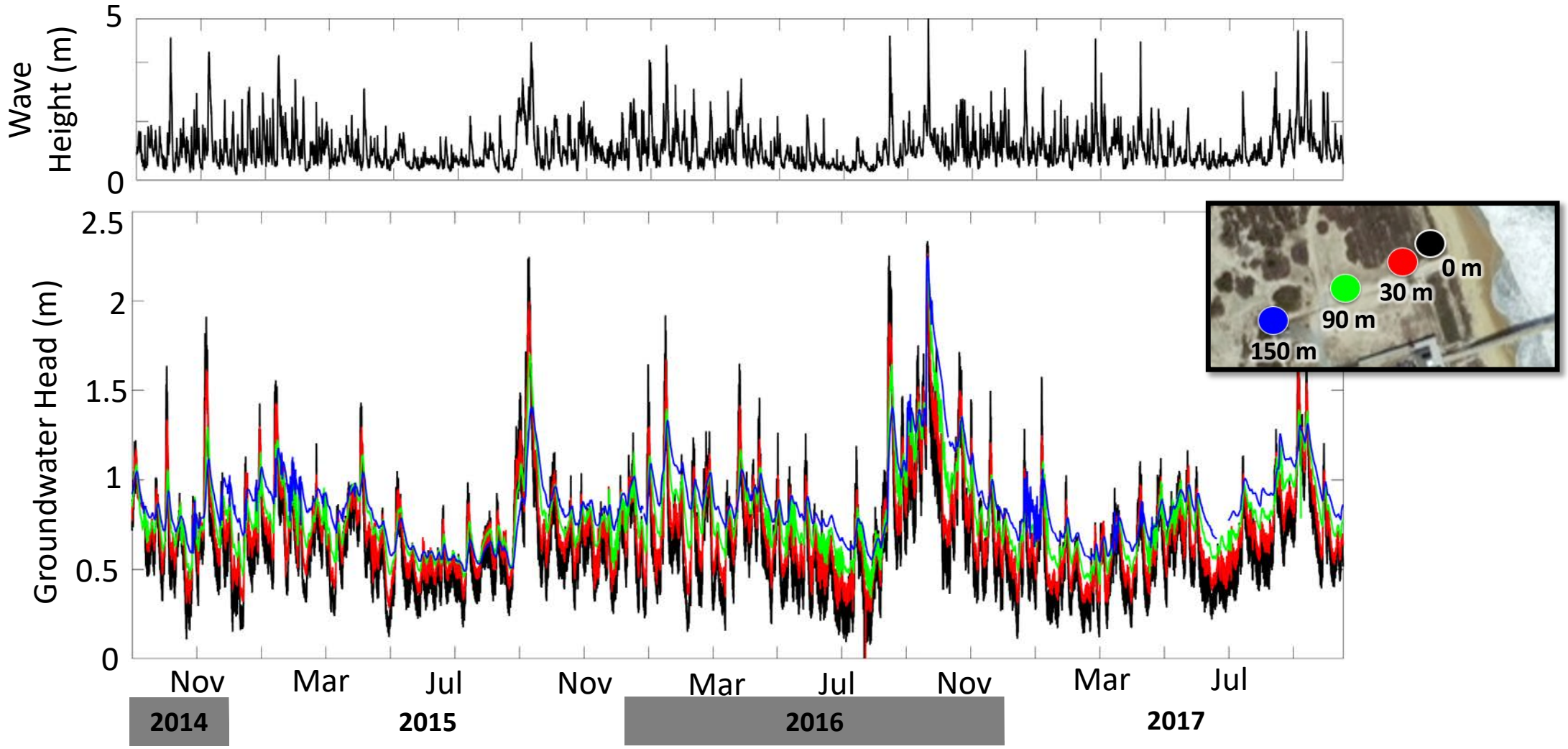
- Coastal water table response to precipitation and changes in the ocean water level at the shoreline (driven by waves, tides, and surge)
- Ocean processes without overtopping causes groundwater flooding
- Modeling and citizen science improve prediction of flood hazards

Work of: Rachel Housego, Britt Raubenheimer, Steve Elgar, WHOI

Case Study: Outer Banks, NC



Surface water and groundwater levels



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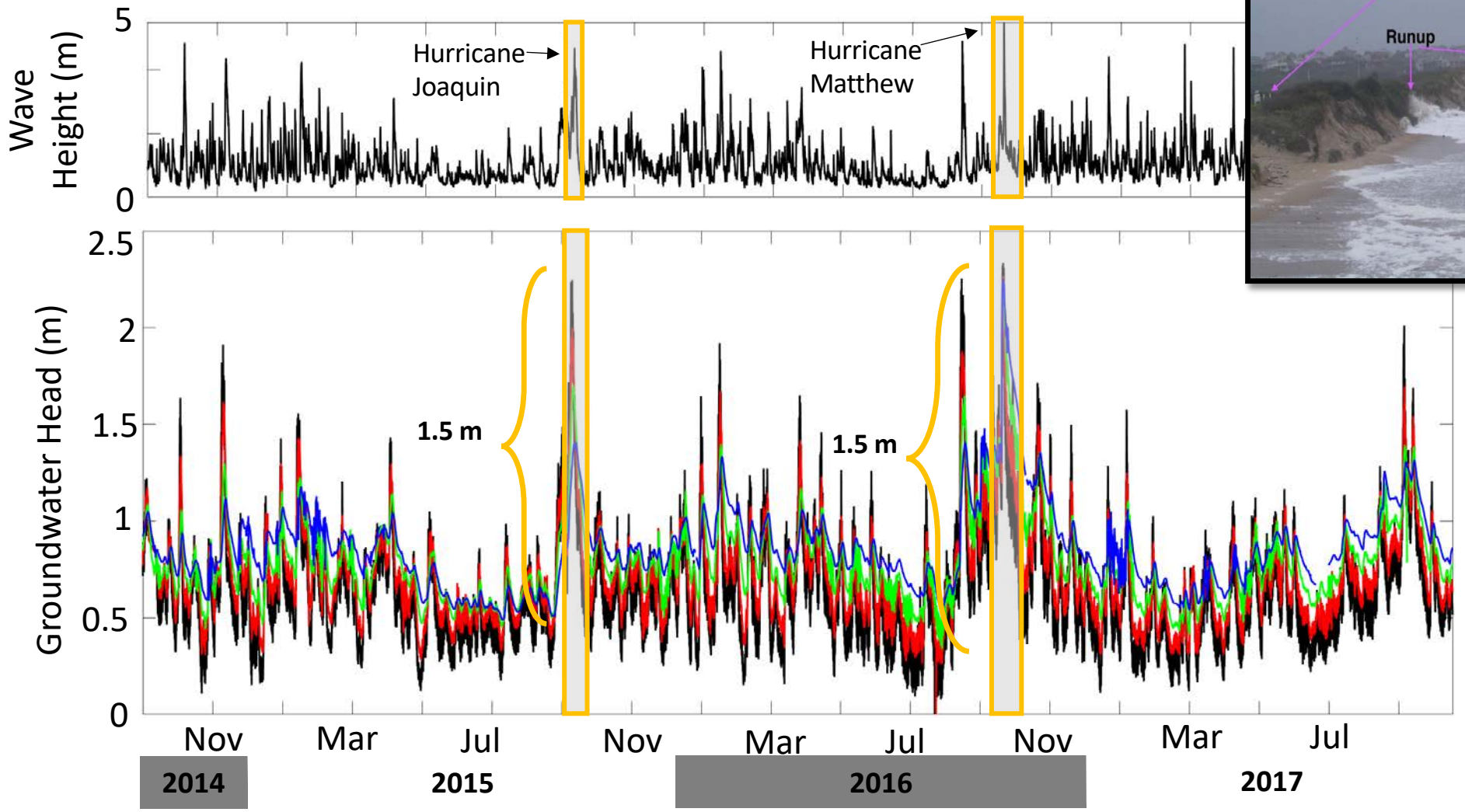
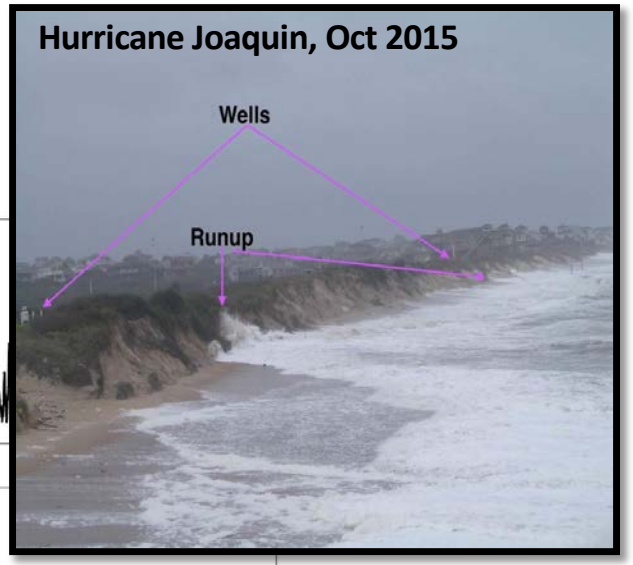
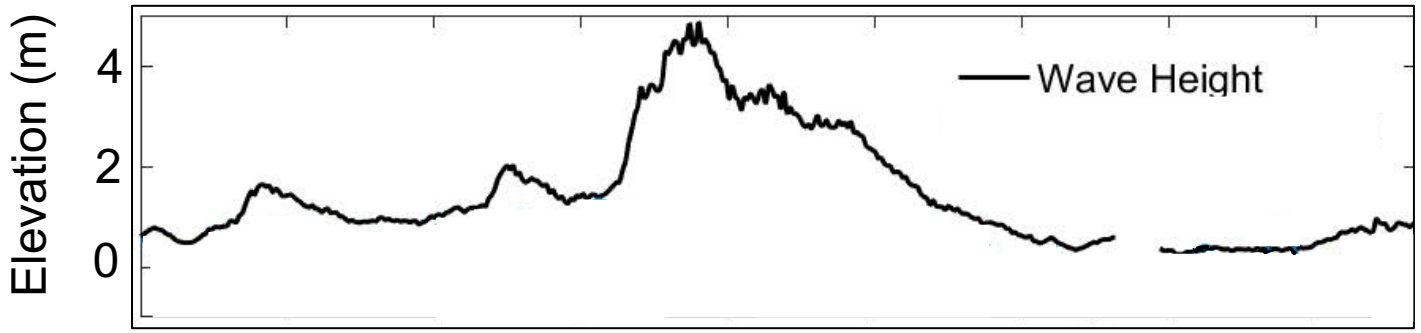
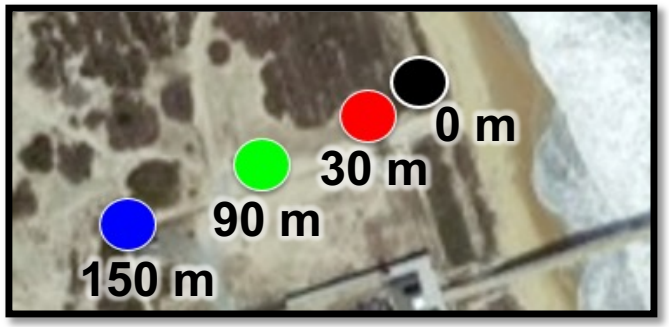
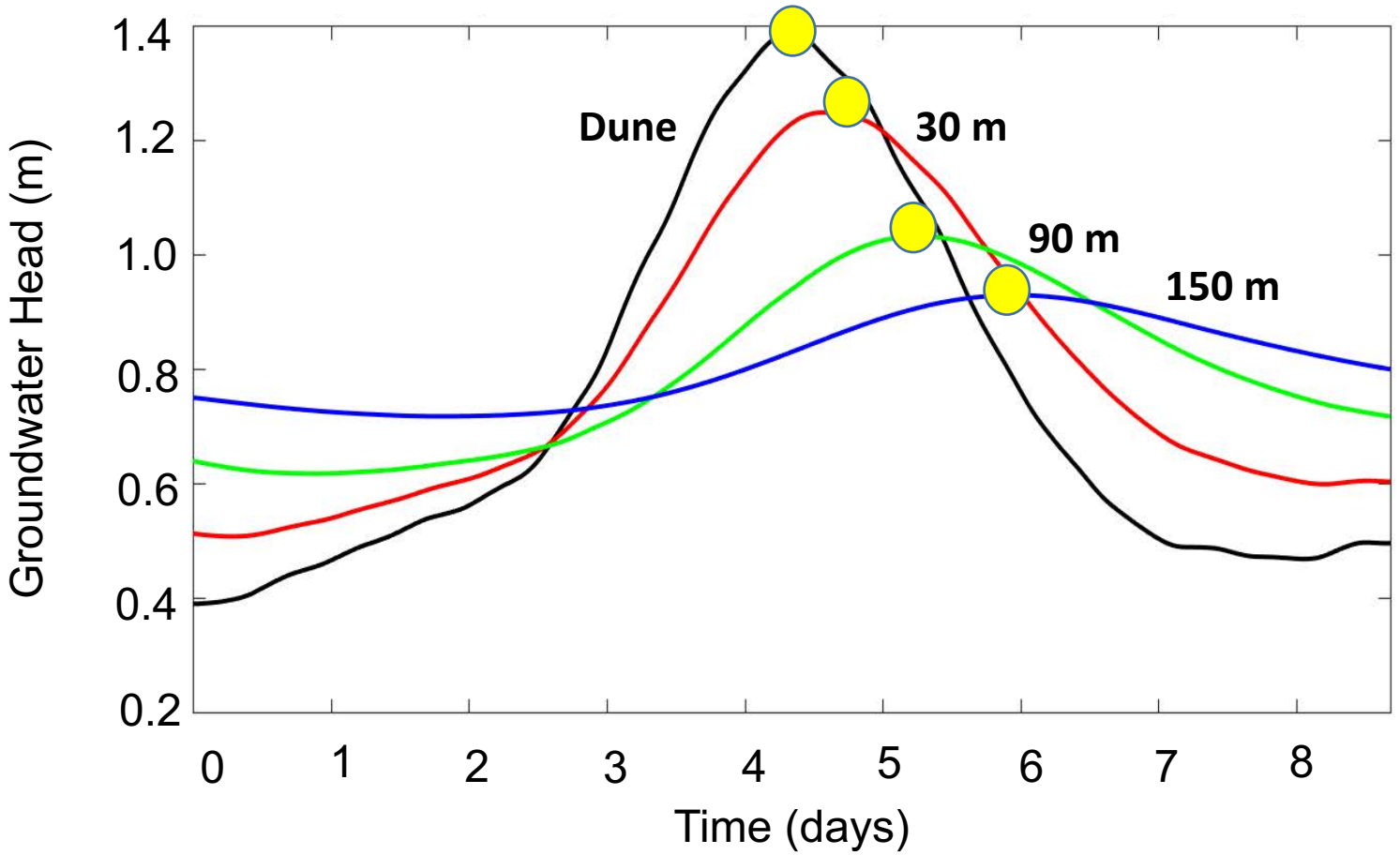




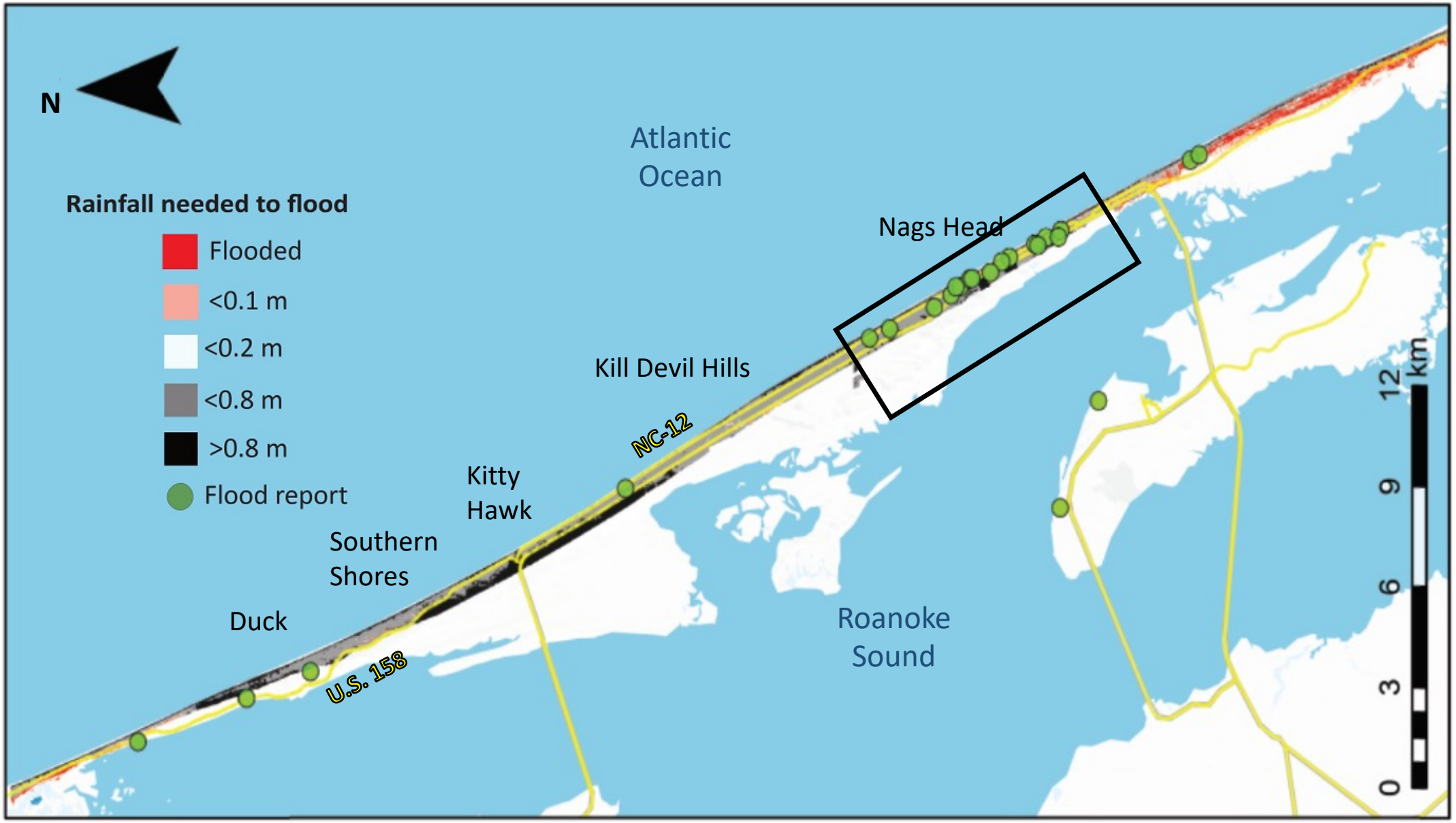






- Amplitude decreases moving inland
- Time lag between max. water levels

Flooding predicted for a 2.25 m increase in the shoreline water level (no overtopping)



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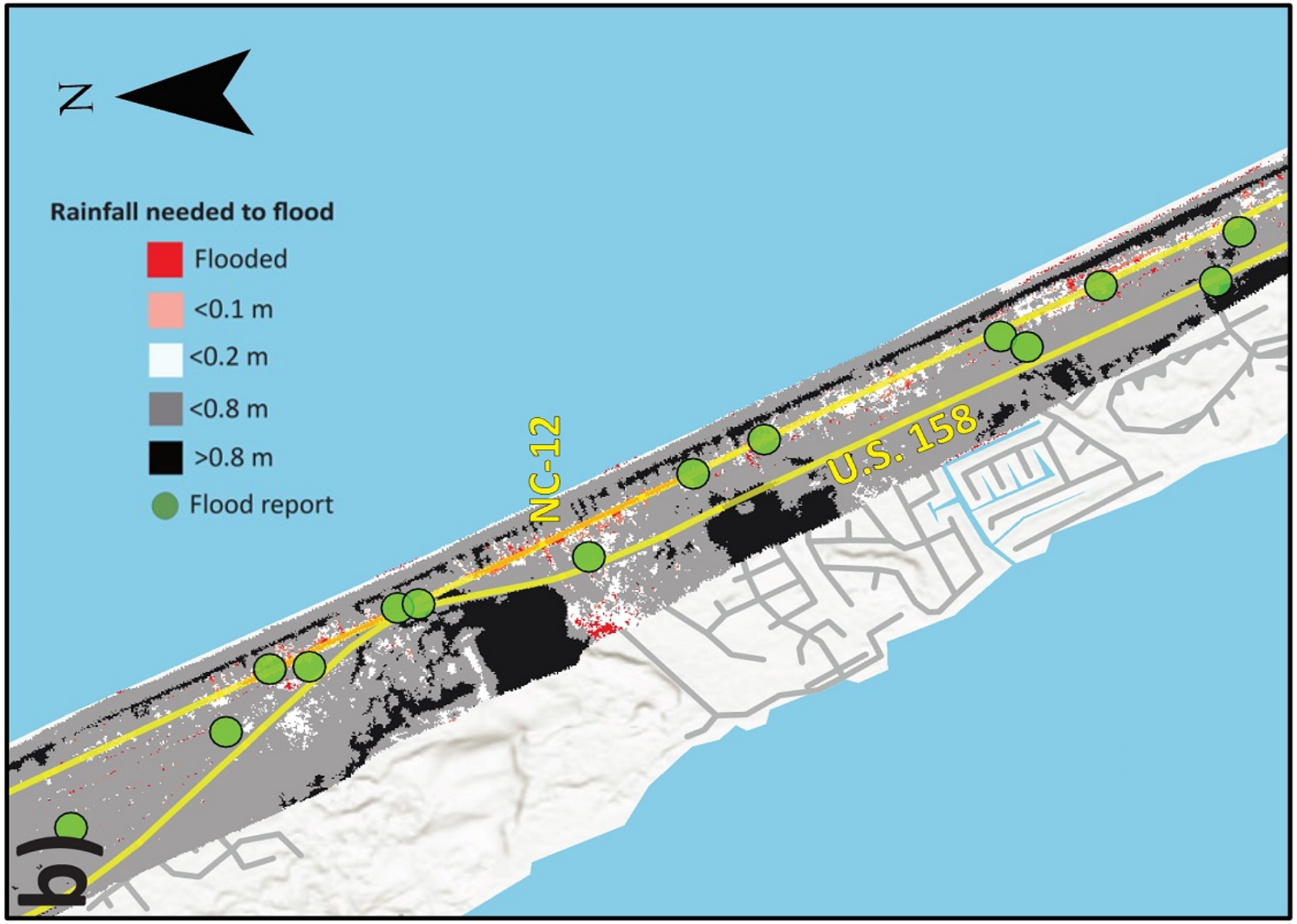


The combination of these two groundwater effects is causing ecosystem change at the land-sea margin

Rising groundwater levels drown the root zone

Flooding with saltwater causes loss of forest, agriculture; increase in saltmarsh

Forest ecosystem transition

THE NEWS JOURNAL
PART OF THE USA TODAY NETWORK

CLIMATE CHANGE ON THE DELAWARE BAY

Rising seas leave lifeless landscape in wake

Ghost forests tell the story

Maddy Lauria Delaware News Journal | USA TODAY NETWORK

As Mark Wells harvested rows of corn from his farm near Fowler Beach, he praised the fertility of eastern Sussex County's soils that sent thousands of golden kernels filtering through his combine.

But it wasn't this healthy crop the farmer wanted to point out.

To the north and east of his 126-acre farm at the corner of Fowler Beach Road, dozens of gray stalks of leafless and lifeless trees litter the landscape's edge. The same saltwater that killed those trees and created one of the state's most striking ghost forests has left chunks of Wells' fields barren.

As the combine hit those decaying areas, he watched his yield drop by more than half. Wells pointed to the ghost forests skirting his farm and tried remembering where a beloved, huge persimmon tree once stood. He couldn't find it.

Ducks flew out of a pond against a backdrop of dead trees and invasive common reed, or phragmites, that no longer feed the wild deer, raccoons and other critters that once roamed in the now-mummified forest.

Some spots where Wells planted seeds earlier in the season are filled with fruitless, stunted stalks or nothing but grasses, evidence of a crop severely impacted by saltwater intrusion.

"It's practically wasteland," he said. "It goes hundreds and hundreds of yards into the field."

See GHOST FORESTS, Page 4A

The ghost forest next to Fowler Beach Road in Sussex County. JERRY HABRAKEN, DELAWARE NEWS JOURNAL

The New York Times

As Sea Levels Rise, So Do Ghost Forests

Moises Velasquez-Manoff, a New York Times contributor, and Gabriella Demczuk, a photographer, traveled to ghost forests in the eastern United States. Ms. Demczuk used seawater collected at each site to create salt prints, a 19th-century technique.

Up and down the mid-Atlantic coast, sea levels are rising rapidly, creating stands of dead trees — often bleached, sometimes blackened — known as ghost forests.

The water is gaining as much as 5 millimeters per year in some places, well above the global average of 3.1 millimeters, driven by profound environmental shifts that include climate change.

NBC News

Agricultural transition

≡ BAY JOURNAL

Saltwater intrusion laying waste to Delmarva farms as sea level rises

"This is how it starts." Bob Fitzgerald looks over what started as a "little wet spot" that
2-acre void.

Dave Harp

Turning Salt-Damaged Fields into Marshes Could Save Maryland Farmland—and The Chesapeake Ba

As sea levels rise, saltwater is entering farms near the bay, damaging crops
releasing legacy nutrients into already-polluted waterways.

CIVIL EATS

BY VIRGINIA GEWIN
ENVIRONMENT, FARMING, Water
Posted on: February 20, 2019 | 1 Comment

The Washington Post

Democracy Dies in Darkness

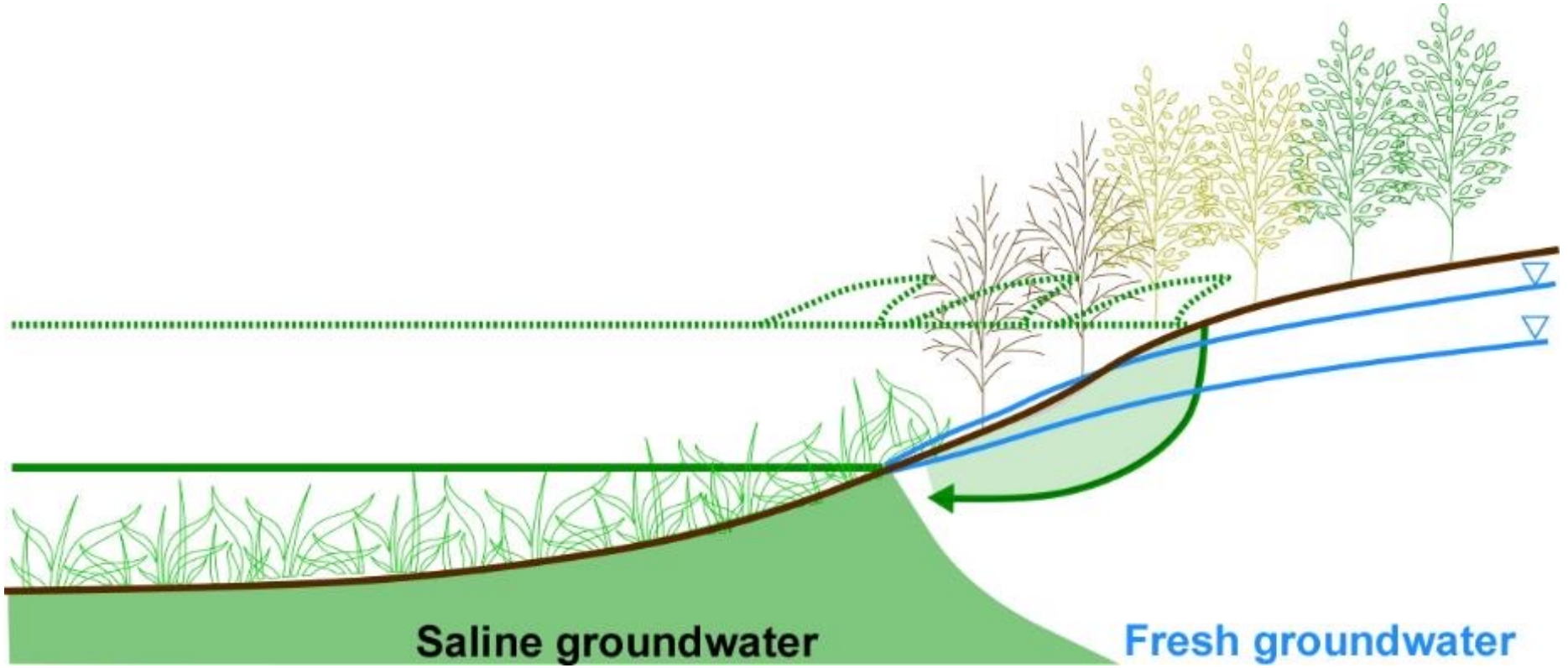
Ruined crops, salty soil: How rising seas are poisoning North Carolina's farmland

East Carolina University graduate students Trevor Burns, left, and Tyler Palochak check gro
near Engelhard, N.C., in January. (Eamon Queeney/for The Washington Post)

By Sarah Kaplan
March 1

The Southern Maryland Chronicle

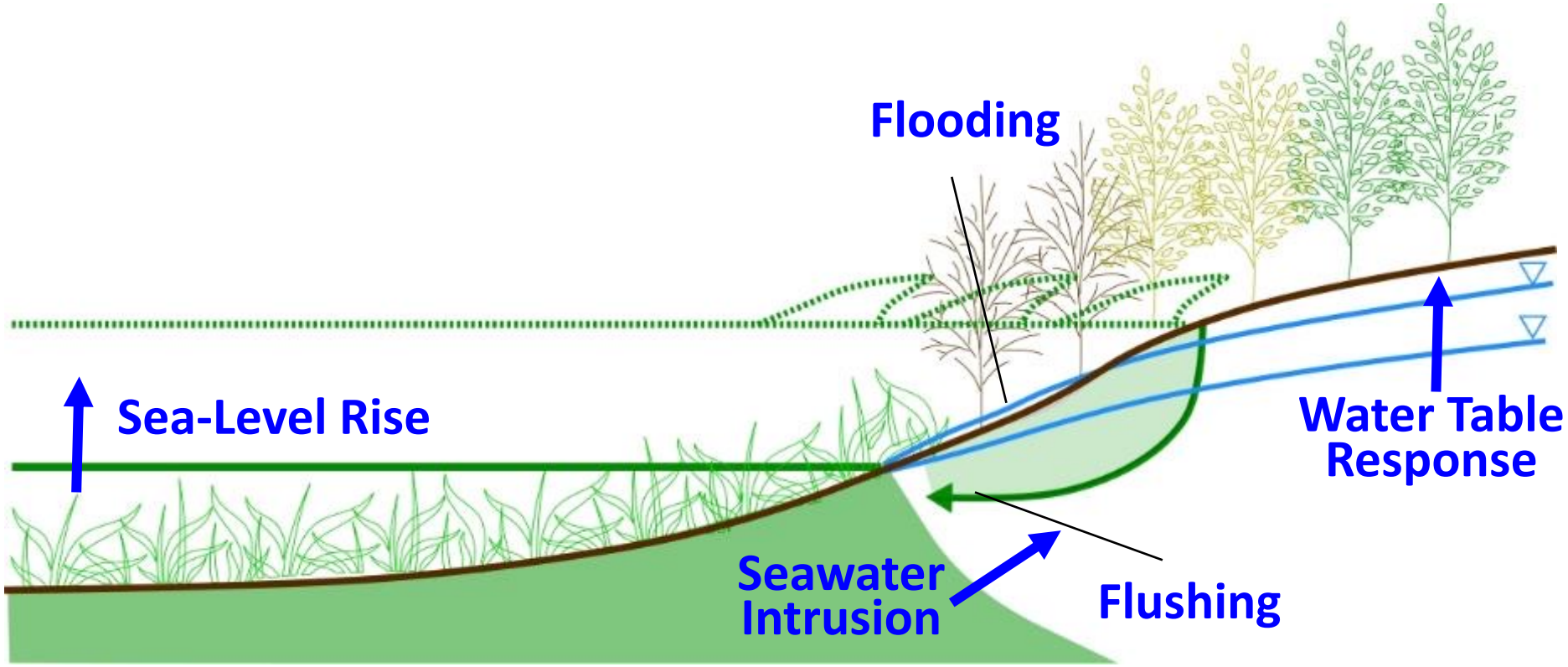
What are the key drivers of these changes?



What are the key drivers of these changes?

Fast and Slow Processes in the Marsh-Upland Transition Zone

Slow Hydrologic Processes



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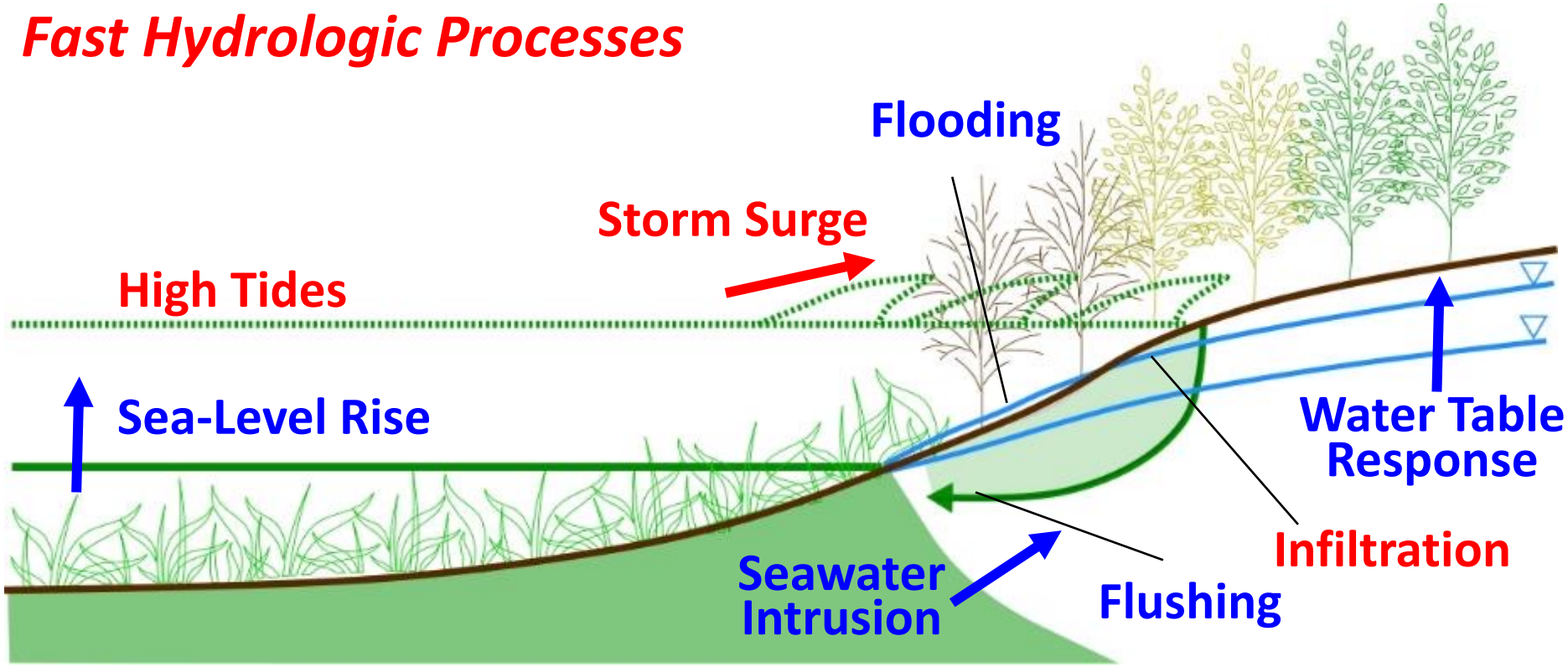
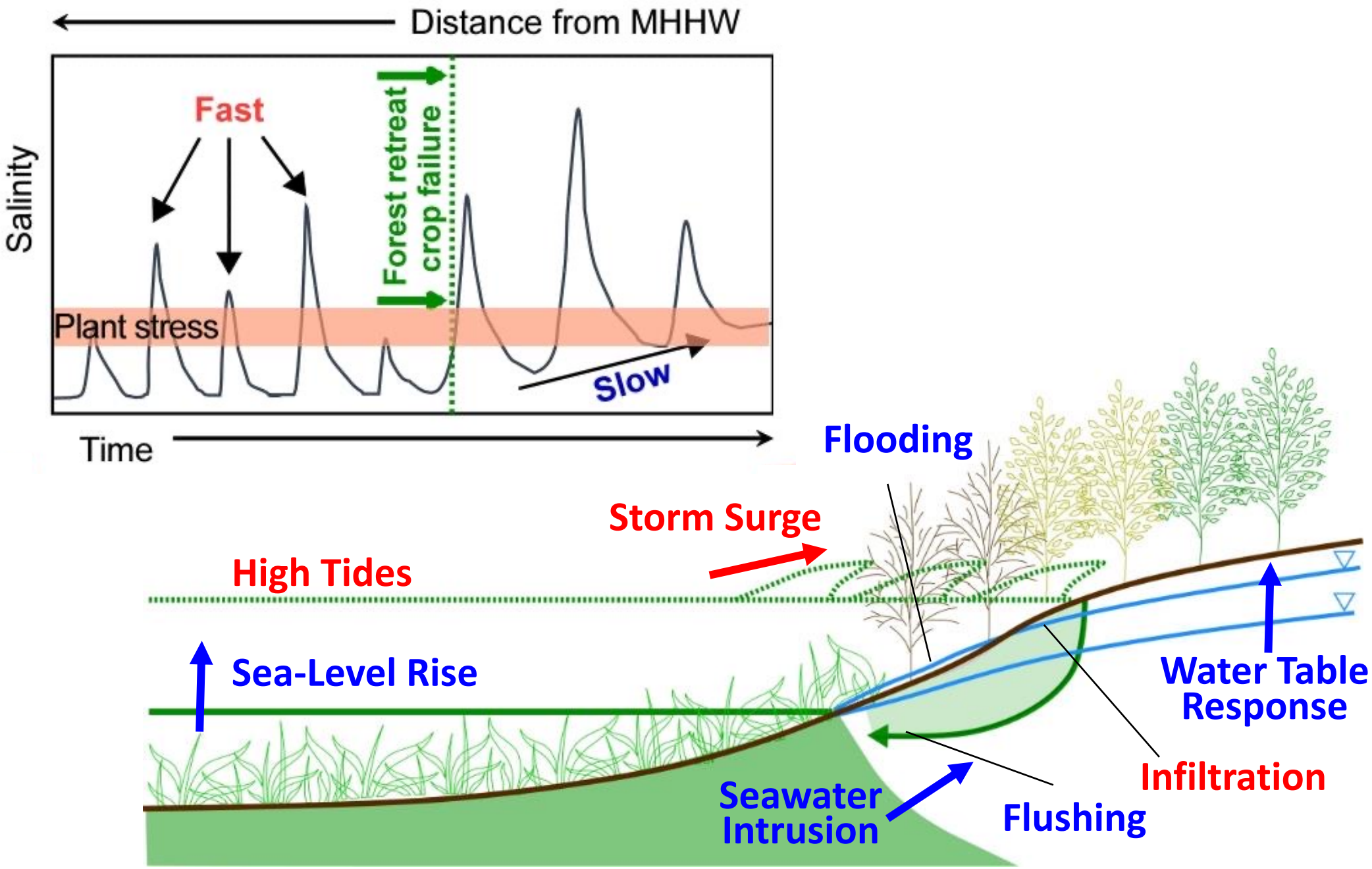
Fast Hydrologic Processes




Distance from MHHW
Salinity
Fast
Forest retreat
crop failure
Plant stress
Slow
Time
Flooding
Storm Surge
High Tides
Sea-Level Rise
Water Table
Response
Infiltration
Seawater
Intrusion
Flushing

Some work that we are doing on salinization…

Storm Surge effects on water salinity and coastal forest mortality

Sunken Forest

Maritime Holly Forest

NATIONAL PARK SERVICE

USGS science for a changing world

Some work that we are doing on salinization…

Storm Surge effects on water salinity and coastal forest mortality

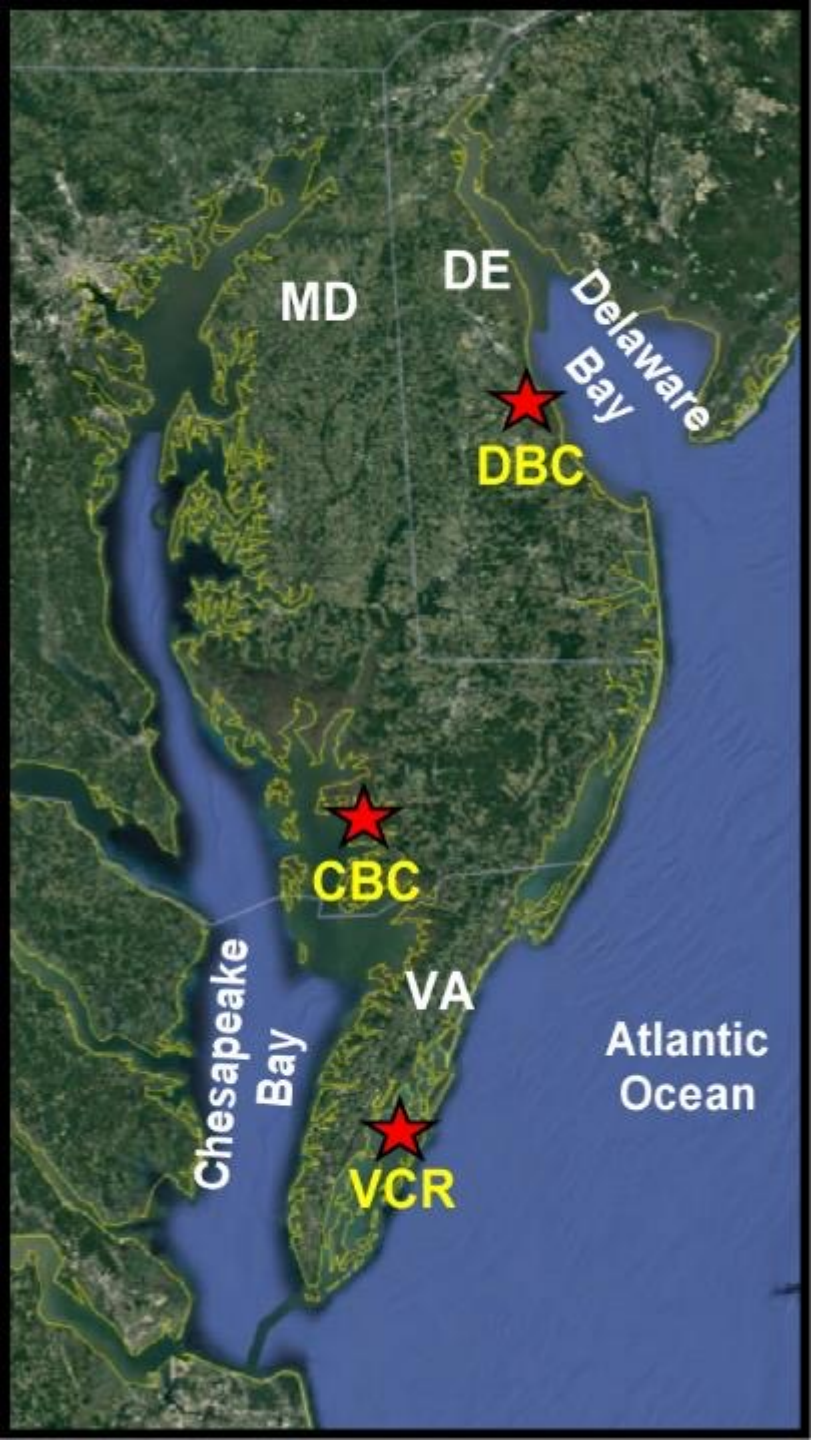
Pine beetle infestation – salinity stress?

NATIONAL PARK SERVICE

USGS
science for a changing world

Some work that we are doing on salinization…

Paired forest-agriculture sites around the Delmarva

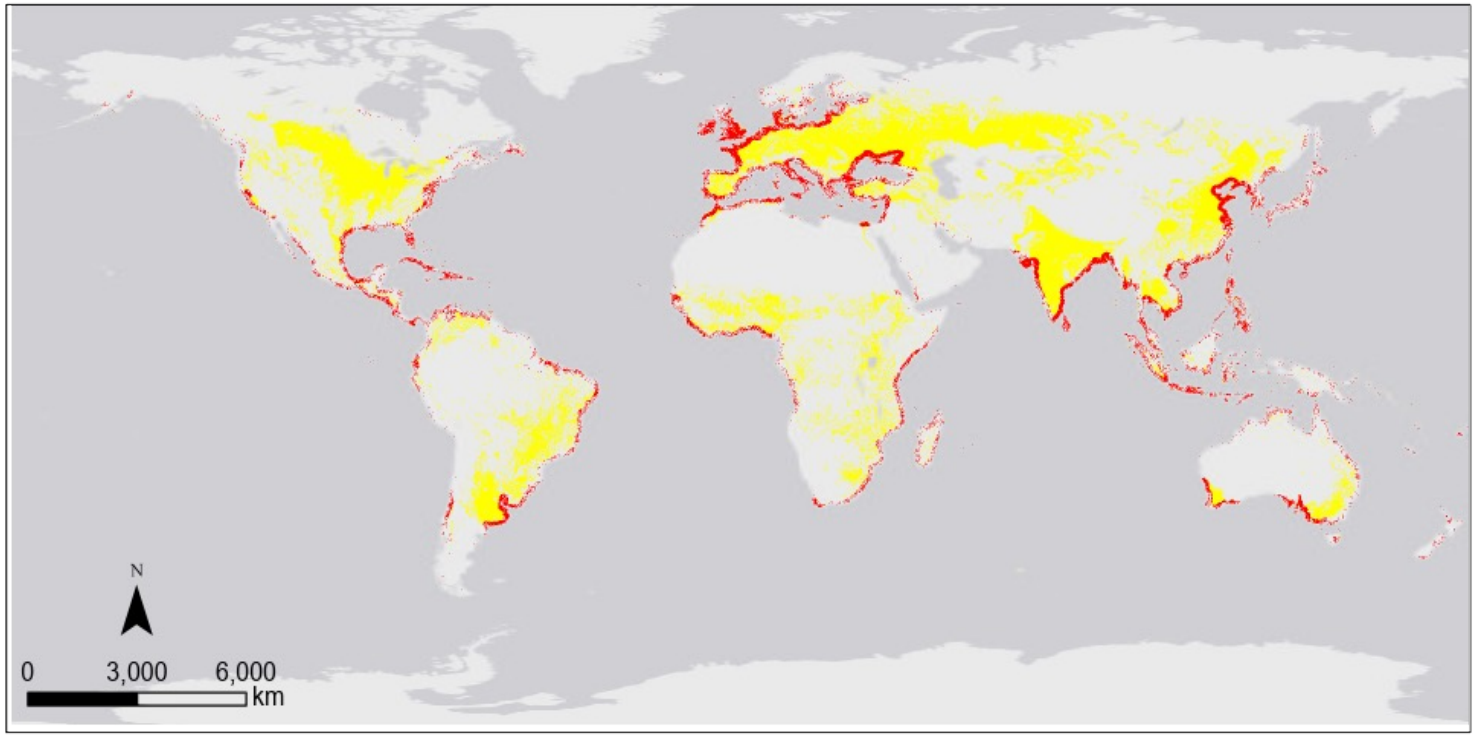


DE Forest

VA Forest

VA Agriculture

This is not just a local problem, it's global.



Yellow is cropland. Red is cropland within 100 km of coastline (~20%).

Cropland data from Global Food Security Support Analysis Data (GFSAD) Crop Mask 2010 Global 1 km V001 shapefiles

1 Billion people live within 10m of sea level

230 Million people live within 1m of sea level

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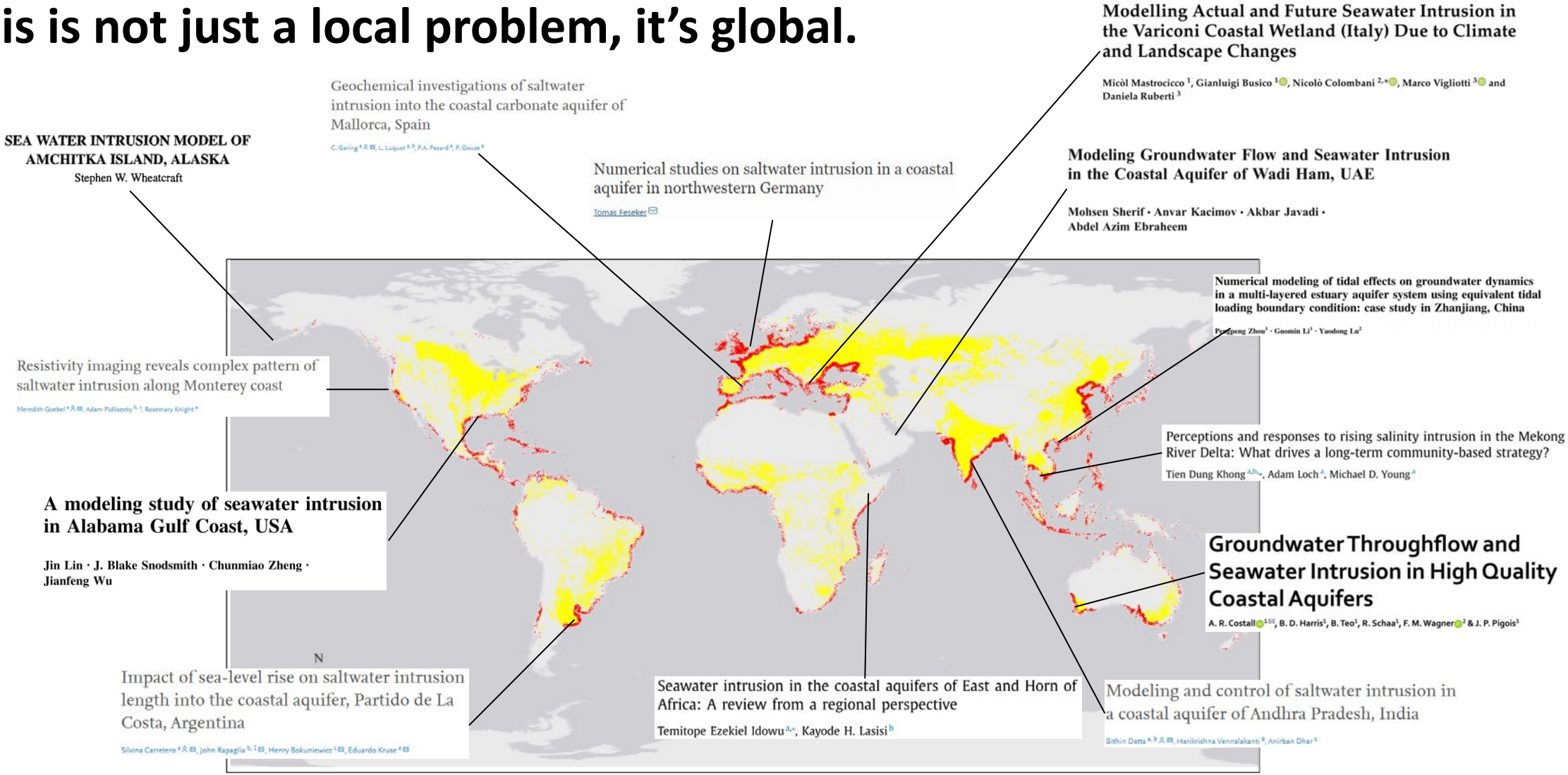

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What causes ecological change?

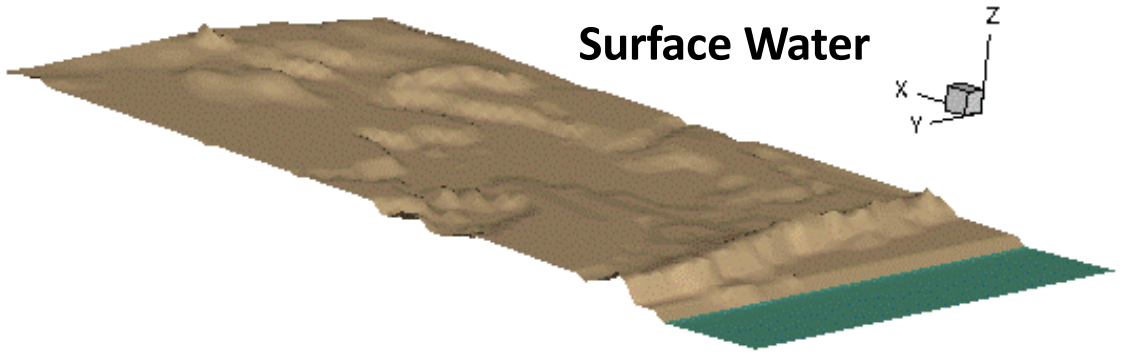
Flooding?

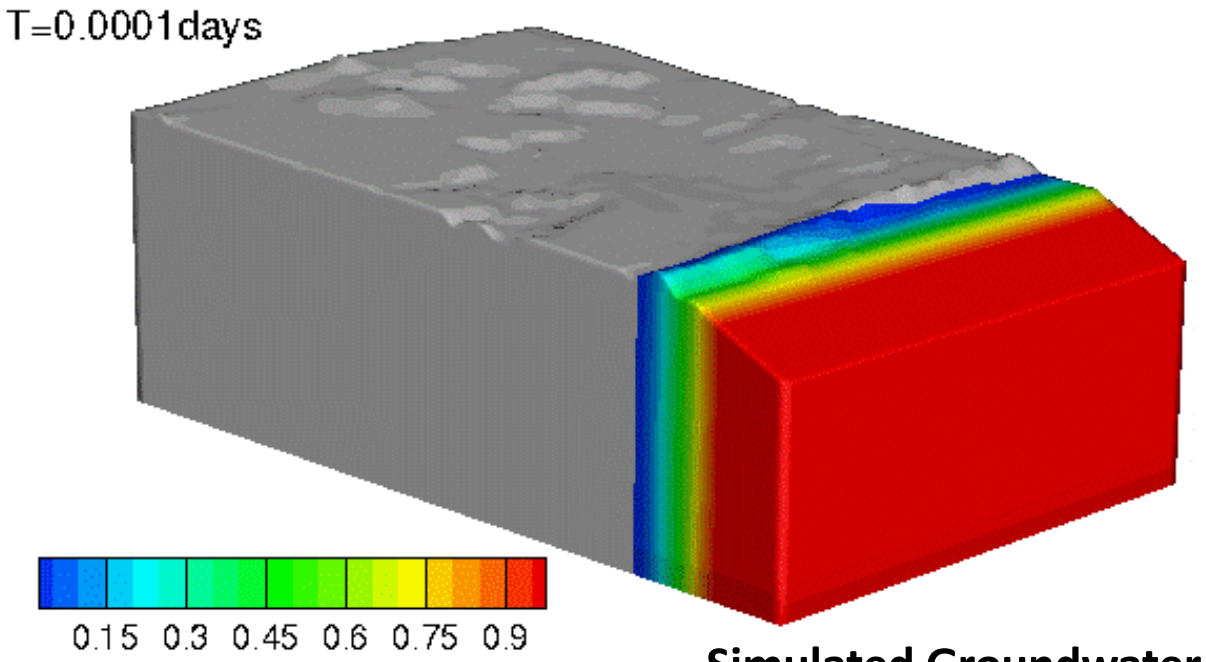
Effects of salt?

https://www.climatehubs.usda.gov/index.php/hubs/southeast/topic/saltwater-intrusion-and-salinization-coastal-forests-and-farms

Coupled Groundwater-Surface Water Surge Modeling to Evaluate Climate Change Effects on Groundwater and Ecosystems

Simulated Surface Water





Simulated Groundwater Salinity

Animation from Yu et al., 2016

Coupled Groundwater-Surface Water Surge Modeling to Evaluate Climate Change Effects on Groundwater and Ecosystems

Models can give us:

- Salinization extent, duration
- Over space and time (short term and long term)
- Surface ponding and slow infiltration post-storm

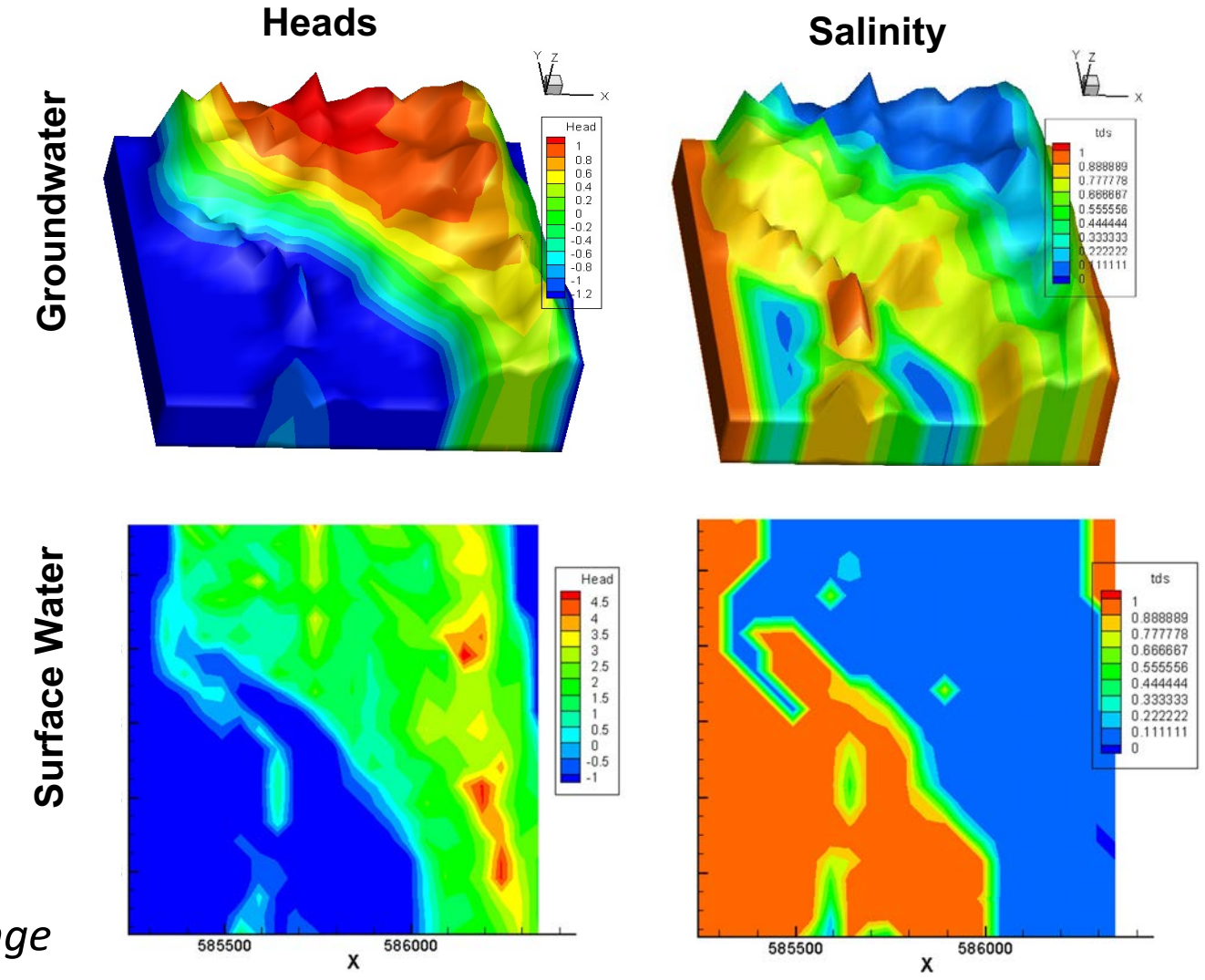
With different inputs:

- Average sea level
- Surge characteristics
- Antecedent moisture conditions
- Hydrologic conditions during storm (i.e., rainfall)

→What areas are vulnerable to salinization?
→How long does it persist?
→Where are water tables too high for trees? How long does that last?
→….

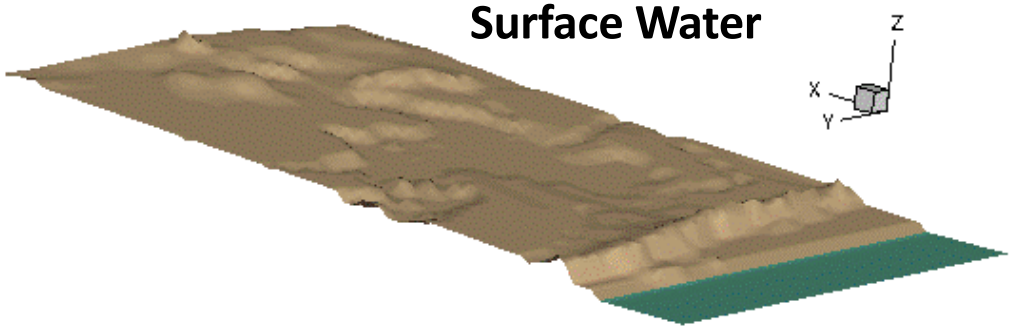
→ *Compare to spatial distribution of ecosystem change*

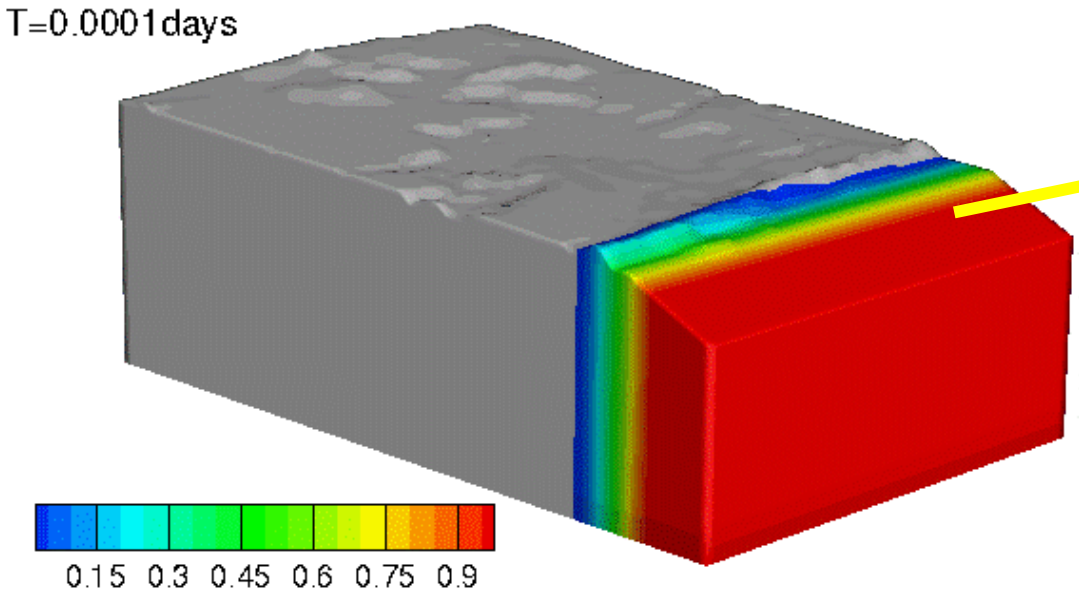
Example simulation results: Sandy Hook



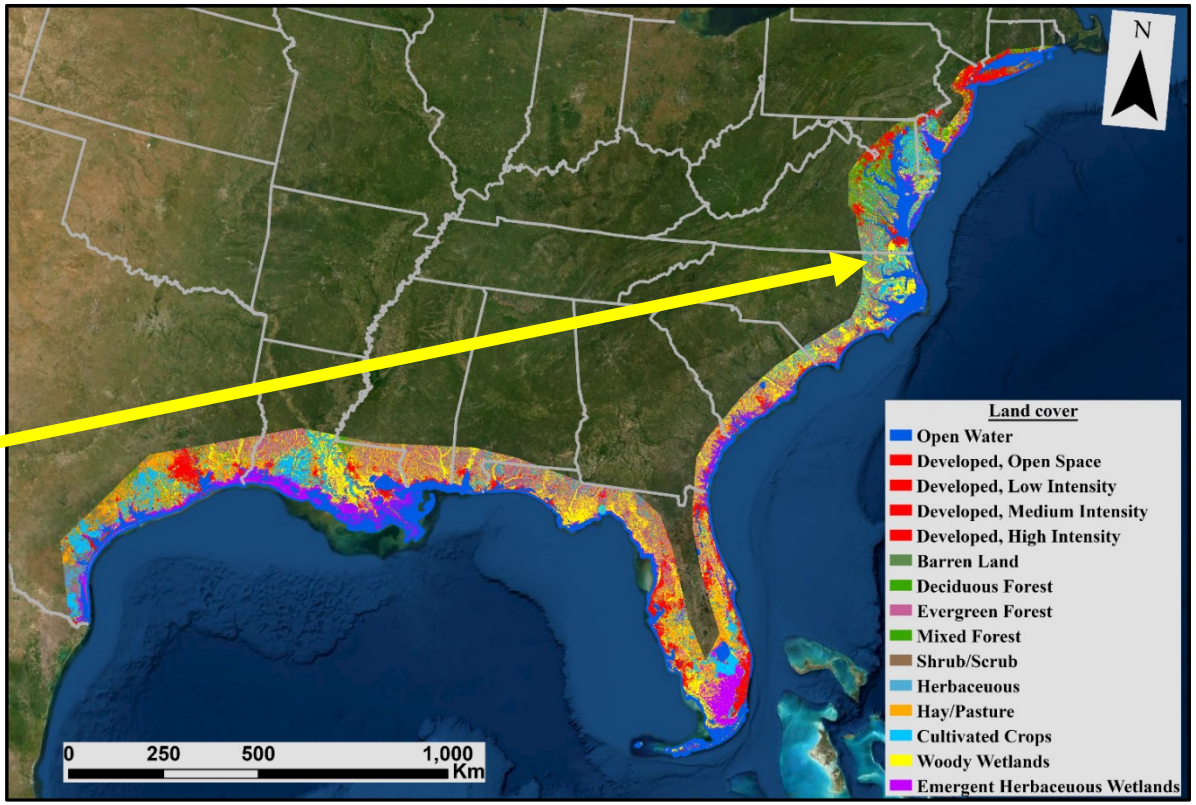
Putting local-scale features into a large-scale vulnerability context

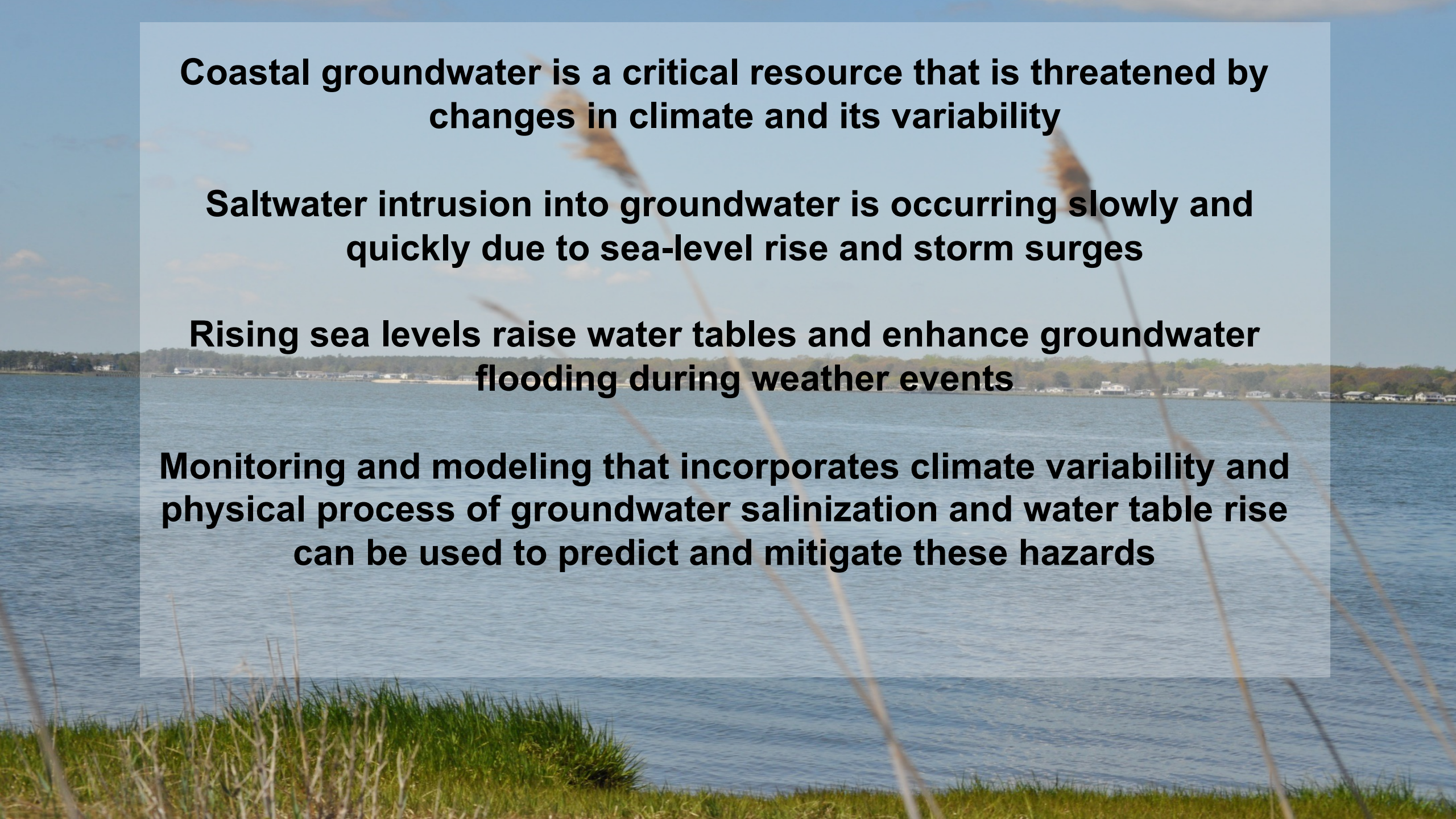
Simulated
Surface Water





Simulated Groundwater
Salinity





Coastal groundwater is a critical resource that is threatened by changes in climate and its variability

Saltwater intrusion into groundwater is occurring slowly and quickly due to sea-level rise and storm surges

Rising sea levels raise water tables and enhance groundwater flooding during weather events

Monitoring and modeling that incorporates climate variability and physical process of groundwater salinization and water table rise can be used to predict and mitigate these hazards