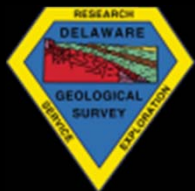


Identifying Groundwater Discharge Locations in Tidal Wetlands using Environmental Thermography at Prime Hook National Wildlife Refuge, Delaware, USA



Thomas E. McKenna
Delaware Geological Survey, University of Delaware



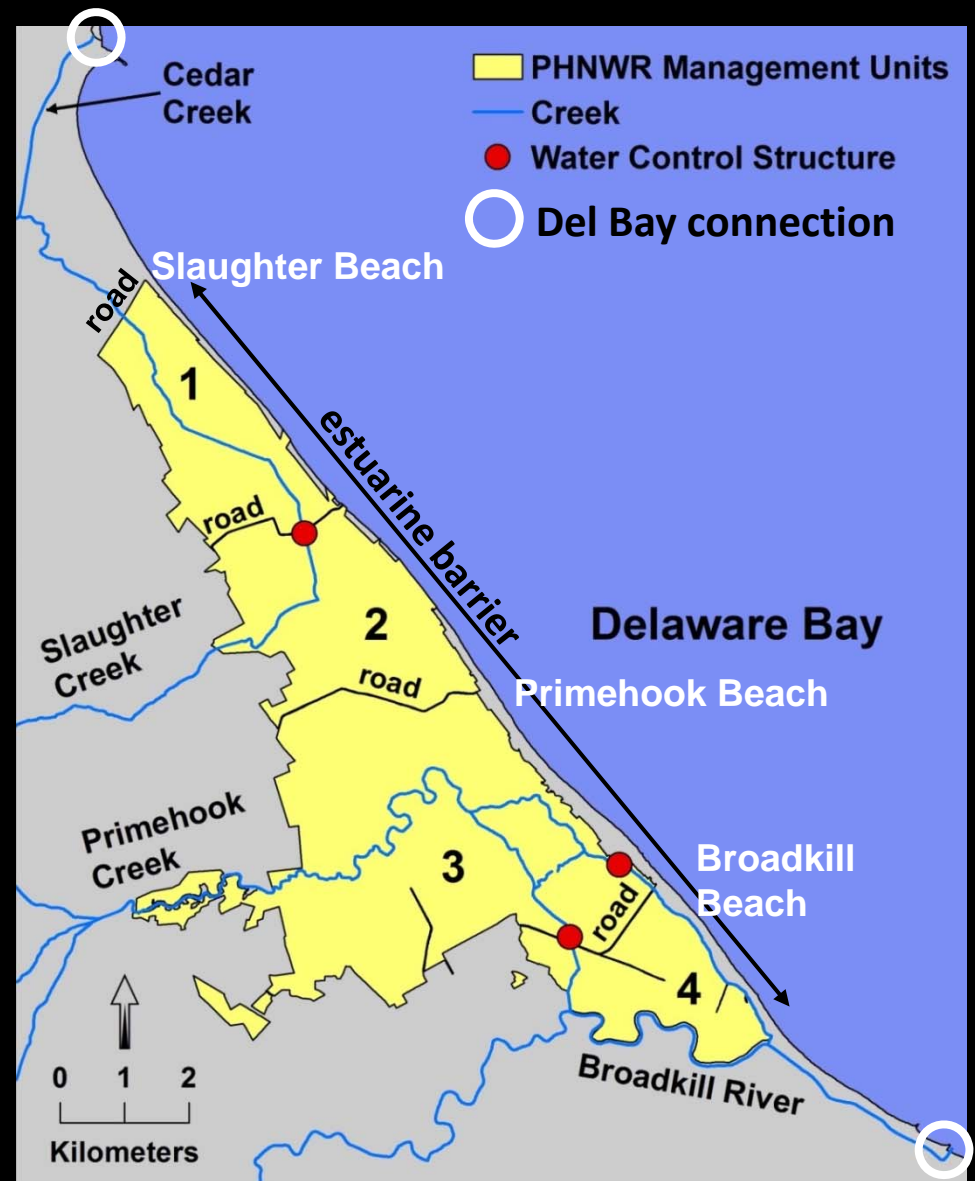
2015 GSA Annual Meeting, Baltimore, MD



Prime Hook National Wildlife Refuge (PHNWR)

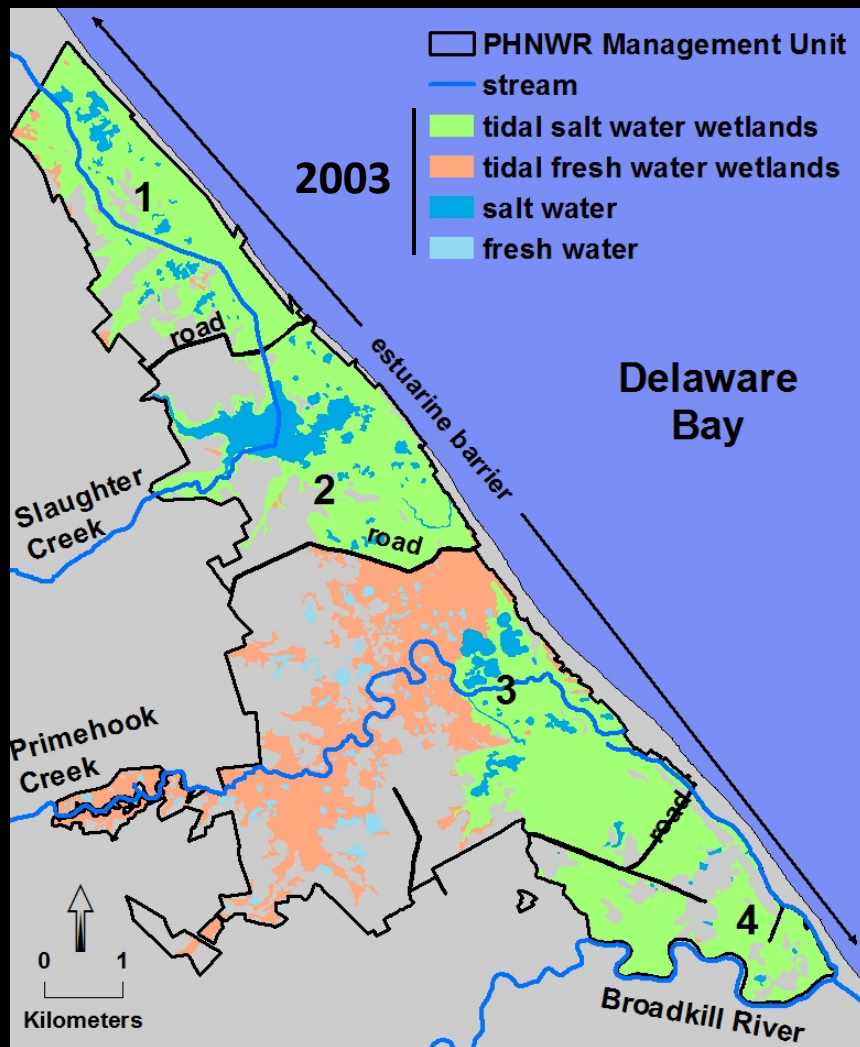


- 10,100 acres (mostly wetlands)
- 3 riverine fresh water sources
- 2 connections to polyhaline Del Bay
- 3 water-control structures
- 4 water-management units bounded by: estuarine barrier / roads / uplands
- Units 2 and 3 managed as fresh water impoundments from 1980s to late 2000s



Prime Hook National Wildlife Refuge (PHNWR)

salt water and fresh water tidal wetlands in 2003



- Historically, wetlands were almost entirely tidal salt water wetlands (salt marsh)
- Many historical impacts/alterations since early 1900s: water control structures, ditching, mosquito management, cattle grazing, hay farming, trapping
- Fresh water impoundments installed in Units 2 and 3 to combat Phragmites invasion and provide waterfowl habitat (very successful in this regard)

(Delaware SWMP, 2003)



Storms impacting the Refuge

Unit 2 - Pre-Hurricane Sandy



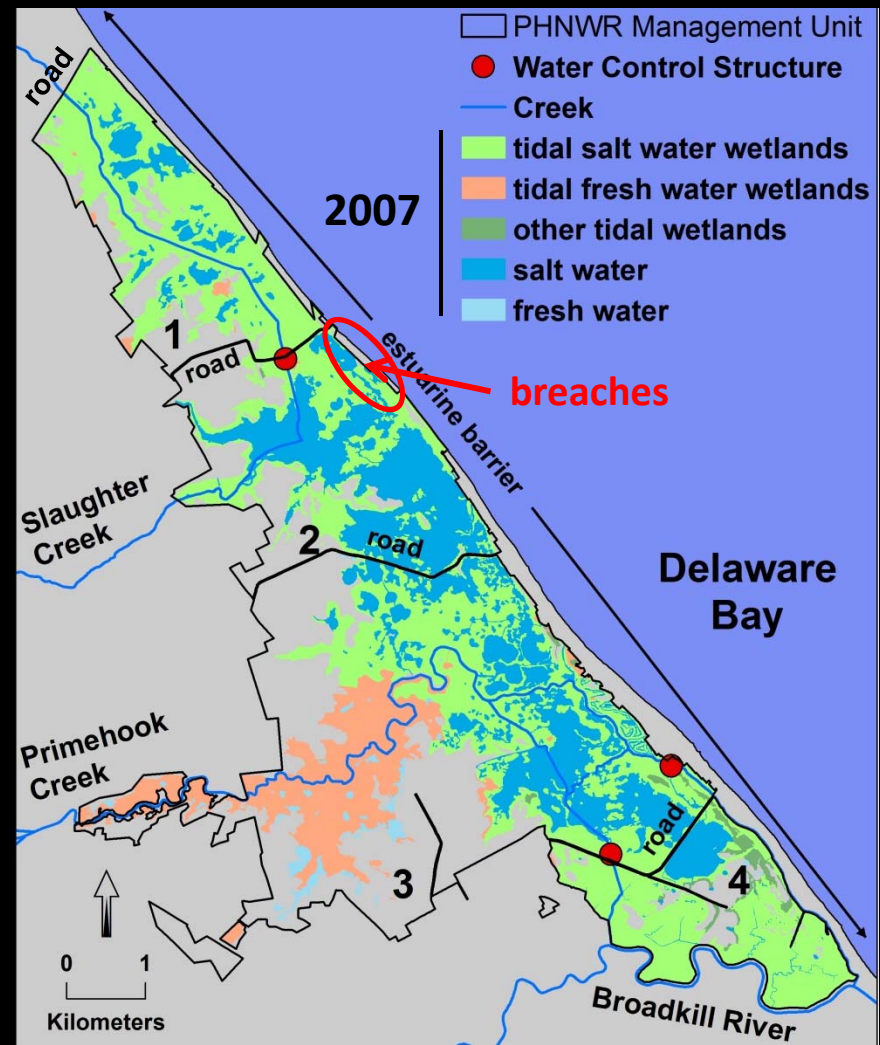
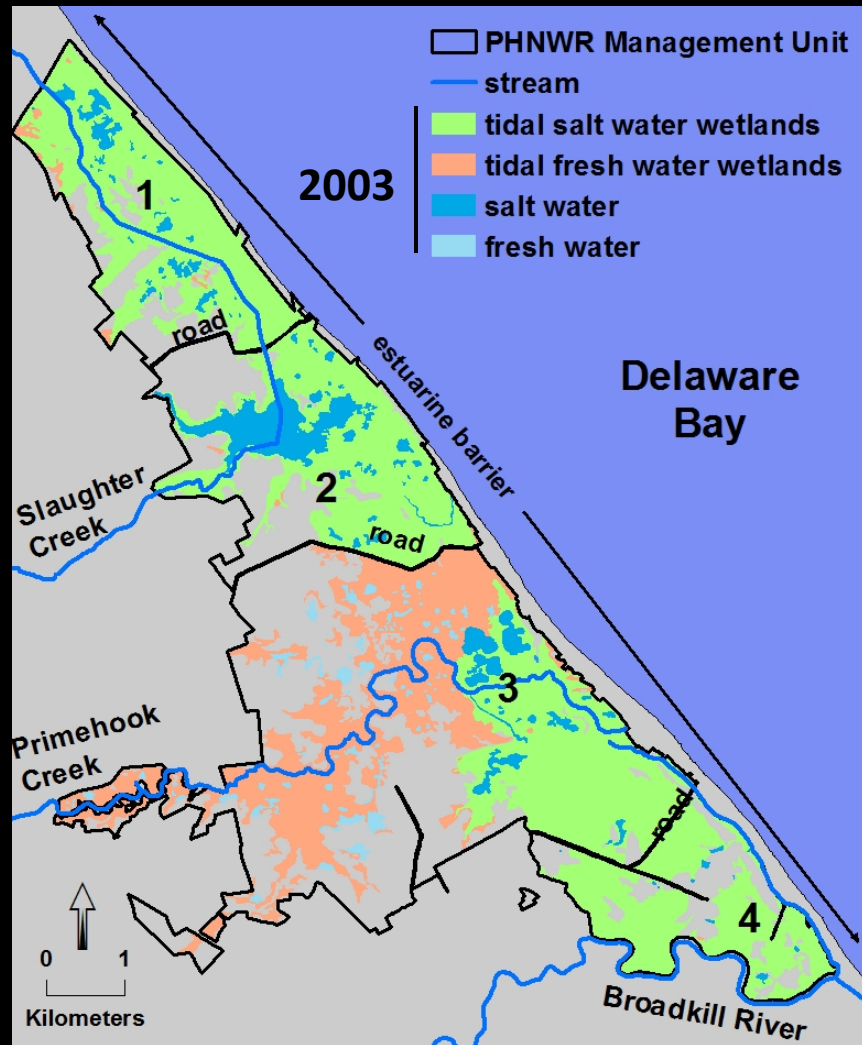
Unit 2 - Post-Hurricane Sandy



- 2008 - small breach of barrier in Unit 2 during nor'easter
- October 2008 - Unit 2 breach repaired
- Summer 2009 - Fresh water vegetation management successful in Units 2 and 3
- November 2009 - 2 breaches in Unit 2 during nor'easter
 > 1,000 acres of marsh - > open water
- October 2012 - 2 additional breaches into Unit 2 (Hurricane Sandy)



Changes in wetlands/water land cover 2003 → 2007

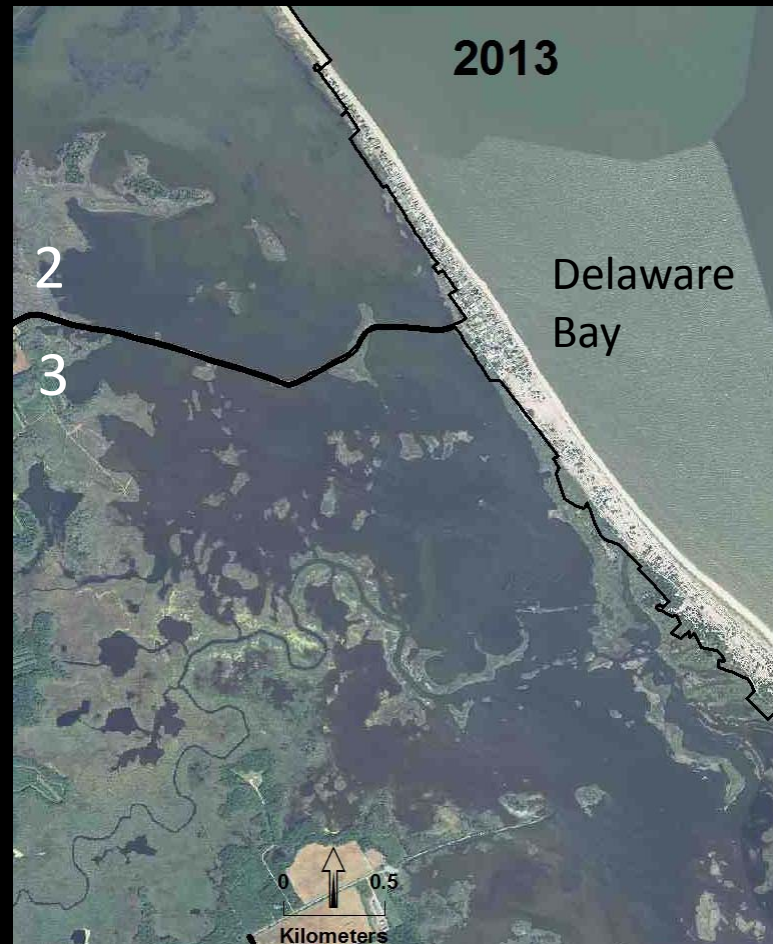


(Delaware SWMP, 2003 & 2007)

continued conversion of wetlands to open water

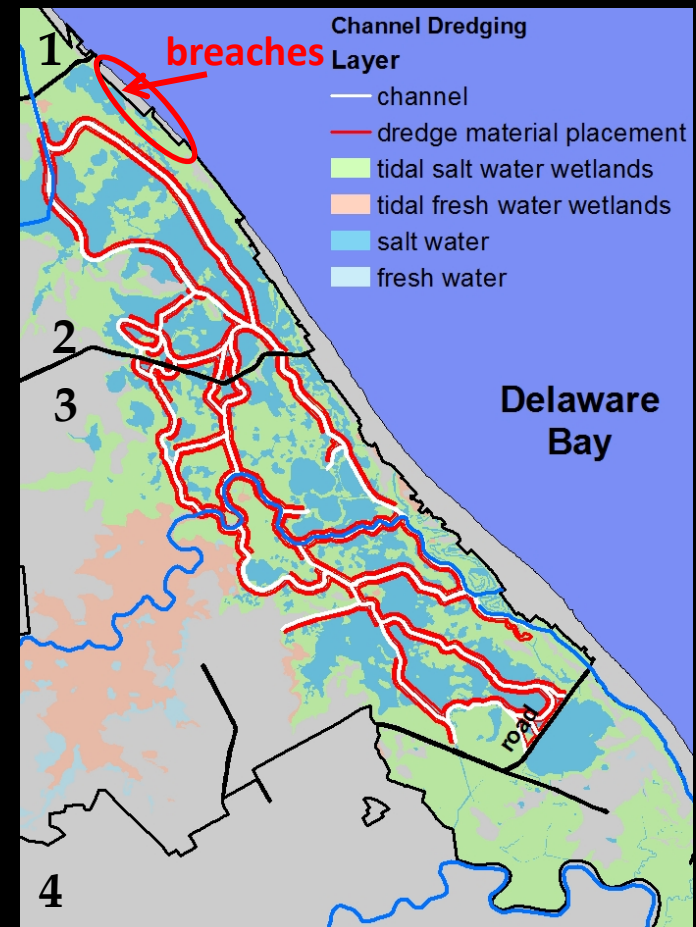
2007 → 2013

example for parts of units 2 and 3



RESTORATION

- restore salt marsh and more natural water flow; repair breaks in existing dunes
- dredge material spread onto areas adjacent to channels
- focus is on sustainable salt marsh restoration but retain fresh water habitat if possible
 - Therefore, my charge is to locate groundwater discharge in the dredging area
- dredging underway and to conclude in 2015
- dredging depth is ~2 m
- have dredged up sand (anecdote)

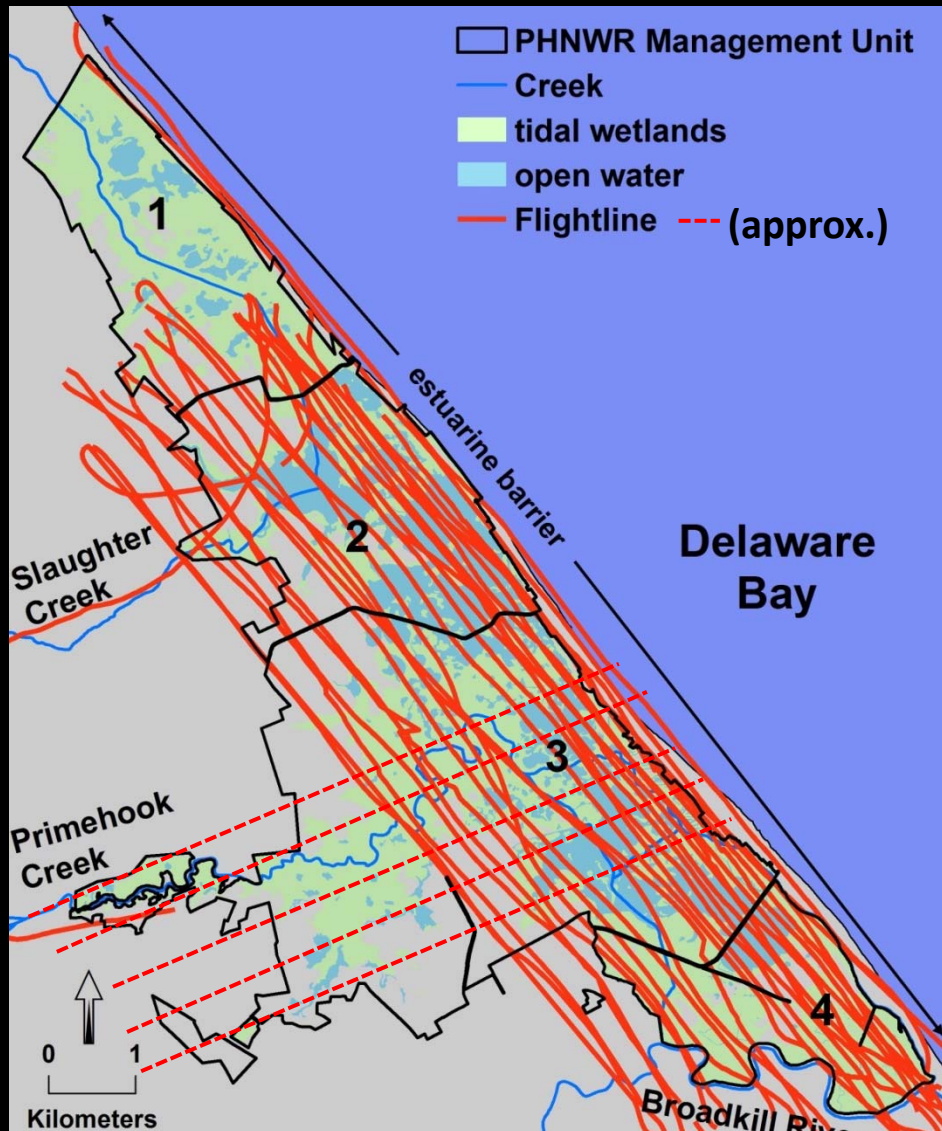


Aquifer Setting

- **Atlantic Coastal Plain**
 - low topographic relief
 - dissected by tidal creeks
- **Columbia Aquifer**
 - surficial, water-table aquifer (locally confined)
 - sand and gravel aquifer
 - 15-45 m thick
 - depth to water table typically < 4 m
 - hydraulic conductivity $\sim 10^{-4} - 10^{-5}$ m/s
- **Beaverdam, Scotts Corners, and Lynch Heights formations**
 - fine to coarse sand, gravelly sand, and sandy gravel with beds of silt and sandy silt

Flights

- April 5, 2015 6:30 – 8:00 am
- April 6, 2015 6:30 – 8:30 am
- 336 km flown at 330 meters altitude
- FLIR SC6000 thermal video
- GoPro Hero 4 visual video
- audio recording, GPS
- 1946 Aeronca Champ aircraft
- Pilot John Chirtea (Refuge friend)

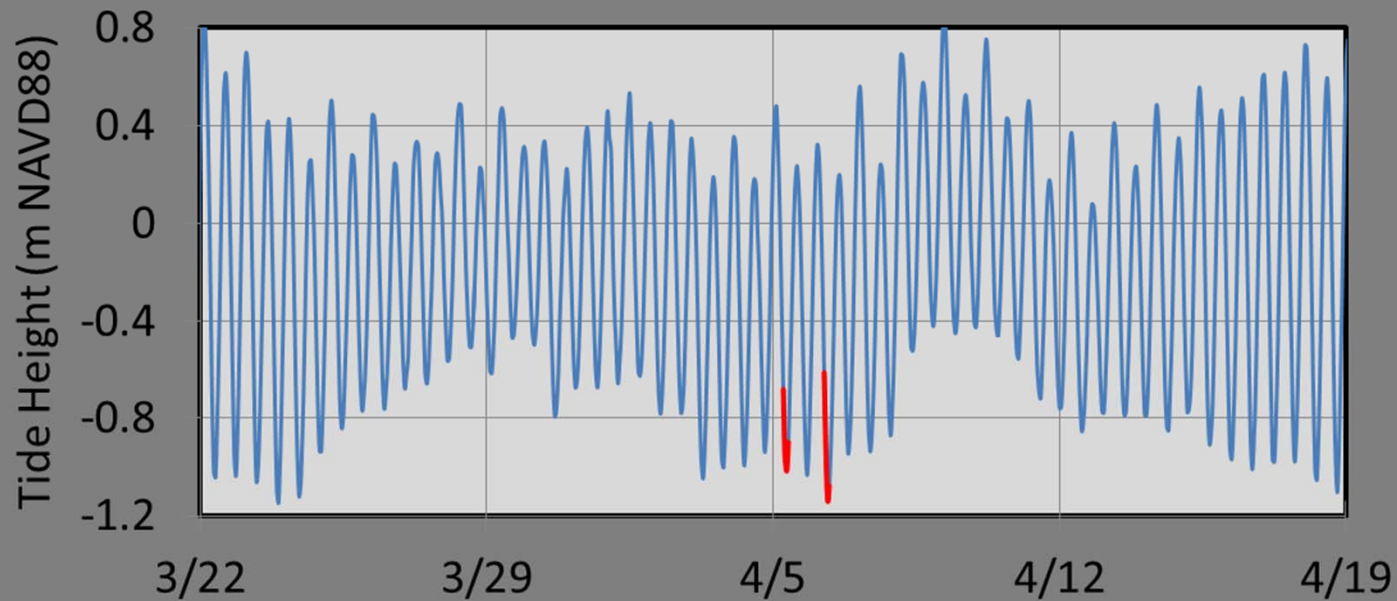
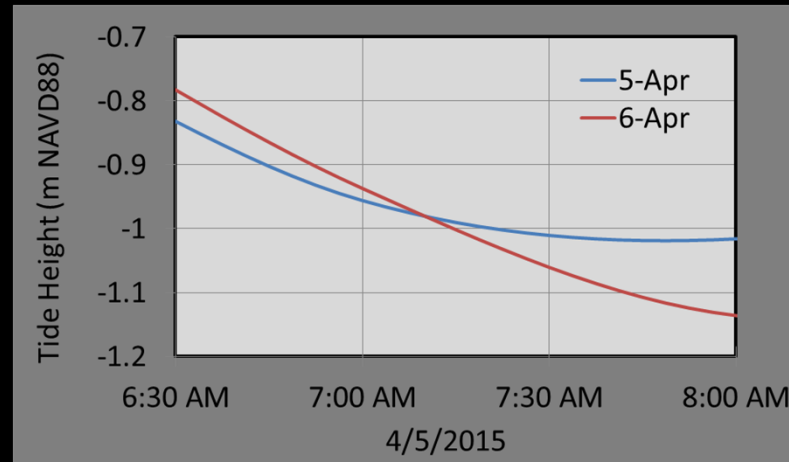


In air at civil twilight before sunrise



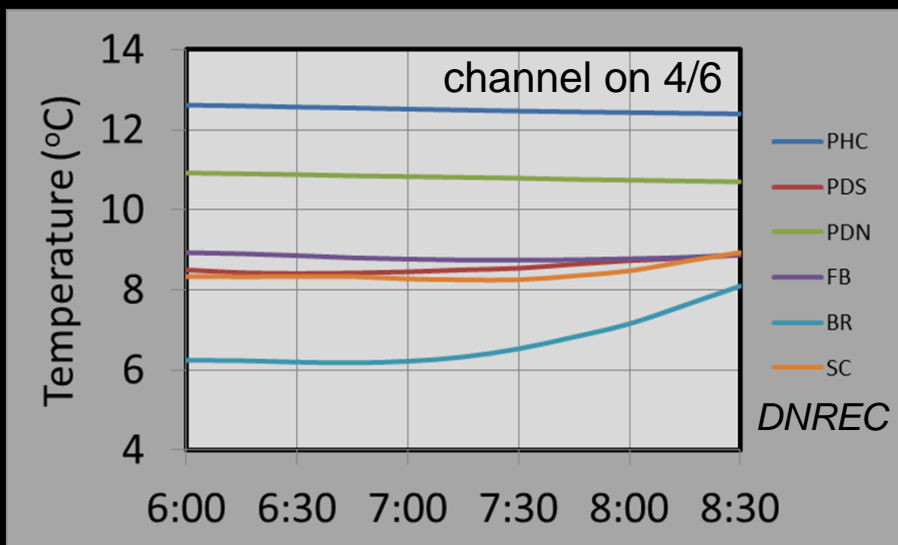
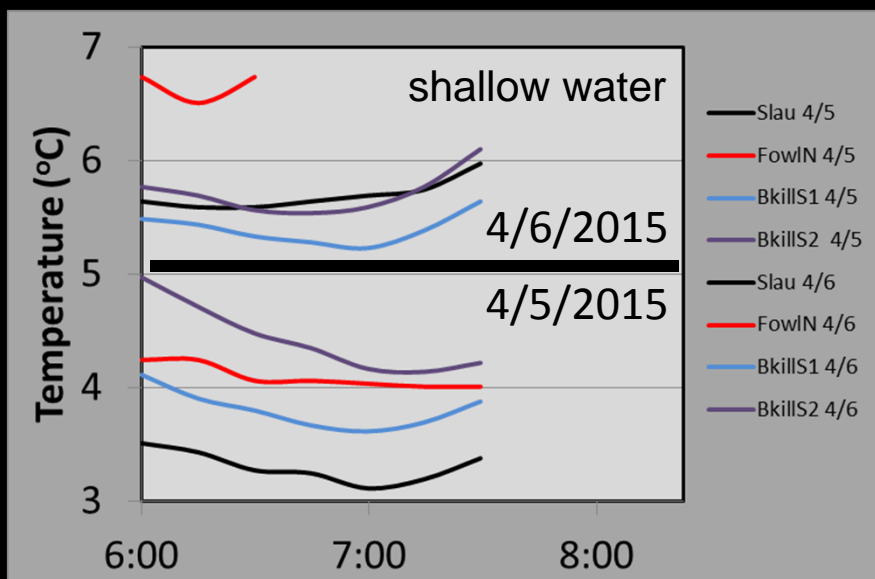
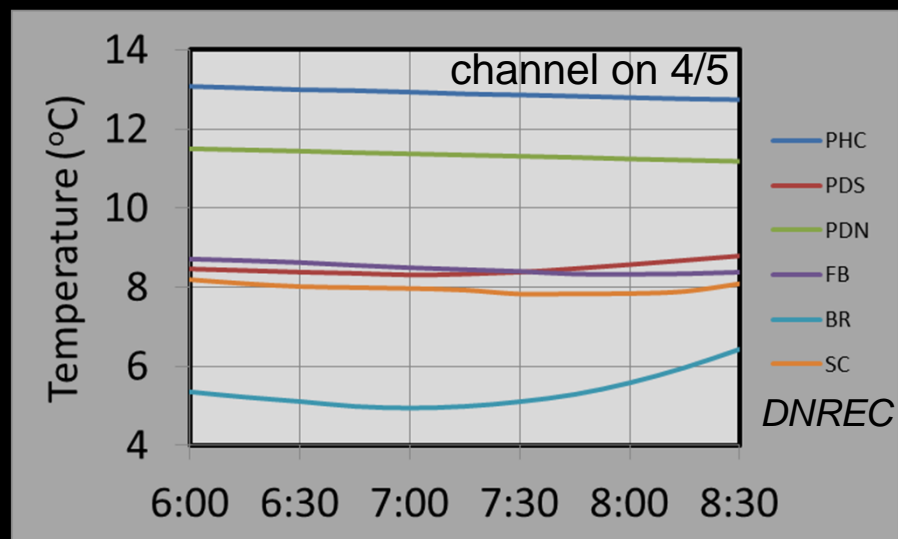
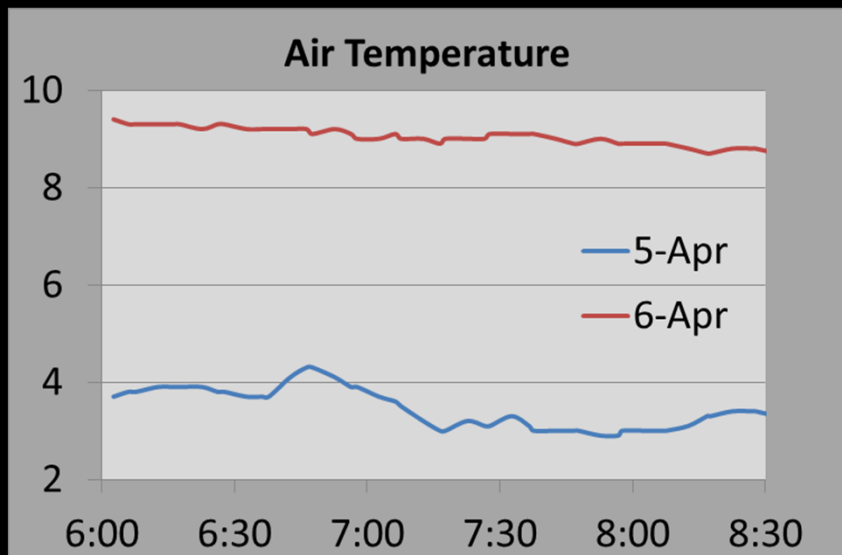
Tide near the southern connection to Delaware Bay

Flights during
ebbing tide

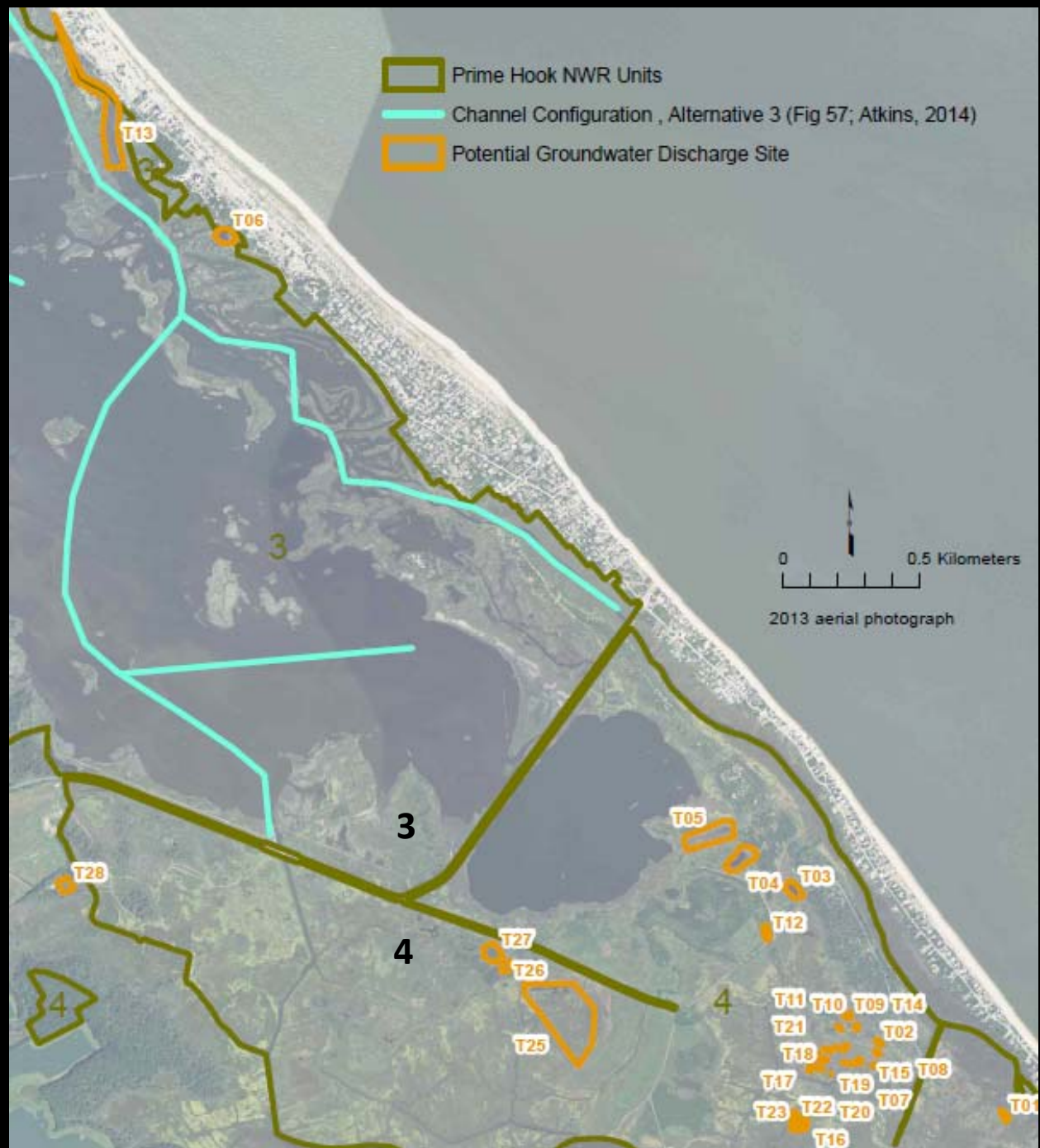


NOAA 8557380 - Lewes, DE

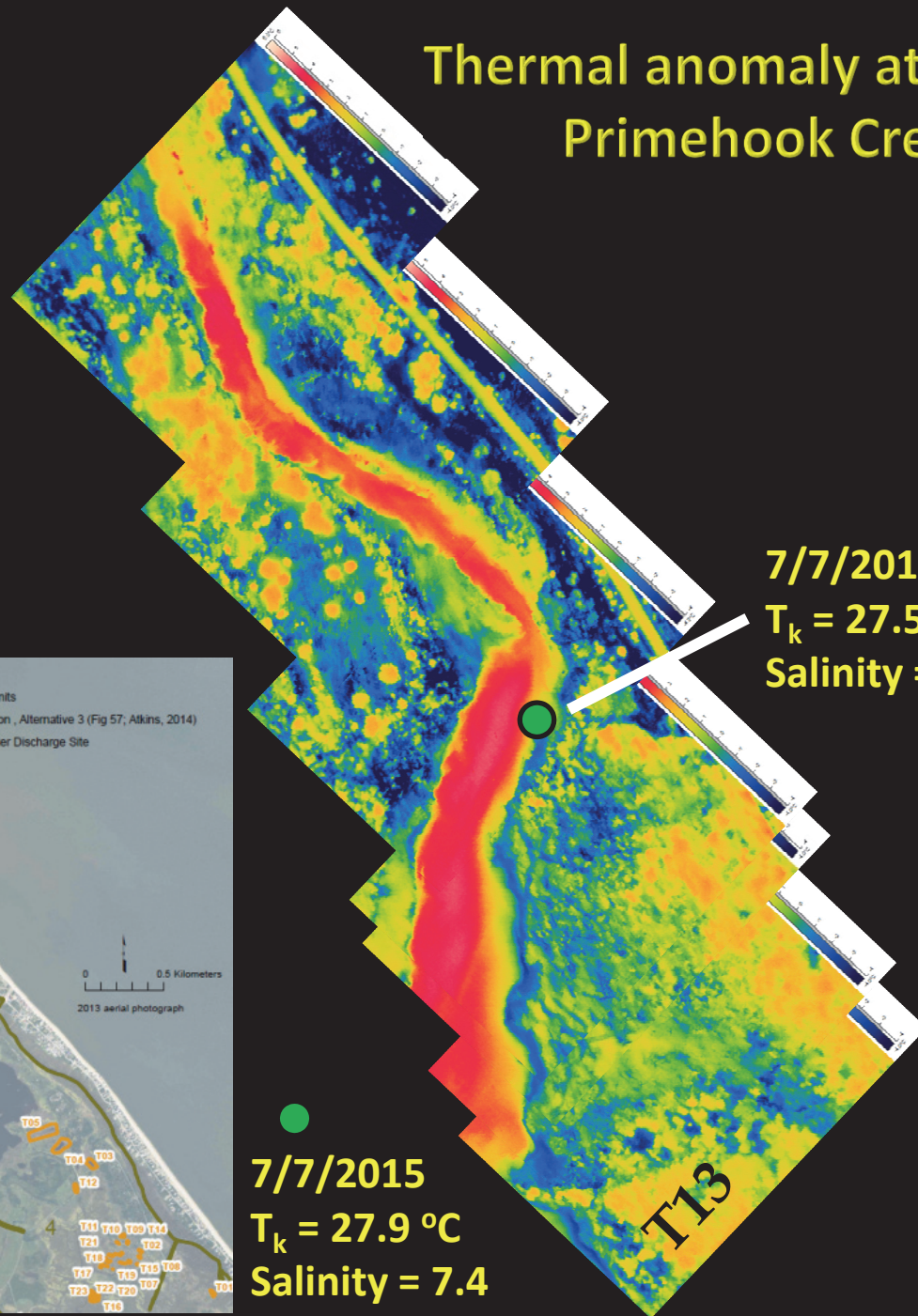
Ambient Thermal Environment



**Locations of thermal anomalies
(potential groundwater
discharge sites)**

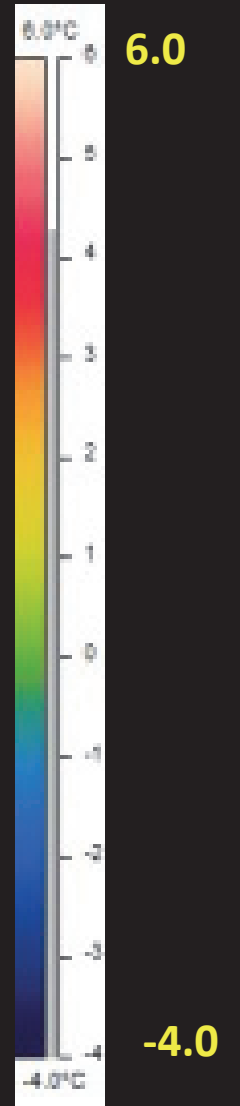


Thermal anomaly at former mouth of Primehook Creek In Unit 3

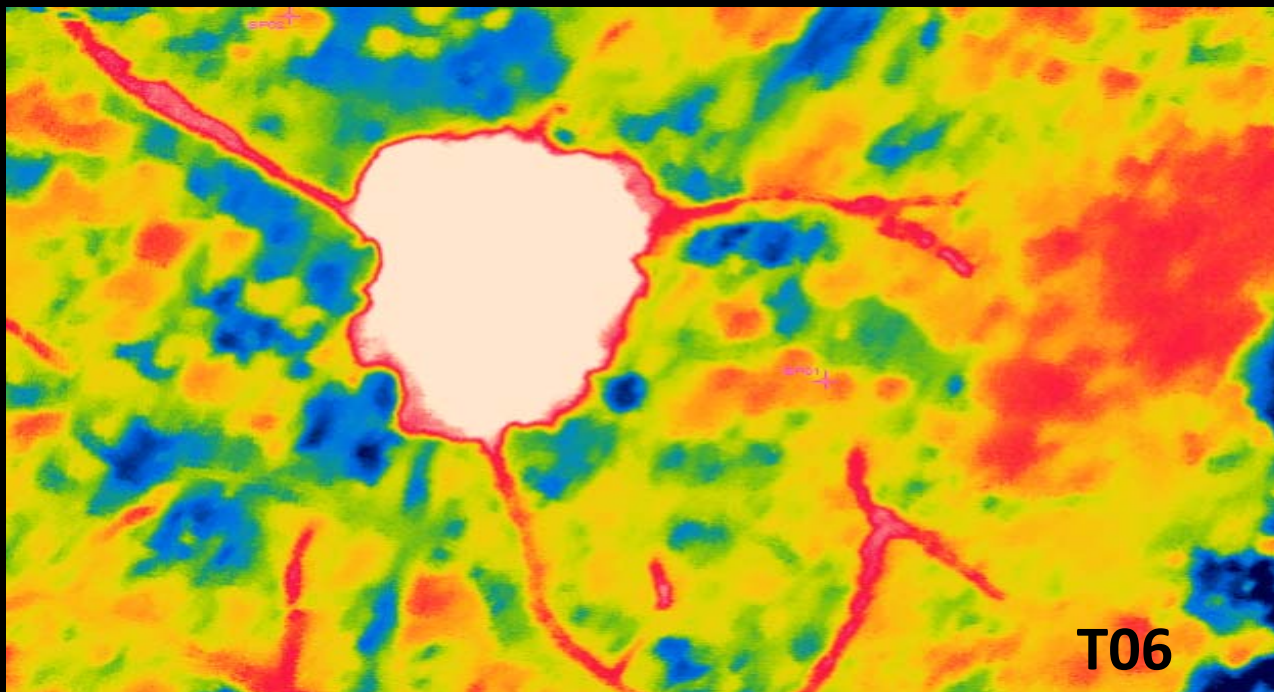


7/7/2015
 $T_k = 27.9\text{ }^{\circ}\text{C}$
Salinity = 7.4

Apparent radiant temperature ($^{\circ}\text{C}$)



Thermal anomaly in eastern part of Unit 3 near Primehook Beach



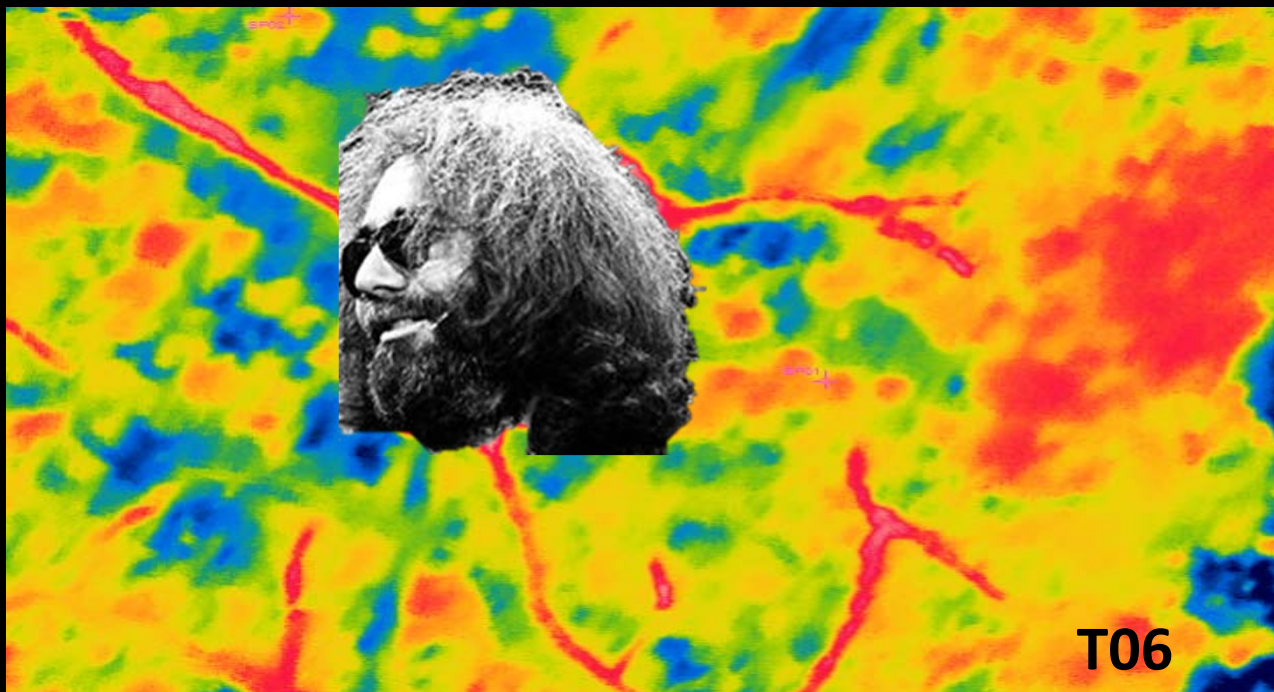
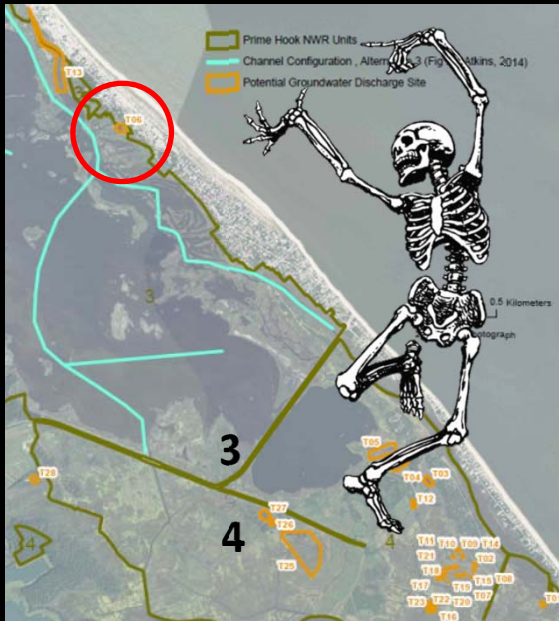
Apparent radiant temperature (°C)



6.0

-4.0

Thermal anomaly in eastern part of Unit 3 near Primehook Beach



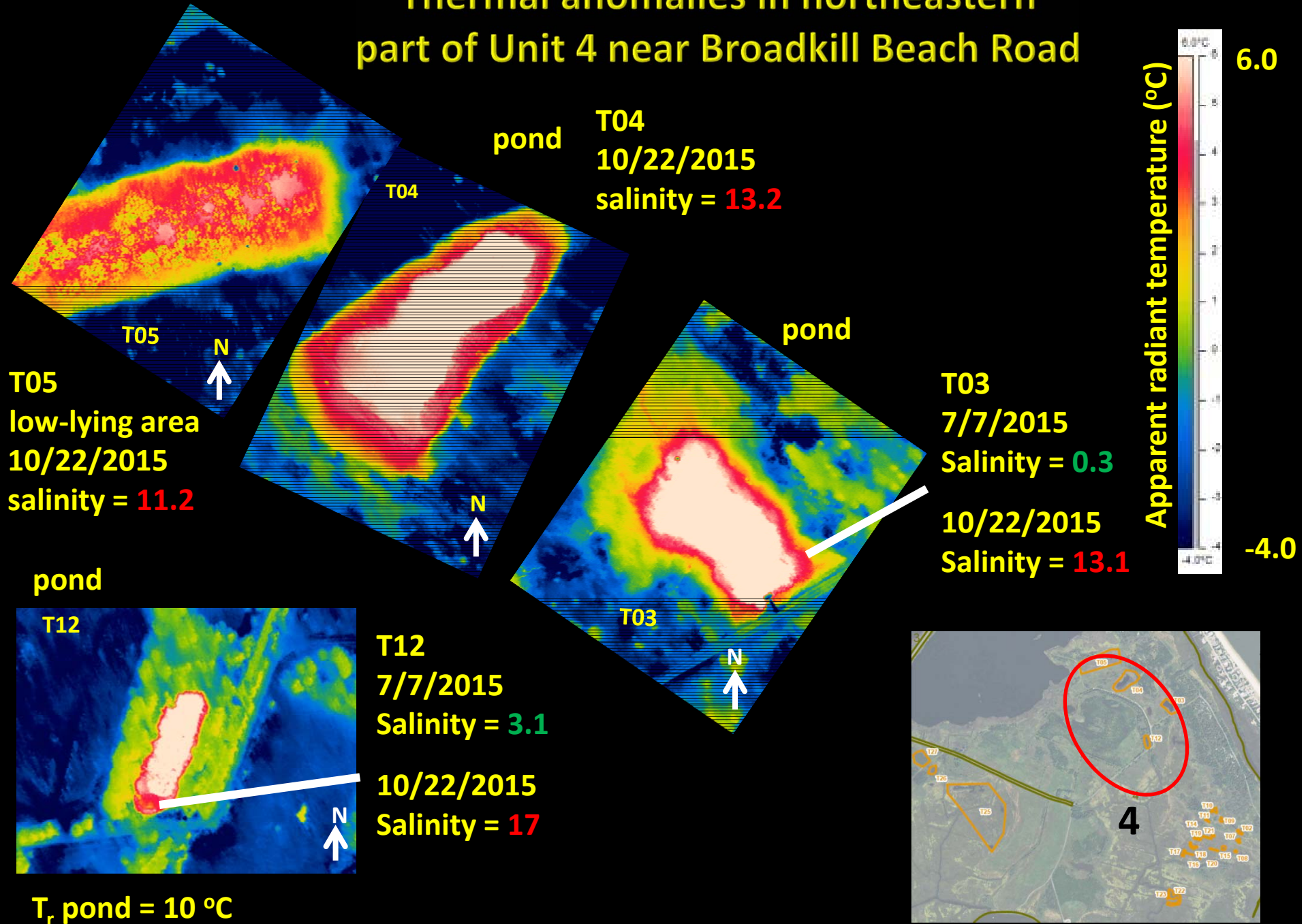
Apparent radiant temperature (°C)



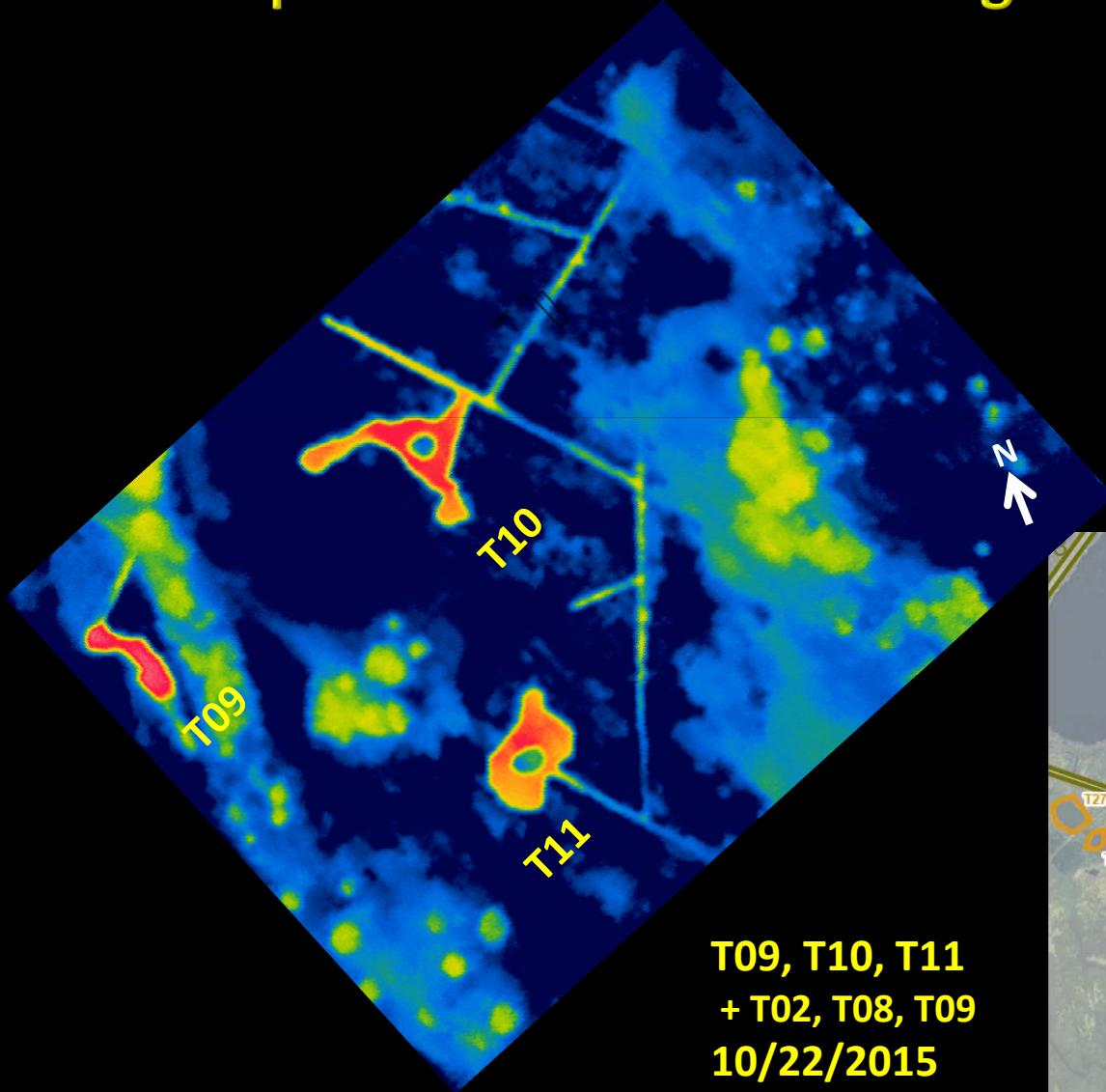
6.0

-4.0

Thermal anomalies in northeastern part of Unit 4 near Broadkill Beach Road



Thermal anomalies in northeastern part of Unit 4 Open Water Marsh Management (OMWM) Ponds



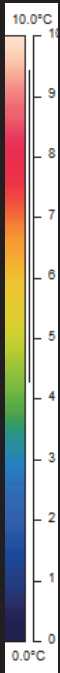
T09, T10, T11
+ T02, T08, T09
10/22/2015
salinity > 18



Primehook Creek

- warm water (groundwater source) cuts through bank of creek at breaches (A)
- creek temperature decreases $>4^{\circ}\text{C}$ (B)

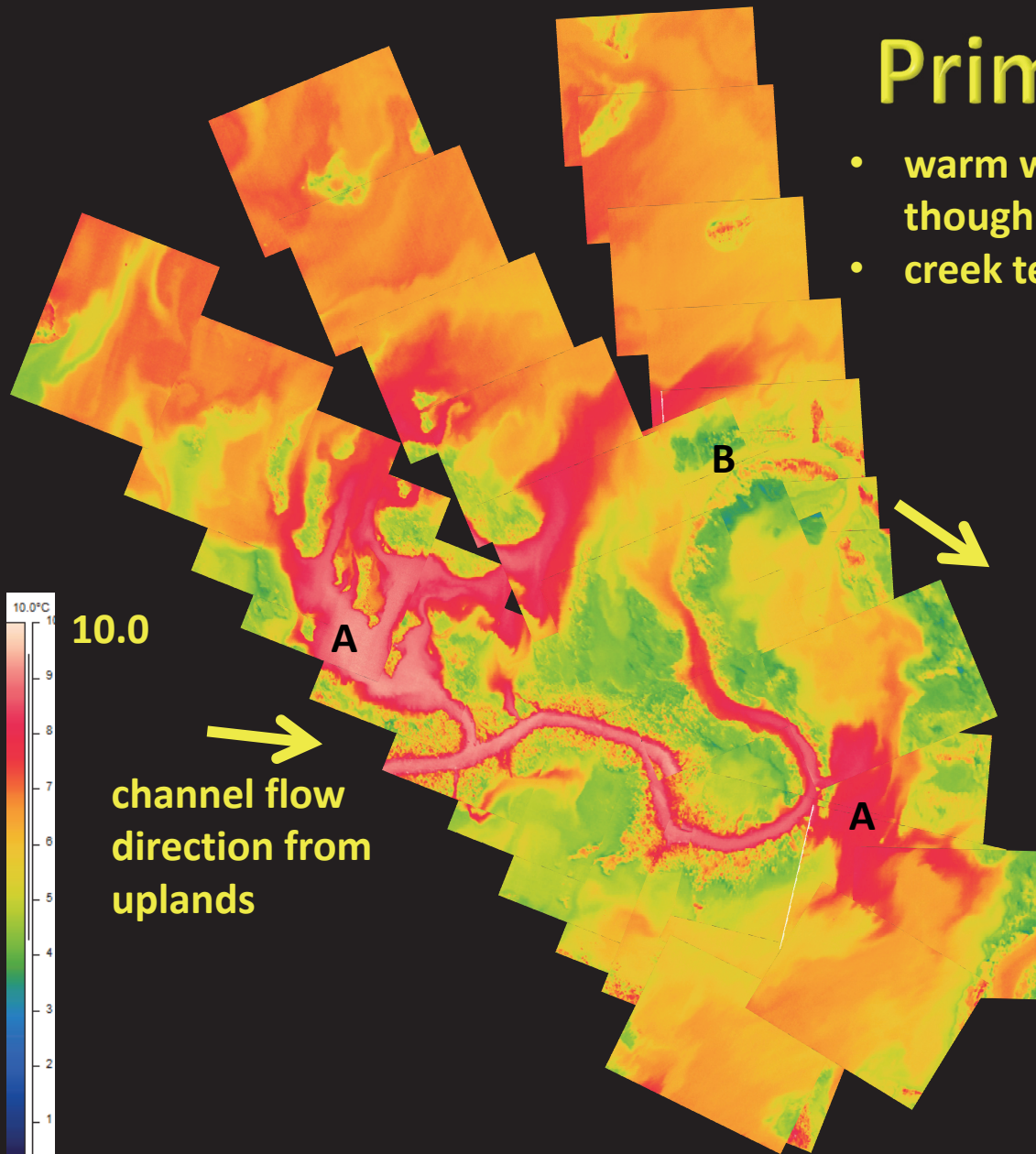
Apparent radiant temperature ($^{\circ}\text{C}$)



10.0

channel flow
direction from
uplands

0





Conclusions



- Thermal Survey
- Late date in the survey season (April) was conducive to locating discharge (ground-cover, atmospheric and tidal conditions , estuarine temperature)
- Groundwater discharge
 - Unit 2
 - no locations identified (but Slaughter Cr not fully surveyed upstream o the first inland bridge)
 - Unit 3
 - open water in former mouth of Primehook Creek
 - one small pond just south of above
 - upstream freshwater PH Creek (and many adjacent ponds not shown)
 - Unit 4
 - ponds in high marsh or upland
 - Open Water Marsh Management ponds and possibly ditches (not confirmed)
- Implications
 - All potential groundwater discharge sites identified are outside of the dredging areas and thin veneer disposal areas (Units 2 and 3)