Understanding the Coastal Plain: Giving Context to Regional Challenges

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Gratefully acknowledging input from:

- François Birgand (NCSU)
- Ryan Boyles (SCO)
- Karen Brashear (City of Goldsboro)
- Kathleen Farrell (NCGS/DEQ)
- Detlef Knappe (NCSU)
- Asko Noormets (NCSU)
- Mike O'Driscoll (ECU)
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- Anthony Whitehead (Greenville Utilities)
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- Nat Wilson (DEQ)
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1630

http://www.georgehoward.net/htmlfiles/tarheelmaps.htm

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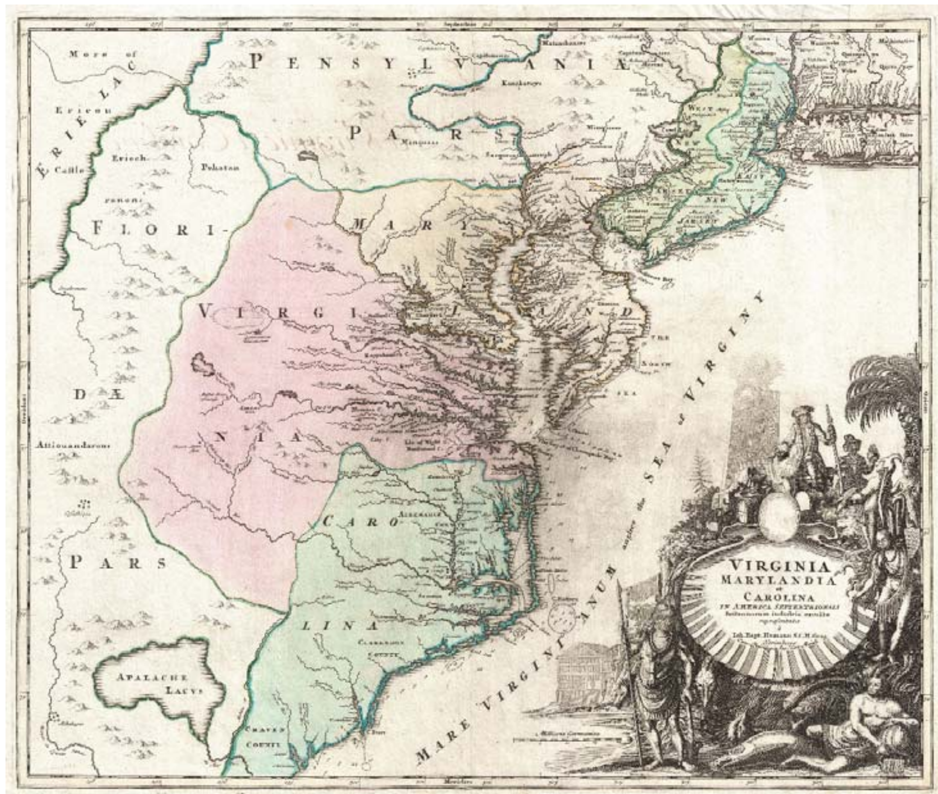
1715

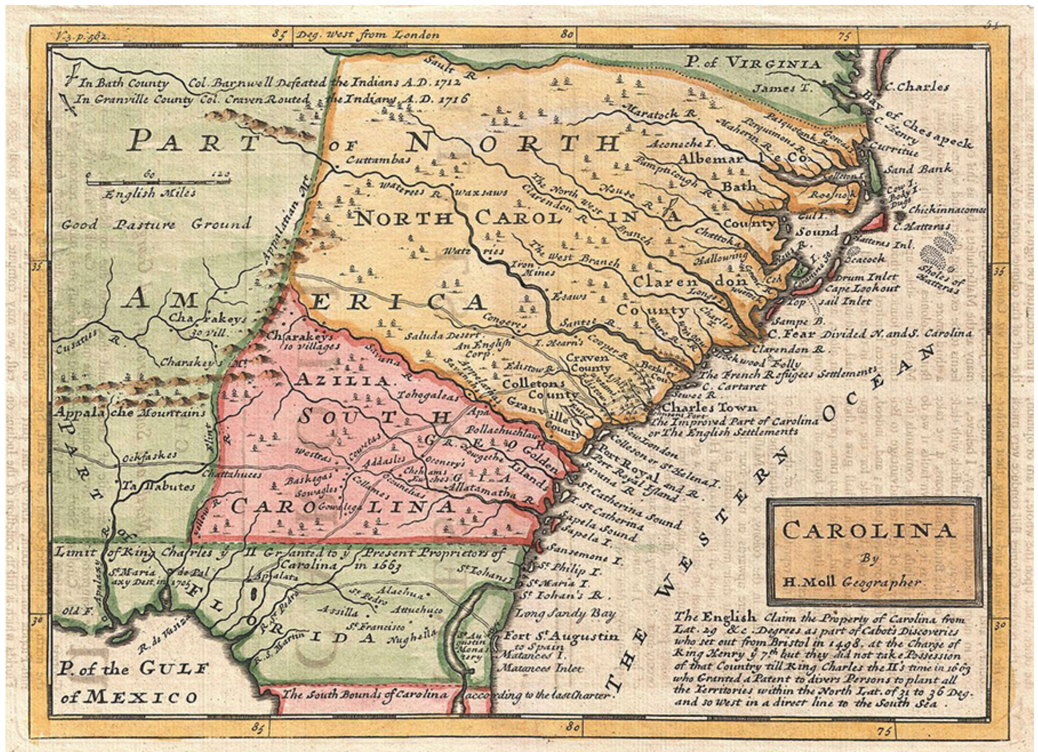
King Charles II



http://southernspaces.org/blog/bulletin%E2%80%94november-29-2012

1746

Our signers, in 1746:
- John Penn, age 6
- William Hooper, age 4
- Joseph Hewes, age 16

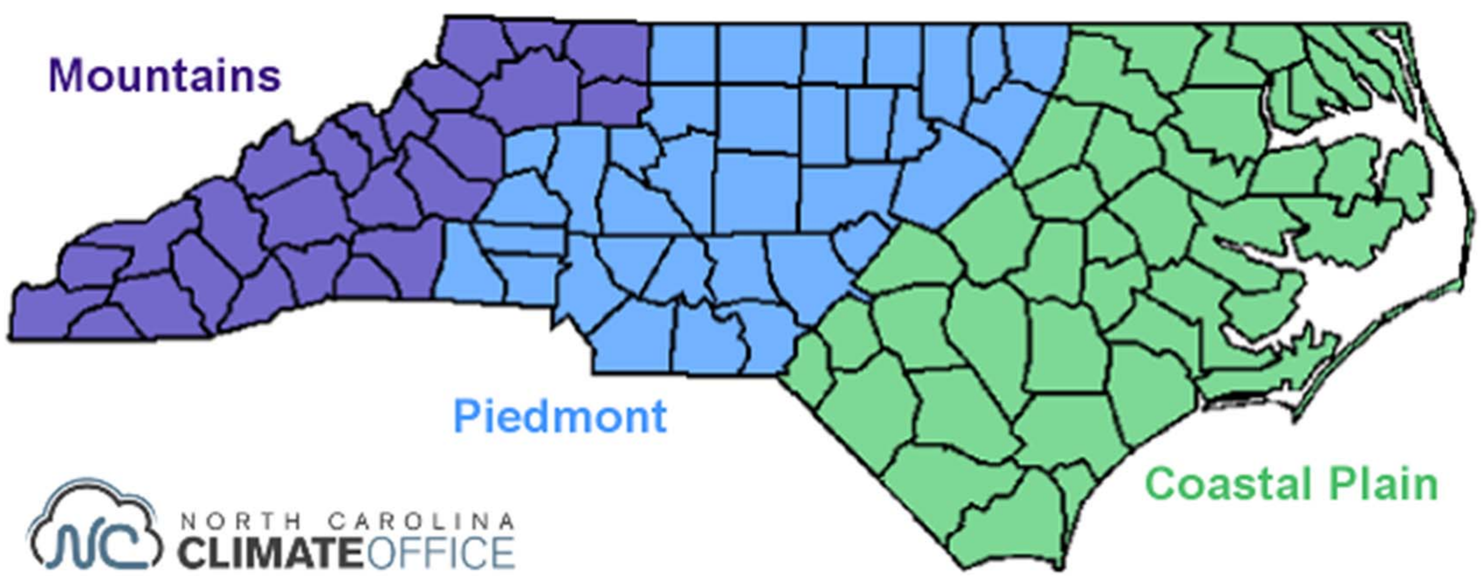


http://southernspaces.org/blog/bulletin%E2%80%94november-29-2012

1770

http://allthingsliberty.com/2013/01/life-in-the-southern-colonies-part-1-of-3/

NC Coastal Plain: 41 Counties



State Climate Office, http://climate.ncsu.edu/images/blog/2014ClimateReview/nc_regions.png

Outline

- Physically, what is the coastal plain? → Geology
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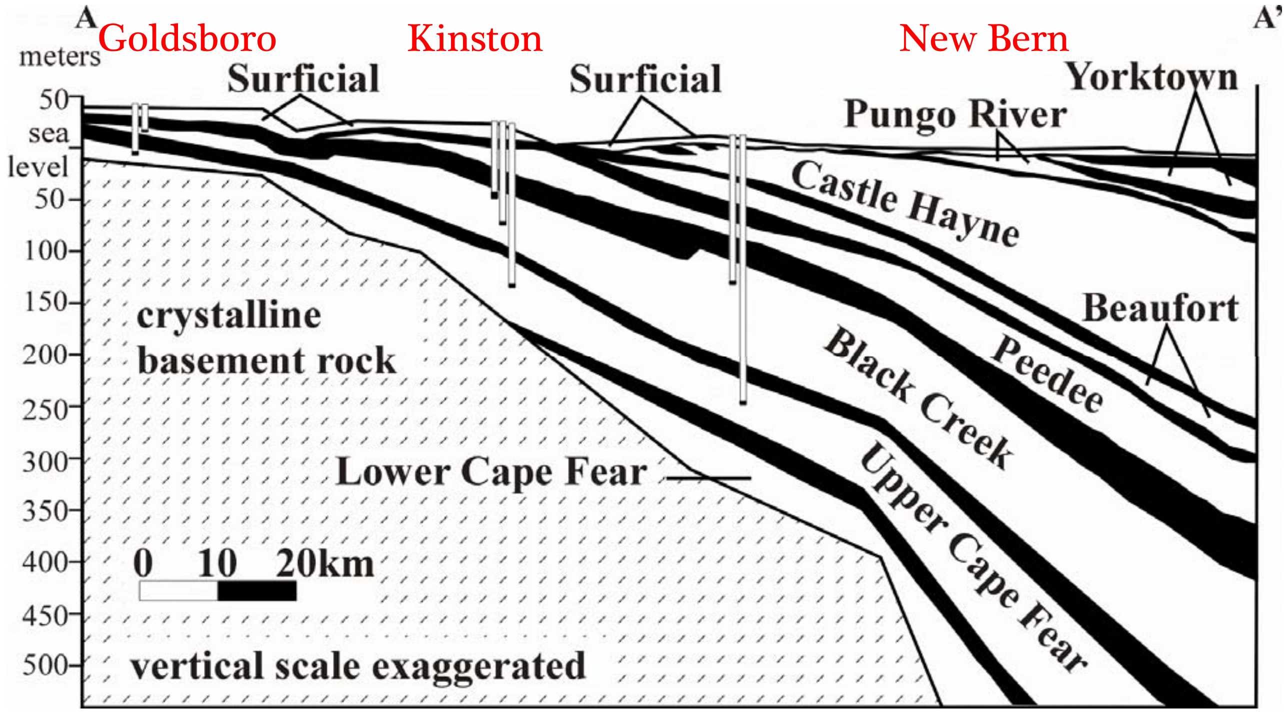
Coastal Plain Geology: A Big Wedge of Sediment

- Wedge-shaped accumulation of sediment (emerged landward portion of the Atlantic continental shelf), thickest at Cape Hatteras (3009 m), pinches out at fall line
- Surface deposits: Pleistocene and Pliocene, ≤ 5 Ma; a series of scarps, or paleo-shorelines, and intervening terraces that step down in elevation and age towards the coast, incised by rivers (7) cutting through toward the coast; complex assemblage of marine, barrier island, estuarine, fluvial and other deposits resulting from multiple sea level changes
- Deeper strata: Cretaceous and earlier pre-Pliocene Tertiary (144-5 Ma) marine deposits; form alternating aquifers and aquitards that dip and thicken coastward

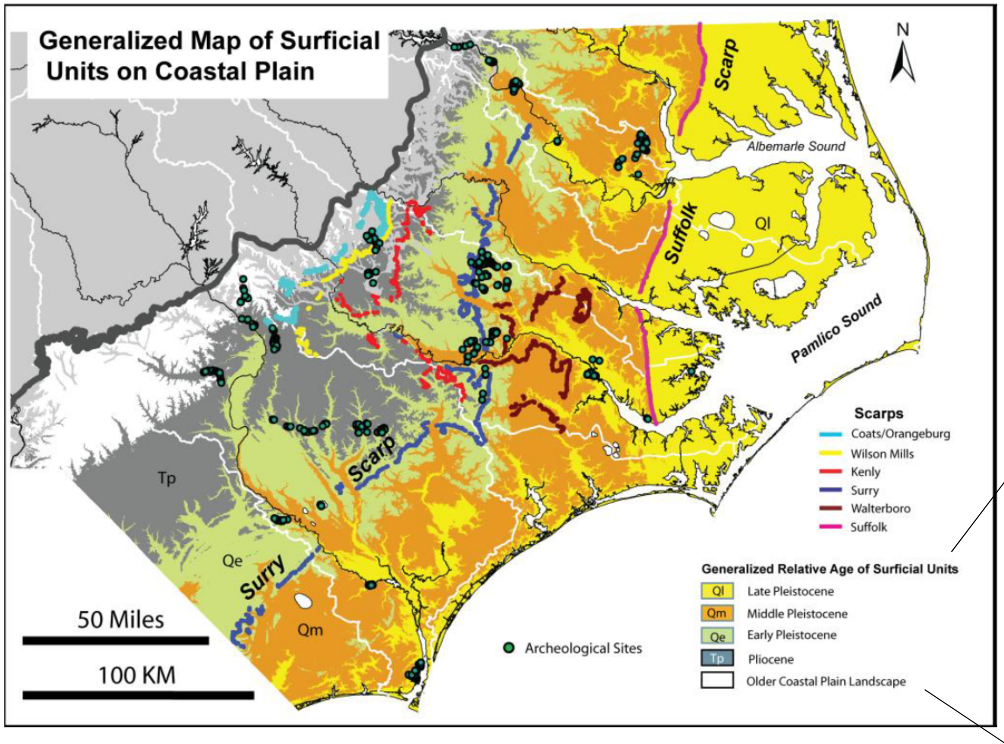
Abbott, L.E., K.M. Farrell, J.G. Nickerson, & N.K. Gay, 2011, http://www.rla.unc.edu/NCAC/Publications/NCAC30/index.html

East-West Coastal Plain Cross Section



Kennedy, C.D., and D.P. Genereux, 2007, *Radiocarbon*, 49(3): 1181-1203; modified from Giese, G.L., J.L. Elmers, and R.W. Coble, 1997, USGS Professional Paper 1404-M

Coastal Plain Surficial Deposits and Scarps



From young to old:
Late Pleistocene
Middle Pleistocene
Early Pleistocene
Pliocene
Older (pre-Pliocene)

Abbott, L.E., K.M. Farrell, J.G. Nickerson, & N.K. Gay, 2011, http://www.rla.unc.edu/NCAC/Publications/NCAC30/index.html

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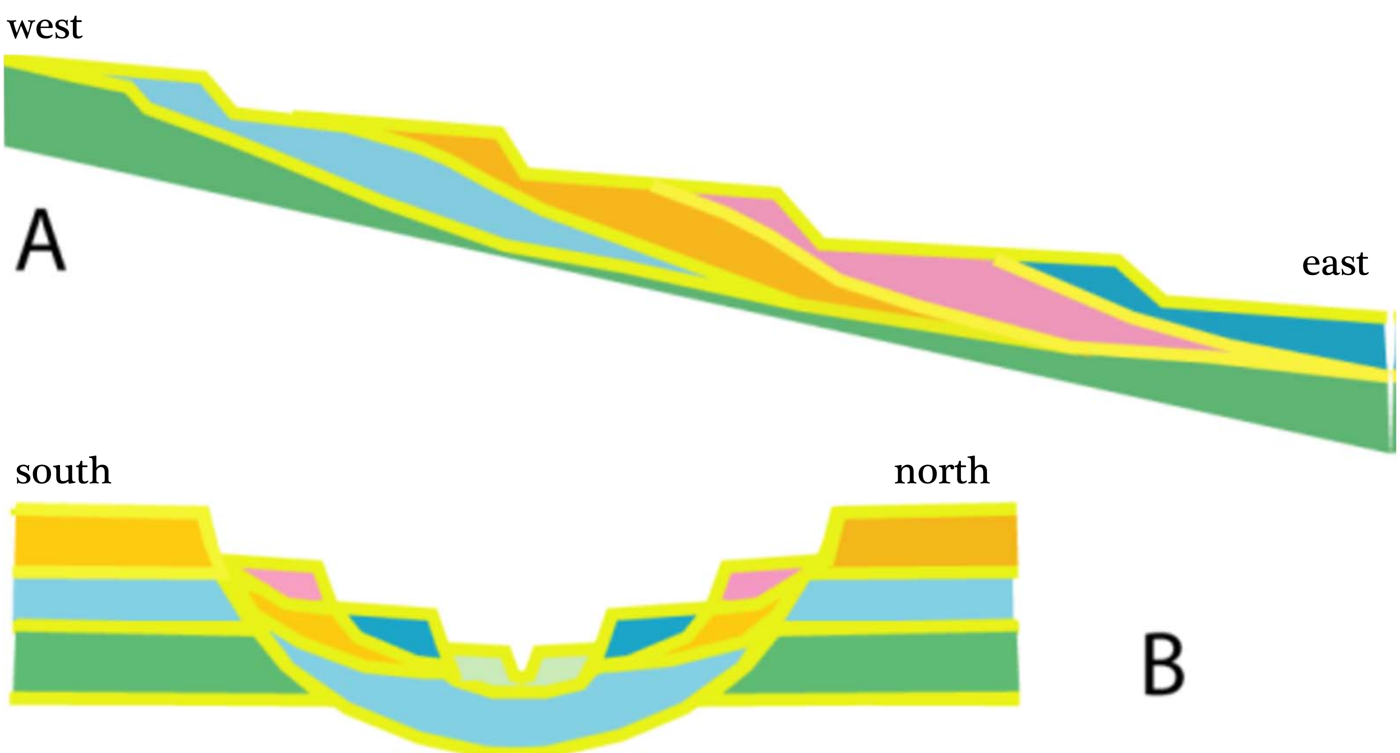
Coastal Plain Surficial Deposits



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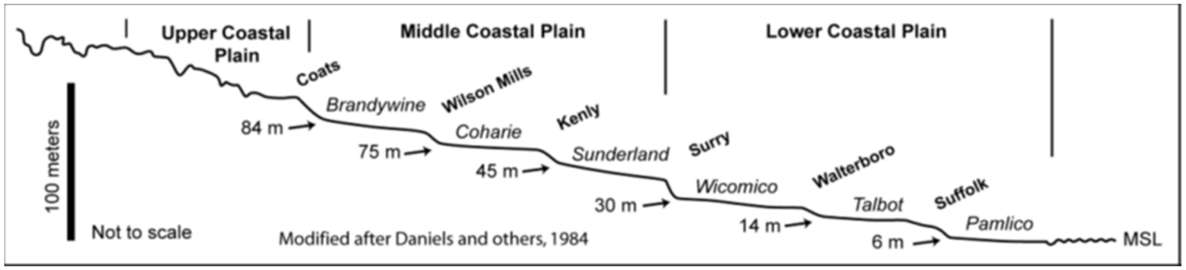
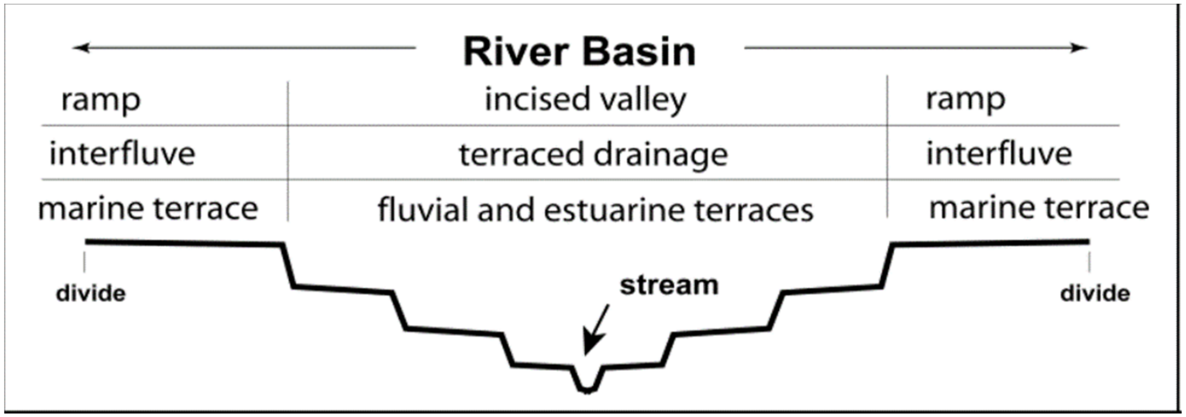
Coastal Plain Geomorphology





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Black Creek Confining Layer and Aquifer, LaGrange, NC

- Many coastal plain deposits include peat, lignitized logs and other plant matter, dispersed solid organic matter, glauconite (marine clay with reduced iron)
- Geological perspective on a modern-day ecosystem service: <u>denitrification</u> (nitrate $\rightarrow N_2$)

Brittany, France

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Brittany, France

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People in the NC Coastal Plain

- Coastal plain is 41 counties, 45% of NC land area, has 28.3% of NC population (2,818,353 of 9,944,000, 2014 US Census)
- Population growth was 2.8% from 2010 to 2014, slower than for NC as a whole (4.3%)
- Population dropped in some counties, 2010 to 2014
- 60% of people live in 10 of the 41 counties: Cumberland (#1, includes Fayetteville), New Hanover (#2, includes Wilmington), Brunswick, Craven, Harnett, Johnston, Onslow, Pitt, Robeson, and Wayne

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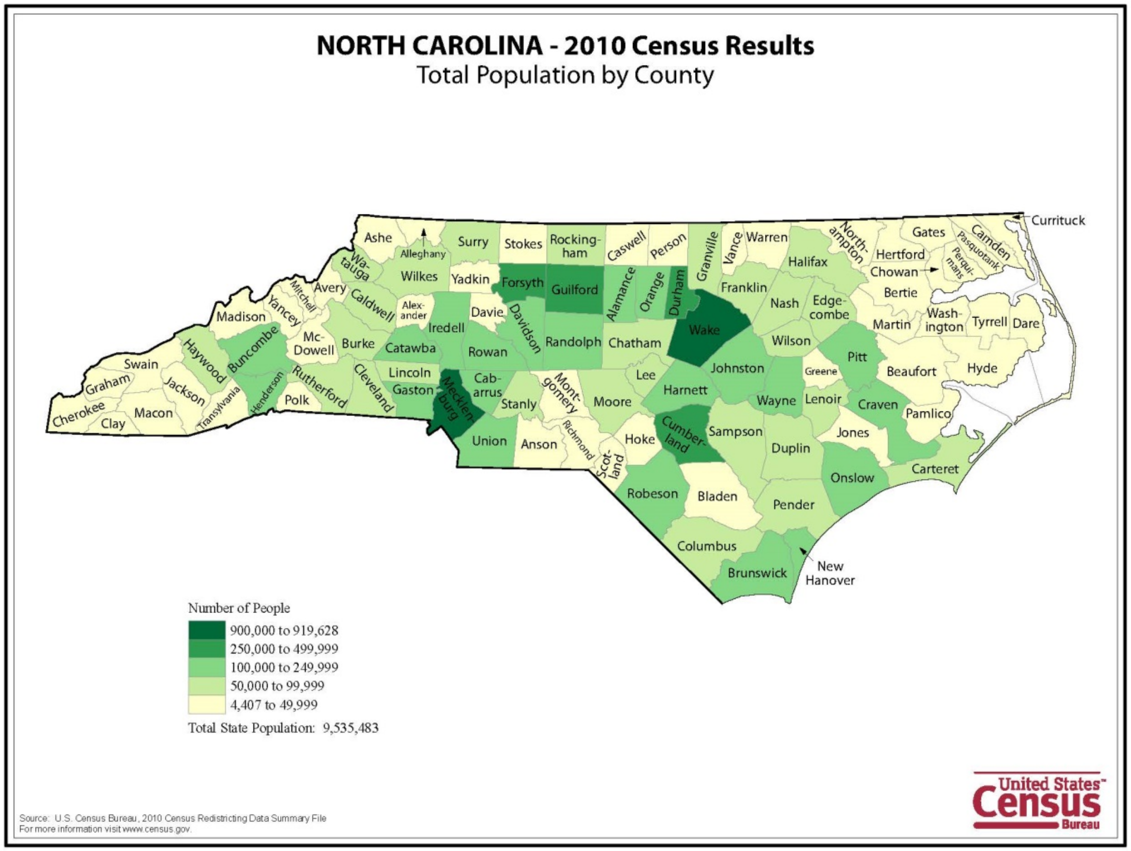
NC Population 2010



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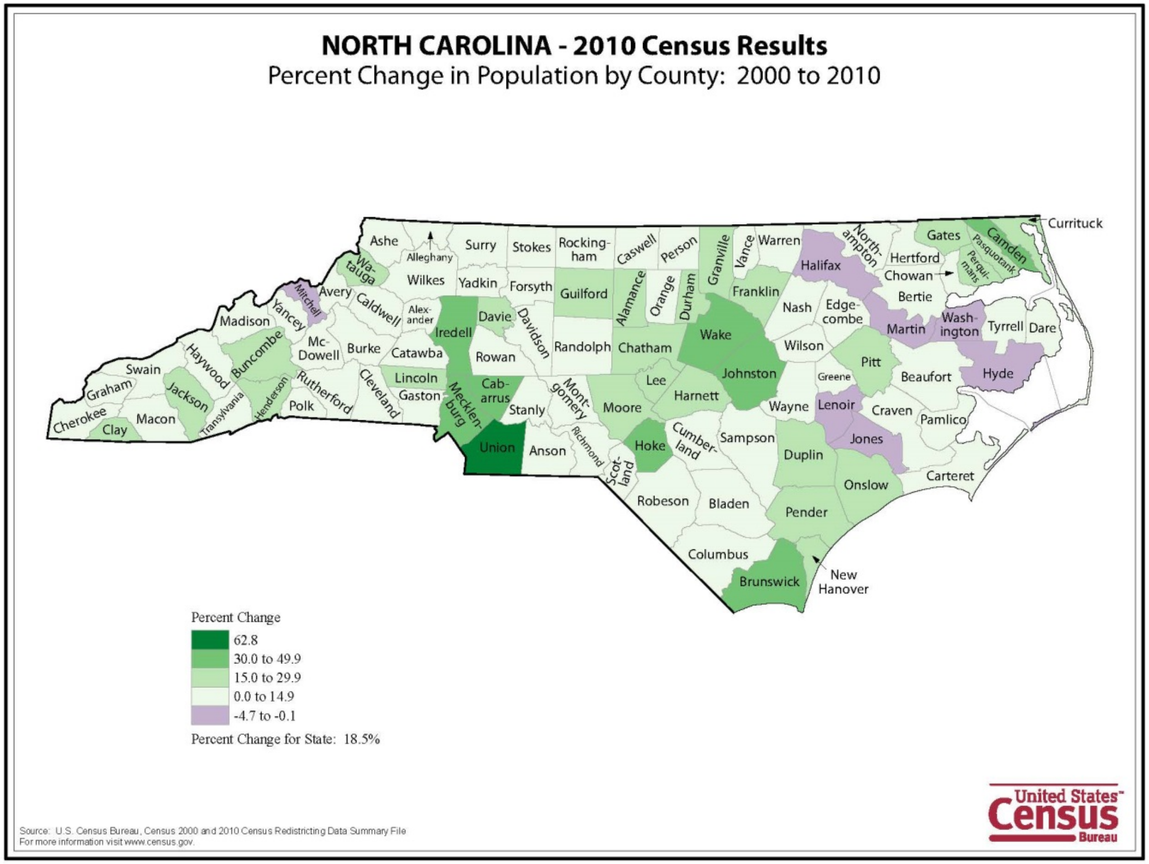
NC Population 2010



Farm Animals in the NC Coastal Plain

- >8,139,000 hogs in coastal plain on Dec. 1 2014, 3 hogs per person in coastal plain, 93% of NC hogs are in coastal plain
- >23,330,000 turkeys produced in coastal plain in 2014, 81.9% of NC total
- >362 million broilers produced in coastal plain in 2014, 45.5% of NC total
- >1,447,600 layers in coastal plain on Dec. 1 2014, 10.0% of NC layers
- >143,600 cattle in coastal plain on Jan. 1 2015, 18.0% of NC total (cattle most widespread farm animal, at least 100 head in 98 of 100 NC counties)

http://www.ncagr.gov/stats/coest/Index.htm

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Net Precipitation, P - ET

- Average coastal plain precipitation about 50 inch/yr (127 cm/yr) corresponds to 52070 MGD
- Average coastal plain evapotranspiration about 85 cm/yr corresponds to 34848 MGD
- P – ET = 17222 MGD (about 1.7 million  per day)
- Annual water use in coastal plain (USGS 2010) is ___% of P-ET:
  - ➢1.2
  - ➢5.8
  - ➢13.7
  - ➢36.0

with input from Ge Sun (USFS/NCSU) and Ryan Boyles (SCO)

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2010 Water Use, MGD

Water use category	NC	NC coastal plain	coastal plain %
thermoelectric cooling	9020	1403	15.6
public water supply	960	308	32.1
industrial self supplied	271	224	82.7
domestic self supplied	231	62	26.8
mining	33	21	63.6
irrigation	367	182	49.6
livestock	72	50	69.4
aquaculture	1470	109	7.4
TOTAL	12424	2359	19.0

45% of land, 28% of people, only 19% of water use

USGS 2010 data, http://water.usgs.gov/watuse/

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Groundwater vs. Surface Water, NC Coastal Plain

- Groundwater is 22.3% of water use in the coastal plain (5.9% in NC)
- Changing? Yes, sw use is down, but gw use went down faster

	2005	2010	% change
gw, MGD	482	431	-10.6
sw, MGD	2030	1929	-5.0
total, MGD	2512	2360	-6.1
gw/total, %	19.2	18.3	

USGS 2010 data, http://water.usgs.gov/watuse/

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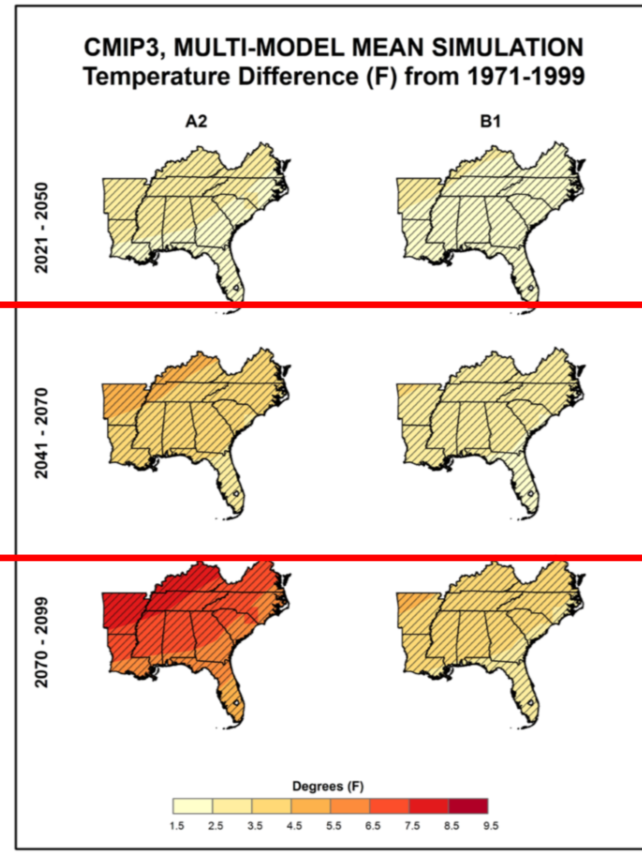
  - Climate: hotter, precipitation more variable
  - CCPCUA: water levels are recovering in overused deep aquifers
  - Pollutant flux through aquifers to surface water: timing, outlook for future, novel measurement/monitoring

Climate: Temperature

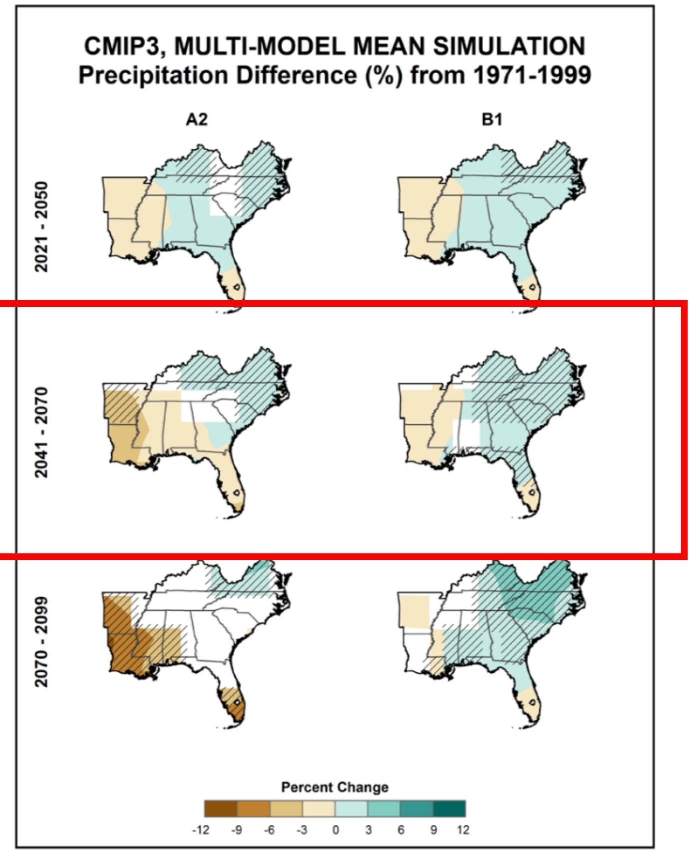
- Last hundred years: hotter in 1930s and 50s, cooler in 60s and 70s, warmer since; increasing frequency of minimum daily temperatures exceeding 75°F (number of day when it never really cools off)
- Outlook for mid century (2041-2070): mean annual temp expected to rise 2.5-4.5°C in NC coastal plain; biggest increase in summer (4-4.5), smallest in spring or winter (2.5-3); number of days with T>95°F will go from 10-20 to 30-40



Kunkel et al. 2013, NOAA Technical Report NESDIS 142-2

Climate: Precipitation

- Last hundred years: upward trend in fall, downward trend in summer, no trend in annual; increased variability, more exceptionally wet and dry summers, more frequent extreme events; snowfall has dropped by 1% per year since late 1930s
- Outlook for mid century (2041-2070): 0-3% increase in annual precip in NC coastal plain, larger increases in spring and fall, small increase or decrease in summer; 10-15% increase in number of days with >1 inch precip



Kunkel et al. 2013, NOAA Technical Report NESDIS 142-2

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Climate: Broad Outlook

- water less available, especially in summer?
- about same total precip, hotter temps raise potential ET
- more large rain events lead to more runoff, more erosion and floods, less recharge

Water-Related Farm Vulnerabilities

- Crops: higher water stress and reduced photosynthetic efficiency in hotter summers, more extremes of drought and flood damage; reduced yields (corn yield ↓4.6% for each 1°F ↑ in average growing season temperature)
- Animals: "Significant effects on beef cattle survival occur with continuous temperatures above 90°F... Water availability is expected to become a major issue in southeastern livestock-intensive operations such as poultry production. Currently, securing water for the purpose of cooling chicken houses is a significant cost in places…"

  "Severe storms could cause power failures leading to catastrophic livestock loss, as well as treatment lagoon and shelter flooding."

McNulty et al., 2015, Southeast Regional Climate Hub Assessment of Climate Change Vulnerability and Adaptation and Mitigation Strategies, USDA, http://www.climatehubs.oce.usda.gov/sites/default/files/Southeast%20Vulnerability%20Assessment%20Final.pdf

Water-Related Farm Adaptations

- Crops:
  - More irrigation, e.g., for cotton, corn, soybeans, "Adaptive management practices may include the initiation of field irrigation through traditional center-pivot systems or more water-efficient drip irrigation."
  - More efficient irrigation, "Improved technologies in subsurface drip irrigation, low-energy precision application irrigation, and furrow-dikes may be viable options for helping producers improve water use efficiency"
  - Other practices, e.g., soybeans are well-suited to no-till agriculture, which helps with accumulation of soil organic matter, which in turn can increase the amount of plant-available water held by the soil

McNulty et al., 2015, Southeast Regional Climate Hub Assessment of Climate Change Vulnerability and Adaptation and Mitigation Strategies, USDA, http://www.climatehubs.oce.usda.gov/sites/default/files/Southeast%20Vulnerability%20Assessment%20Final.pdf

Water-Related Farm Adaptations

- Animals:
  - "Although housing animals indoors helps minimize the effect of heat waves, management and energy costs will increase for confined-production enterprises and may require modification of shelter and more water used for cooling…"
  - "In general, intensively managed livestock systems have more potential for adaptation than crop systems, and some of these adaptations may be enabled by the use of alternative energy sources on farm (Fraisse et al., 2009)." (Will we see even more animals in the coastal plain?)

McNulty et al., 2015, Southeast Regional Climate Hub Assessment of Climate Change Vulnerability and Adaptation and Mitigation Strategies, USDA, http://www.climatehubs.oce.usda.gov/sites/default/files/Southeast%20Vulnerability%20Assessment%20Final.pdf

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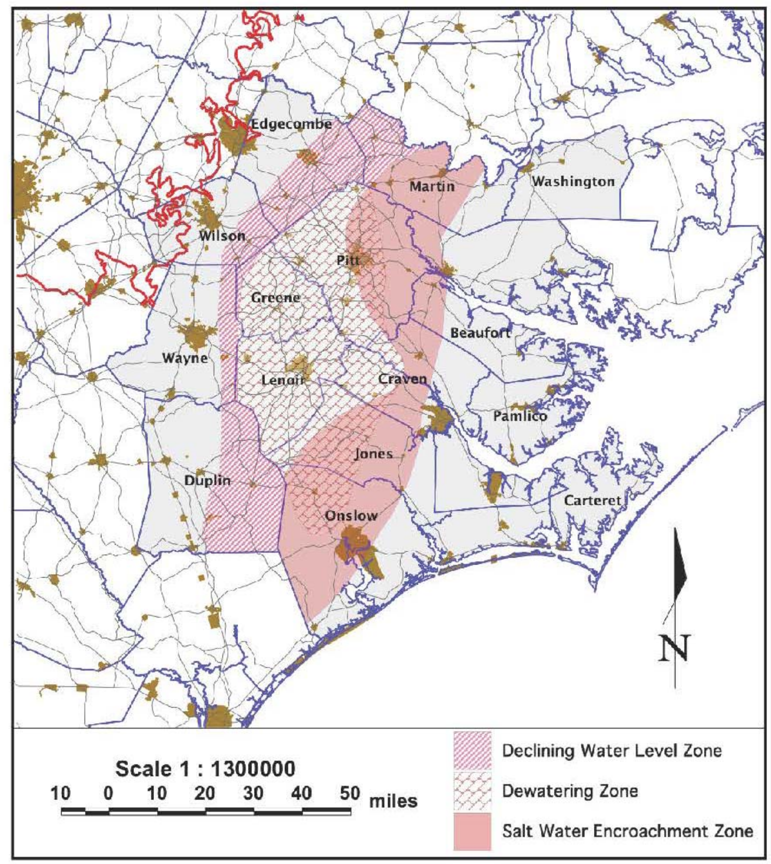
CCPCUA: Regional Groundwater Management

- Central Coastal Plain Capacity Use Area (CCPCUA): 15 county area with water use permitting requirements designated in August 2002 (use of $>10^4$ gal/day, gw or sw, requires annual registration, and use of $>10^5$ gal/day of gw requires a permit)
- In part of CCPCUA, users required to reduce Cretaceous aquifer water withdrawals by 30-75% from 2002 to 2018 (water levels were down >100 ft in some places)

CCPCUA Cretaceous Aquifer Zones



Can old groundwater bounce back?

- At Kinston and further east, groundwater in the Black Creek and Upper Cape Fear aquifers is 14,000-26,000 years old (Kennedy and Genereux 2007, ^{14}C dating)

- Is the depletion of this groundwater like mining a non-renewable resource?
- Depends; do water levels recover under reduced pumping?

CCPCUA: Recovery of Cretaceous Aquifers

- First required reductions in pumping from deep confined Cretaceous aquifers were in 2008
- From 2007 to 2015, permitted and registered groundwater withdrawals dropped 20% (34.3 MGD) in the CCPCUA, and 45% (21.5 MGD) in the Cretaceous aquifer system
- Groundwater from Cretaceous aquifers went from 27% to 18% of total permitted/registered groundwater withdrawals
- Water levels have recovered over 50 ft in some places, in only 8 years (pressure moves through aquifers a lot faster than does water…)

http://www.ncwater.org/?page=49&menu=Home

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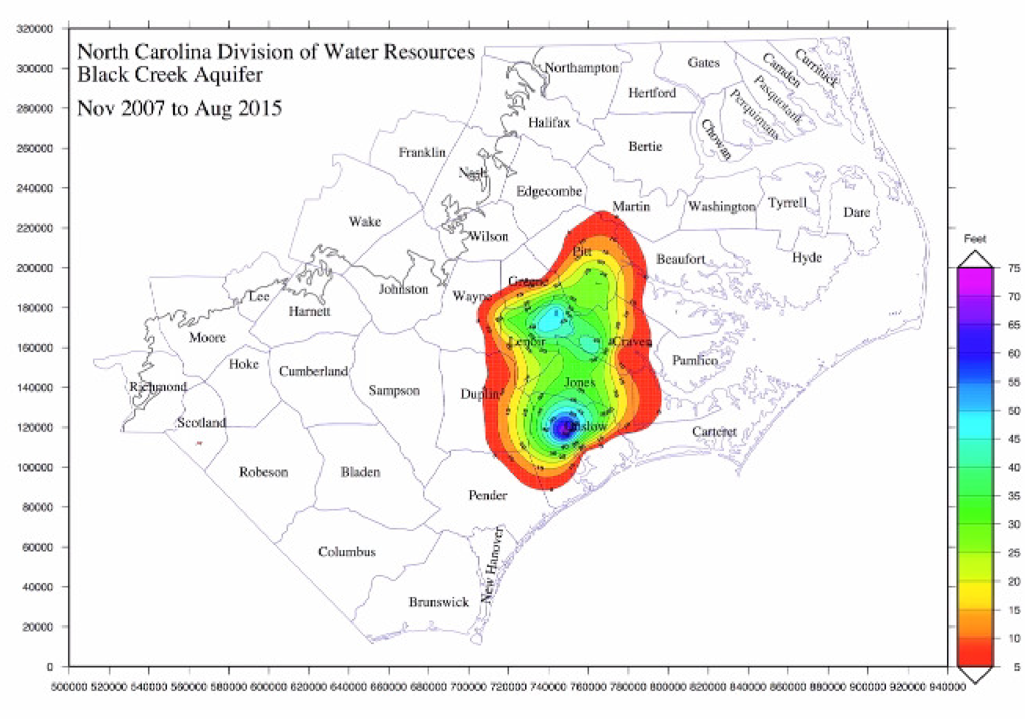
Recovery of Black Creek aquifer, 2007-2015



http://www.ncwater.org/Permits_and_Registration/Capacity_Use/Central_Coastal_Plain/Recovery/BC_Recovery_18.m4v

CCPCUA: "Replacement" sources

- More use of surface water, and shallow groundwater
- Requires vigilance regarding water quality
- Potential upstream sources of chemicals and resultant exposure (Detlef Knappe, noon presentation today)
- Shallow groundwater has a variety of point- and non-point-source pollutants

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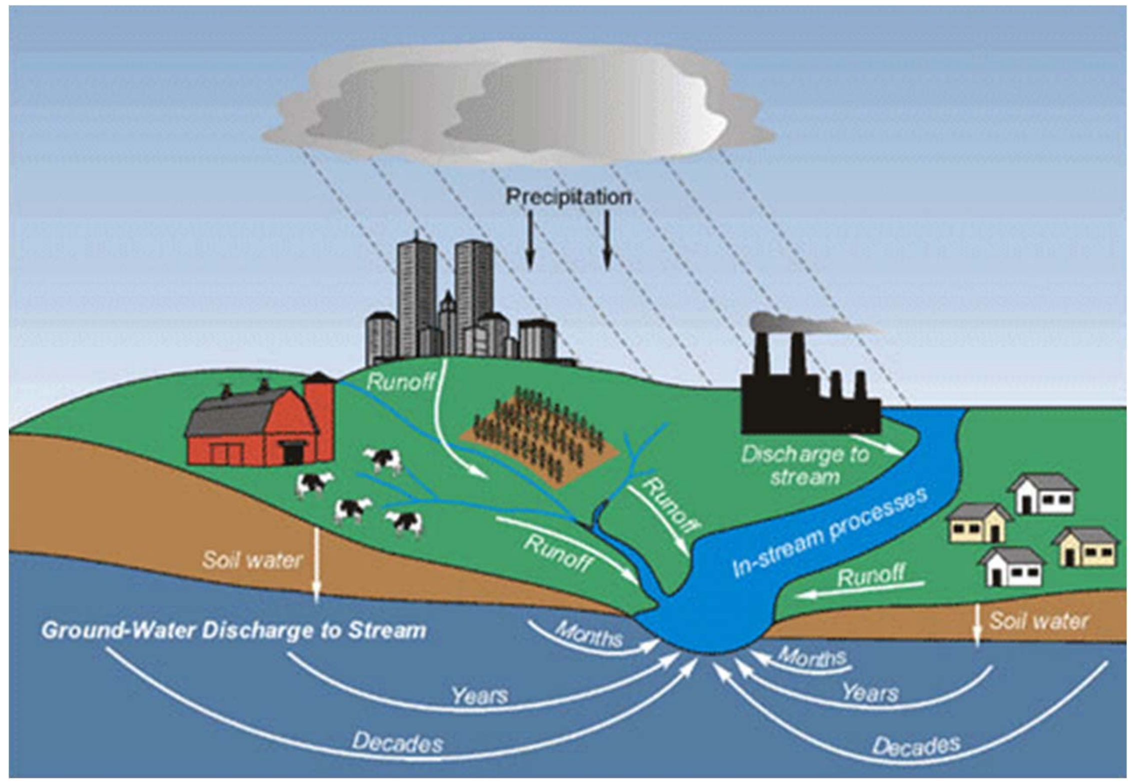
Pollutant Movement through Aquifers to Streams

The obvious stuff:

- It's slow
- Long lag time between pollutant input to aquifer and output to stream
- Wide range of time lags ("transit times" from recharge to discharge)



http://www.chesapeakebay.net/issues/issue/groundwater

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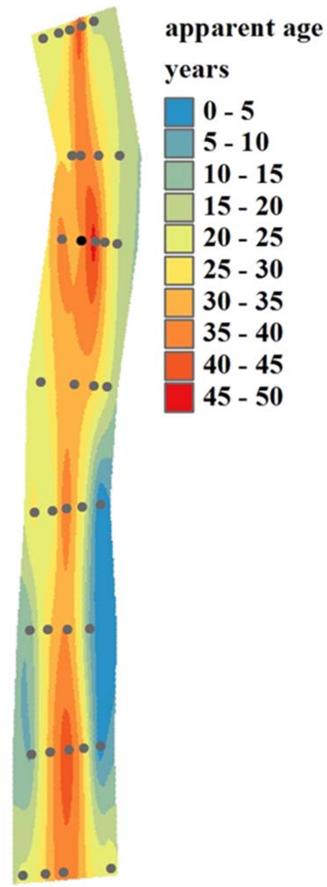
The Age of Groundwater Discharging into West Bear Creek, NC



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Replicate Estimates of Groundwater Mean Transit Time (MTT) at West Bear Creek, NC

Spatial arrangement	# of age values	Month	Location in West Bear Creek	Tracer	MTT
seven 3-point transects	21	April 2007	613 m to 688 m	CFC-12	**30 yr**
eight 5-point transects	34	July 2012	466 m to 524 m	$^3H/^3He$	**29 yr**
six 5-point transects	23	March 2013	300 m to 2530 m	$^3H/^3He$	**31 yr**
two 3-well nests	6	June 2013	near West Bear Cr.	$^3H/^3He$	**32 yr**

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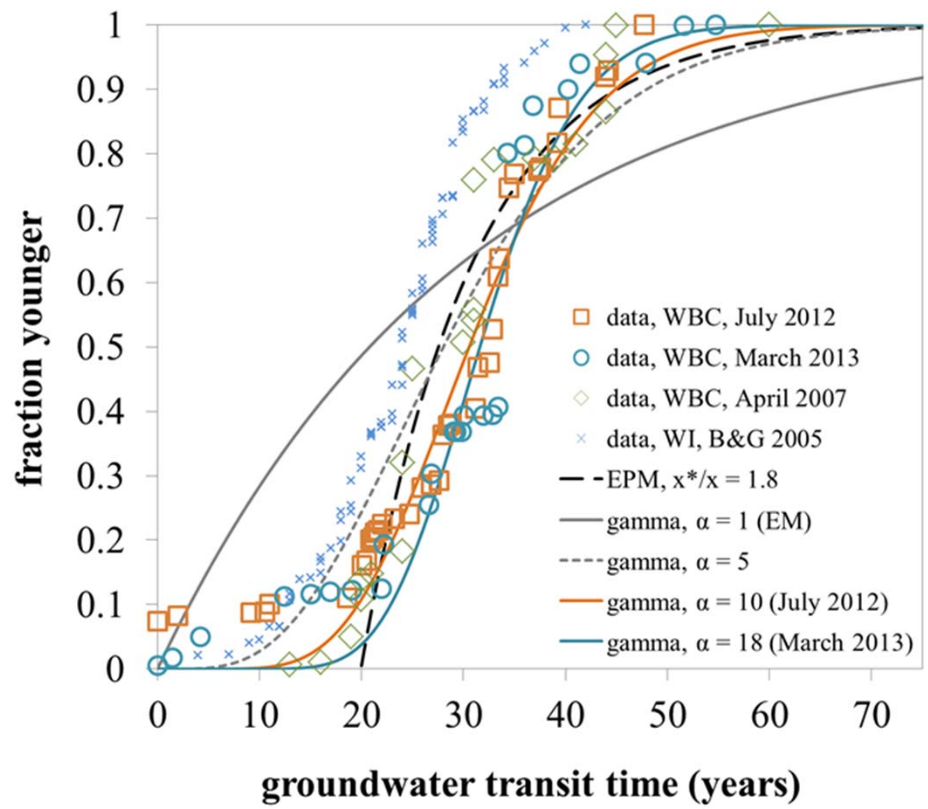
Groundwater Transit Time Distributions (TTDs)

(based on sampling beneath streambeds)



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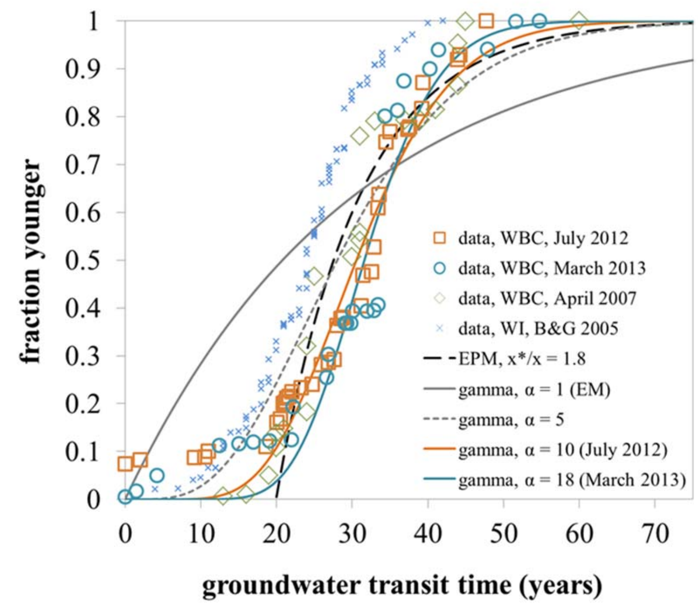
Groundwater Transit Time Distributions (TTDs)

(based on sampling beneath streambeds)

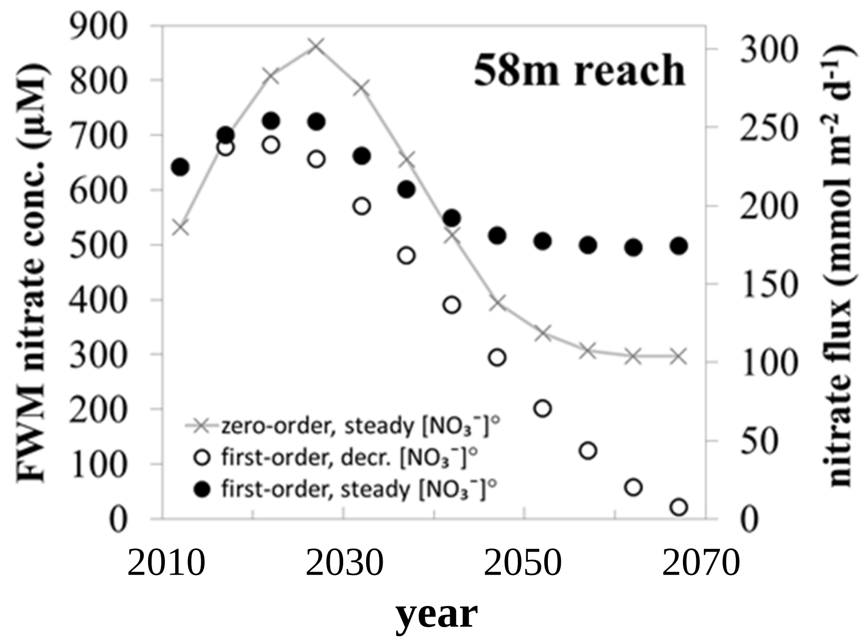
Compared to idealized completely uniform aquifer, pollutant output from real aquifer responds to a change in input:

- More slowly at first
- More rapidly in mid-range (20-40 yr)
- More completely by ~60 yr (no long tail approaching or exceeding a century)



Future Nitrate Output from Aquifer to Stream

- Use only streambed sampling results (gw age, flux, and nitrate concentration)
- No complex numerical models or long-term monitoring data
- Scenarios based on future nitrate concentration in recharge, and rate law (zero- or first-order) for aquifer denitrification kinetics



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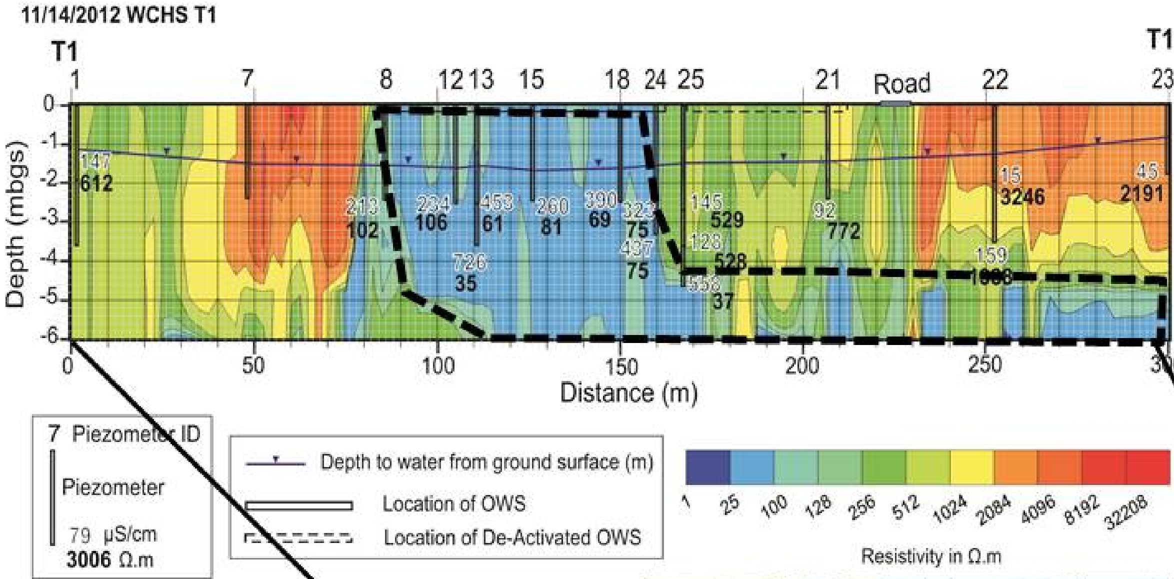
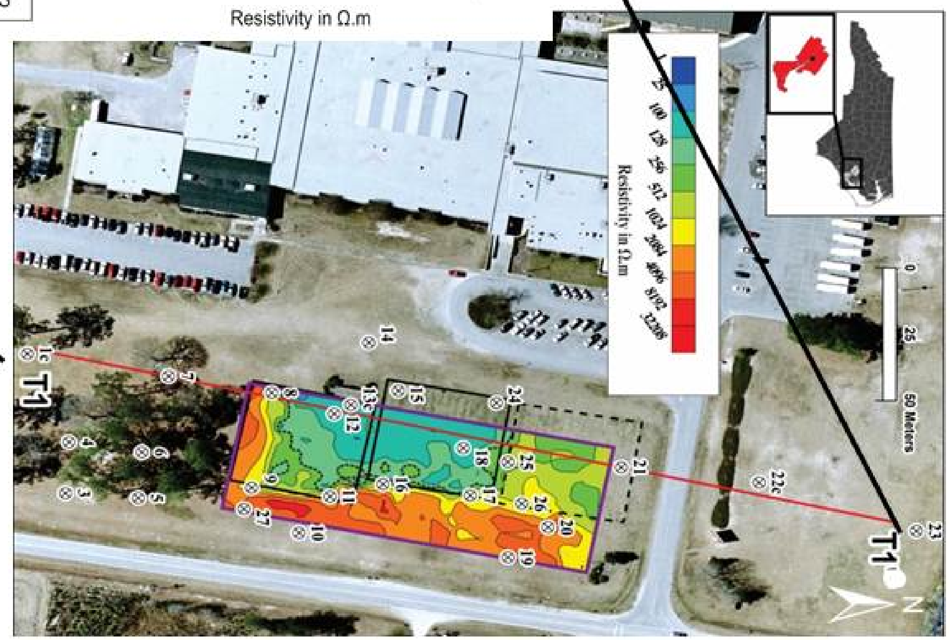
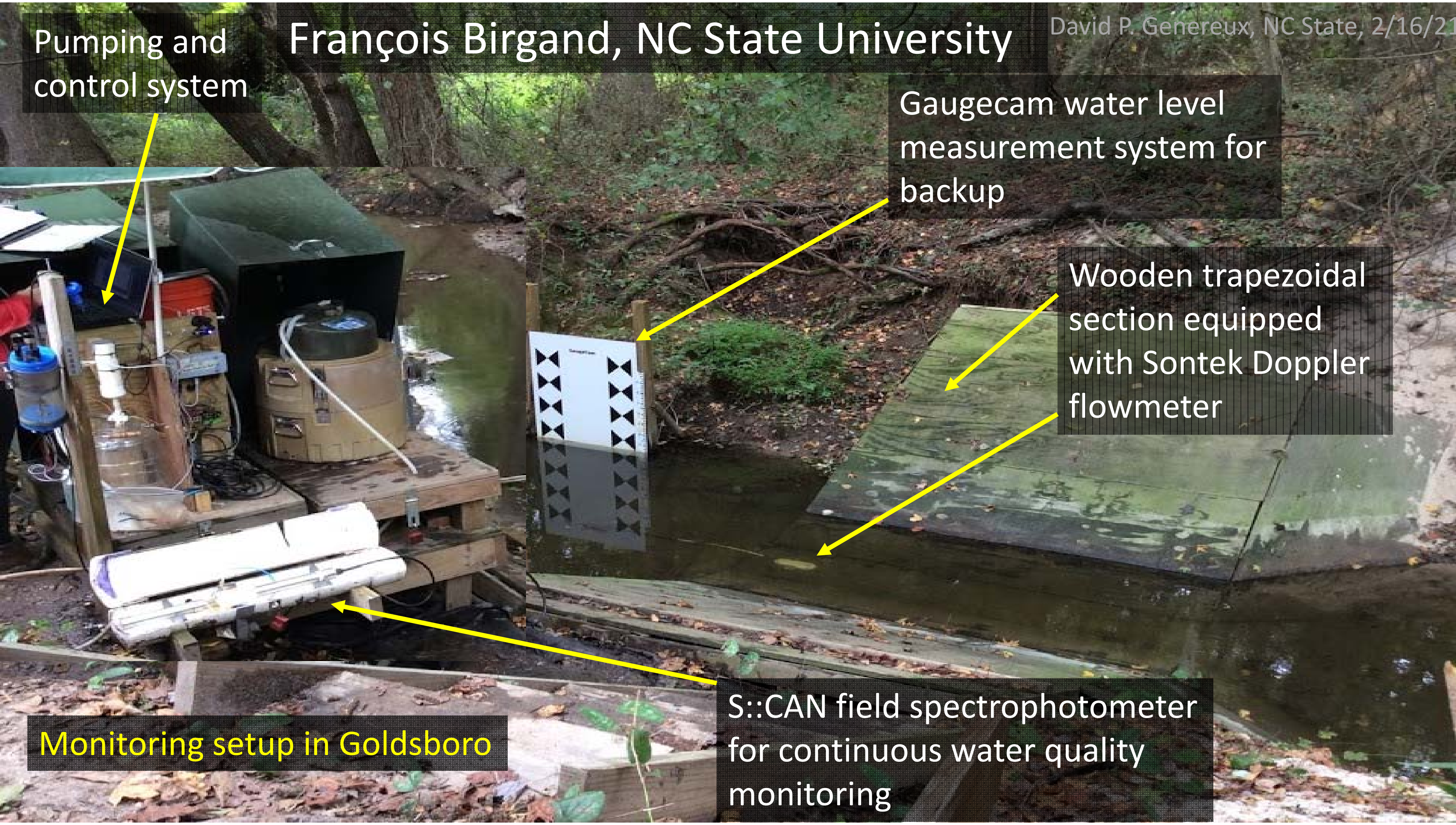


Approximate location of wastewater plume indicated by low resistivity (blue)

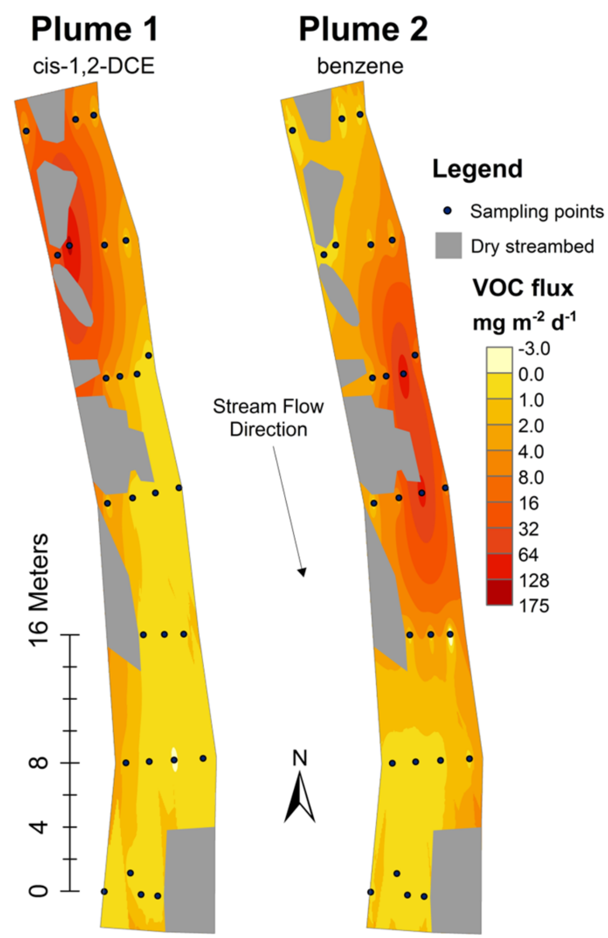


Wastewater Plume Delineation using Electrical Resistivity, Craven County, NC
(courtesy of Mike O'Driscoll, ECU)


François Birgand, NC State University
David P. Genereux, NC State, 2/16/2
Pumping and control system
Gaugecam water level measurement system for backup
Wooden trapezoidal section equipped with Sontek Doppler flowmeter
S::CAN field spectrophotometer for continuous water quality monitoring
Monitoring setup in Goldsboro

VOC Flux from Groundwater to Stream

- VOC = volatile organic compound
- Hominy Swamp Creek, Wilson, NC
- Two distinct groundwater contaminant plumes (enter streambed at different locations, with different VOCs)
- Water samples analyzed in Dr. Knappe's lab at NC State
- VOC loss from aquifer~1 kg/yr



Lisa Babuin, NC State

Understanding the Coastal Plain: Giving Context to Regional Challenges

- There are a lot of people growing a lot of food and using a moderate amount of water on a big wedge of sediment in a warming climate
- Things are changing (as they always have)
- We're capable of adapting
- Fortunately, no shortage of smart people with insights to show the way forward
- Let's hear the rest of the talks!

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