Existing Data for Evaluating Coastal Plain Ecological Flows in the Albemarle-Pamlico Basin

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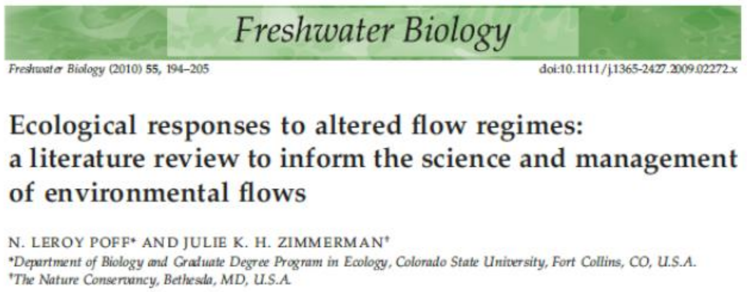
APNEP Coastal Ecological Flows Action Team

Outline

- Why is coastal ecological flow assessment needed?
- Defining ecological flows and past work
- What data is out there for this effort?
- What are challenges/limitations based on the data availability?
- What aspects require more research and future efforts?

Why is coastal ecological flow assessment needed?

- Flow alterations have been shown to affect fish and macroinvertebrates.
- Recent evidence suggests that groundwater inputs and low flows may be declining along many Coastal Plain rivers.
- Population and economic growth in the Coastal Plain (and Piedmont) suggest we will need more water in the future presumably leading to less instream flows.
- Changes in climate, land use, and water use may affect streamflow and water quality.
- Based on Session Law 2010-143, DEQ is required to develop basinwide hydrological models for each of NC's 17 river basins to predict the places, times, and frequencies at which ecological flows may be adversely affected in North Carolina (NC DEQ 2013).
- NC ecological flow efforts in the Piedmont didn't cover the majority of the Coastal Plain, these streams may differ based on low slope, tidal influence, and salinity.


Freshwater Biology

Freshwater Biology (2010) 55, 194–205 doi:10.1111/j.1365-2427.2009.02272.x

Ecological responses to altered flow regimes: a literature review to inform the science and management of environmental flows

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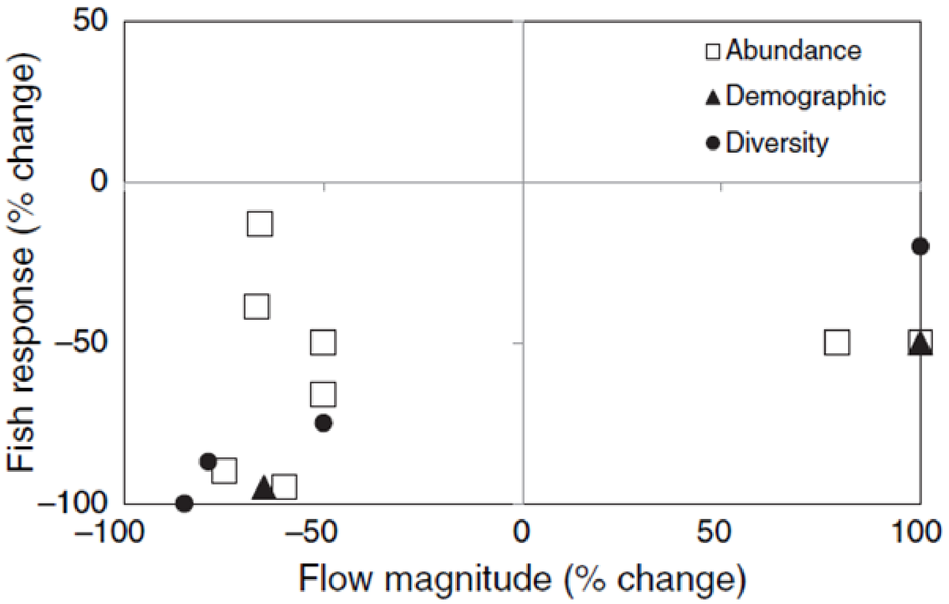


Defining ecological flows

“stream flow necessary to protect ecological integrity” (amount and timing)

ecological integrity : “the ability of an aquatic system to support and maintain a balanced, integrated, adaptive community of organisms having a species composition, diversity, and functional organization comparable to prevailing ecological conditions and, when subject to disruption, to recover and continue to provide the natural goods and services that normally accrue from the system” (NC DEQ 2013).

Session Law 2010-143 (https://www.ncleg.net/EnactedLegislation/SessionLaws/HTML/2009-2010/SL2010-143.html) was enacted in response to concerns over water availability in North Carolina.

Required NC DEQ to develop basinwide hydrological models for each of NC’s 17 river basins to evaluate if there is adequate water for all needs, essential water uses, and to predict the places, times, and frequencies at which ecological flows may be adversely affected in North Carolina (NC DEQ 2013).

Coastal streams - present particular challenges for ecological flow assessment due to the lack of streamflow data in tidal areas, flow reversals from wind and tides, spatiotemporal variability of salinity in coastal waters, and complex river-gw interactions.

Earlier Work by Coastal Ecological Flows Working Group

Summary

The low elevation, flat terrain and proximity to tidal, saline waters combine to prevent the use of current hydrologic models in the coastal plain. Different approaches to ecological flows from those described are required, although we lack detailed understanding to provide specific protocols for this region. A more general framework is recommended that categorizes coastal plain streams and identifies four ecological flow approaches to be considered based on stream category. The approaches include extension of the state-wide flow-by criteria; condition of habitat, primarily for anadromous fish; downstream salinity; and overbank flow. Each stream category may be subjected to more than one, but not all, approach. We propose that agencies and organizations within and outside of DENR form a joint committee to further develop this framework.

APPENDIX C – Recommendations for Establishing Ecological Flows in Coastal Waterways

Membership of Coastal Ecological Flows Working Group (CEFWG)

Bob Christian, ECU, chair
Eban Bean, ECU
Dean Carpenter, APNEP
Scott Ensign, AquACo
Mike Griffin, ECU
Kevin Hart, NC DMF
Mike O'Driscoll, ECU
Mike Piehler, UNC IMS
Judy Ratcliffe, Natural Heritage
Fritz Rohde, NOAA
Bennett Wynne, NC Wildlife Resources

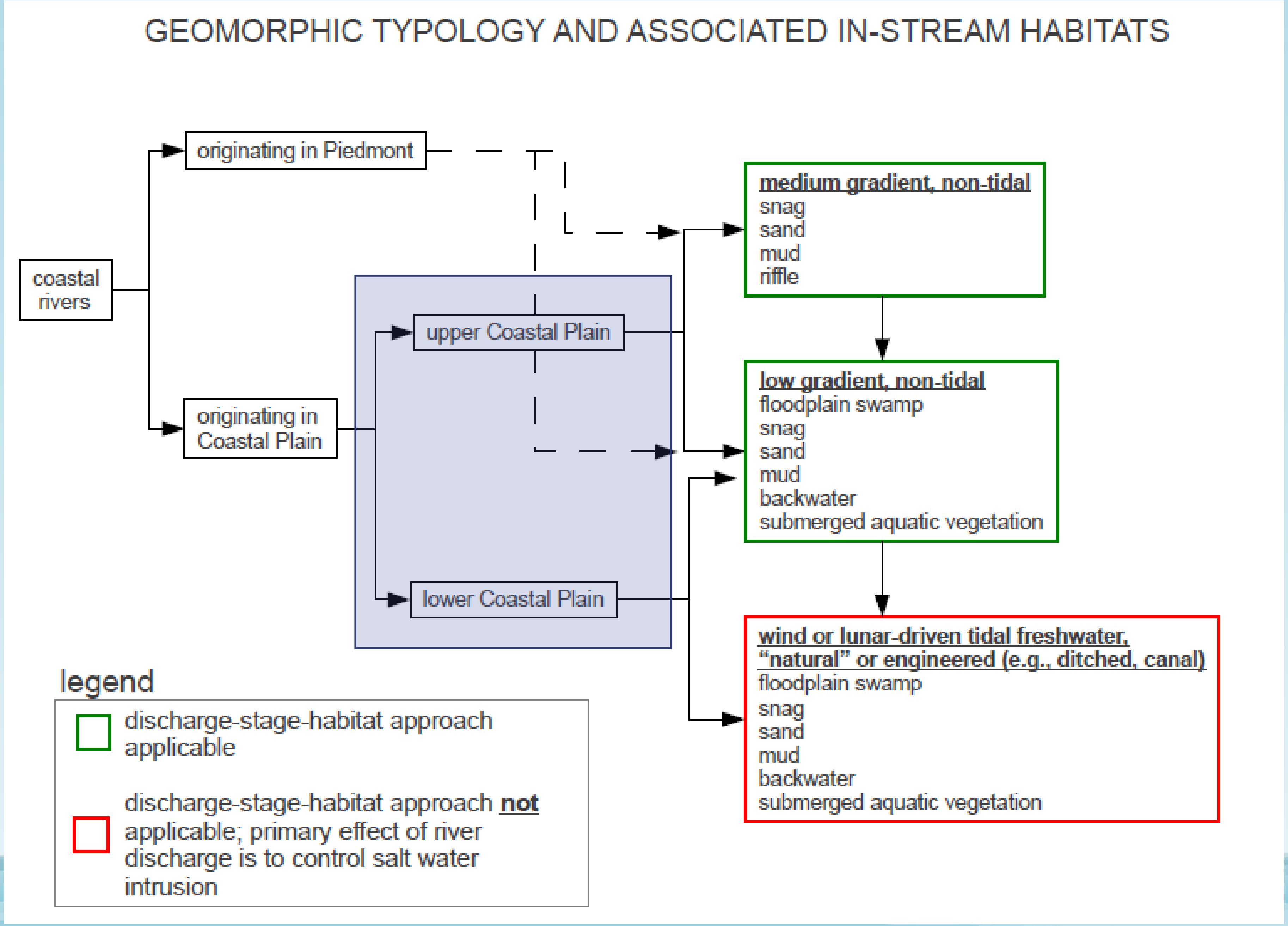
Recommendations for Estimating Flows to Maintain Ecological Integrity in Streams and Rivers in North Carolina

Submitted to the
North Carolina Department of
Environment and Natural Resources
by the
North Carolina Ecological Flows
Science Advisory Board

November 2013

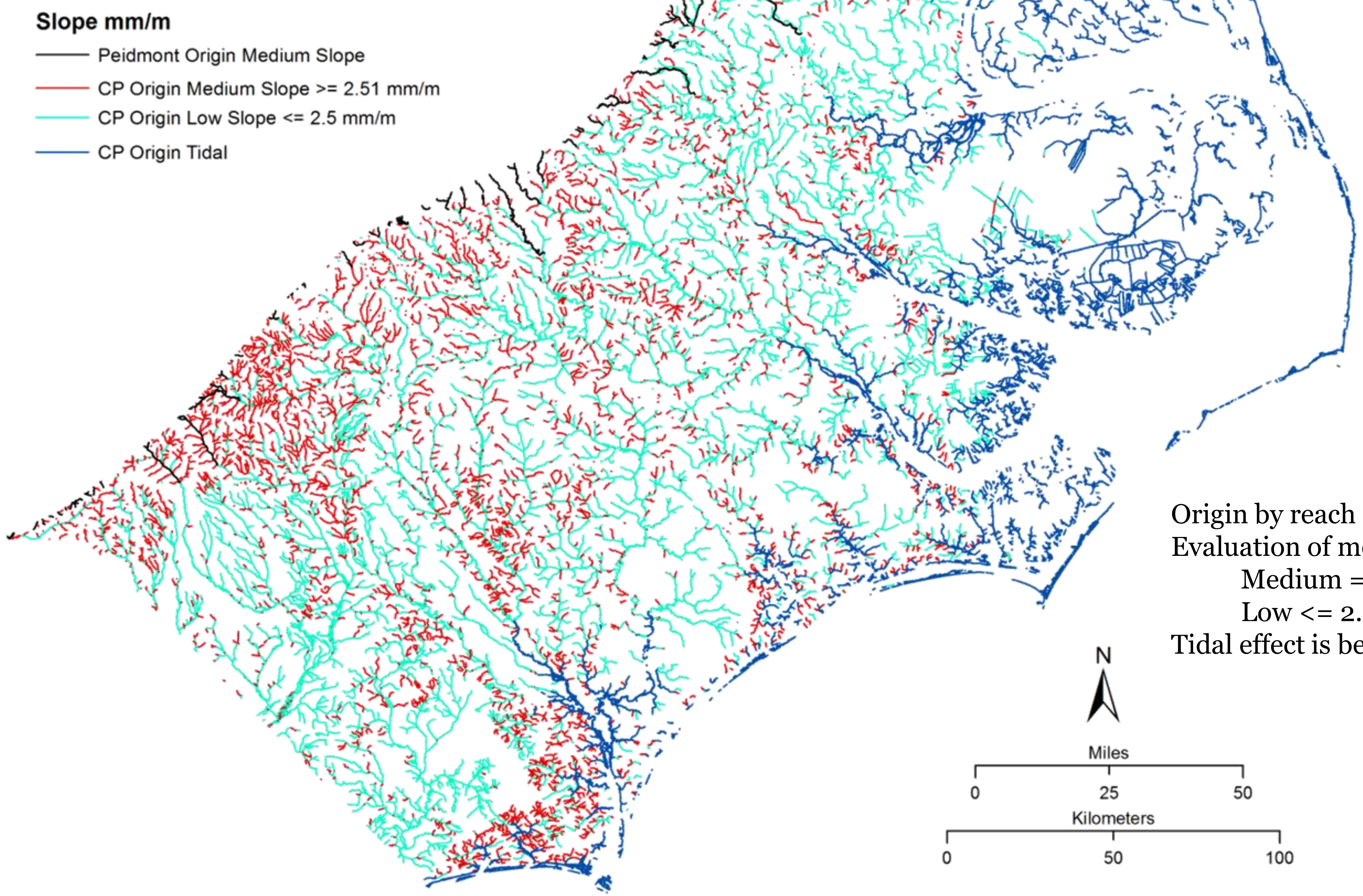
https://files.nc.gov/ncdeq/Water%20Resources/files/eflows/sab/EFSAB_Final_Report_to_NCDENR.pdf

Earlier work by Coastal Ecological Flows Working Group



by Scott Ensign

Earlier work by Coastal Ecological Flows Working Group By Eban Bean and Mike Griffin



Origin by reach

Evaluation of medium vs low slope cutoff

Medium =>2.51 mm/m

Low <= 2.50 mm/m

Tidal effect is below 1 m elevation

Recommendations from past work

NC DEQ, 2013

Suggested research within coastal systems

Considerable information is needed before a quantitative approach can be established for the coastal plain. Below is a list of research or development that would benefit this effort.

1. Determine correspondence of known discharge patterns with nearby coastal plain stream flow patterns.
2. Determine the upper-most extent of tidal influence across coastal plain.
3. Evaluate juvenile abundance indices vs. flow and salinity/conductivity.
4. Map salinity distribution across coastal plain.
5. Quantify stream typology classes.
6. Evaluate Roanoke slabshell and other mussel distributions and abundance as informative of salinity and flow patterns.
7. Determine hydrologic metrics and characteristics of coastal streams.
8. Determine reference flow regimes for each river basin.
9. Assess the balance of withdrawals from and discharges to coastal streams.

Most challenging!

Next steps….

What data is out there to support the development of Coastal Plain ecological flow guidelines for the Albemarle-Pamlico Basin?

Existing Data for Evaluating Coastal Plain Ecological Flows in the Albemarle-Pamlico Estuary Region

By Michael O'Driscoll [1,2], Ryan Bond[3], Isabel Hillman[2], Caitlin Skibiel[4], Charles Humphrey[5], and Christa Sanderford[5]

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[2]Nicholas School of the Environment, Duke University
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DRAFT submitted August 23, 2018

Albemarle - Pamlico National Estuary Partnership

Duke | NICHOLAS SCHOOL OF THE ENVIRONMENT

East Carolina University

Ecological Flow Studies in NC and Southeastern U.S.

- Included a literature review and annotated bibliography, highlights include:
- Pearsall et al (2017) summarized four articles related to developing ecological flows in NC. They found:
  - Fish guild diversity & macroinvert. richness showed negative responses to flow reductions.
  - Space-for-time approach appears valid for establishing flow-biology relationships.
  - Flow-biology relationships showed seasonality with greater sensitivity to reduced streamflow during lower flow seasons.
- Numerous studies found that anthropogenic flow alteration-> negative effects on stream biota.
- Much of the previous ecological flow work performed in other states included cooperative efforts with the USGS, Nature Conservancy, and US Army Corps of Engineers, working alongside state agencies.

Ecological Flow Efforts in other Southeastern States

Virginia Ecological Limits of Hydrologic Alteration (ELOHA): Development of Metrics of Hydrologic Alteration

Task 3 Draft Flow-Ecology Models

Task 4 Ability of Stream Classification Systems to Improve the Flow-Ecology Models

Draft Report

Prepared for:

U.S. Environmental Protection Agency, Office of Wetlands Oceans and Watersheds
1200 Pennsylvania Avenue, NW
Washington, DC 20460

and

Virginia Department of Environmental Quality
P.O. Box 1105
Richmond, VA 23218

Prepared by:

Tetra Tech, Inc.
Center for Ecological Sciences
400 Red Brook Blvd., Suite 200
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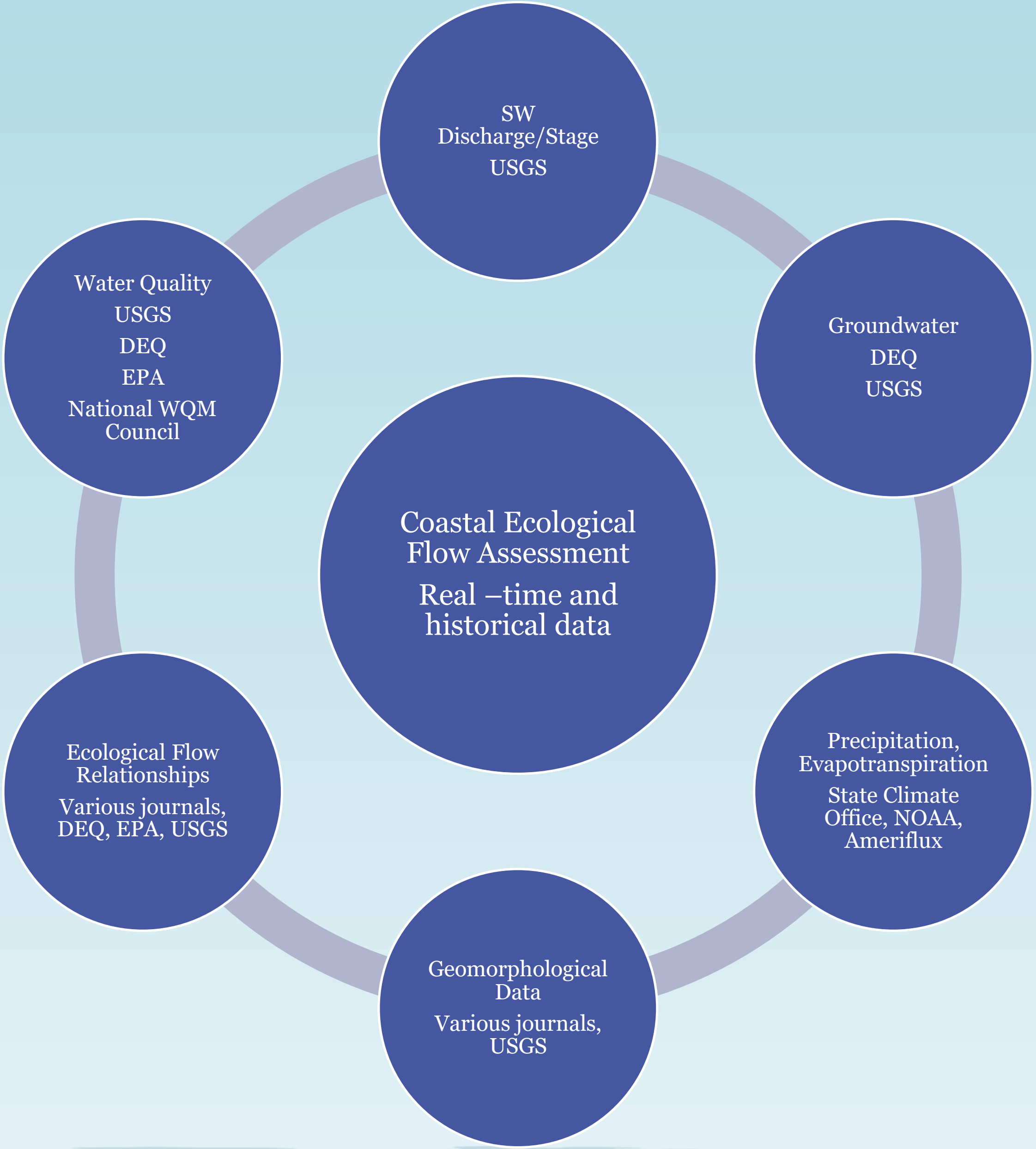
January 9, 2012

Data Needs:

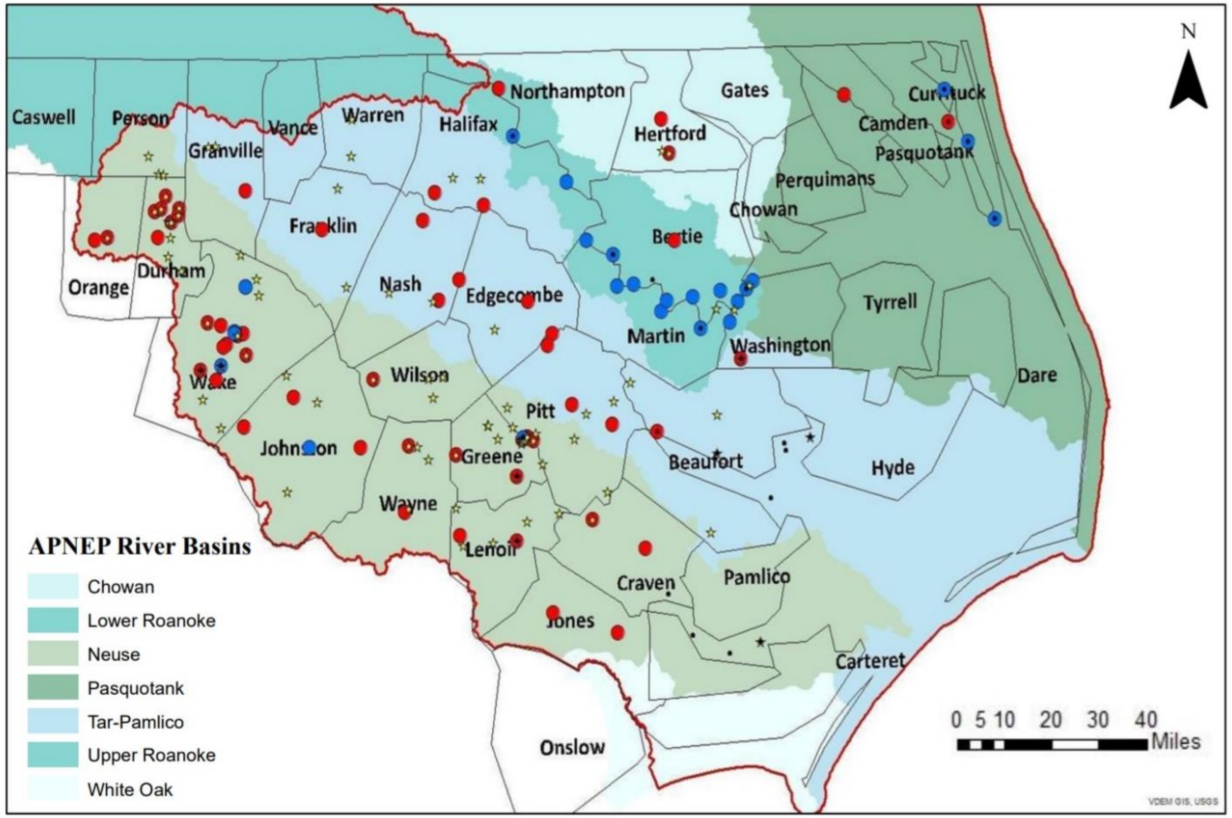
To understand reference conditions and classify streams



Data Needs:

To understand the magnitude and timing of flow alterations and ecological effects

Abundant Data (> 100 websites with water/ecological flow related data), but…. some Notable Data Gaps



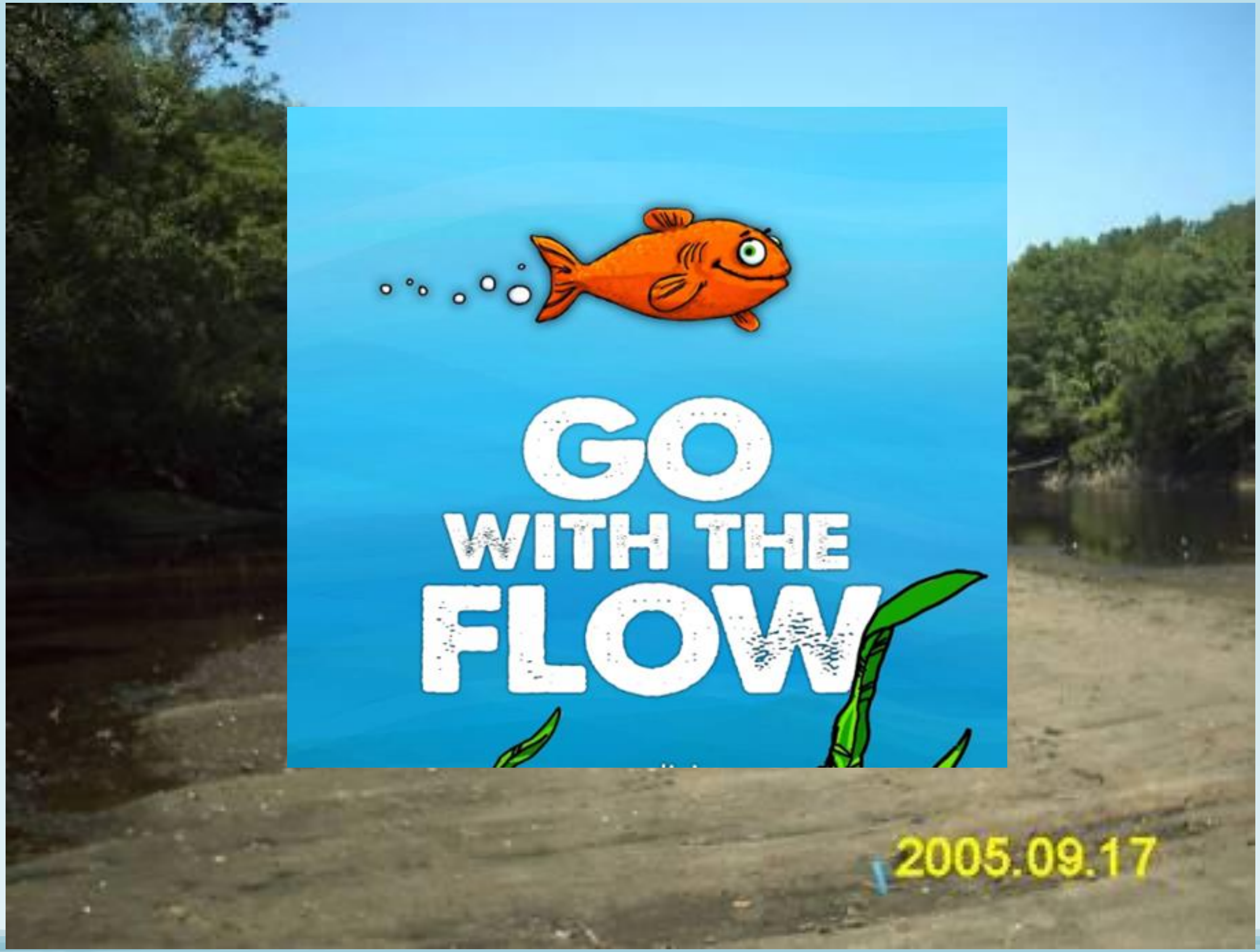
Streamflow and Stage Network- USGS

Long-term flow records:
19 currently operational gages with
➢ 30 year records

USGS station #	Station Name	Lat	Long	County	Drainage Area (mi^2)	Period of record	Years of Record
2085500	FLAT RIVER AT BAHAMA	36.182	-78.879	Durham	149	July 1925 to current	92
2085070	ENO RIVER NEAR DURHAM	36.072	-78.908	Durham	141	August 1963 to current	51
2097314	NEW HOPE CREEK NEAR BLANDS	35.885	-78.966	Durham	75.9	October 1982 to current	35
2082585	TAR RIVER AT NC 97	35.95472	-77.78722	Edgecombe	925	August 1976 to current	41
2083000	FISHING CREEK NEAR ENFIELD	36.151	-77.693	Edgecombe	526	October 1923 to current	94
2083500	TAR RIVER AT TARBORO	35.894	-77.533	Edgecombe	2183	July1896 to December 1900; October 1931 to current	90
2081747	TAR R AT US 401 AT LOUISBURG	36.093	-78.297	Franklin	427	October 1963 to current	54
2081500	TAR RIVER NEAR TAR RIVER	36.195	-78.583	Granville	167	October 1939 to current	78
2091000	NAHUNTA SWAMP NEAR SHINE	35.489	-77	Greene	80.4	April 1954 to current	63
2091500	CONTENTNEA CREEK AT HOOKERTON	35.428	-77.582	Greene	733	November 1928 to current	89
2082950	LITTLE FISHING CREEK NEAR WHITE OAK	36.186	-77.876	Halifax	177	October 1959 to current	58
2053200	POTECASI CREEK NEAR UNION	36.371	-77.027	Hertford	225	March 1958 to current	59
2053500	AHOSKIE CREEK AT AHOSKIE	36.28	-77	Hertford	63	January 1950 to current	67
2092500	TRENT RIVER NEAR TRENTON	35.065	-77.457	Jones	168	January 1951 to current	66
2088500	LITTLE RIVER NEAR PRINCETON	35.511	-78.161	Johnston	229	February 1930 to current	87
2082770	SWIFT CREEK AT HILLIARDSTON	36.112	-77.921	Nash	166	July 1963 to current	54
2085000	ENO RIVER AT HILLSBOROUGH	36.072	-79.104	Orange	66	October 1927 to August 1971; October 1985 to current	76
2084160	CHICOD CR AT SR1760	35.56167	-77.23083	Pitt	45	October 1975 to March 1987; May 1992 to current	35
208732885	MARSH C NR NEW HOPE	35.81694	-78.59306	Wake	6.84	January 1984 to current	33

Quantifying low flow conditions

7Q10 is a useful metric to characterize low flows. It is determined by statistical analysis of stream flow records, and represents the lowest stream flow average for seven consecutive days (in a given year) with a recurrence interval of ten years.



Low-flow conditions can lead to:

- reduced water supply
- deteriorated water quality
- diminished power generation
- disturbed riparian habitats

problems are likely to become more frequent under enhanced climate variability and increasing water demands.

Groundwater inputs are critical to low flow maintenance (baseflow=100% groundwater inputs)

Average vs 7Q10 low flows at Tar River - Falkland, NC

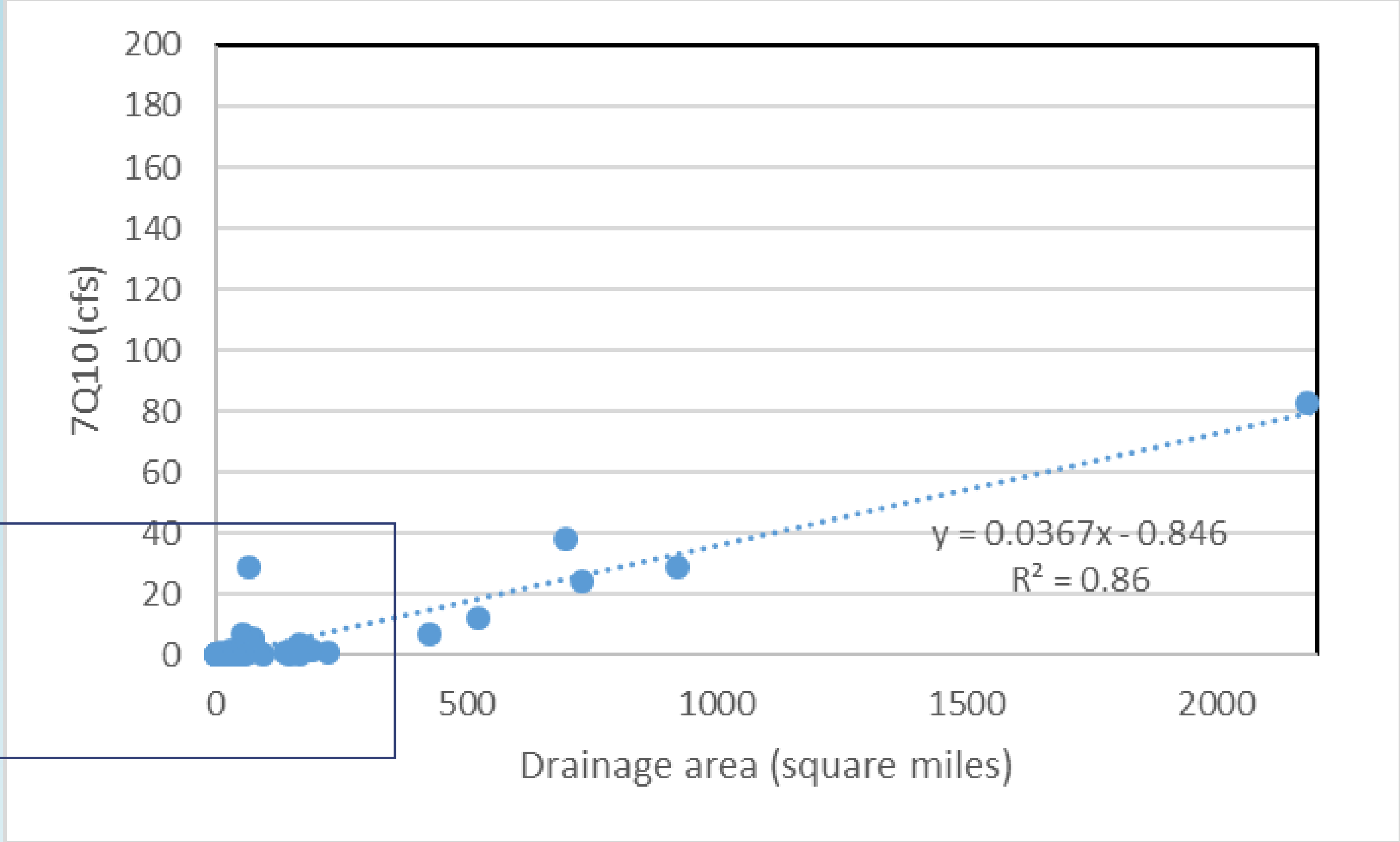
Preliminary low-flow analyses on streams w/ > 30 years of discharge data in A-P Basin (Hillman et al. 2018)

Station Name	Zero Day Slope	Base Flow Index Slope	Extreme Low Flow Frequency Slope
FLAT RIVER AT BAHAMA	↑	↓	↑
ENO RIVER NEAR DURHAM	–	↓	↑
NEW HOPE CREEK NEAR BLANDS	↑	↓	↓
TAR RIVER AT NC 97	–	↑	↓
FISHING CREEK NEAR ENFIELD	–	↓	↑
TAR RIVER AT TARBORO	–	↓	↑
TAR R AT US 401 AT LOUISBURG	–	↓	↑
TAR RIVER NEAR TAR RIVER	↑	↓	↑
NAHUNTA SWAMP NEAR SHINE	–	↓	↑
CONTENTNEA CREEK AT HOOKERTON	–	↑	↑
LITTLE FISHING CREEK NEAR WHITE OAK	–	↓	↑
POTECASI CREEK NEAR UNION	↑	↑	↑
AHOSKIE CREEK AT AHOSKIE	↓	↑	↓
TRENT RIVER NEAR TRENTON	↑	↓	↑
LITTLE RIVER NEAR PRINCETON	↑	↓	↑
SWIFT CREEK AT HILLIARDSTON	–	↓	↑
ENO RIVER AT HILLSBOROUGH	–	↓	↑
CHICOD CR AT SR1760	↓	↑	↓
MARSH C NR NEW HOPE	↑	↓	↑

Shaded boxes indicate declining low flows over time

13/19 streams indicated at least 2 indicators of lower flows over time

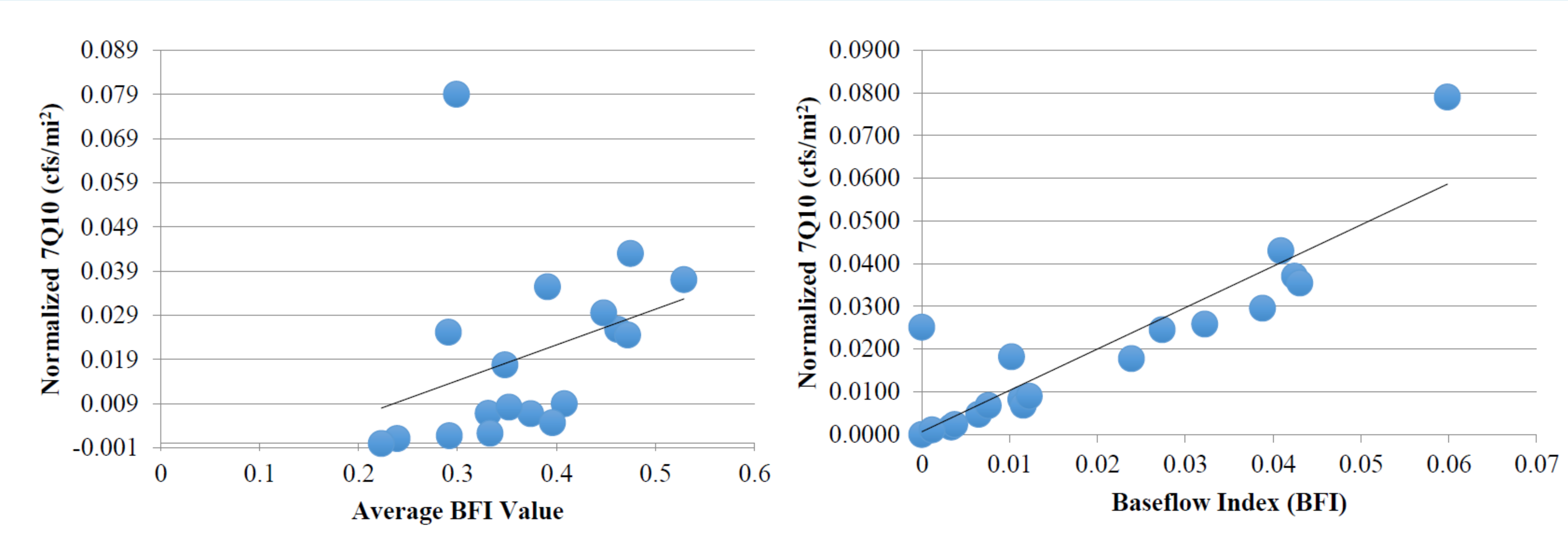
7Q10 vs Drainage Area for A-P streams



Smaller watersheds(<250 mi²)- May be affected by lower magnitude withdrawals, especially in summer

Lower order streams- more likely to dry up (watershed area < 250 mi²)
Higher order streams- like Tar and Neuse have more gages, most of the low-order streams lack gages (limited capability to understand which lower order streams are drying up more frequently)

Baseflow Index- May help to predict 7Q10 for ungaged streams or streams with shorter discharge records

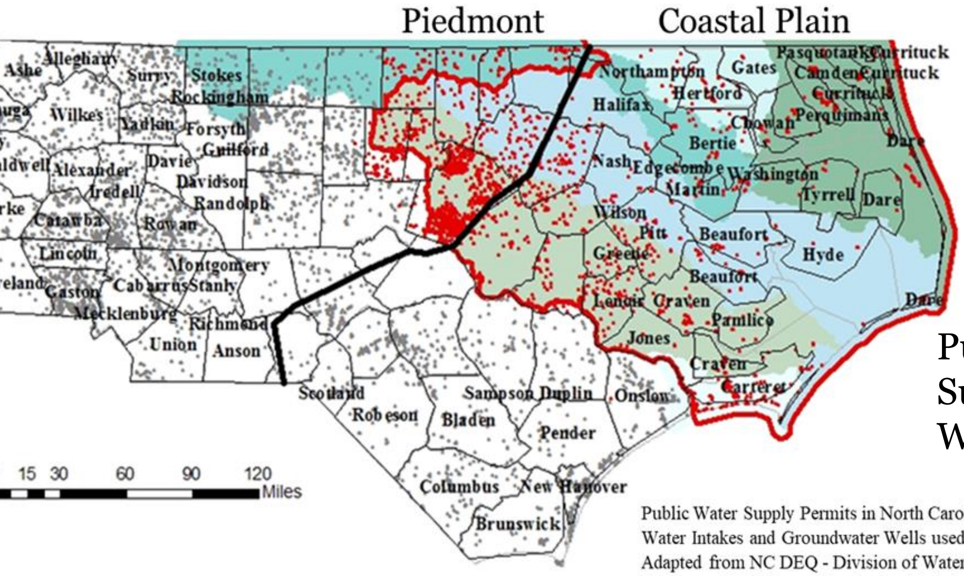


USGS approach
(% gw of annual runoff)

TNC approach
(7-day min. flow/annual mean flow)

Flow Alterations

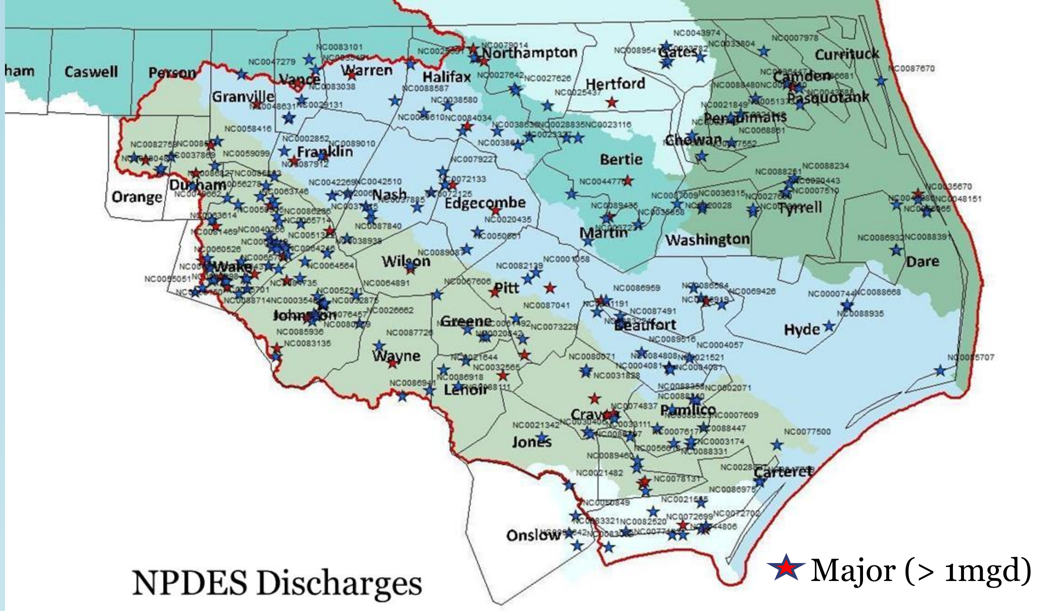
Withdrawals



Public Water Supply Withdrawals

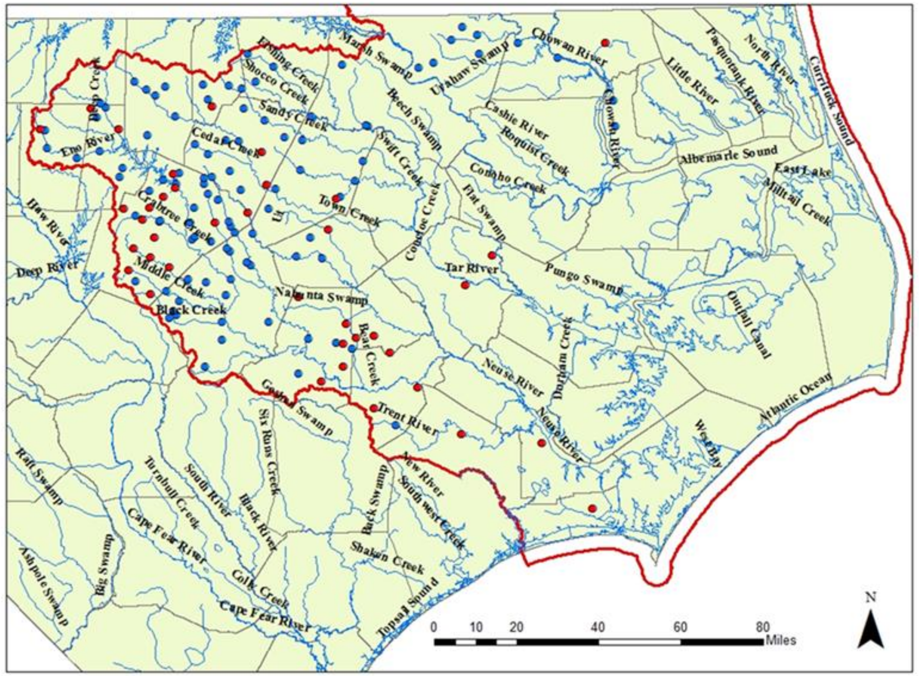
Public Water Supply Permits in North Carolina APNEP Counties. Surface Water Intakes and Groundwater Wells used for Public Water Supply. Adapted from NC DEQ - Division of Water Resources, published February, 2017. Feature Service by Melanie M. Williams.

Discharges



Obstructions

Dams



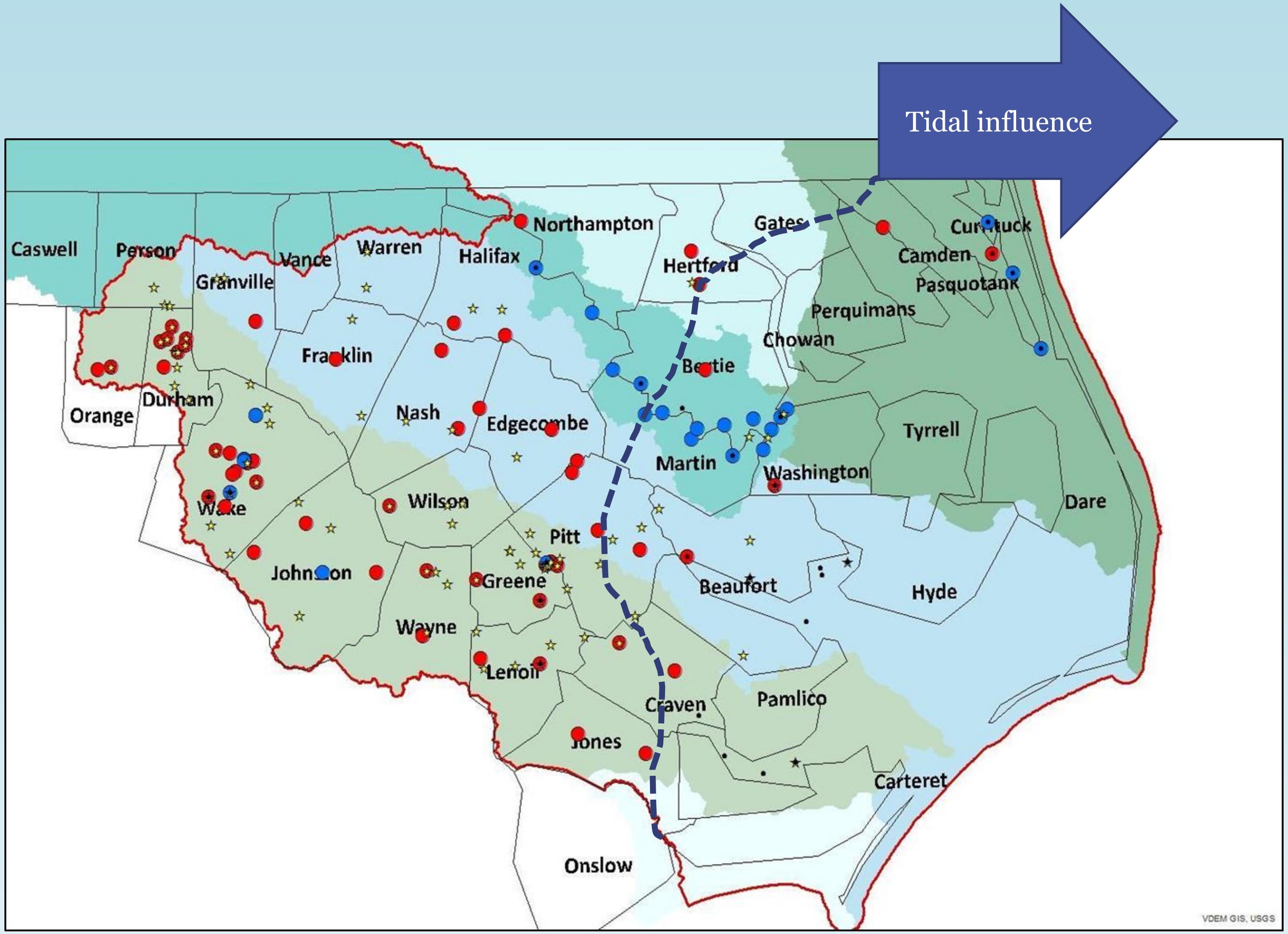
High hazard dams in red

Database and maps developed by Cait Skibiel
Source data from DEQ and Nationalmap.gov

What are limitations based on the data availability? (Data Gaps)

- Streamflow- low order and tidal coastal streams – less monitoring stations < 3 m above sea level (tidal/wind)
- Groundwater- more info on gw inputs to streams (magnitude, spatiotemporal variability, source aquifer).
- Salinity - most data in estuaries, for future monitoring of sw intrusion need more info in inland watersheds.
- Evapotranspiration - Only one Ameriflux site in region (Plymouth, NC) where actual ET data is collected.
- Ecological response-In Ecological Responses to Stream Flow Regional Database (McNamanay et al. 2013) - 114 studies for the CP only 9 (4 on unregulated and 5 on regulated rivers) were conducted in NC (Appendix III).
- Water use- There were a variety of gaps in water use data that would prevent the construction of accurate water budgets in the region. However, approximate water budgets may be possible.

USGS Streamflow and Stage Monitoring Network



Minimal flow data available in zone of tidal influence (stage/discharge USGS red circles)

Map of where current USGS streamflow gages are in NC APNEP watersheds. Red gages indicate stage and discharge sites. Blue gages indicate stage only. Yellow stars indicate inland water quality data available. Black circles indicate water quality data available in the estuary.

Data Gaps - Water Use

- The USGS NC water use dataset is a great resource for tracking water use by County and over large (5 year) timesteps. However, data are too coarse to evaluate withdrawal effects on summer low-flows.
- Lack of a comprehensive (publicly available) water withdrawal database that can evaluate temporal variations in use at the sub-watershed scale and for individual aquifers, e.g. the surficial aquifer.
- Use data are generally unavailable for smaller-scale and residential uses outside of municipal suppliers.
- Agricultural water use data are voluntary and generally provided at longer timescales (monthly to annual) and on a county basis.
- >Differences in agricultural use estimates between the USGS and NCDA&CS data ? Which is accurate?
- Little information is available for irrigation return flows & consumptive use for specific watersheds.

We will need more detailed water use data to answer several major questions………

- Why are low flows along Coastal Plain streams declining over the last ~several decades?

- What is the relative role of meteorological controls and water withdrawals (or anthropogenic sources) on declines in low-flows along Coastal Plain rivers?

- How does groundwater pumping and surface water withdrawals affect low-flow characteristics?

- At what magnitude do these low flow declines affect ecological integrity?

Due to reliance on groundwater in the Coastal Plain: potential for groundwater withdrawals to influence streamflow

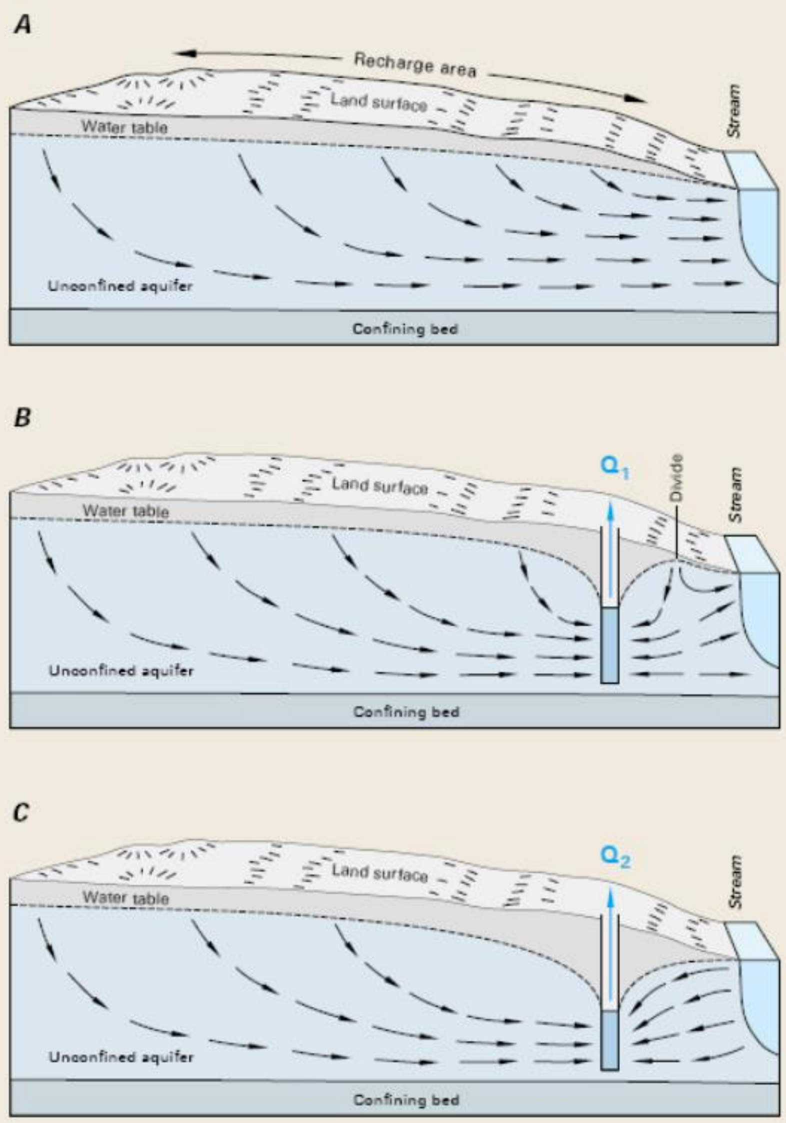
Groundwater Pumping May Affect the Water Table and Streams

-can remove source of baseflow from streamflow

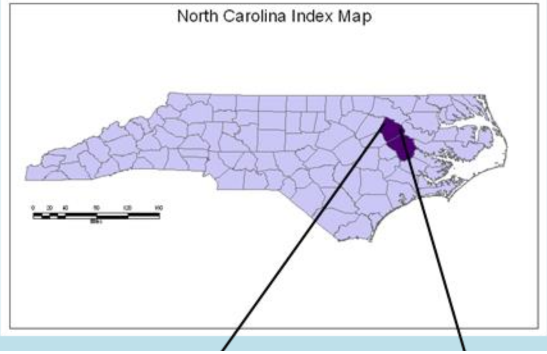
-over time can reverse stream-groundwater relationship

- may lead to declines in baseflow over time

What is the relative role of meteorological controls and water withdrawals on changes in low-flow statistics?

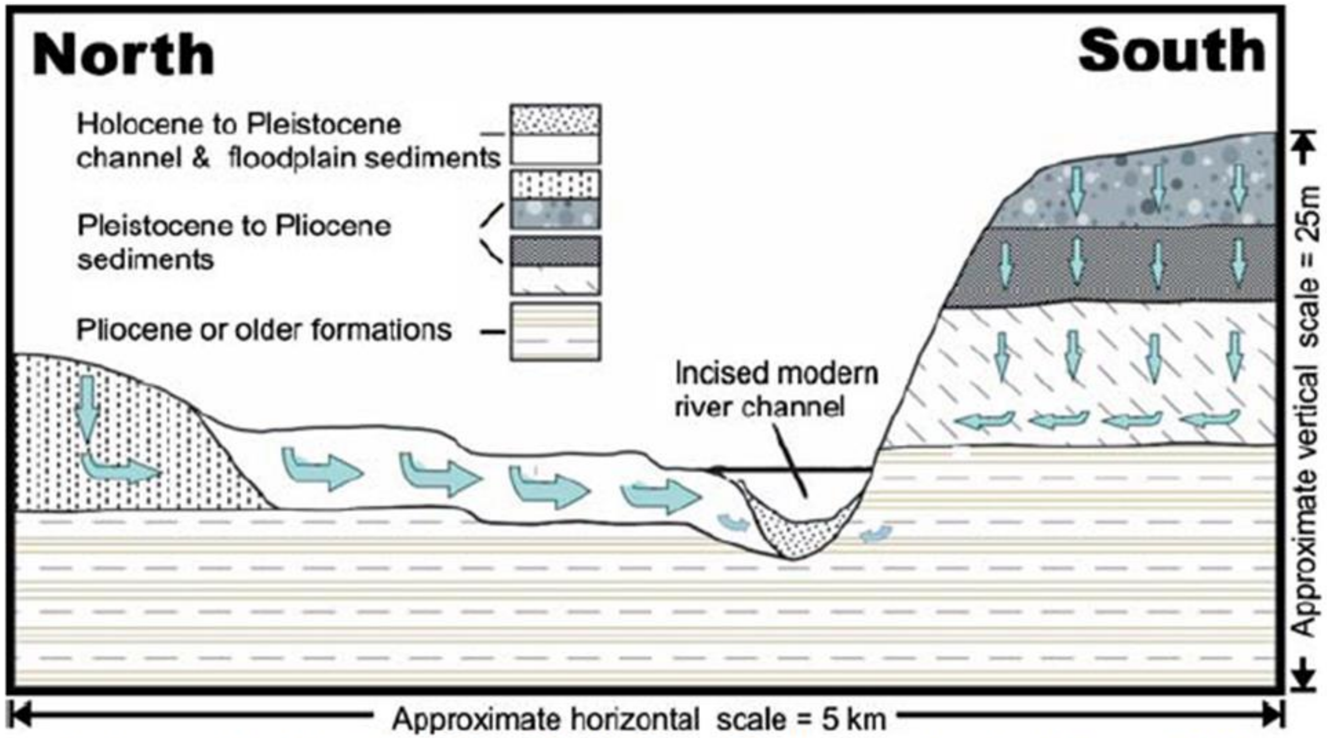


Winter et al. 1998



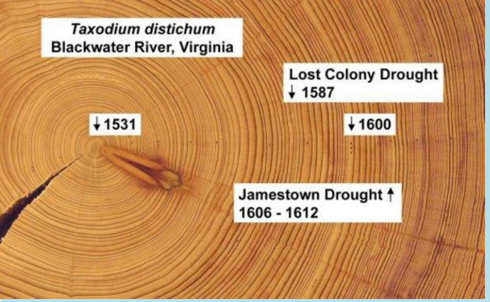
River-Groundwater Interactions are Complex in the Coastal Plain –
Need a better understanding of baseflow sources throughout the watershed.

Often surficial aquifer is feeding streams, we do not have a comprehensive understanding of all of the groundwater withdrawals from that system



O'Driscoll et al. 2010

Conceptual hydrogeologic model of the Tar River, floodplain and adjacent uplands (Johnson 2007). *Arrows* indicate direction of groundwater flow. Stratigraphic interpretations are based on NC DENR well logs, cores and auger samples collected during this study, GPR data, and a conceptual model for the evolution of the Roanoke River developed by S.R. Riggs (East Carolina University, Greenville, NC, personal communication, 2007). Regional confining units inhibit the downward infiltration of water to deeper units, causing lateral flow atop the confining unit and towards the river channel. Coarse-grained channel and floodplain sediments, frequently located on the *north* side of the river, transmit larger quantities of groundwater than older (and lower permeability) Pleistocene through Cretaceous (typically marine) sediments on the *south* side of the river



Annual rings are thicker when water is plentiful, thinner when it is not. (R.D. Griffin/University of Arkansas Tree-Ring Laboratory).

Drought Cycles in Eastern North Carolina

North Carolina Climate Changes Reconstructed from Tree Rings: A.D. 372 to 1985

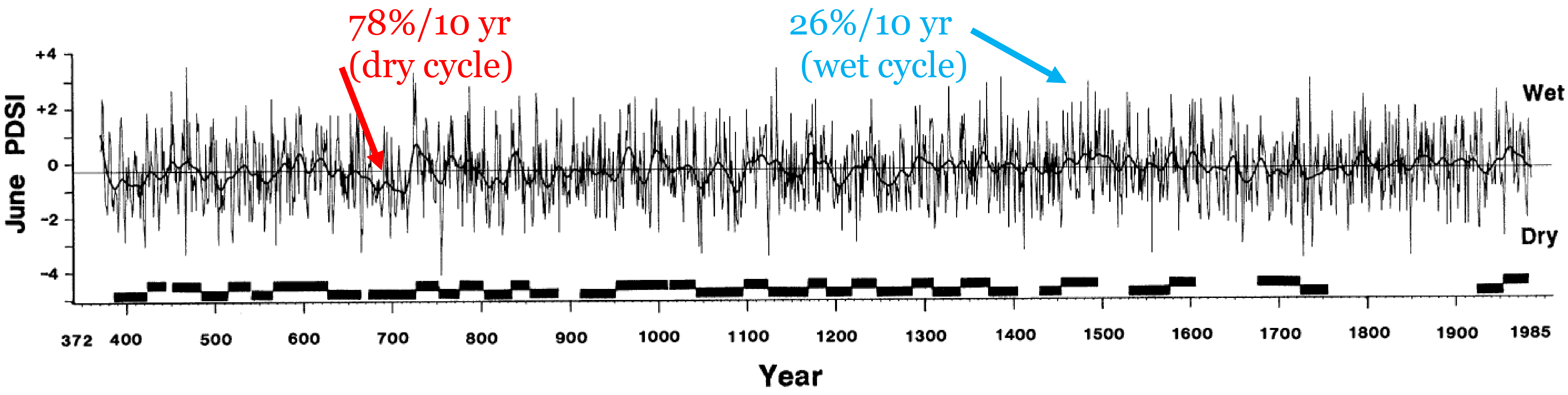
D. W. Stahle; M. K. Cleaveland; J. G. Hehr

Science, New Series, Vol. 240, No. 4858 (Jun. 10, 1988), 1517-1519.

From bald cypress tree rings from the Black River, NC- Stahle et al. (1988) reconstructed a ~1600 yr drought history

Drought cycles ~ 30 years

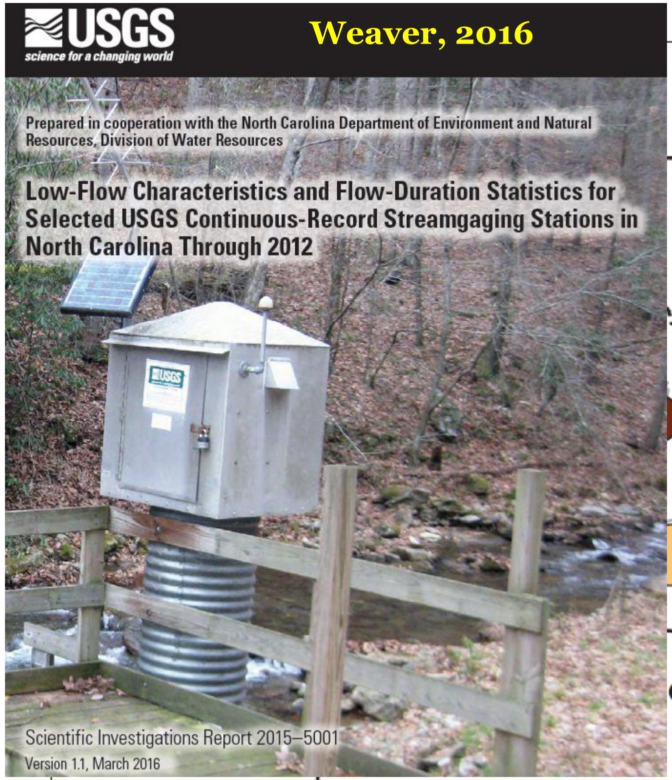
<u>NC Severe Drought Probability :</u> 56% /10 yr

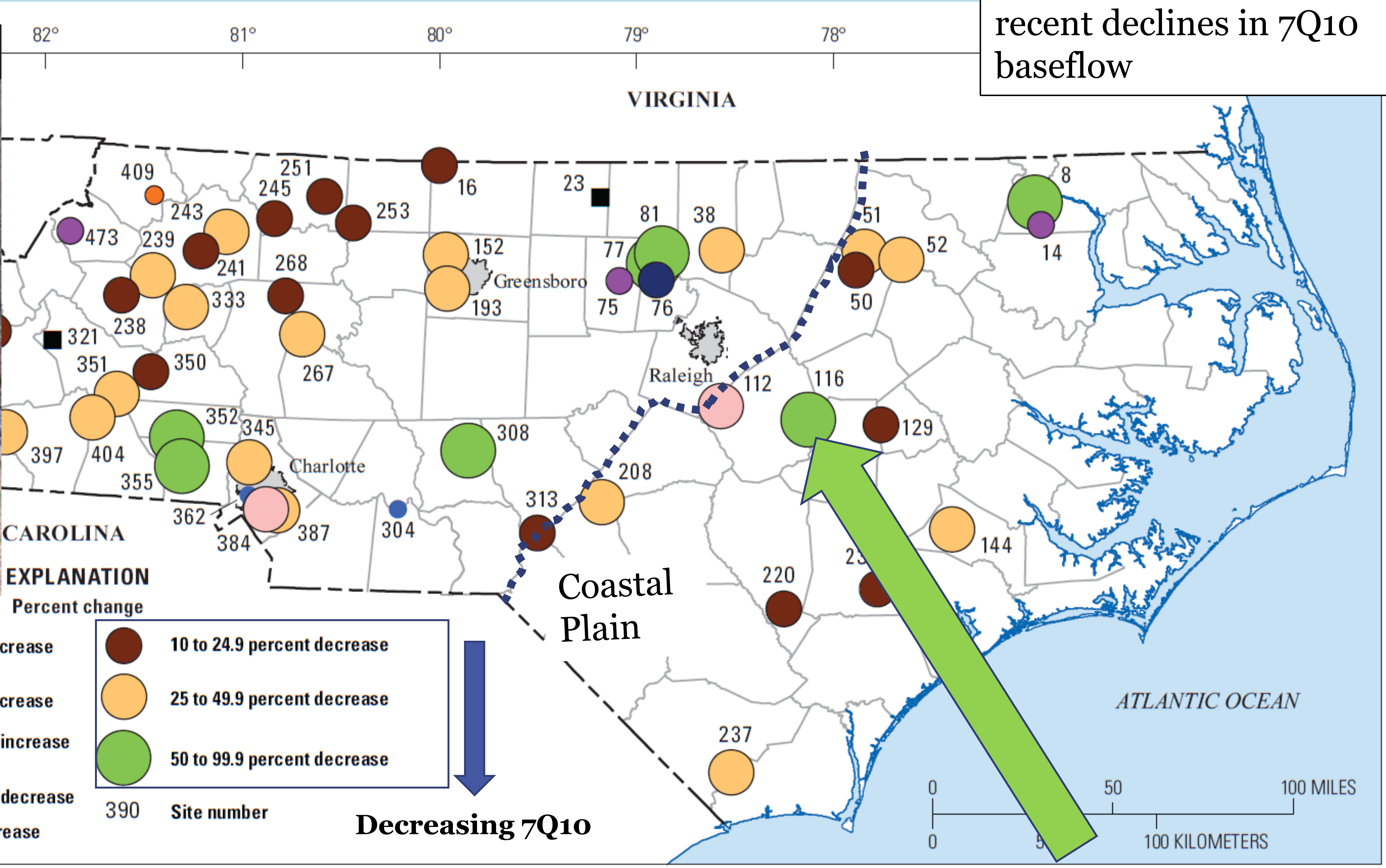


PDSI- Palmer Drought Severity Index

Recent USGS Low-Flow Characterization: Evidence that baseflow is declining in the NC Coastal Plain (pre-1998 vs pre-2011)

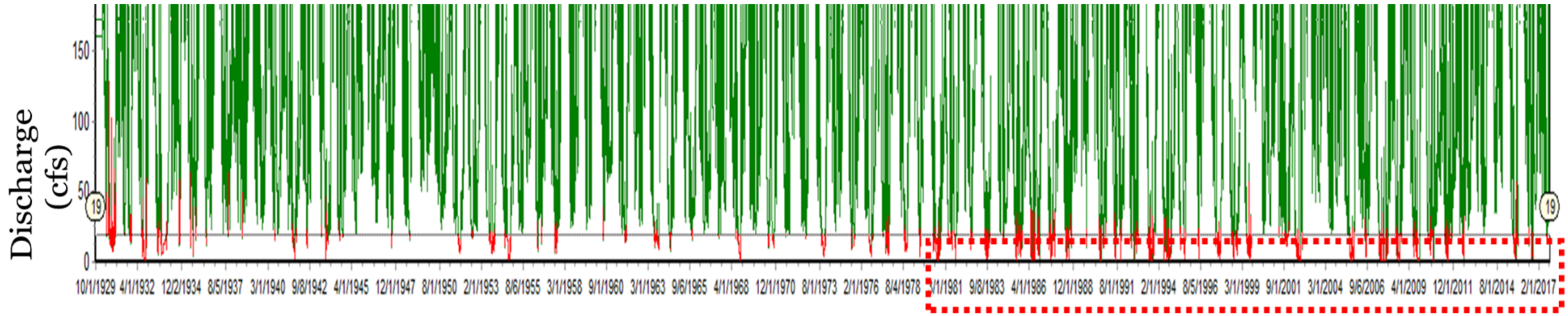
ALL Coastal Plain stream gauge sites that were evaluated showed recent declines in 7Q10 baseflow





Example: Little River near Princeton, NC: 2.4 cfs to 0.95 cfs (decline of 60.4%)

Low flows are getting lower along many Coastal Plain Rivers



Suggests groundwater inputs to the stream are declining.
Potential reasons may include:

- reductions in groundwater recharge
- shifting precipitation and/or evapotranspiration patterns
- effects of groundwater (GW) and surface water (SW) withdrawals
- interbasin transfers of water and/or wastewater

Example: Little River near Princeton, NC: 2.4 cfs to 0.95 cfs (decline of 60.4%) = 1.45 ft3/s decline= 125,280 ft3/d =937,159 gallons/d= 0.94 Million Gallons/day
(approximately 10 large unregistered withdrawers of less than 100,000 gallons/day could cause this level of decline)

Geomorphology 252 (2016) 171–184

Contents lists available at ScienceDirect

Geomorphology

journal homepage: www.elsevier.com/locate/geomorph

Stream flow changes across North Carolina (USA) 1955–2012 with implications for environmental flow management

Kimberly M. Meitzen

Texas State University, Department of Geography, 601 University Dr., San Marcos, TX 78666, USA

Recent work by Meitzen, 2016
Also showed low flow declines in NC Coastal Plain
Particularly in summer

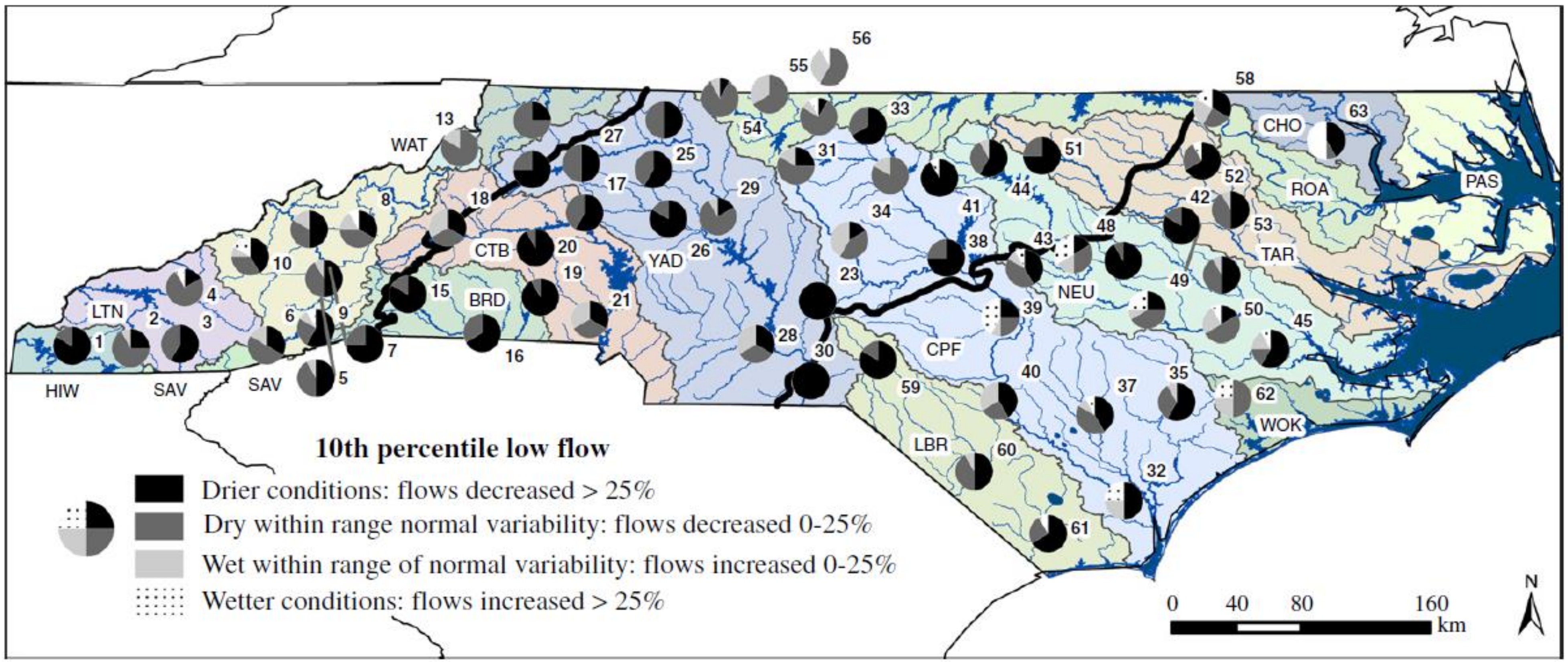


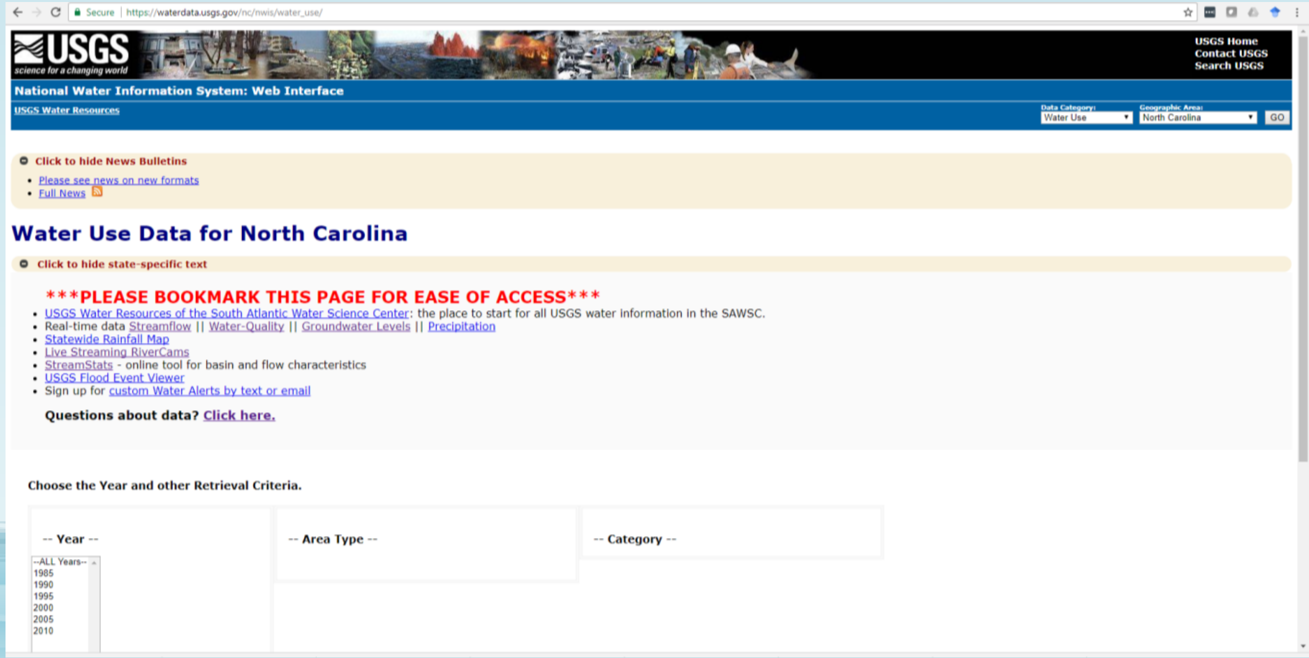
Fig. 4. Flow changes to the 10th percentile low flows.

Changes in streamflow between 1995-1980 and 1984-2012 periods

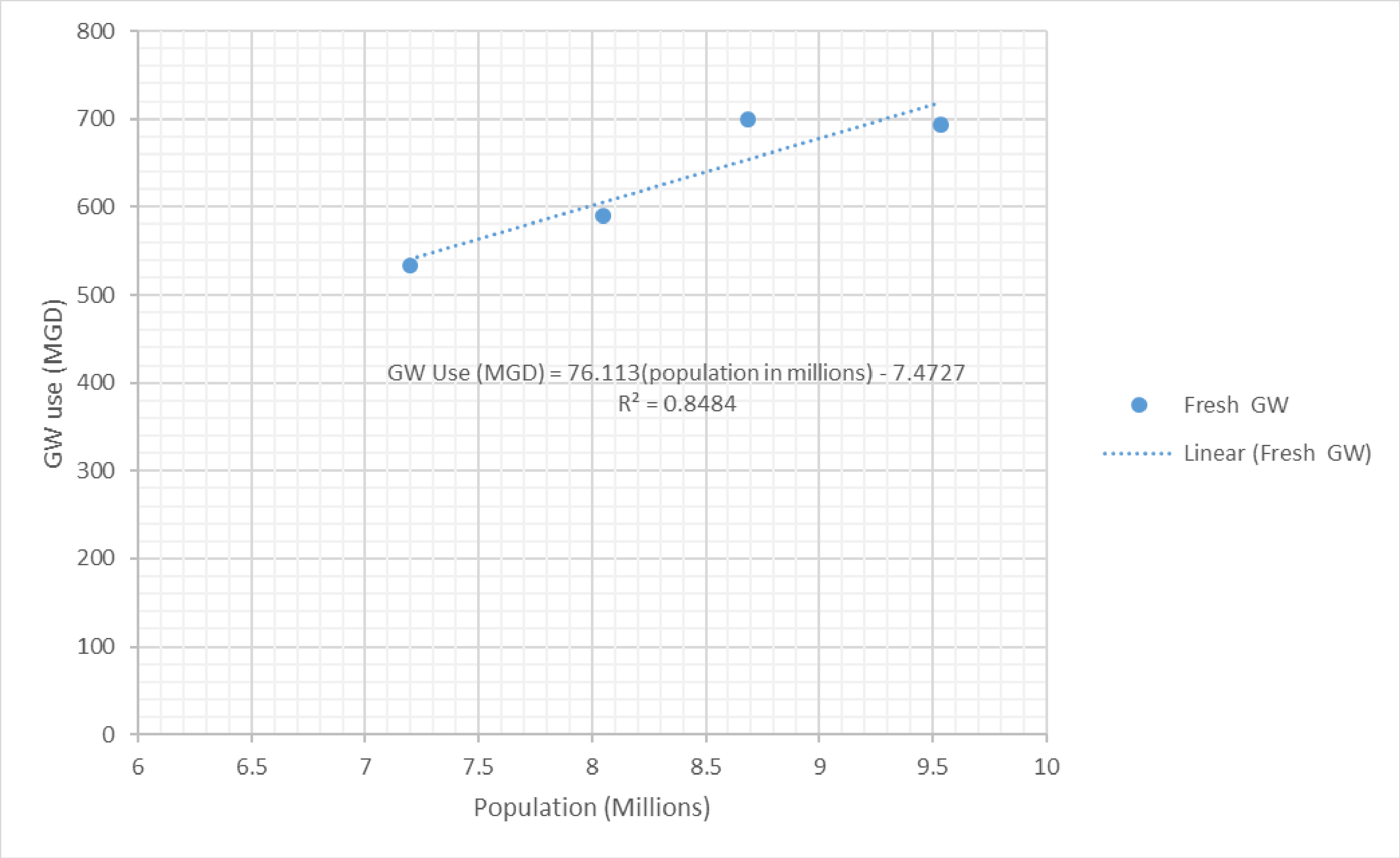
Meitzen, 2016

Water Use Data

- More challenging than dealing with discharge due to differences in reporting thresholds, when programs were implemented, and data availability
- Need to work with DEQ, USGS, and NCDACS
- Currently, comprehensive, publicly available water use estimates in NC are available every 5 years (since 1985) from USGS

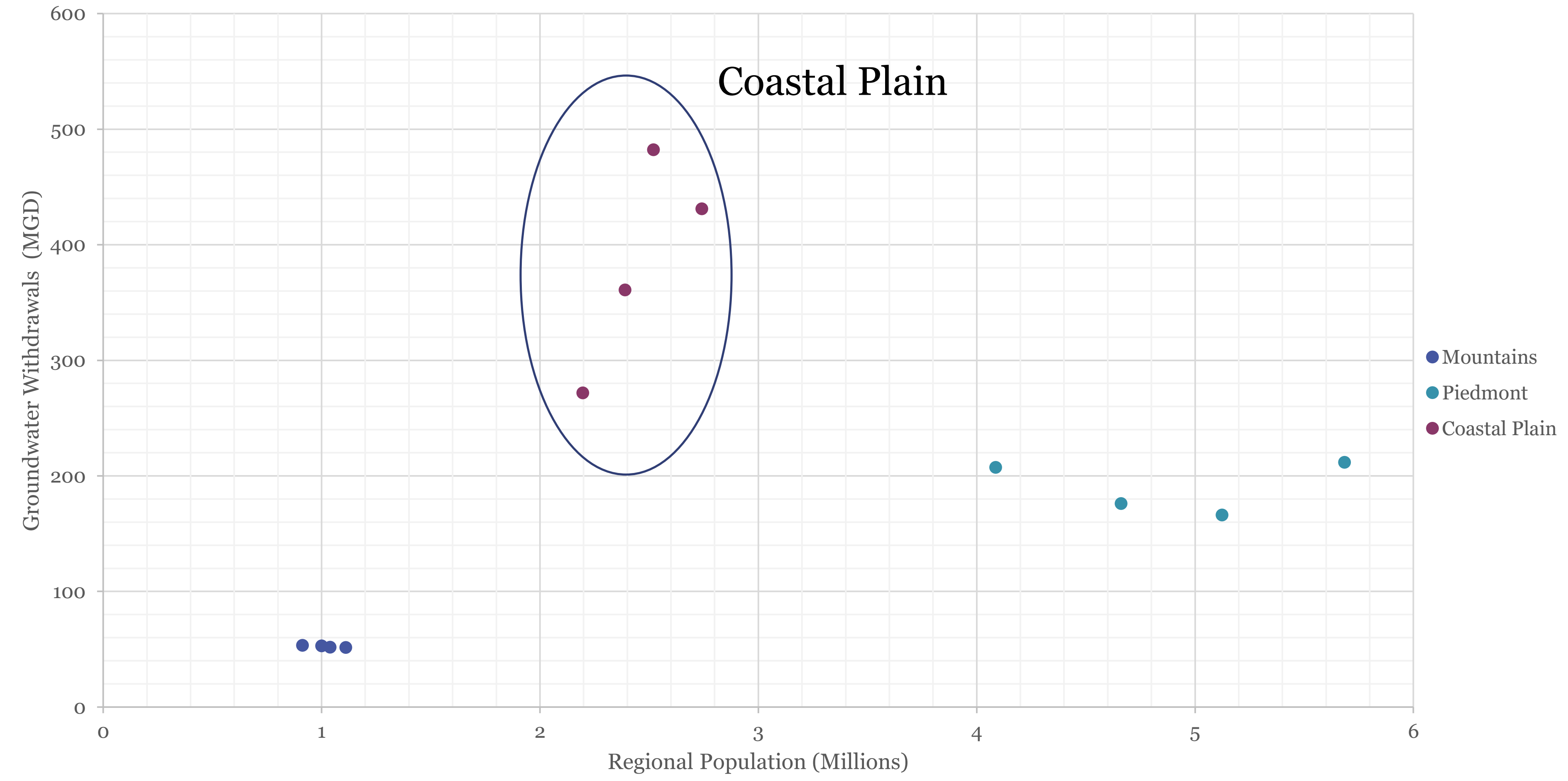


Statewide Population vs Groundwater Withdrawals



- Groundwater use statewide has increased from 533 from 1995 to 694 MGD in 2010 (30% increase).
- Based on recent trends the gw withdrawals increase by 76 MGD with every 1 million increase in population

Groundwater Withdrawals by Region (1995-2010)



Largest GW withdrawals by county

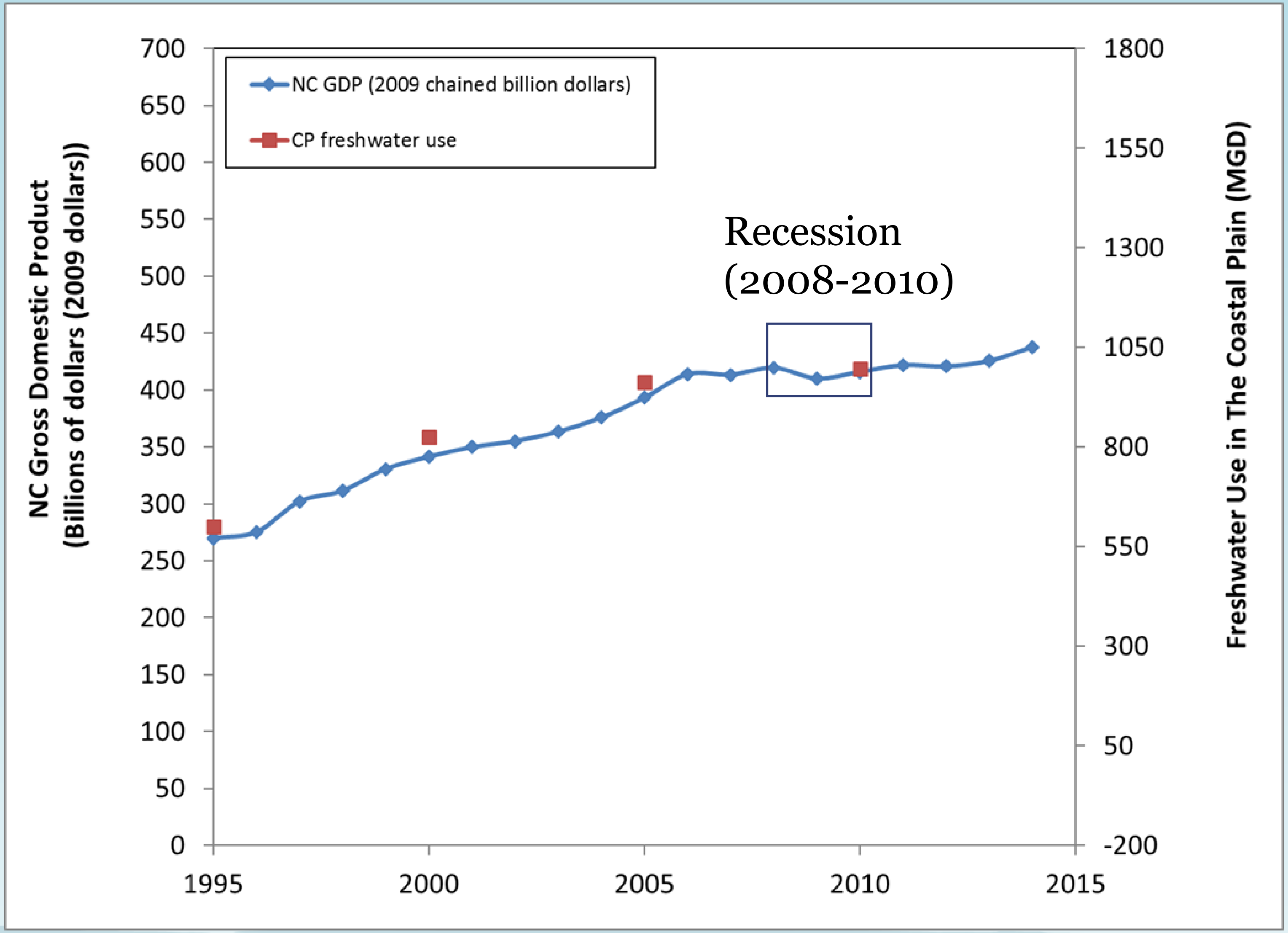
- CP- Beaufort (88.9 MGD)
- P- Wake (29.5 MGD)
- M- Buncombe (6.1 MGD)

Economic Conditions also Influence Coastal Plain Water Use

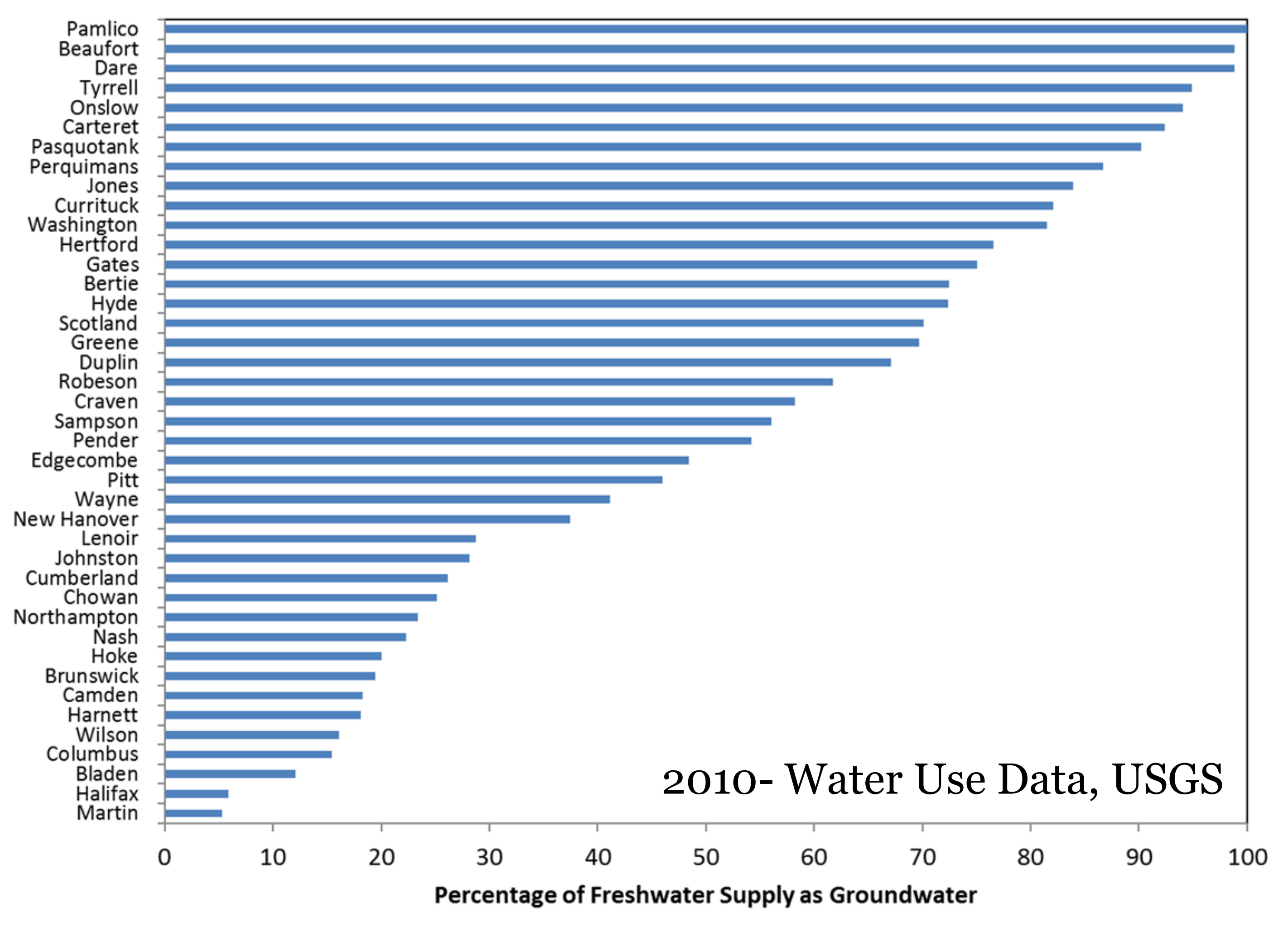
NC Gross Domestic Product (GDP) increased from 270 billion (1995) to 437 billion (2014) (US BEA 2016).

Coastal Plain freshwater use increased with GDP, suggesting a relationship between economic activities and water use.

If economic conditions continue to improve- should expect increased water use



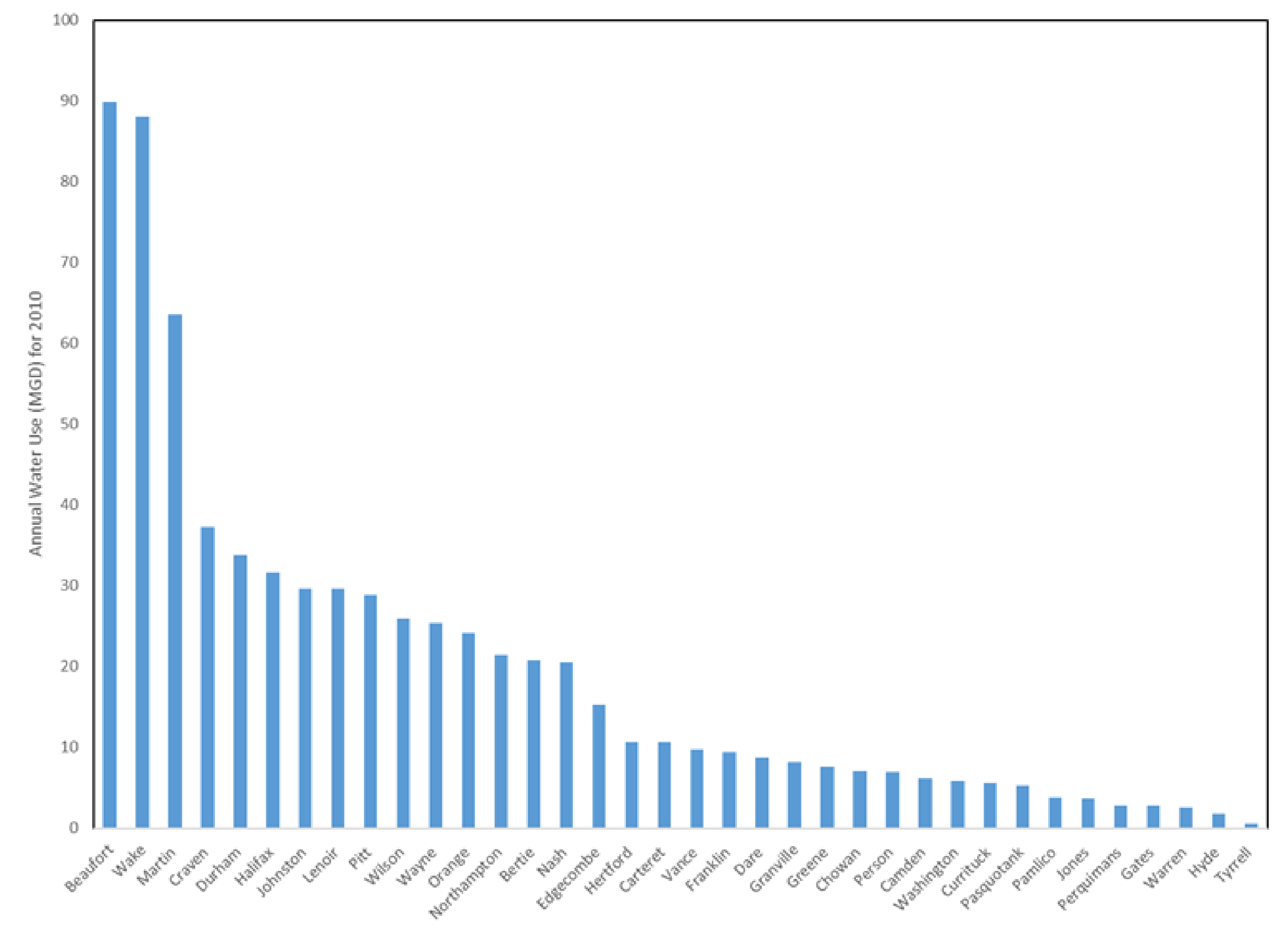
Coastal Plain Counties: Heavy Reliance on Groundwater



- 54% of Coastal Plain Counties utilized groundwater for more than 1/2 of their supply.

- The total groundwater use from Coastal Plain counties was 62% (431 million gallons/day) of groundwater usage statewide (694 million gallons/day) (2010)

2010 Water Use in Albemarle-Pamlico Drainage Basin Counties



Beaufort, Wake, and Martin counties had largest estimated withdrawals in 2010 (USGS data) (excludes thermoelectric)

Water Use Data in the Coastal Plain

Thanks to Fred Tarver, Linwood Peele, Nat Wilson, and Craig Caldwell at DEQ for helping to clarify!

- Data
  - 85 Counties
    - Registration – Monthly Withdrawals Reporting
      - Withdrawals Greater Than 100,000 Gallons / Day
      - Irrigation Withdrawals Greater Than 1,000,000 Gallons / Day
  - 15 Counties
    - CCPCUA Registration/Permits
      - Withdrawals Greater Than 10,000 / Day – Registration
      - Withdrawals Greater Than 100,000 / Day – Permit

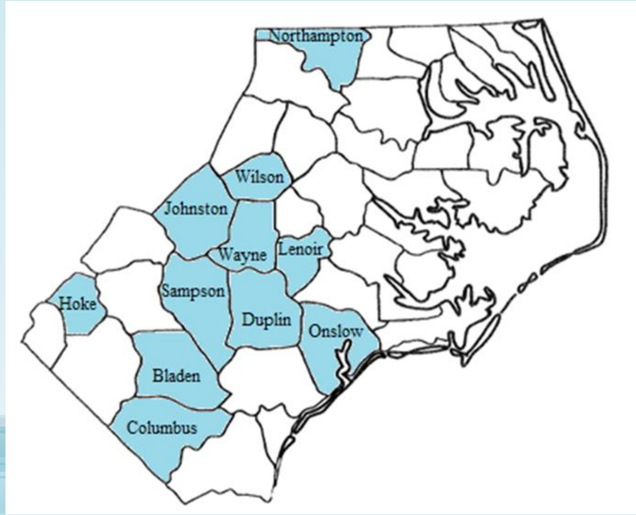
(DEQ, 2018)

Challenges Tracking Water Use in the Coastal Plain

- Reporting based on different rules that were put in place at various times and reporting thresholds may vary
- Generally speaking online data is not available before 1997 (paper data back to 1991)
- Comparisons of estimates across the different groups may not always be in agreement
- Example: Coastal Plain agricultural water use estimates for 2010
  USGS estimate: 350 MGD
  NC Dept. of Agriculture and Consumer Services: 21 MGD

	USGS 2010	NCDA&CS 2010	
County	Total (Mgal/day)	Total (Mgal/day)	Difference (Mgal/day)
Bladen County	42.74	2.01	40.73
Columbus County	12.59	0.00	12.59
Duplin County	28.34	2.02	26.32
Hoke County	21.72	0.00	21.72
Johnston County	14.13	0.88	13.25
Lenoir County	15.72	0.16	15.56
Northampton County	18.32	0.28	18.04
Onslow County	10.20	0.09	10.11
Sampson County	31.23	3.07	28.16
Wayne County	10.55	0.52	10.03
Wilson County	14.16	0.00	14.16

Coastal Plain counties where estimates from USGS and NCDA&CS differ by more than 10 million gallons per day (approximately 15 cubic feet/s) (I. Hillman)



Growing number of states and watersheds are recognizing the need to improve water accounting………

complexity arises from having hundreds of independently governed water systems, each with its own water accounts; from the widespread practice of managing linked surface water and groundwater as separate systems; and from a lack of clarity on how much water is reserved for environmental purposes.

Modified from Escriva-Bou et al. 2016, Accounting for California's Water

Water Use Data for Ecological Flow Assessment (and other uses….)

- Based on the number of agencies collecting water use (and wastewater discharge data), it would be worthwhile to bring together water use and water flux experts from USGS, NC DEQ, NC Dept. of Agriculture and Consumer Services, NC Climate Office, NC Dept. of Health and Human Services, water utilities, and other stakeholders with the goal of improving water accounting in the region.
- An interagency plan is needed to address the challenges, costs, and other issues associated with coordinating a more comprehensive water use and wastewater return-flow database for the Albemarle-Pamlico Drainage Basin.

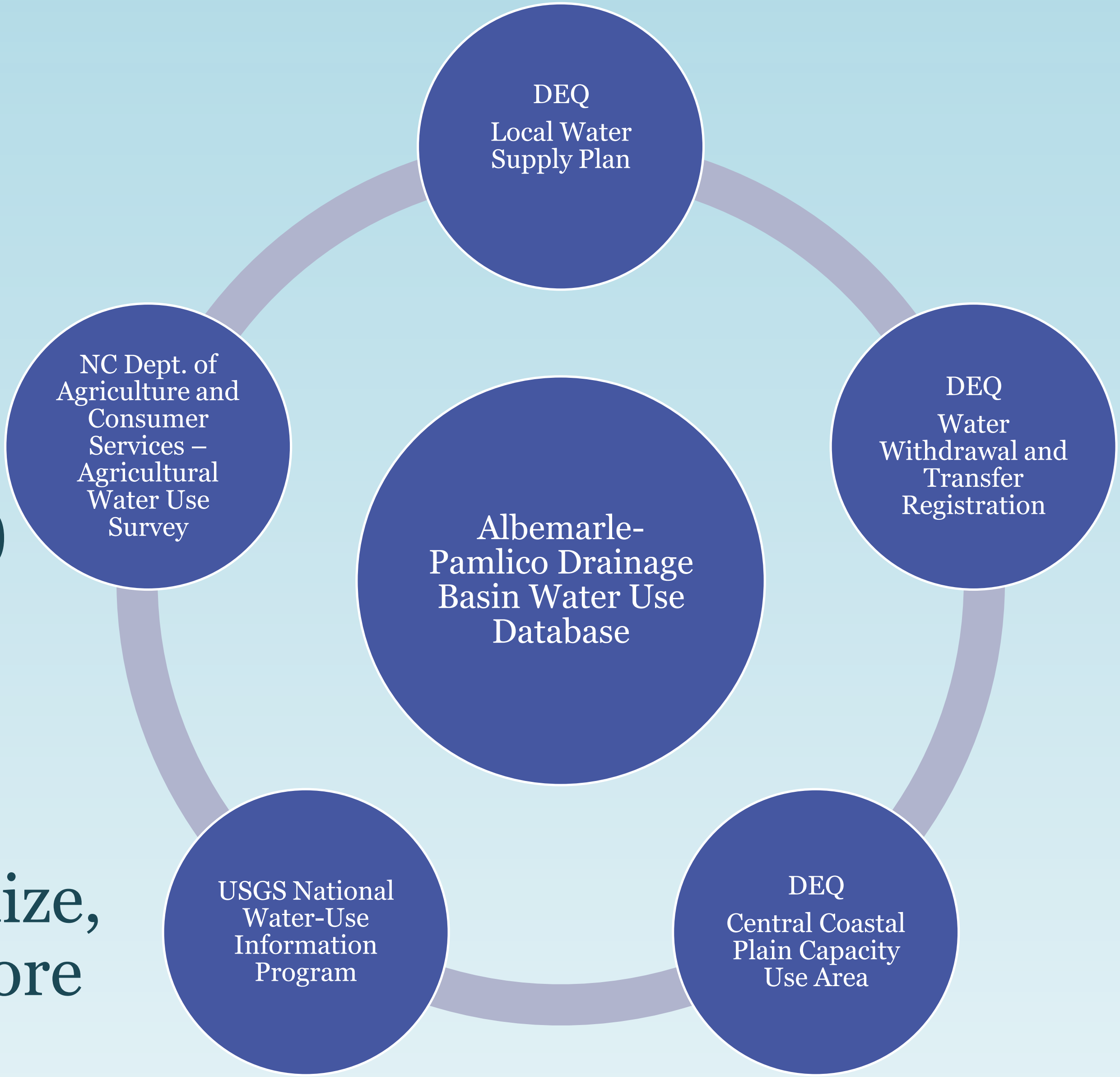
A-P Water Use Data

What if.....
We pull all of these data into one publicly available database

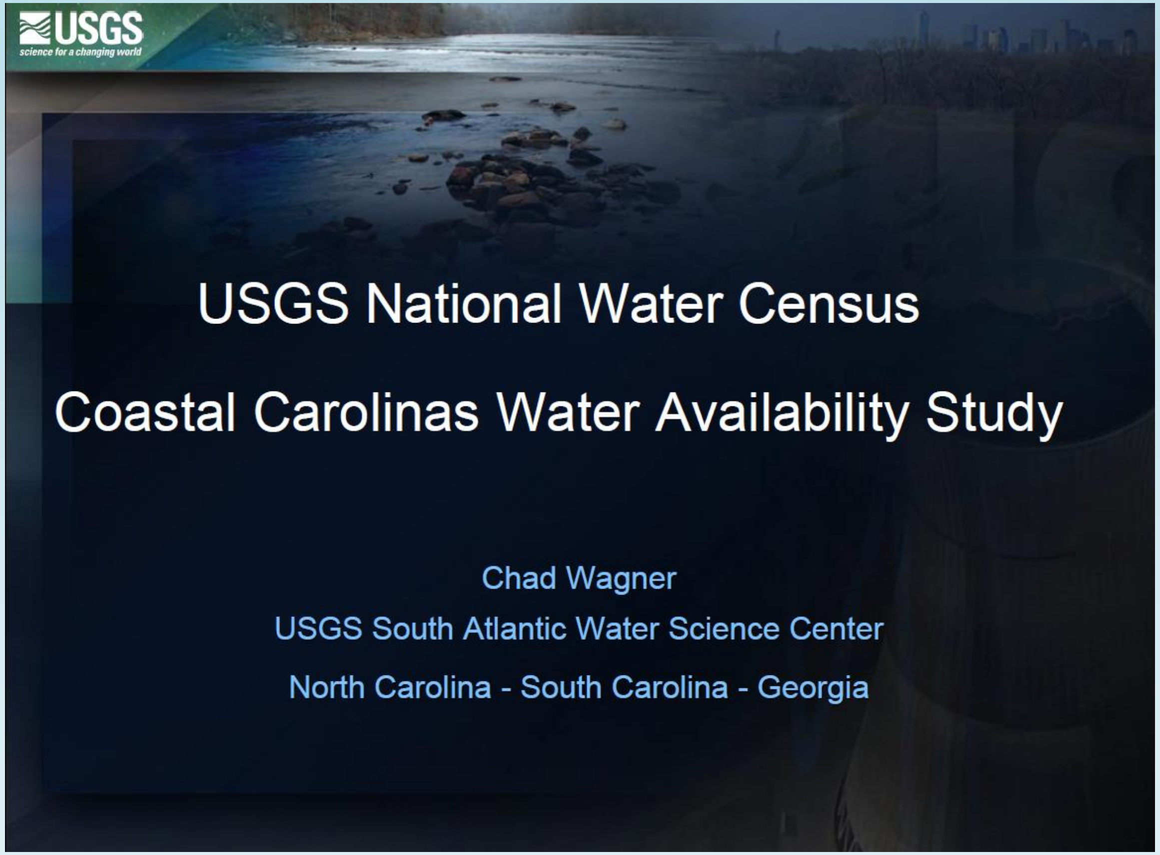
with georeferenced data
(cluster to manage privacy concerns)

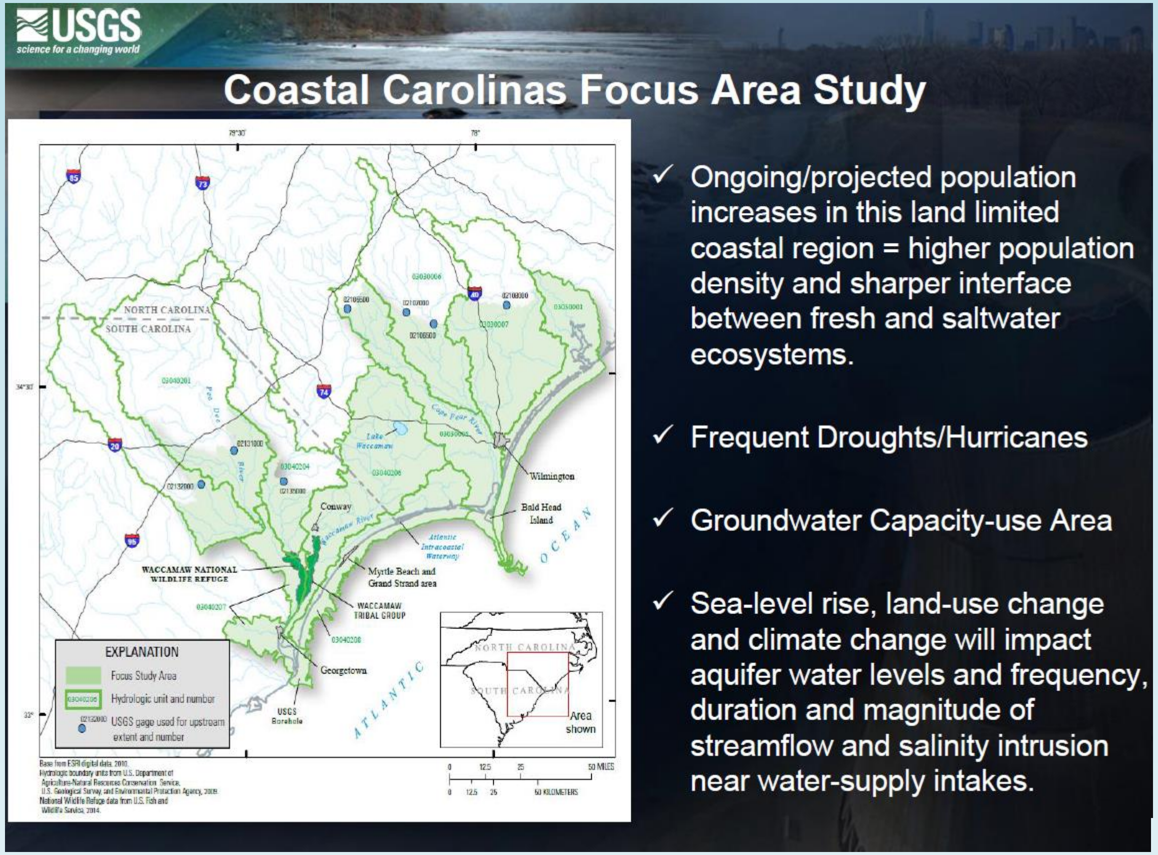
available online?

Seek to increase water use measurements, modernize, standardize, enhance transparency, make data more available



The ongoing USGS Coastal Carolinas Water Availability Study may also help overall efforts…….





Potential Future Work….

- a pilot study to determine if accurate water budgets can be constructed with pre-existing data at the watershed-scale.
- an interagency plan is needed to address the challenges, costs, and other issues associated with coordinating a more comprehensive water use and wastewater return-flow database for the Albemarle-Pamlico Drainage Basin.
- watershed-based ecological flows research focused on potential changes to flows, salinity, and ecological responses
- flow analysis on the long-term discharge records along unregulated river reaches in the Albemarle-Pamlico drainage basin. Flow metrics can be compared with diversity indices for fish or macroinvertebrates where available.
- numerous states in the southeast have data and experience developing ecological flow criteria. Many suggest that adaptive management with stakeholder involvement is an important component of ecological flow management.
- programs where federal, state, and local agencies work in cooperation with stakeholders to achieve ecological flow management objectives may be the most likely to succeed. In most states, the water or environmental agency in the state takes the lead, in this case that would be the NC DEQ.
- moving forward, APNEP and DEQ could collaboratively develop a process to define ecological flow goals and criteria for the drainage basin. Based on Session Law 2010-143, future work on ecological flows in the Albemarle-Pamlico drainage basin should aim to complement the mandated efforts by NC DEQ.

Potential Research Questions

- What are the most accurate and least accurate water flux and use estimates and how can gaps in water use data be filled?
- What are the relative influences of meteorological forcing vs water withdrawals on low-flows?
- Are current low flows protective of ecological integrity? What threshold of water use would adversely affect streamflow and/or ecological integrity?
- How will climate change, withdrawals, and land-use change affect low flows in the future?
- What are the general stressor-response relationships between flow alteration and ecological health?
- Based on pre-existing data, can the stressor-response relationships be adequately evaluated and if not, what types of data are needed in the future?
- What are barriers to understanding the dominant influences on ecological flows at the watershed-scale?
- How do river-groundwater interactions vary across the basin and over time, and how do these influence low flows?

Next steps…

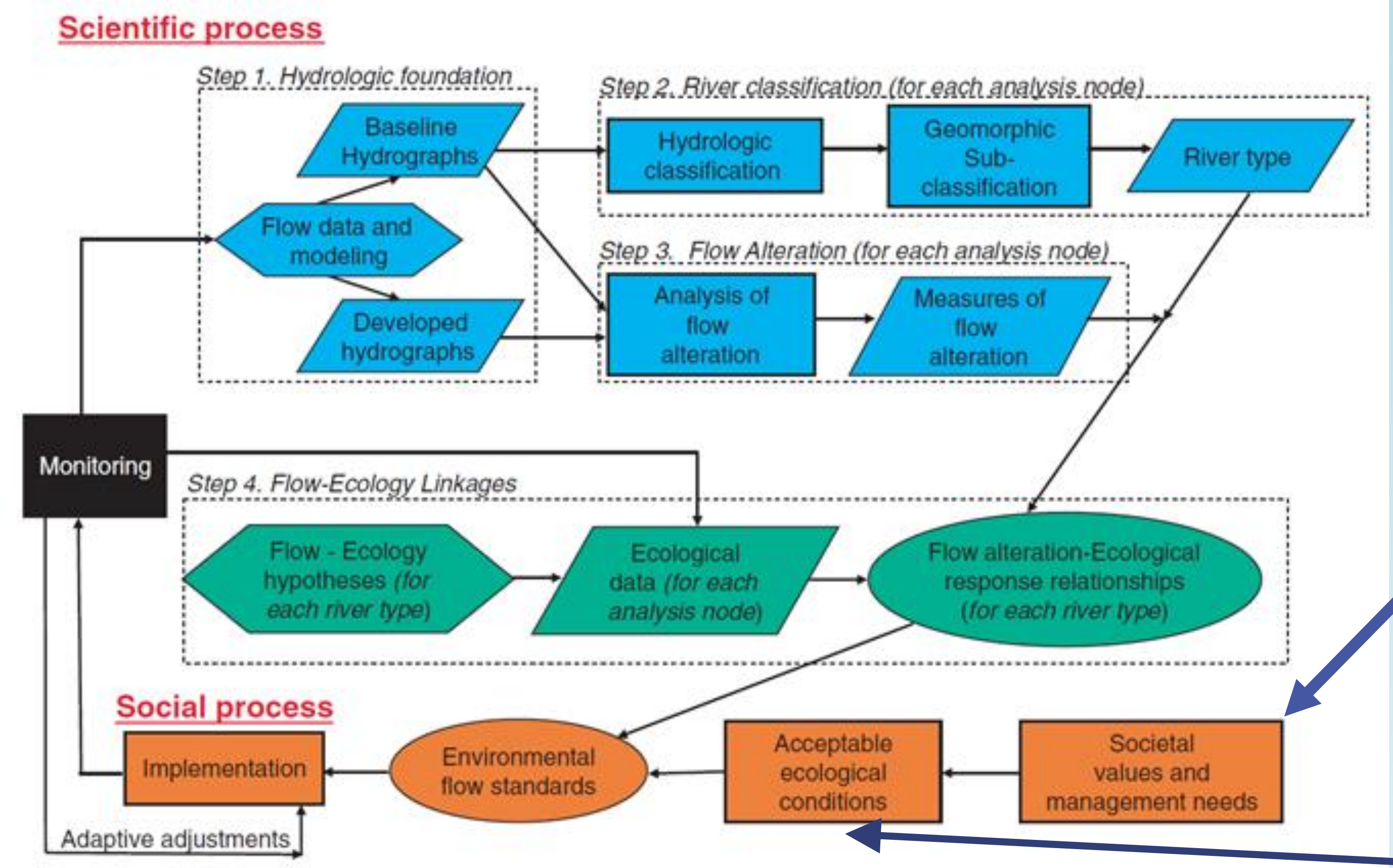


Figure 22. The framework for evaluating Ecological Limits of Hydrologic Alteration (ELOHA). Modified from Poff et al. 2010.

Thanks for your attention! Questions?

When ecological flows are a low priority……..

Ecological flows humor from down under