The Nature Conservancy's Environmental Flows Project for North Carolina

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A presentation to the NC Ecological Flows Science Advisory Board, July 16th, 2013

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TNC Environmental Flow Project Outline

1. Conduct literature review to develop flow-ecology relationships for NC riverine biota and physical stream processes

2. Analyze changes in (a.) flow patterns and (b.) biota over recent history of flow impacts

3a. Identify patterns of biotic changes

3b. Identify spatial and temporal patterns of flow changes

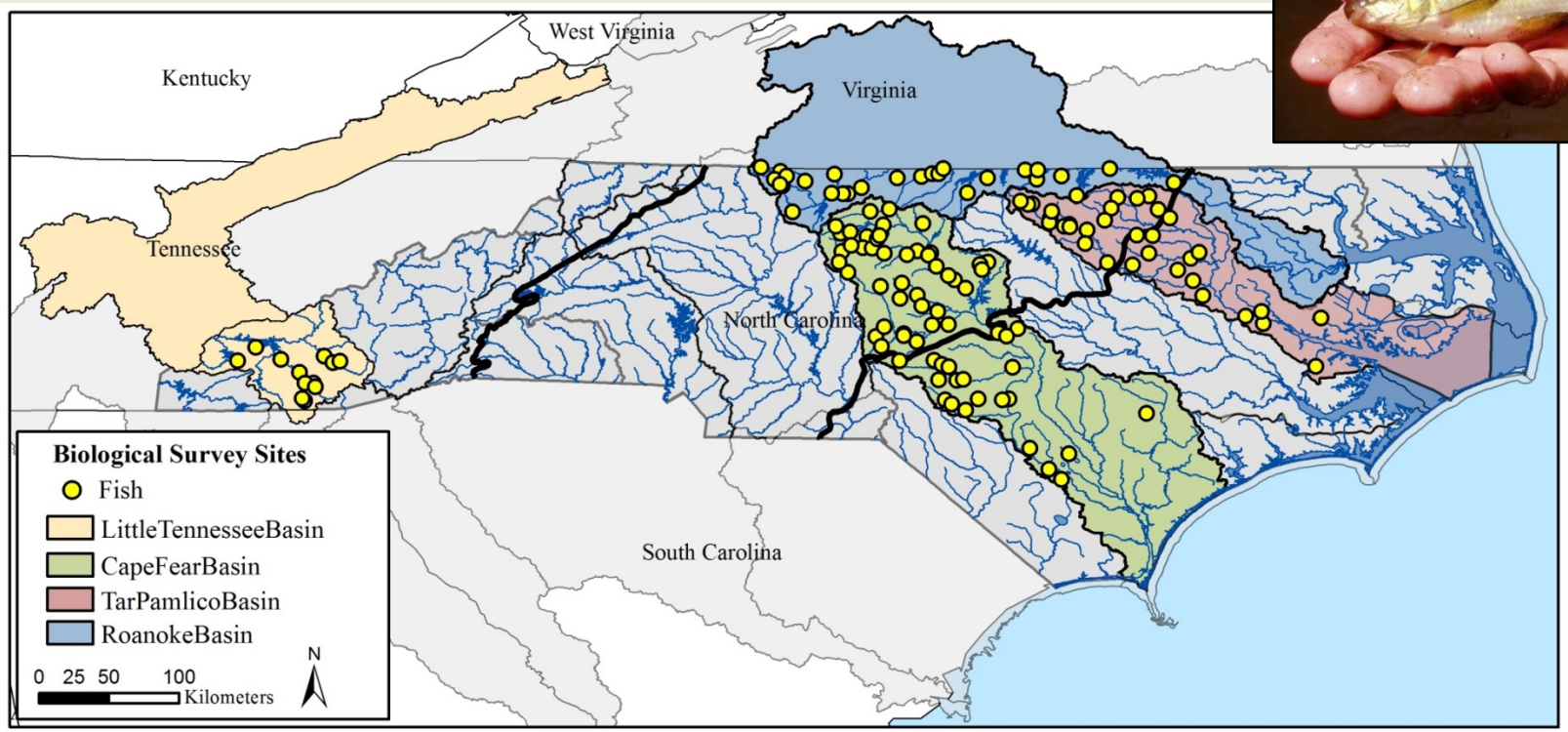
4. Develop flow-ecology criteria and flow recommendations to protect riverine ecosystem integrity characteristic of NC's biotic and physiographic diversity *(Decision Support System for Environmental Flows DSSEF)*

5. Identify areas of conservation priority relative to freshwater ecosystem resilience and vulnerability

6. Provide information and resources to the EFSAB for TNC environmental flow recommendations

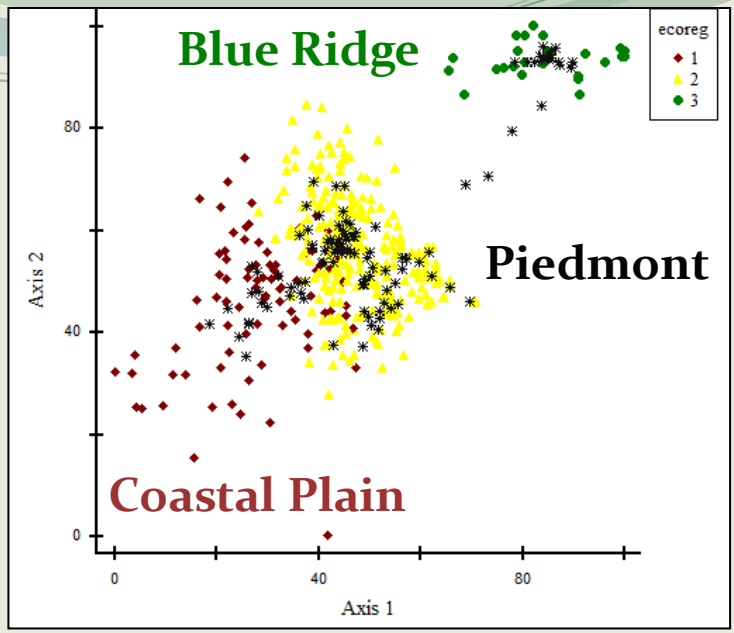
Biological Data Evaluation

- **What are the prevailing patterns of fish communities?**
- **How have fish diversity and abundance at-a-site changed over time?**
- **How has water-use affected fish diversity and abundance ?**
  - **Can we define a flow-ecology response relationship?**
- NC DWQ wadeable streams
  - Fish ≥ 2 survey dates per site, 1992 - 2009



Biological Data Evaluation

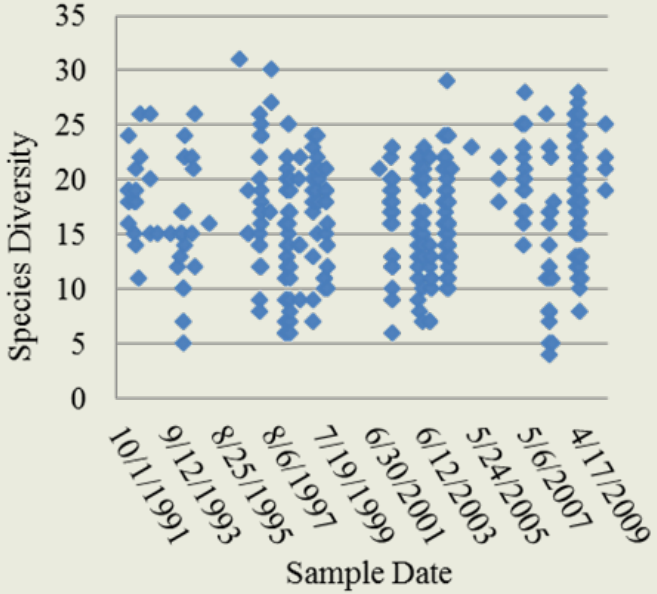
- NC DWQ wadeable streams fish survey data
- Fish data: sites with ≥ 2 survey samples
- Species distribution by ecoregion
- Wadeable stream sample sites only include sub-set of all potential species present in a basin

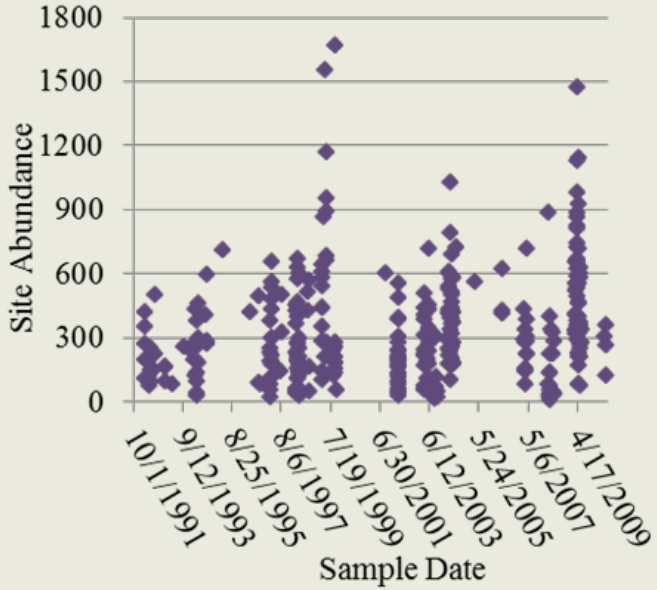


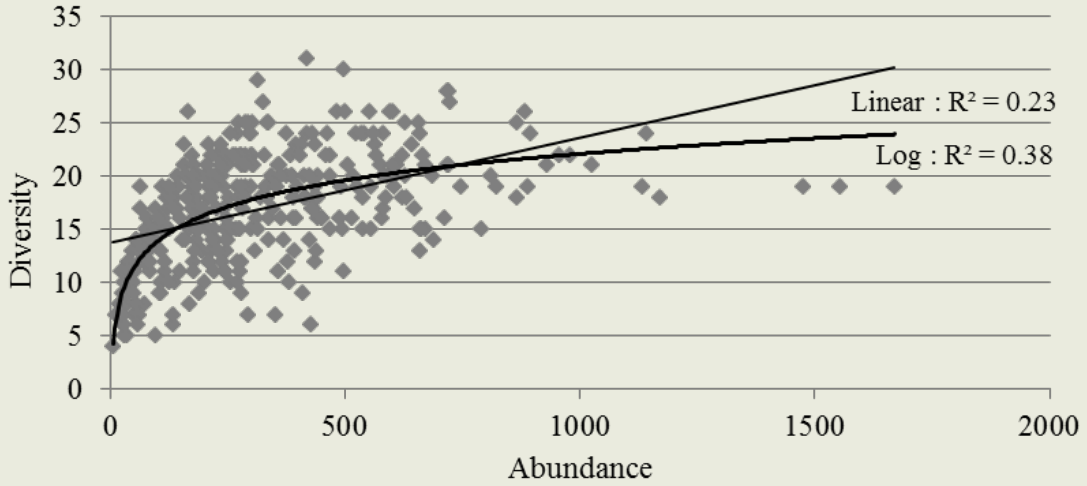
River Basin	Fish Sites	Fish Diversity	Fish Density	% of fish represented for each basin
Roanoke	27	58	1,218	50 %
Cape Fear	69	68	2,650	63%
Tar Pamlico	33	59	1,740	66%
Little Tennessee	12	36	415	50%

Descriptive Info on Fish Survey Data

- Diversity:
  - Avg.: 17
  - Range: 4-31
- Abundance:
  - Avg.: 328
  - Range: 7 – 1670



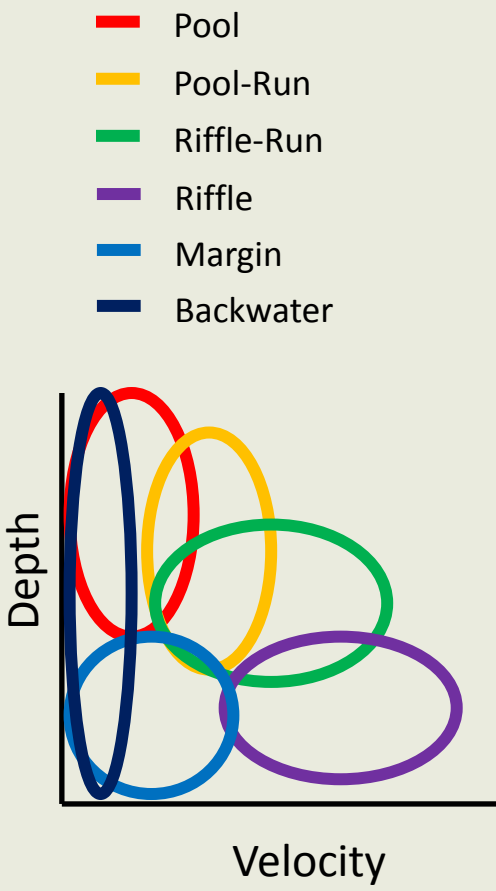




Fish Distribution by Guilds

Guilds developed by WRC for NC

Adult/Juvenile	Count	Total	%	Spawn	Count	Total	%
backwater	14			**backwater**	20		
backwater; pool	2	17	**10**	backwater; pool	2	22	**13**
backwater; pool-margin	1						
pool	50			**pool**	29		
pool; backwater	5	64	**37**	pool; backwater	4	36	**21**
pool; pool-margin	3			pool; margin	2		
pool; pool-run	6			pool; pool-run	1		
pool-margin	2	2	**1**	**pool-margin**	3	5	**3**
				pool-margin; pool-run	2		
pool-run	41			**pool-run**	32		
pool-run; backwater	1	50	**29**	pool-run; backwater	1	42	**24**
pool-run; pool	2			pool-run; margin	2		
pool-run; riffle-run	6			pool-run; riffle-run	7		
riffle	12		**9**	**riffle**	13	21	**12**
riffle; riffle-run	3	15		riffle; riffle-run	8		
riffle-run	19			**riffle-run**	41		
riffle-run; pool-run	2	25	**14**	riffle-run; pool-run	2	47	**27**
riffle-run; riffle	3			riffle-run; riffle	4		
riffle-run; riffle; pool-run	1						



Calculated from fish presence data for Little Tennessee, Cape Fear, Tar-Pamlico, and Little Tennessee

Influence of Environmental Variables on Fish Community Patterns

What influence do these 14 environmental factors have the on fish community patterns in wadeable streams?

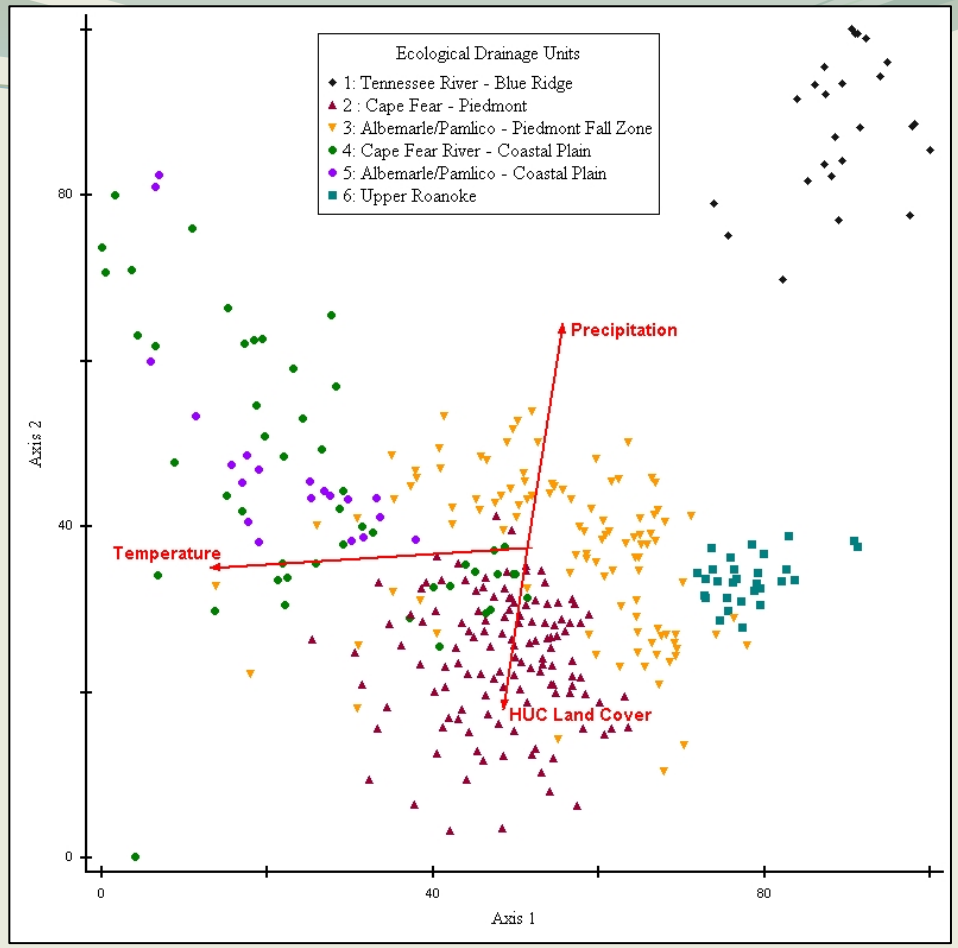
- Physiographic (2):
  - drainage basin area, stream gradient,
- Hydro-climatic variables (4):
  - precipitation, temperature, mean annual flow, mean annual flow velocity
- Land use variables (2):
  - departure from natural conditions in the active river area and HUC 12
- Habitat condition (3):
  - Statewide condition, ecoregional condition, Conservation Planning Tool condition
- Biogeographic (3):
  - river basin, ecoregion, Ecological Drainage Units (EDUs)

Environmental Variables used in NMS

Environmental Variables	Range or Categories	Description/Source
Drainage Basin Area	0.82 - 872	Cumulative Drainage Basin (sq. km)
Stream Gradient	0.00001 - 0.03	Local NHD catchment slope calculated from USGS 30m DEM
Precipitation	1088 - 1785	USGS PRISM mean annual precip (mm)
Temperature	122 - 165	USGS PRISM AIR TEMP Model (area weighted mean annual temp in degree C * 1)
Mean Annual Flow	0.35 - 312	Mean annual flow (cfs) computed from unit runoff method
Mean Annual Flow Velocity	0.650 - 1.42	Mean annual velocity (fps) computed from unit runoff method
HUC 12 Land cover	0.85 - 3.66	% departure from natural land cover, z-scores (low = excellent, high = poor)
ARA Land cover	0.67 - 4.85	% departure from natural land cover in Active River Area (ARA), z-scores (low = poor, high = excellent)
Statewide Condition	1.11 - 3.82	Summation of habitat condition from Burns et al. 2012, z-scores (low = poor, high = excellent)
Ecoregional Condition	0.43 - 4.18	Habitat conditions relative to ecoregion from Burns et al. 2012, z-scores (low = poor, high = excellent)
Freshwater Conservation Targets	0.18 - 3.56	Natural Heritage Program Conservation Planning Tool results, z-scores (low = poor, high = excellent)
River Basin	4 groups	(1) Little Tennessee, (2) Cape Fear, (3) Tar-Pamlico, (4) Roanoke
Ecoregion	3 groups	(1) Coastal Plain, (2) Piedmont, (3) Appalachian Blue Ridge
Ecological Drainage Units	6 groups	(1) Tennessee River-Blue Ridge, (2) Cape Fear River - Piedmont, (3) Albemarle/Pamlico-Piedmont/Fall Zone, (4) Cape Fear River - Coastal Plain, (5) Albemarle/Pamlico-Coastal Plain, (6) Upper Roanoke River

NMS Ordination of Community Patterns

- 77% of the variance explained
  - Axis 1 = 55%, Axis 2= 22%
- Temperature, Precipitation, HUC 12 departure from natural conditions, and Ecological Drainage Units strongest control on community patterns
- Mean annual flow velocity and drainage basin area were only variables without significance



Pearson's results for quantitative variables

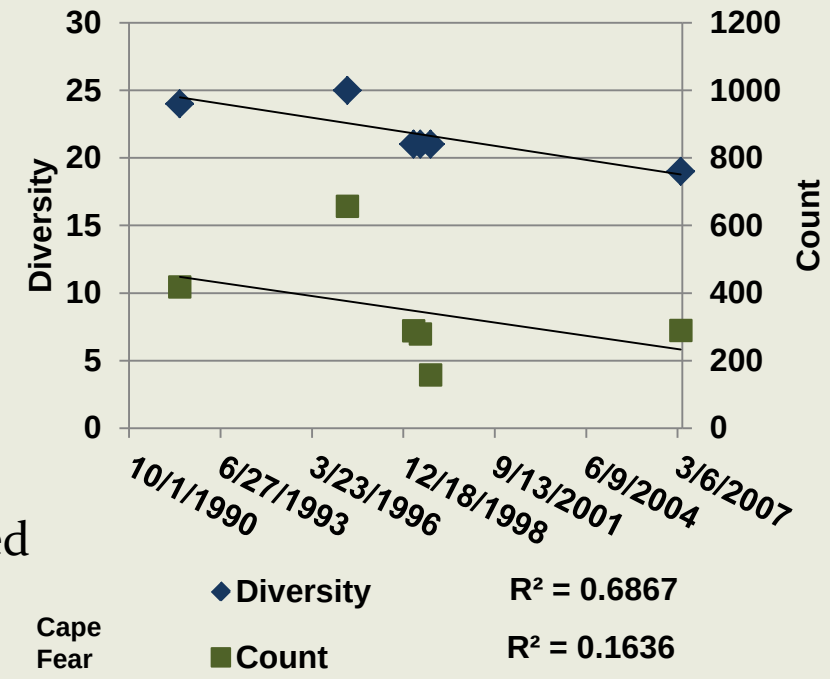
Variables	*r* – Axis 1	*r* – Axis 2
Mean Flow	0.253	0.293
Mean Velocity	0.336	0.343
Stream Gradient	0.285	
Precipitation	0.296	0.737
Temperature	-0.875	
ARA Land Cover		-0.320
HUC Land Cover		-0.624
Statewide Habitat Condition		-0.423
Ecoregional Habitat Condition		-0.332
CPT Habitat Condition		-0.419

MRPP results for categorical variables

Variables	*p*	*A*
Ecoregion	0.000	0.128
Ecological Drainage Unit	0.000	0.227
River Basin	0.000	0.168

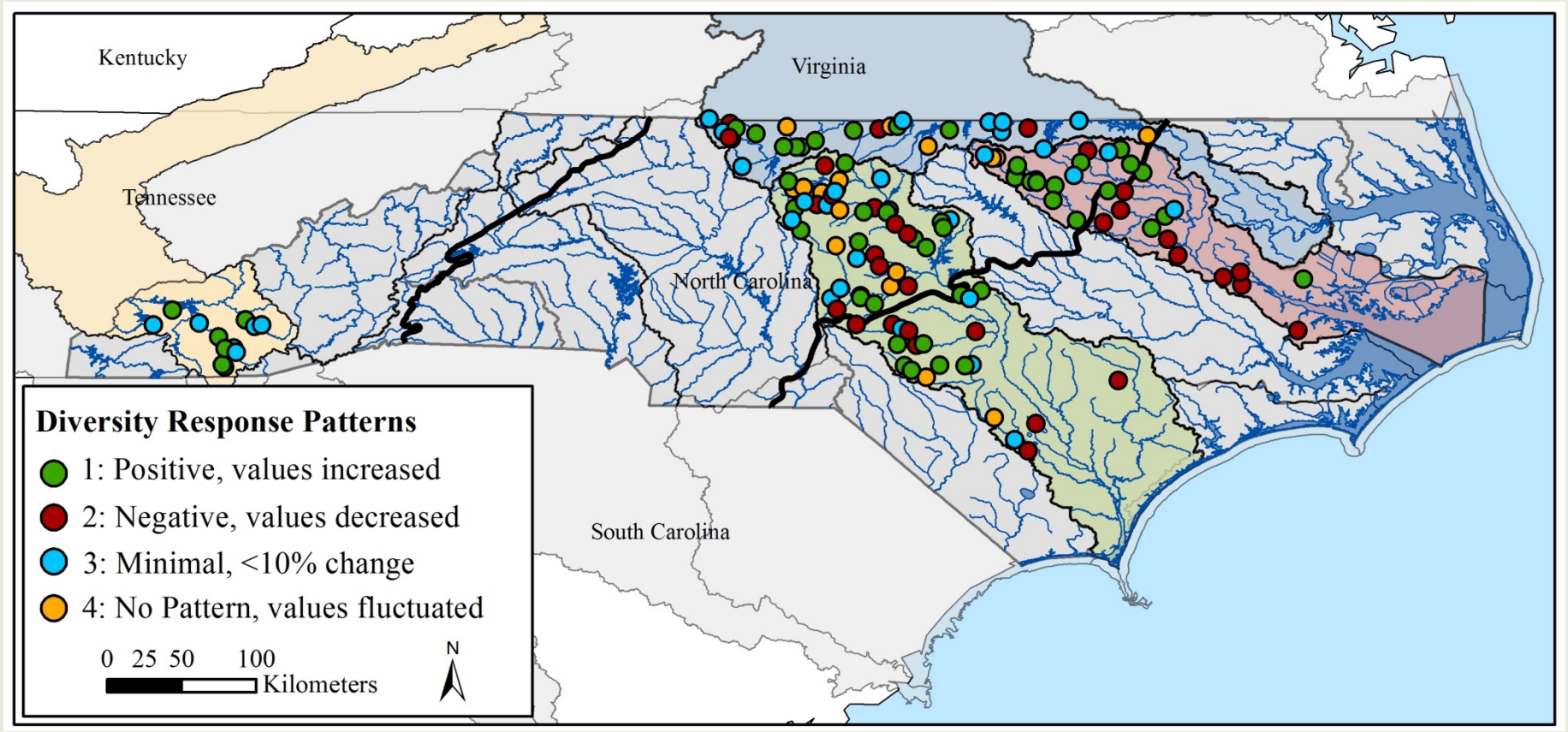
Fish Diversity and Abundance Patterns and Changes Over Time

- Fish diversity and abundance changes over time
- Plotted graphs for 141 fish sites, number of events and dates vary between 1992-2009
- Calculated Coefficient of Variation
  - (CV = st.dev. /mean)
- Calculated direction of change:
- 1. Positive: values increased > 10%
- 2. Negative: values decreased > 10%
- 3. Minimal: < 10% change either direction
- 4. No Pattern: >10% changed, values fluctuated



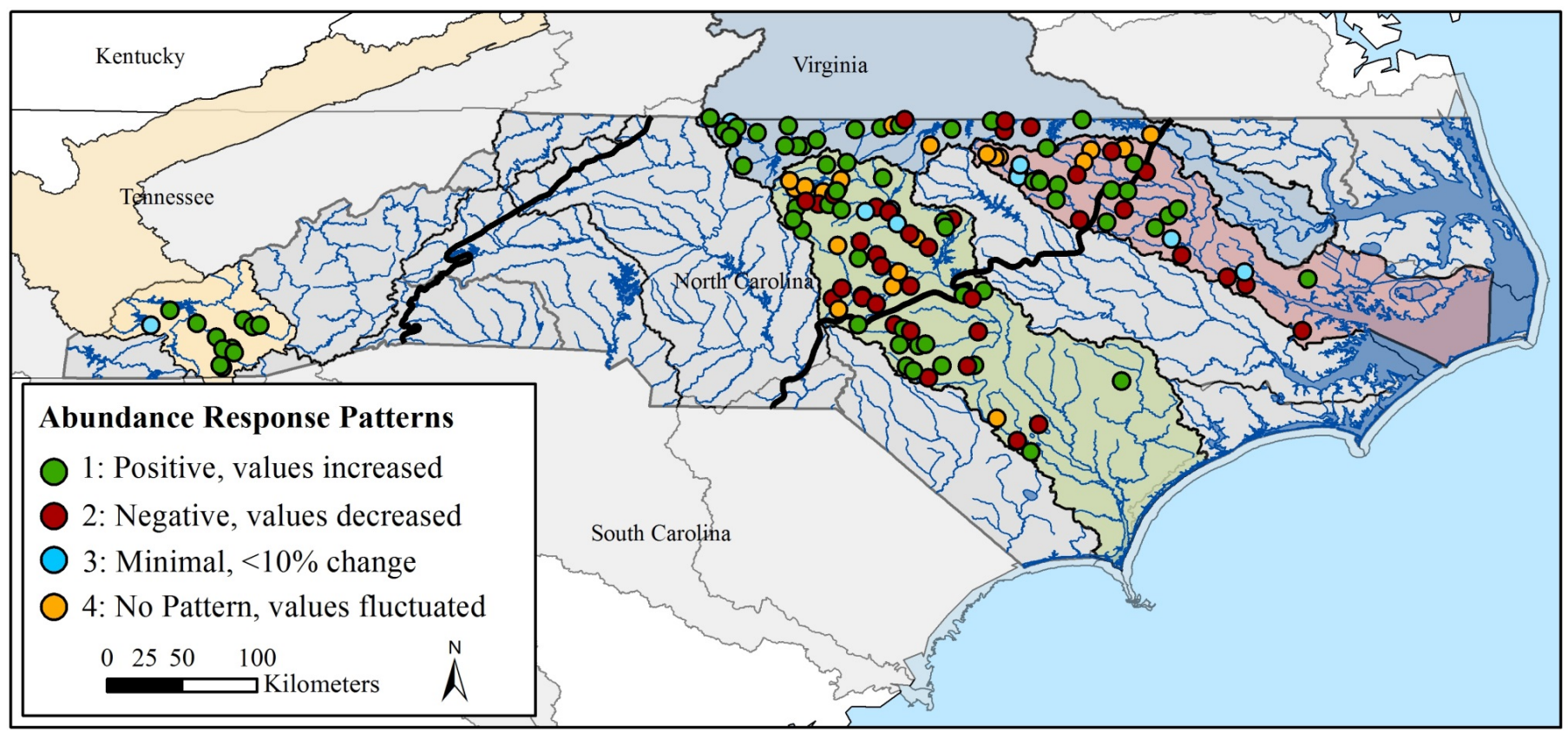
Patterns of Fish Diversity Changes Overtime

- 1. Positive: species diversity increased > 10% (green)
- 2. Negative: species diversity decreased > 10% (red)
- 3. Minimal: < 10% change overtime (turquoise)
- 4. No Pattern: >10% changed, values fluctuated positive and negative (orange)



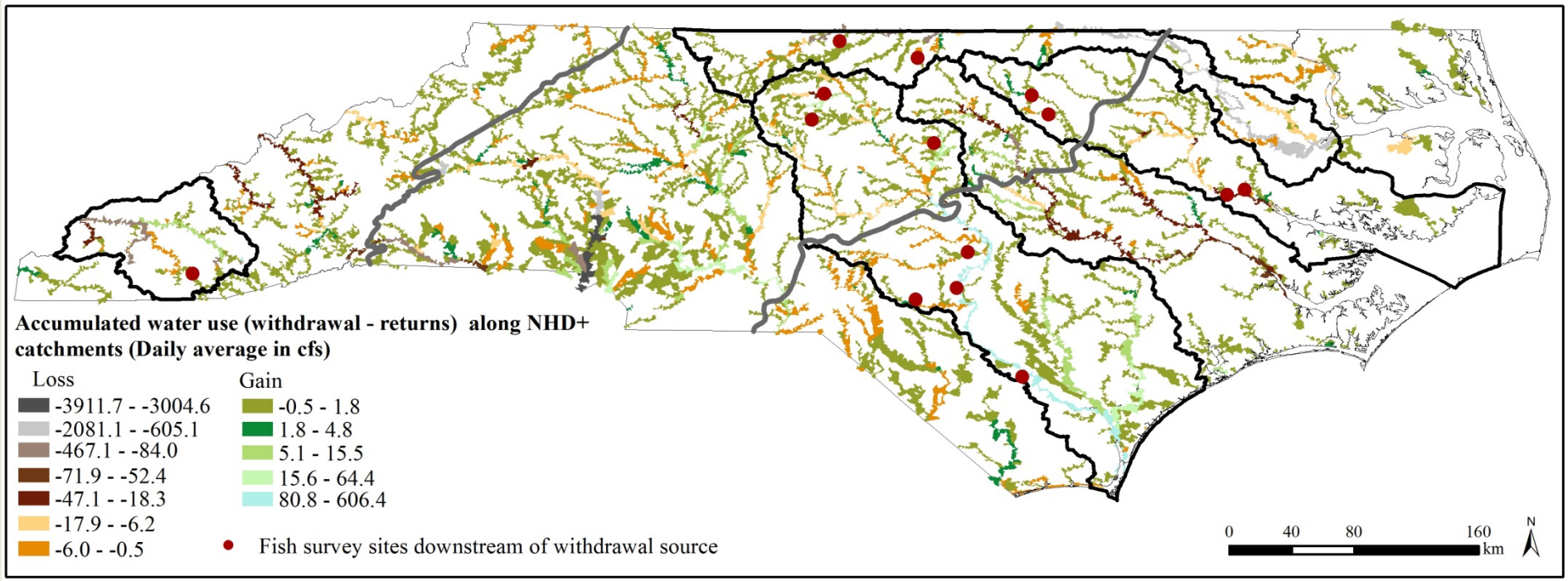
Patterns of Fish Abundance Changes Overtime

- 1. Positive: species diversity increased > 10% (green)
- 2. Negative: species diversity decreased > 10% (red)
- 3. Minimal: < 10% change overtime (turquoise)
- 4. No Pattern: >10% changed, values fluctuated positive and negative (orange)



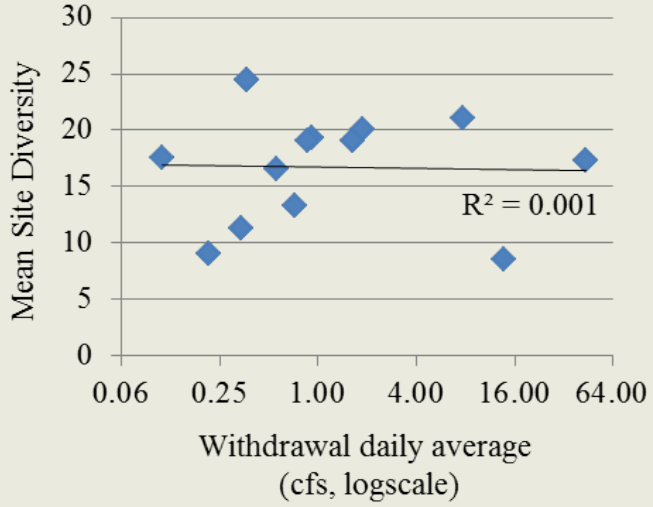
Water Use and Fish Survey Sites

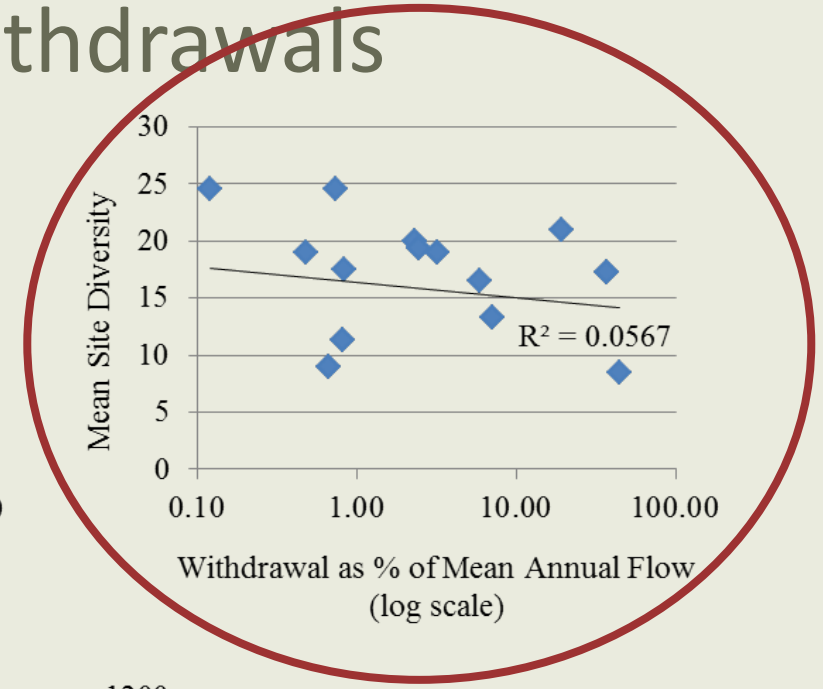
- **Only 10% (14 sites) of the 141 fish sites occurred downstream of a withdrawal source, the other 90% occurred upstream of withdrawal source**
- **Calculated relationship between withdrawals and fish diversity and abundance for sites downstream of water use source**

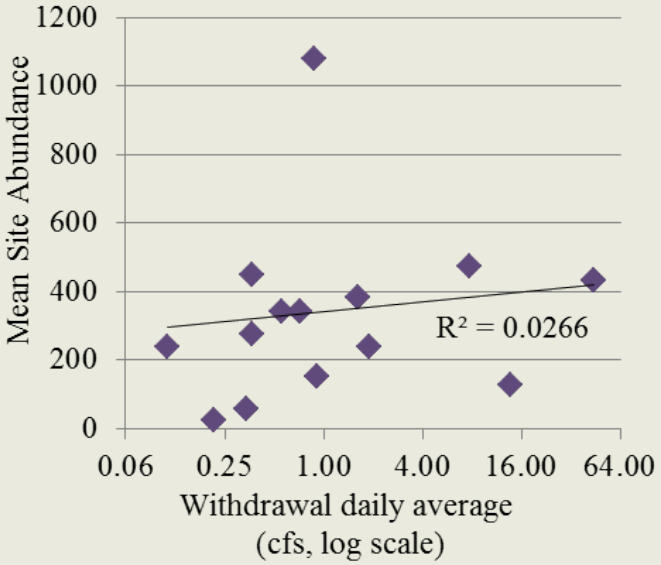


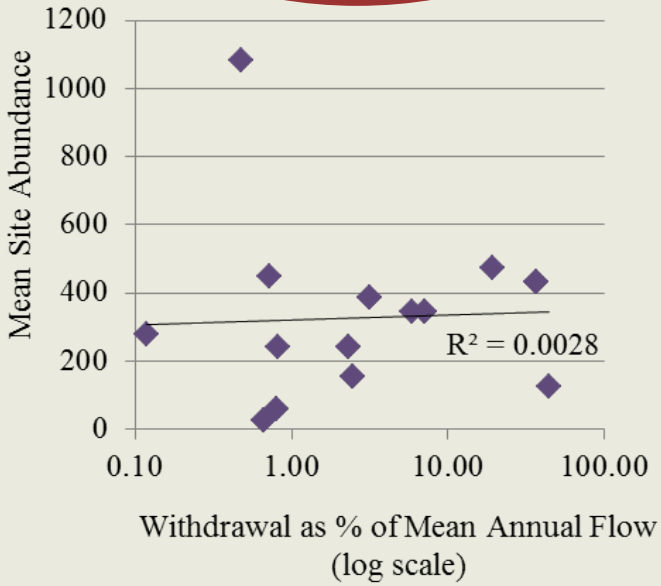
Cumulative withdrawal and return discharges: Catchment level flow alteration data (withdrawals and returns) accumulated difference downstream through NHD+ catchment. Catchement level data courtesy of RTI, post-processing of cumulative downstream calculations by TNC

Fish response to withdrawals



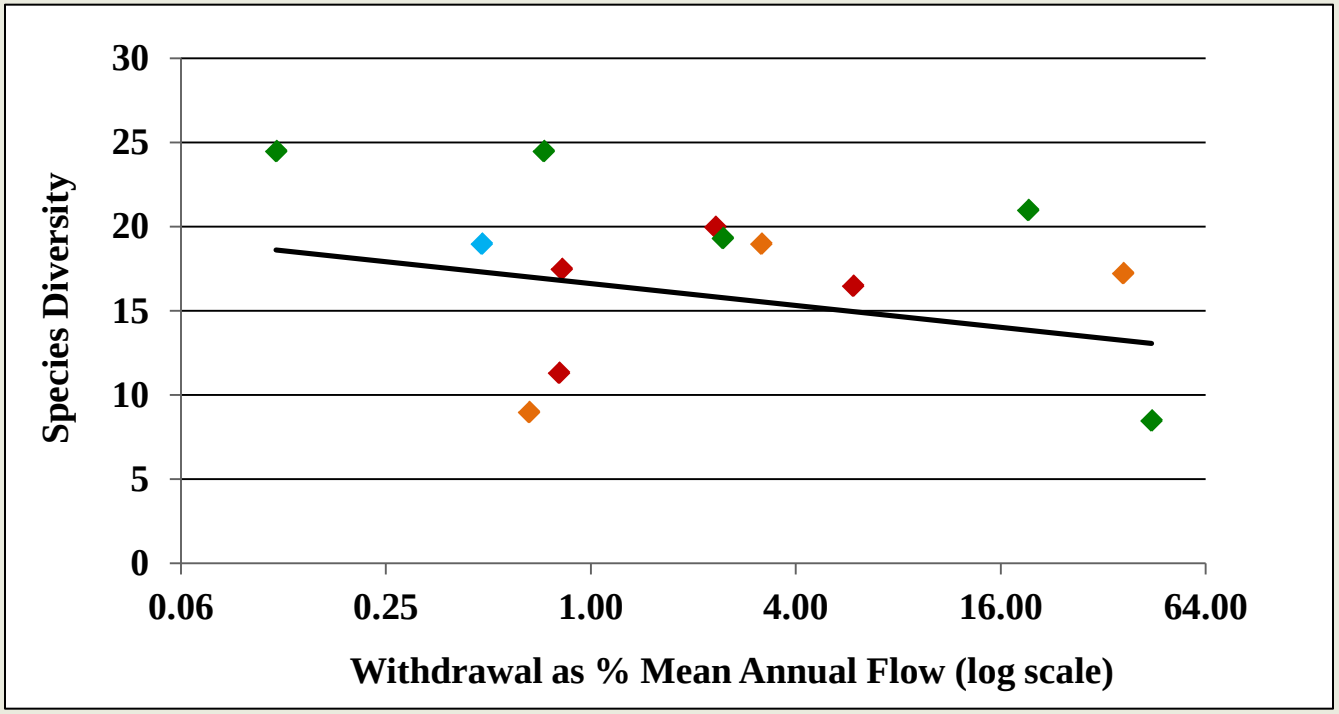


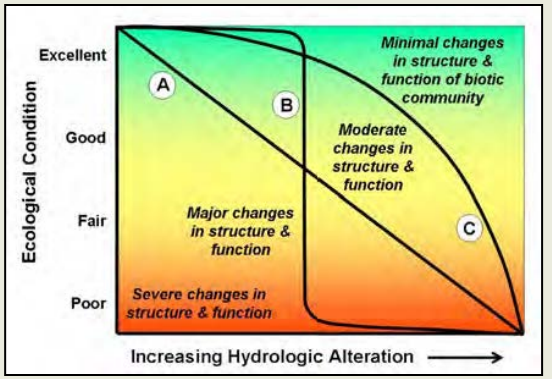




Fish response to withdrawals

- **5-10% species diversity decline relative to 10% mean annual flow withdrawal**
- **25-30% species diversity decline with 50% mean annual flow withdrawal**
- Considerations: only 14 data points, mean annual flow calculated by unit-area-runoff method, not controlling for other factors, inconsistent pattern with at-a-site diversity responses
- Recommend more fish survey points and accounting for LULC and water quality





Diversity Response Patterns

- 1: Positive, values increased
- 2: Negative, values decreased
- 3: Minimal, <10% change
- 4: No Pattern, values fluctuated

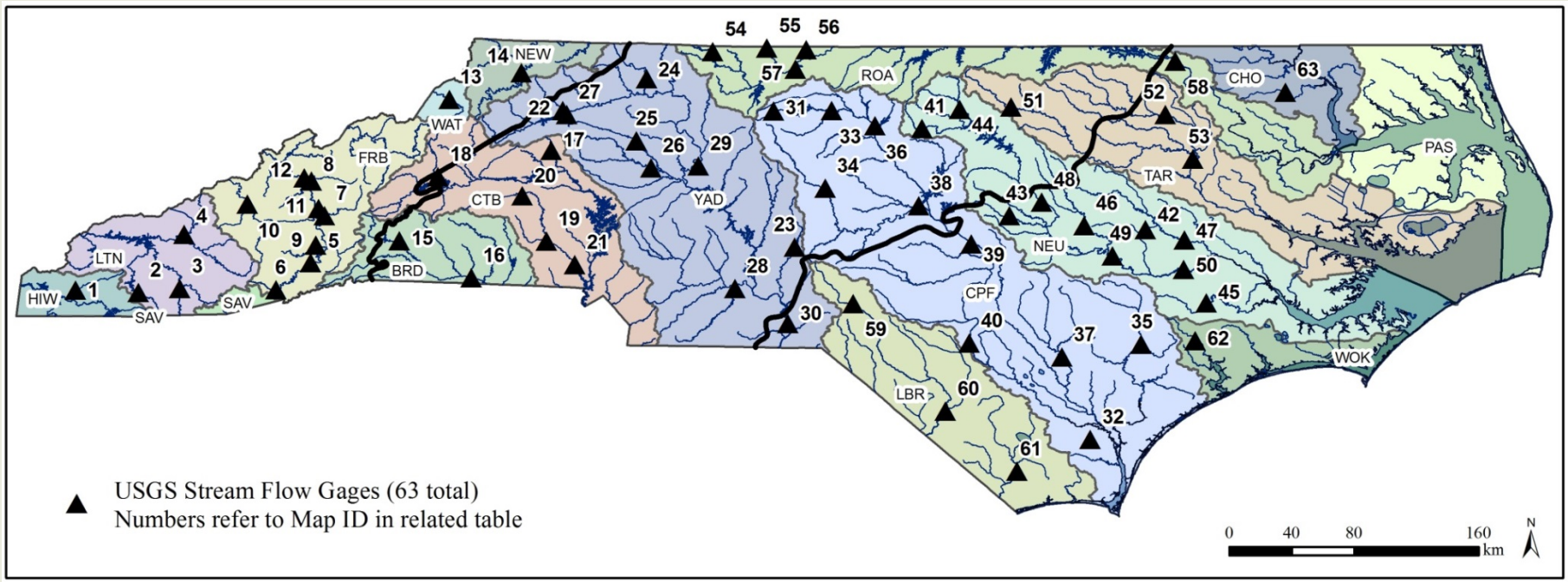
Fish Community Analysis

- Strengths:
  - Useful for characterizing fish ecology of wadeable streams
  - Community analysis showed importance of hydro-climatic variables, EDU classification, and land use impacts
    - Supports the need and importance for protecting naturally variable flow regimes indicative of different hydro-climatic areas and EDU's
  - Diversity and abundance response patterns help identify areas of concern and show potential for monitoring fish impacts from flow alteration
    - Need to better quantify land use effects on aquatic ecology to separate them from water – use (withdrawal and return) related effects
  - Fish diversity and withdrawal plots shows negative relationship
    - 5-10% diversity decline with withdrawal > 10% of the mean annual flow
    - 25-30% diversity decline with withdrawal >50% of mean annual flow

- Weaknesses:
  - Only applicable to wadeable streams (50-34% of other fish species from each basin absent from the analysis, ex. anadromous fish)
  - Data limitation prevented including water quality and water use-related effects
    - Only fraction of the sites had these data associated with them
  - Few wadeable stream sites occur in proximity to monitored stream flow gages making it challenging to develop flow-ecology relationships

Stream Flow Changes Over Time

- **What are the changes in flow patterns over recent history?**
- **How do they vary spatially (among gaging sites) and temporally (months) and by flow magnitude (percentiles) ?**
- **How can changes in flow patterns inform environmental flows?**
- 63 USGS gages with 57 years of record, 1955 - 2012
  - Period 1 (recent historic conditions): 1955 – 1980 (25 years)
  - Period 2 (current contemporary conditions) : 1980 – 2012 (28 years)



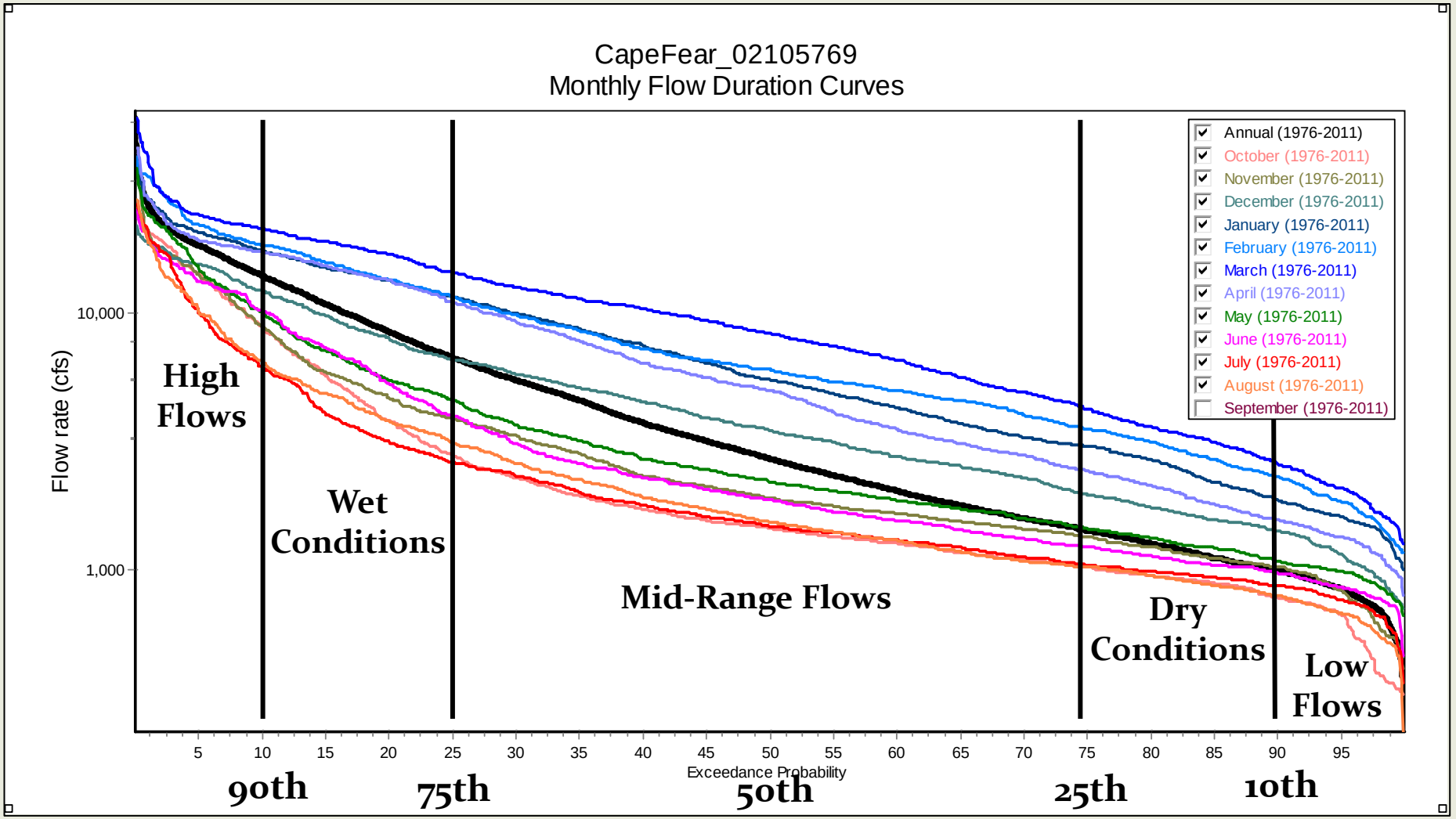
USGS Stream Flow Gages

- Mean Daily Flow
- IHA for calculating monthly percentiles for both periods:
  - 90th, 75th, 50th, 25th, 10th
- % change between time periods calculated post-processing
- Mapped % change across the state for each percentile

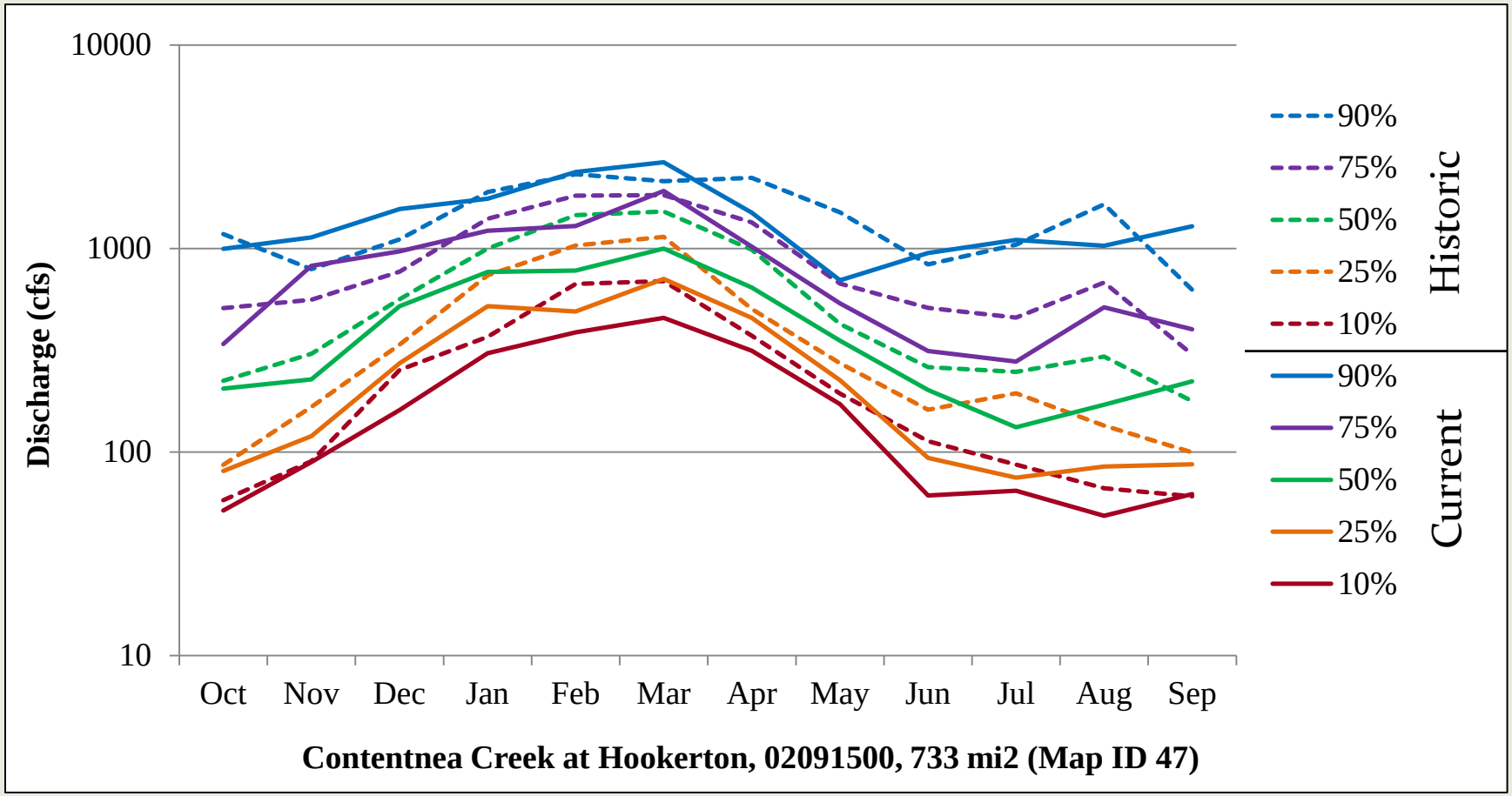
Map	Basin	Station	Station Name	Eco.Reg.	D.A. (mi.^{2})	Major Dams Upstream
1	Hiwassee	03550000	VALLEY RIVER AT TOMOTLA	BR	104	none
2	Little Tennessee	03504000	NANTAHALA RIVER NEAR RAINBOW SPRINGS	BR	52	none
3	Little Tennessee	03500000	LITTLE TENNESSEE RIVER NEAR PRENTISS	BR	140	none
4	Little Tennessee	03512000	OCONALUFTEE RIVER AT BIRDTOWN	BR	184	none
5	French Broad	03446000	MILLS RIVER NEAR MILLS RIVER	BR	67	none
6	French Broad	03439000	FRENCH BROAD RIVER AT ROSMAN	BR	68	none
7	French Broad	03451000	SWANNANOA RIVER AT BILTMORE	BR	130	none
8	French Broad	03453000	IVY RIVER NEAR MARSHALL	BR	158	none
9	French Broad	03443000	FRENCH BROAD RIVER AT BLANTYRE	BR	296	none
10	French Broad	03459500	PIGEON RIVER NEAR HEPCO	BR	350	none
11	French Broad	03451500	FRENCH BROAD RIVER AT ASHEVILLE	BR	945	none
12	French Broad	03453500	FRENCH BROAD RIVER AT MARSHALL	BR	1332	Craggy Dam 1904
13	Watauga	03479000	WATAUGA RIVER NEAR SUGAR GROVE	BR	92	none
14	New	03161000	SOUTH FORK NEW RIVER NEAR JEFFERSON	BR	205	none
15	Broad	02149000	COVE CREEK NEAR LAKE LURE	BR	79	none
16	Broad	02151500	BROAD RIVER NEAR BOILING SPRINGS	P	875	Lake Lure Dam; Burlington Mills Dam
17	Catawba	02142000	LOWER LITTLE RIVER NR ALL HEALING SPRINGS	P	28	none
18	Catawba	02138500	LINVILLE RIVER NEAR NEBO	P	67	none
19	Catawba	02143500	INDIAN CREEK NEAR LABORATORY	P	69	none
20	Catawba	02143000	HENRY FORK NEAR HENRY RIVER	P	83	none
21	Catawba	02145000	SOUTH FORK CATAWBA RIVER AT LOWELL	P	628	none
22	Yadkin/PeeDee	02111500	REDDIES RIVER AT NORTH WILKESBORO	P	89	none
23	Yadkin/PeeDee	02128000	LITTLE RIVER NEAR STAR	P	106	none
24	Yadkin/PeeDee	02113000	FISHER RIVER NEAR COPELAND	P	128	none
25	Yadkin/PeeDee	02118500	HUNTING CREEK NEAR HARMONY	P	155	none
26	Yadkin/PeeDee	02118000	SOUTH YADKIN RIVER NEAR MOCKSVILLE	P	306	none
27	Yadkin/PeeDee	02112000	YADKIN RIVER AT WILKESBORO	P	504	W. Kerr Scott Dam 1963
28	Yadkin/PeeDee	02126000	ROCKY RIVER NEAR NORWOOD	P	1372	none
29	Yadkin/PeeDee	02116500	YADKIN RIVER AT YADKIN COLLEGE	P	2280	W. Kerr Scott Dam 1963
30	Yadkin/PeeDee	02129000	PEE DEE R NR ROCKINGHAM	CP	6863	W. Kerr Scott Dam 1963; High Rock 1927; Tillery 1928; Blewitt Falls 1912
31	Cape Fear	02093800	REEDY FORK NEAR OAK RIDGE	P	21	none
32	Cape Fear	02105900	HOOD CREEK NEAR LELAND	CP	22	none
33	Cape Fear	02094500	REEDY FORK NEAR GIBSONVILLE	P	131	Brandt Dam, Townsend Lake Dam
34	Cape Fear	02100500	DEEP RIVER AT RAMSEUR	P	349	Randleman 2004
35	Cape Fear	02108000	NORTHEAST CAPE FEAR RIVER NEAR CHINQUAPIN	CP	599	Randleman 2004
36	Cape Fear	02096500	HAW RIVER AT HAW RIVER	P	606	Townsend Lake Dam, Lake Cammack
37	Cape Fear	02106500	BLACK RIVER NEAR TOMAHAWK	CP	676	none
38	Cape Fear	02102000	DEEP RIVER AT MONCURE	P	1434	none
39	Cape Fear	02102500	CAPE FEAR RIVER AT LILLINGTON	CP	3464	B. Everett Jordan 1982; Harris Dam
40	Cape Fear	02105500	CAPE FEAR R AT WILM O HUSKE LOCK NR TARHEEL	CP	4852	B. Everett Jordan 1982; Harris Dam
41	Neuse	02085000	ENO RIVER AT HILLSBOROUGH	P	66	none
42	Neuse	02091000	NAHUNTA SWAMP NEAR SHINE	CP	80	none
43	Neuse	02088000	MIDDLE CREEK NEAR CLAYTON	CP	84	none
44	Neuse	02085500	FLAT RIVER AT BAHAMA	P	149	none
45	Neuse	02092500	TRENT RIVER NEAR TRENTON	CP	168	none
46	Neuse	02088500	LITTLE RIVER NEAR PRINCETON	CP	232	none
47	Neuse	02091500	CONTENTNEA CREEK AT HOOKERTON	CP	733	none
48	Neuse	02087500	NEUSE RIVER NEAR CLAYTON	CP	1150	Falls Lake Dam 1981
49	Neuse	02089000	NEUSE RIVER NEAR GOLDSBORO	CP	2399	Falls Lake Dam 1981
50	Neuse	02089500	NEUSE RIVER AT KINSTON	CP	2692	Falls Lake Dam 1981
51	Tar	02081500	TAR RIVER NEAR TAR RIVER	P	167	none
52	Tar	02083000	FISHING CREEK NEAR ENFIELD	CP	526	none
53	Tar	02083500	TAR RIVER AT TARBORO	CP	2183	none
54	Roanoke	02068500	DAN RIVER NEAR FRANCISCO	P	129	none
55	Roanoke	02070500	MAYO RIVER NEAR PRICE	P	242	none
56	Roanoke	02074000	SMITH RIVER AT EDEN	P	538	none
57	Roanoke	02071000	DAN RIVER NEAR WENTWORTH	P	1053	Belew's Lake
58	Roanoke	02080500	ROANOKE RIVER AT ROANOKE RAPIDS	CP	8384	Lake Hyco Dam, Mayo Lake Dam, John H. Kerr Dam 1953; Gaston 1963; Roanoke Rapids 1955
59	Lumber	02133500	DROWNING CREEK NEAR HOFFMAN	CP	183	none
60	Lumber	02134500	LUMBER RIVER AT BOARDMAN	CP	1228	none
61	Waccamaw	02109500	WACCAMAW RIVER AT FREELAND	CP	680	none
62	White Oak	02093000	NEW RIVER NEAR GUM BRANCH	CP	94	none
63	Chowan	02053500	AHOSKIE CREEK AT AHOSKIE	CP	63	none

IHA Monthly Flow Duration Curves

- Exceedance Probabilities for the 90th, 75th, 50th, 25th, 10th %tile Flows



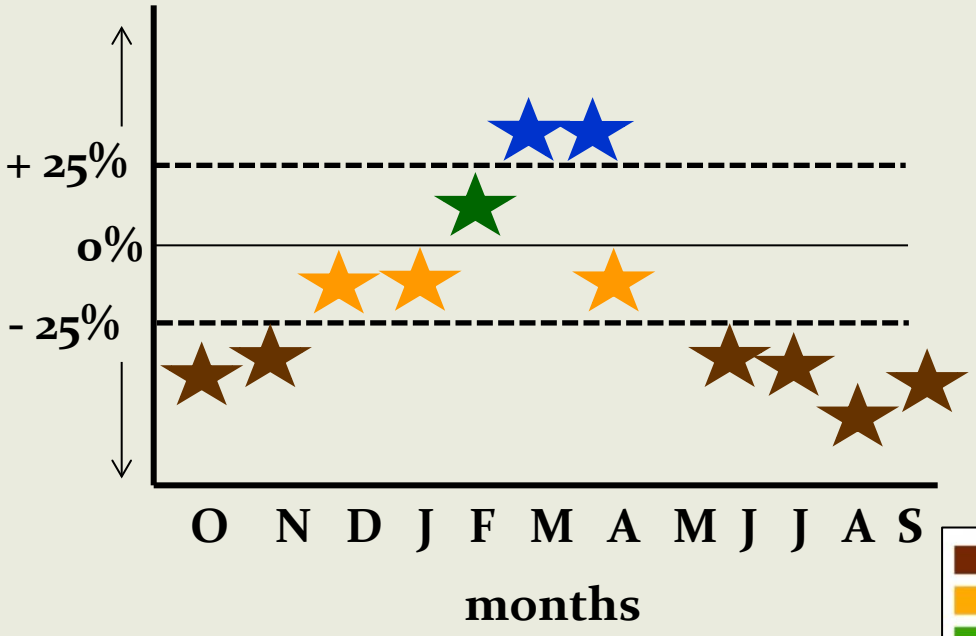
Change among percentiles between periods



- ***Understanding contemporary conditions and spatial and temporal patterns of flow changes will inform management of sustainable water use and environmental flow protection.***

Plotting scheme for % change to percentile

- Example: % change to one percentile for one gage
- Calculated % change for the 5 percentiles for each month
- Grouped % change into 4 categories: 1) 0-25% drier, 2.) > 25% drier, 3.) 0-25% wetter, 4.) >25% wetter (all 5 percentiles for every month – 60 metrics)
- >25% drier or wetter is significant change (Kennard et al., 2010)

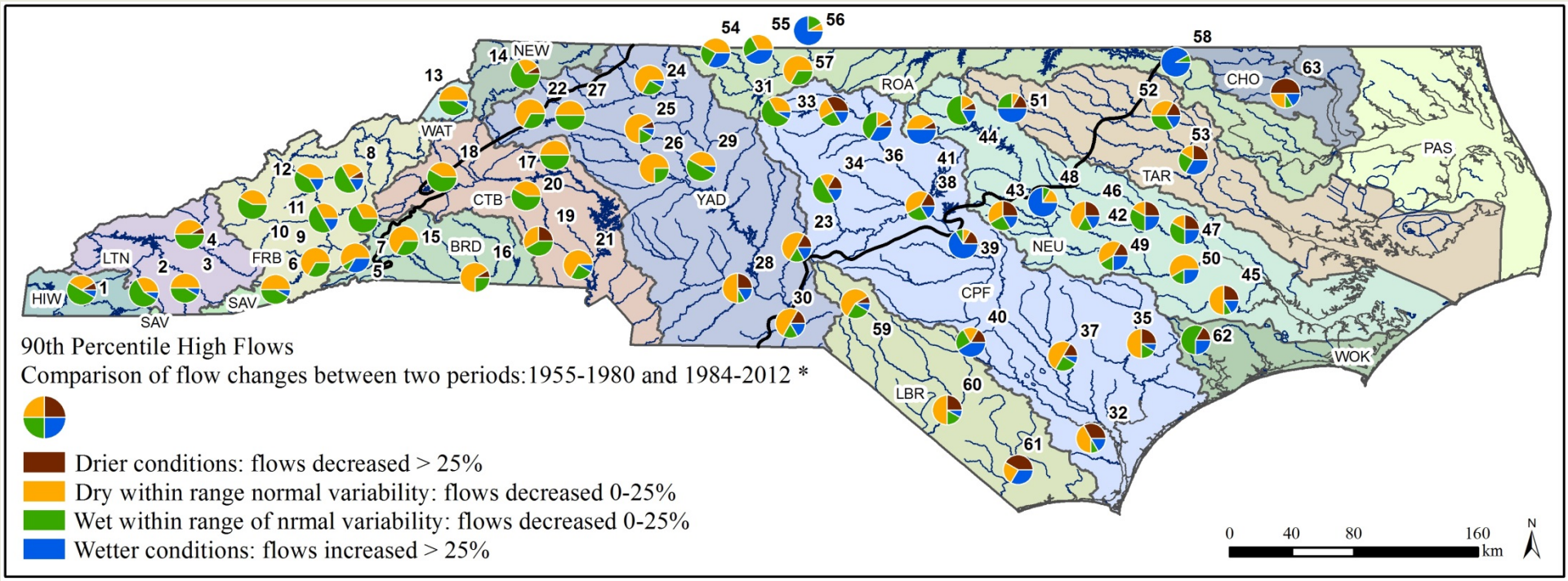


- 50% of months are drier
- 17% are wetter
- 33% are normal

Drier conditions: flows decreased > 25%
Dry within range normal variability: flows decreased 0-25%
Wet within range of nrmal variability: flows decreased 0-25%
Wetter conditions: flows increased > 25%

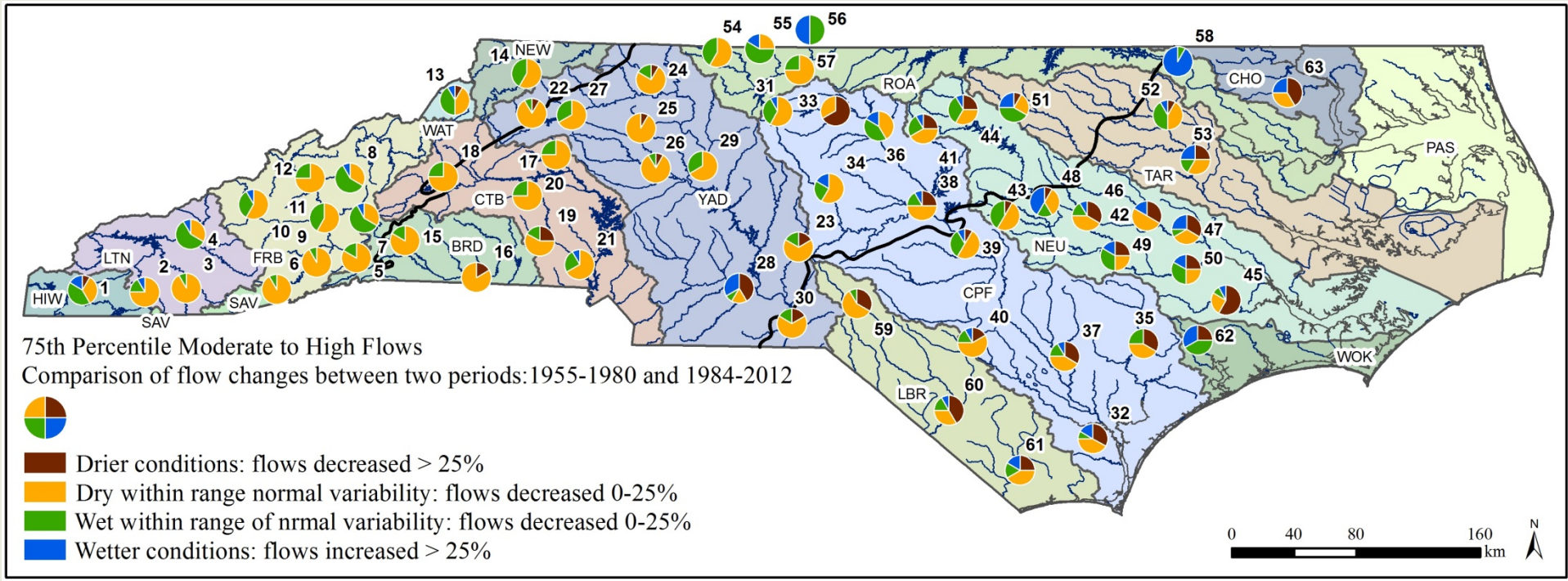
Changes to the **90th percentile**: highest flows

- 90th percentile flow magnitudes are increasing more than decreasing
- Blue Ridge region most stable relative to high flow changes
- Dam regulated high flow increases: Cape Fear below Lake Jordan, Neuse below Falls, and Roanoke below Roanoke Rapids
- Coastal Plain increased intensity of precipitation events?



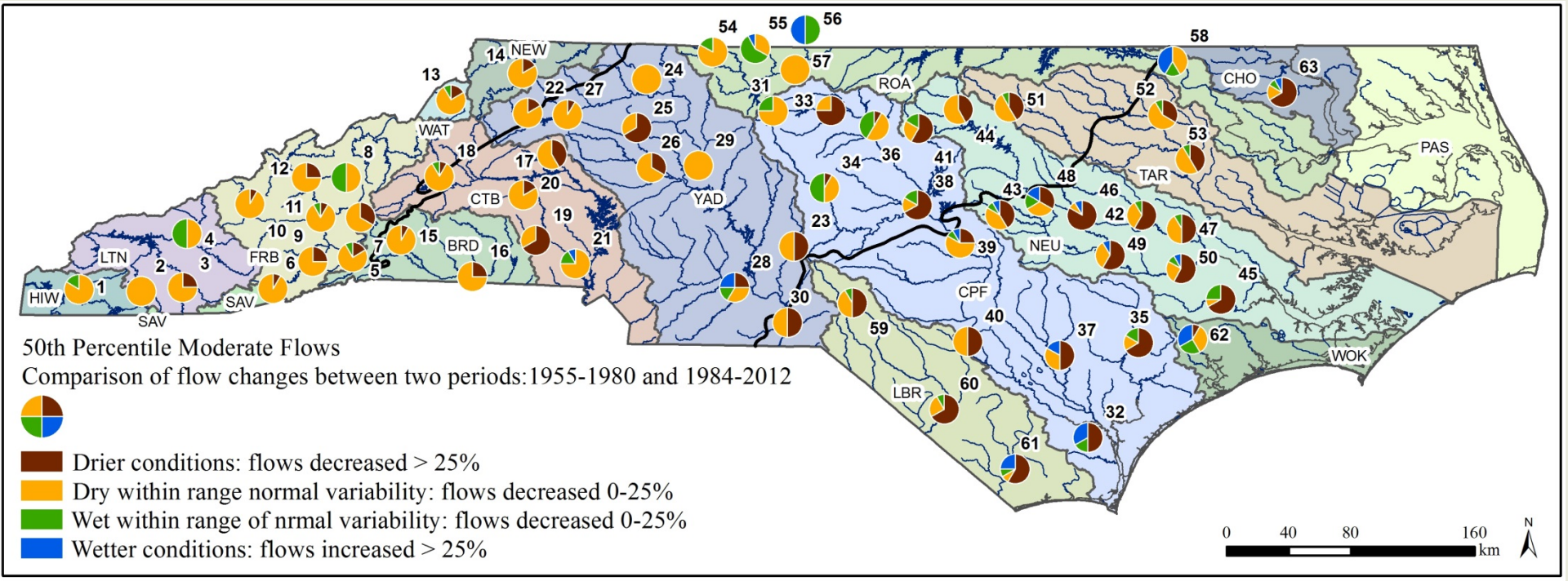
Changes to the **75th percentile**: wet conditions

- Percentile with overall least amount of change
- Blue Ridge region most stable relative to high flow changes
- Coastal Plain increased intensity of precipitation events?
- Dam regulated high flow increases: Cape Fear below Lake Jordan, Neuse below Falls, and Roanoke below Roanoke Rapids



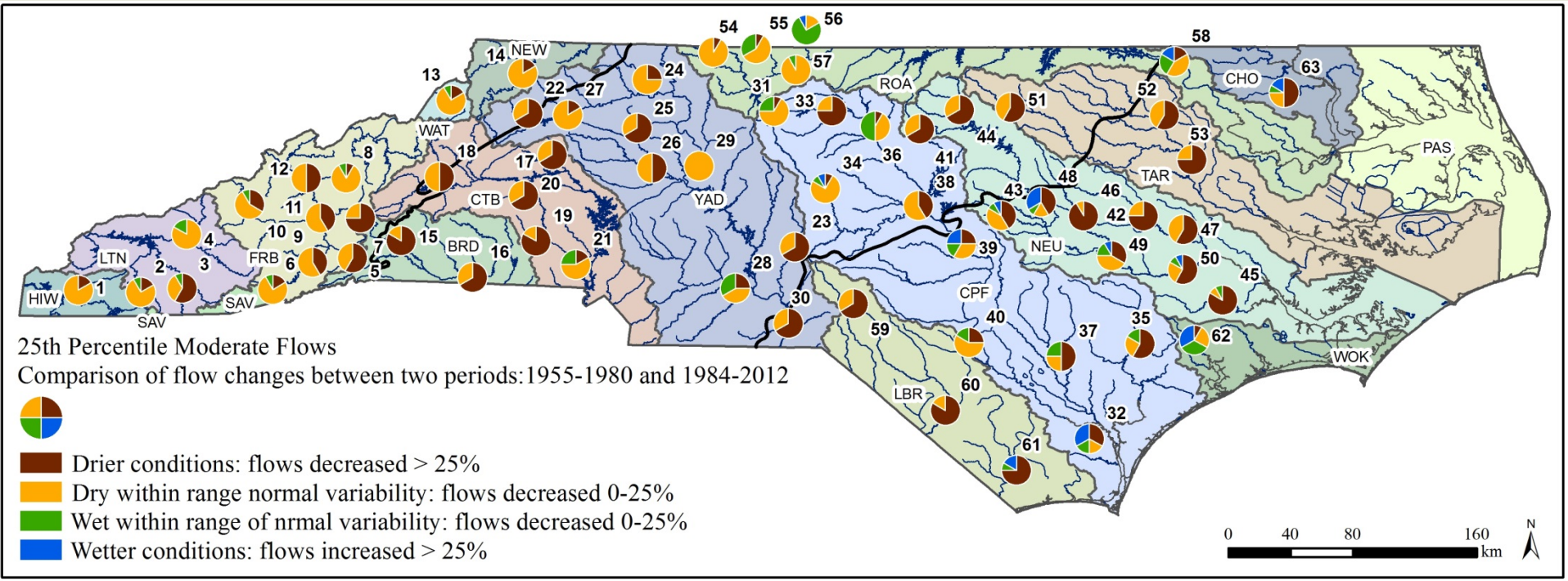
Changes to the **50th percentile**: moderate flows

- Median flows are indicative of central tendency and most prevalent flows
- 32% of gages have significantly drier conditions for more than half the year
- Changes greatest in Piedmont and Coastal Plain, upper Roanoke an exception
- Blue Ridge tending toward drier 50th percentile flows but still within range of normal variability



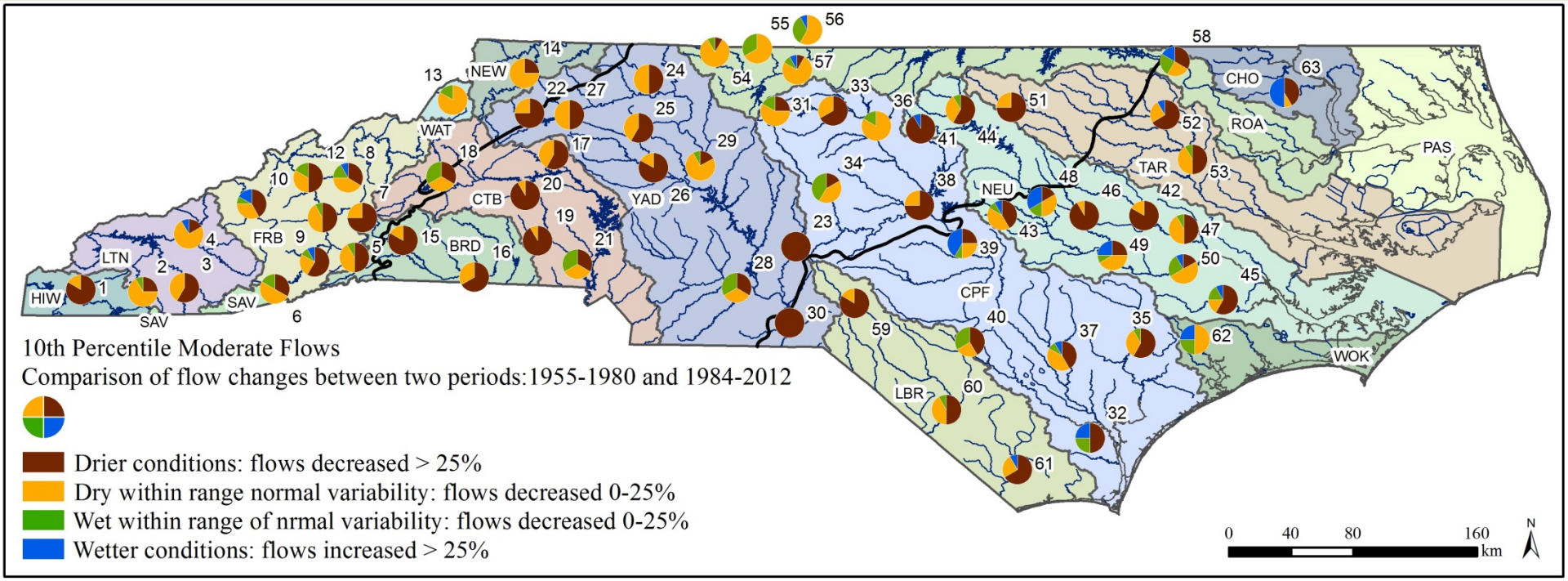
Changes to the **25th percentile**: low flows

- Statewide decreases in 25th percentile flow magnitudes, 51% of gages showed significant flow decreases with conditions being much drier >50% of the time
- Most emphasized in Piedmont and Coastal Plain with exception of Roanoke Basin
- Climate change and increased pressure on water resources



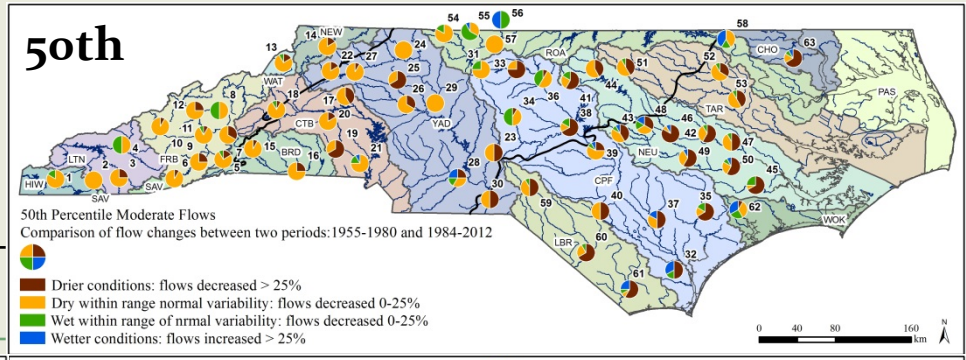
Changes to the **10th percentile**: lowest flows

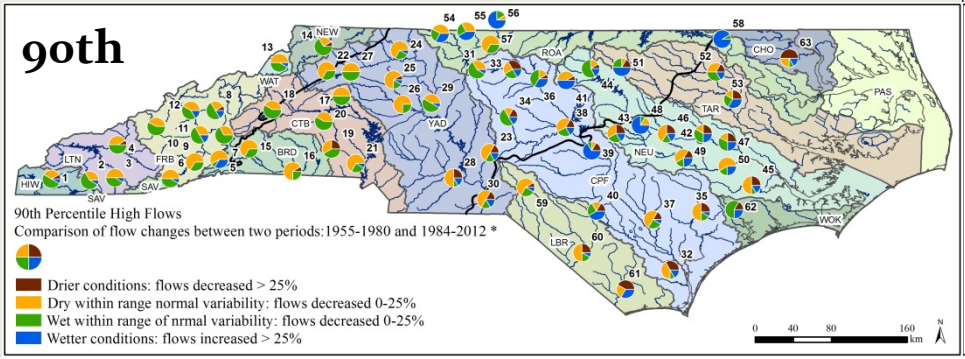
- Statewide decreases in 10th percentile flow magnitudes, 57% of gages showed significant flow decreases with conditions being much drier >50% of the time
- Most emphasized in Piedmont and Coastal Plain with exception of Roanoke Basin
- Climate change and increased pressure on water resources
- The 10th percentile low flows need better protection from water users

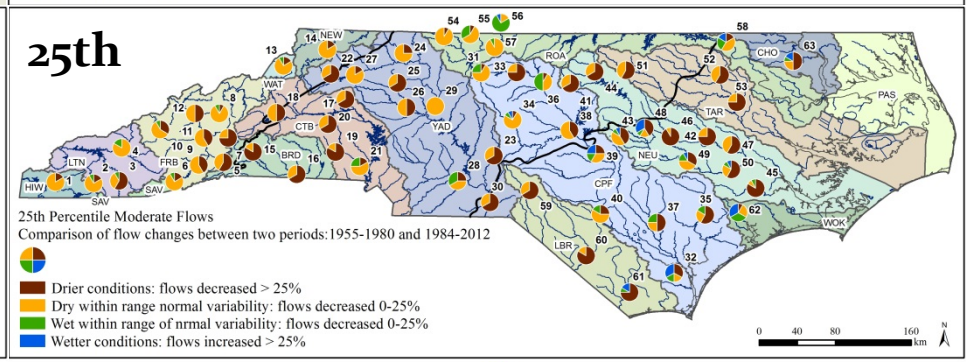


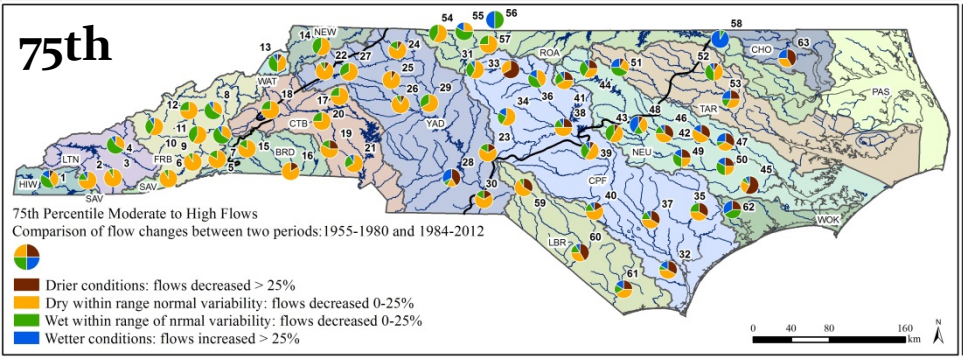
Statewide changes to flow conditions

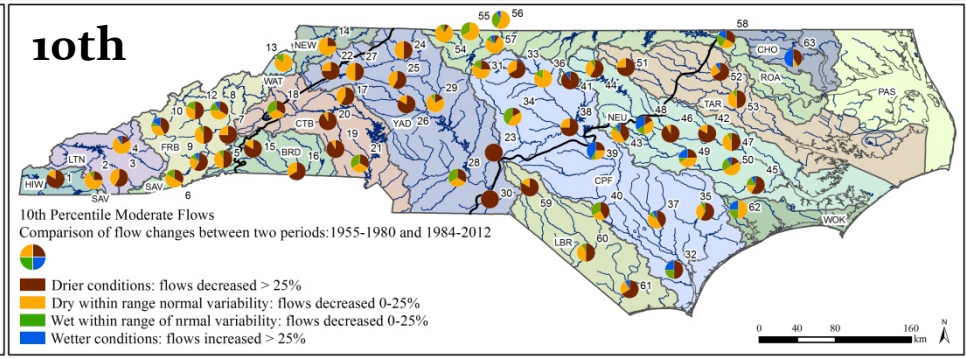
	10th	25th	50th	75th	90th
% of gages drier	57	51	32	3	2
% of gages wetter	2	0	2	3	10
Combo of drier and wetter	10	5	6	14	11
% of gages out of range of normal variability	68	56	40	21	22





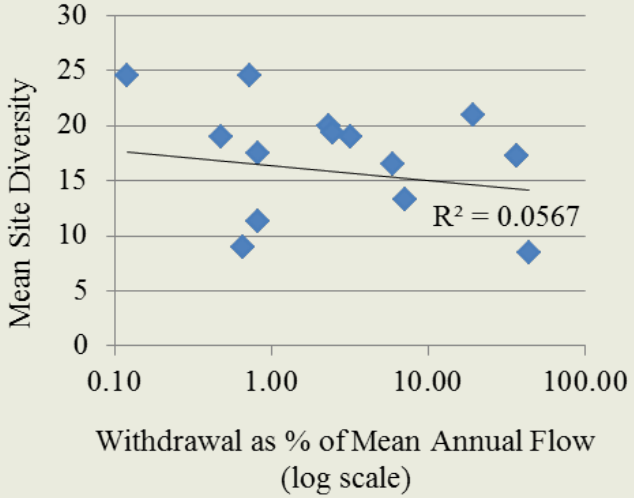


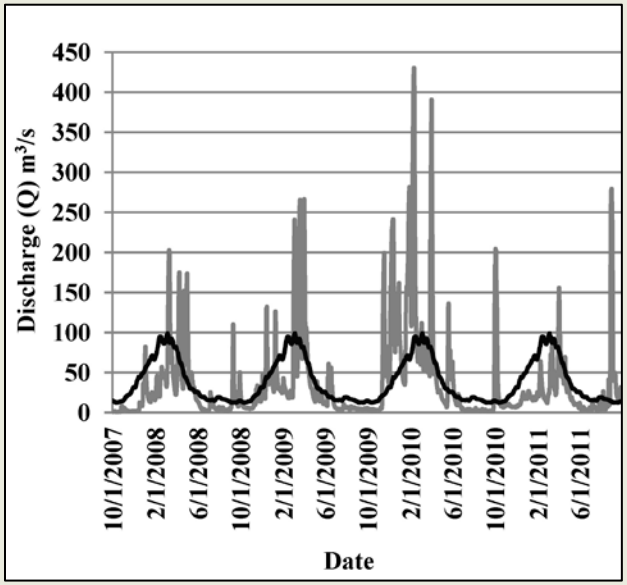


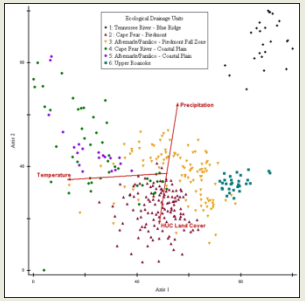


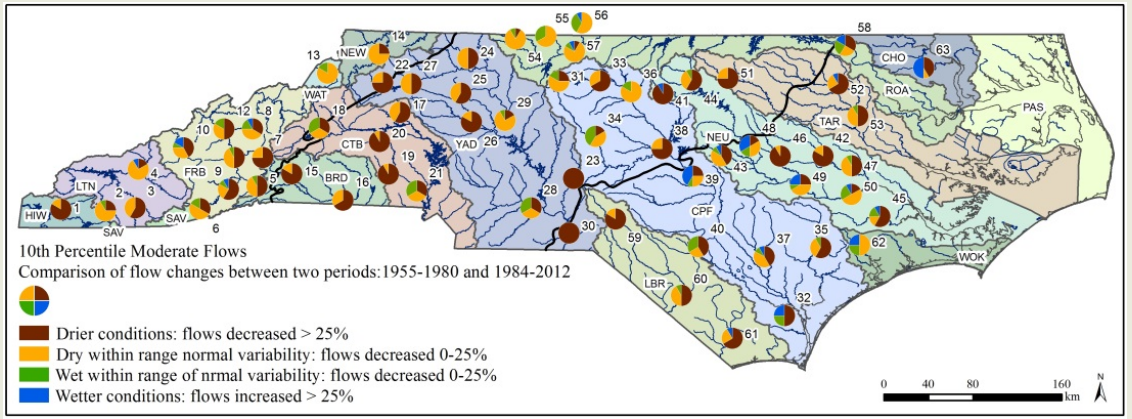
Context for Environmental Flow Recommendations

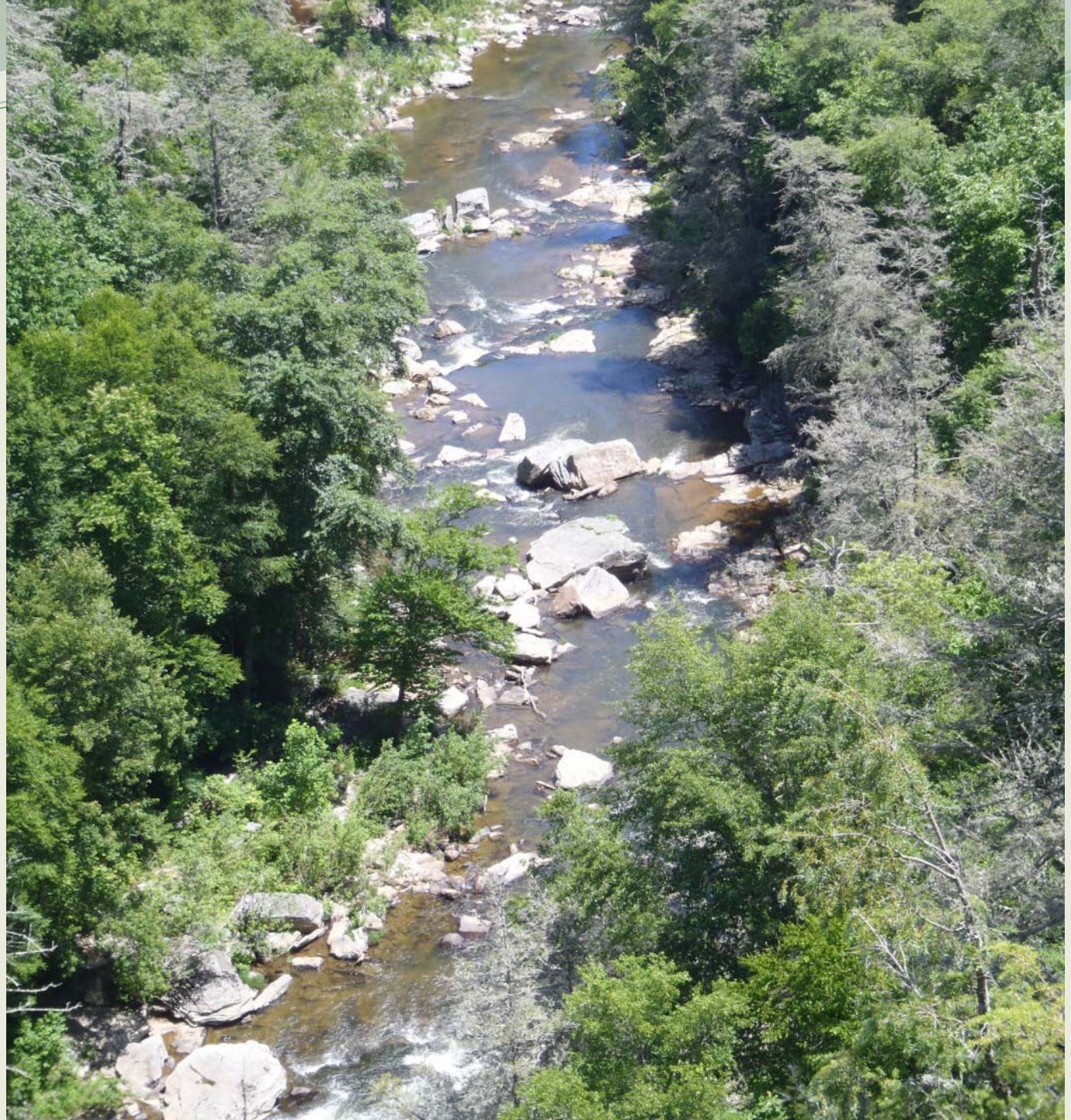
- 1. Protect flows from withdrawals > 10% of MAF
- 2. Preserve seasonal and inter-annual variability of flow patterns
- 3. Protect ecoregional and river basin related variability of flow patterns
- 4. Prevent further water use related impacts to 10th percentile low flows
- 5. Protect headwaters











Decision Support System for Environmental Flows (DSSEF): 3 Parts

- **1. Protect the natural flow regime and specifically the seasonal and ecoregional patterns of flow variability**
  - Daily average allocation using presumptive standard Percent-of-Flow (POF)
  - Separate criteria for: 1.) normal and wet years, and 2.) drought years
- **2. Prevent further water use-related decreases to 10th percentile flows**
  - Pass-by flow flow criteria for minimum flows based off of a P-O-F
- **3. Restrict withdrawals in drainages <25 sq.mi. and limit withdrawals to drainages 25-50 sq. miles to set limit (e.g. 1 MGD avg. per day)**
  - Statewide rule, protects headwaters and flow accumulation
- All flow criteria should be established using the same period of record
  - Prevent climate, land use, and pre dam-related biases
  - Our study uses 1984-2012, 28 year contemporary record
  - Reasonable length record most indicative of "current prevailing conditions"

Protect Natural Flow Regime

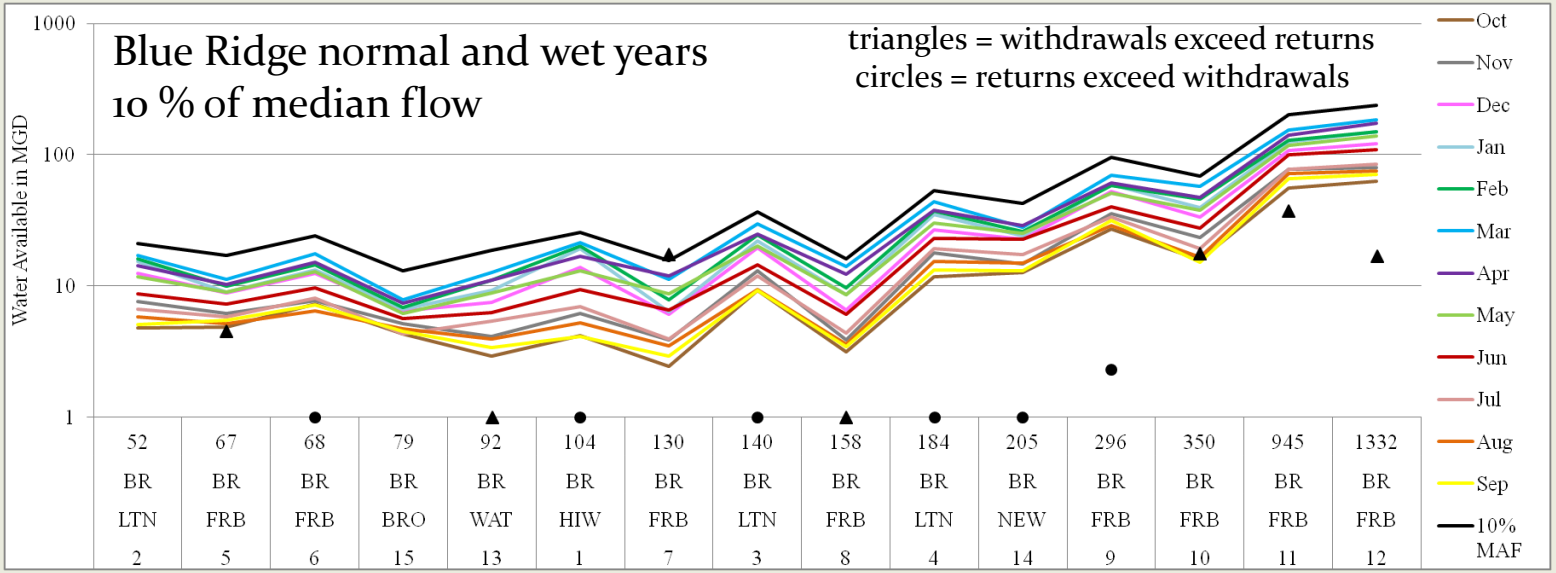
- **Allocate a percent of the monthly median flow to net water use**
  - **5% allowable in drought conditions**
  - **10% allowable in normal to wet conditions**

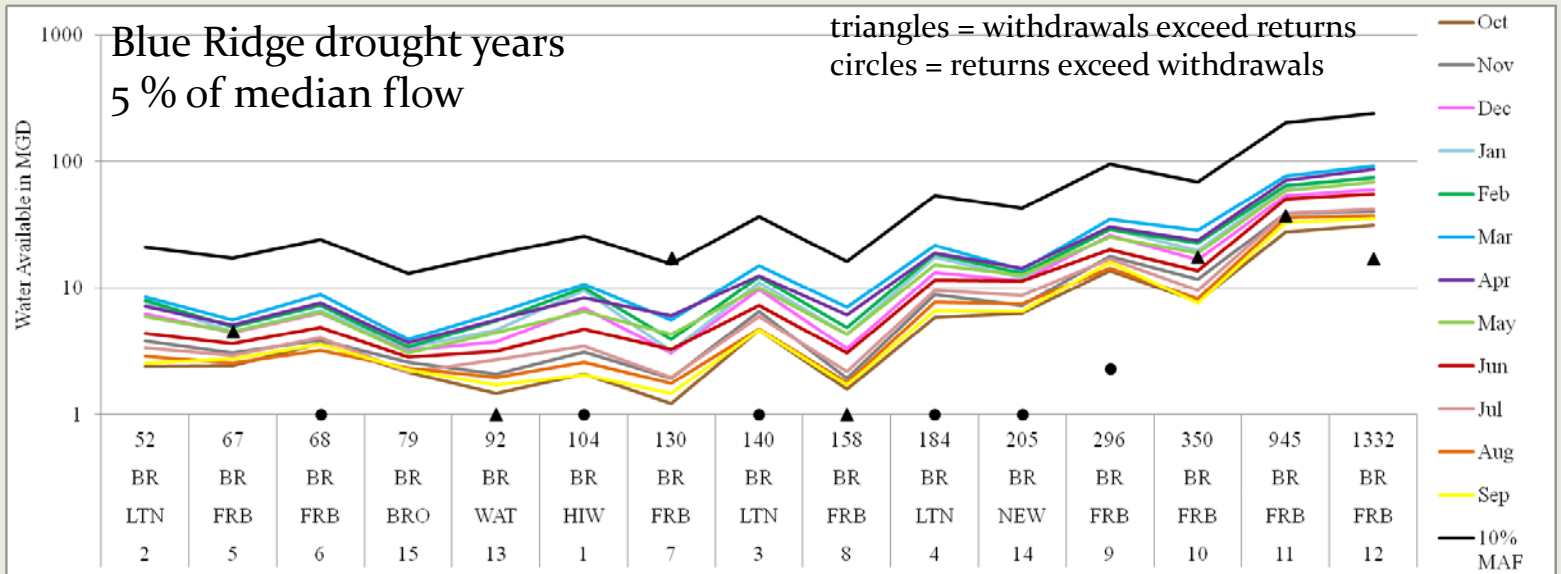
- Protects range of natural variability and normal periods of drought stress
  - Calculated from monthly medians, protects seasonal flow patterns
  - Amount available varies geographically
  - More indicative of prevalent conditions and central flow tendency
  - Consistently lower impacts than allocating 10% Mean Annual Flow

- Following example show this recommendation relative to the 63 gages used in the stream flow change analysis
  - Available MGD calculated from current statewide flow conditions from the current period (1984-2012) and grouped by eco-region and compared to 10% of Mean Annual Flow

Water available in million gallons per day (MGD)

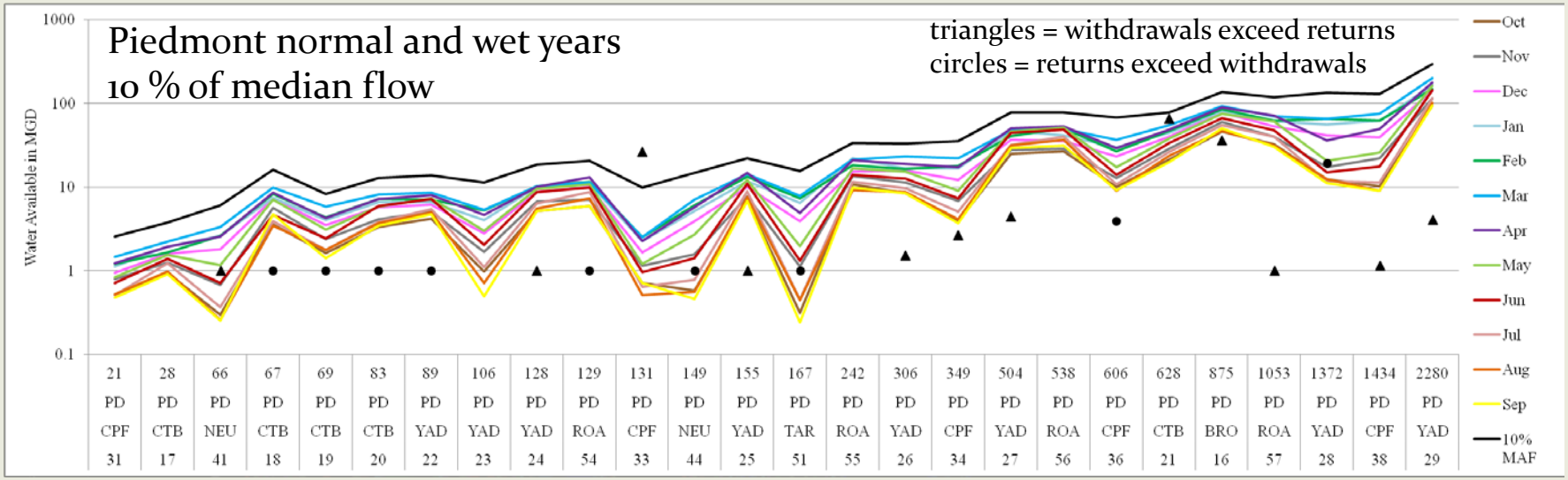
- Calculated relative to 5 and 10% of the monthly median flow average
- Compared to 10% of the Mean annual flow for reference

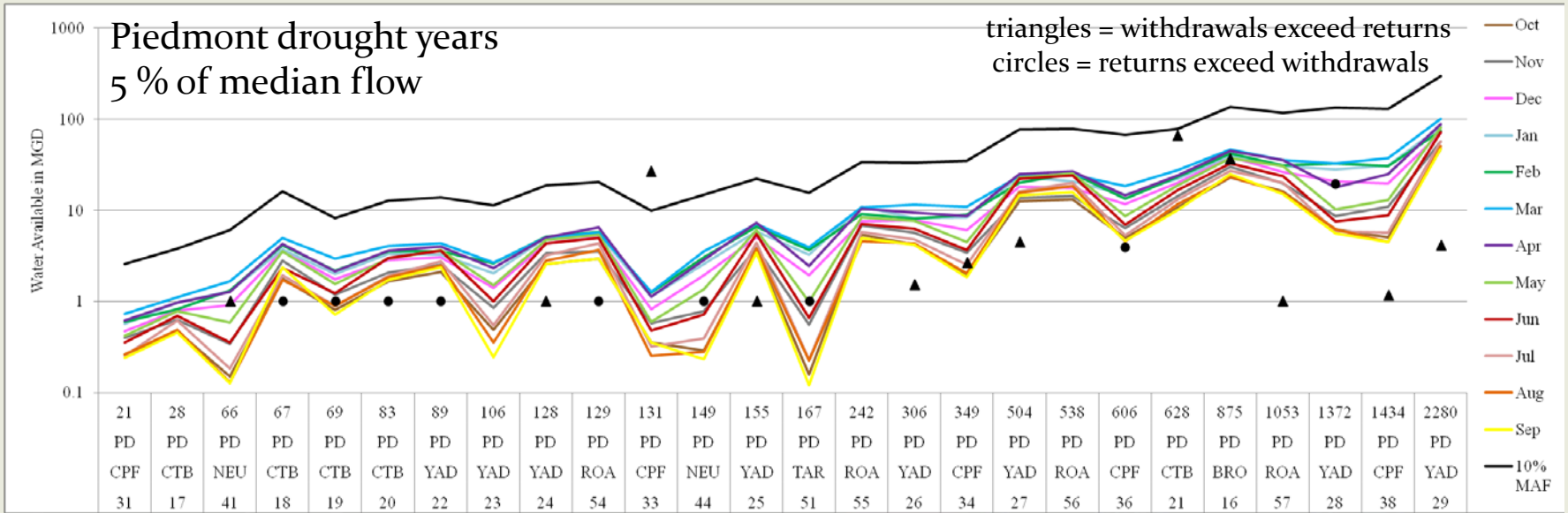




Water available in million gallons per day (MGD)

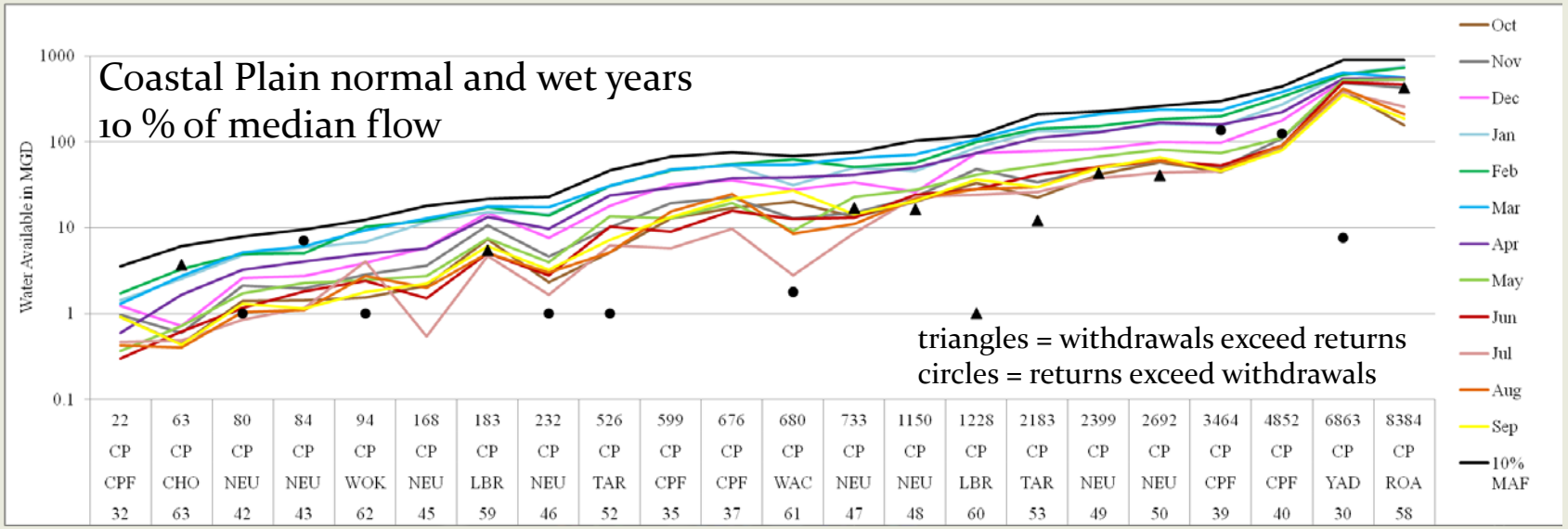
- Calculated relative to 5 and 10% of the monthly median flow average
- Compared to 10% of the Mean annual flow for reference

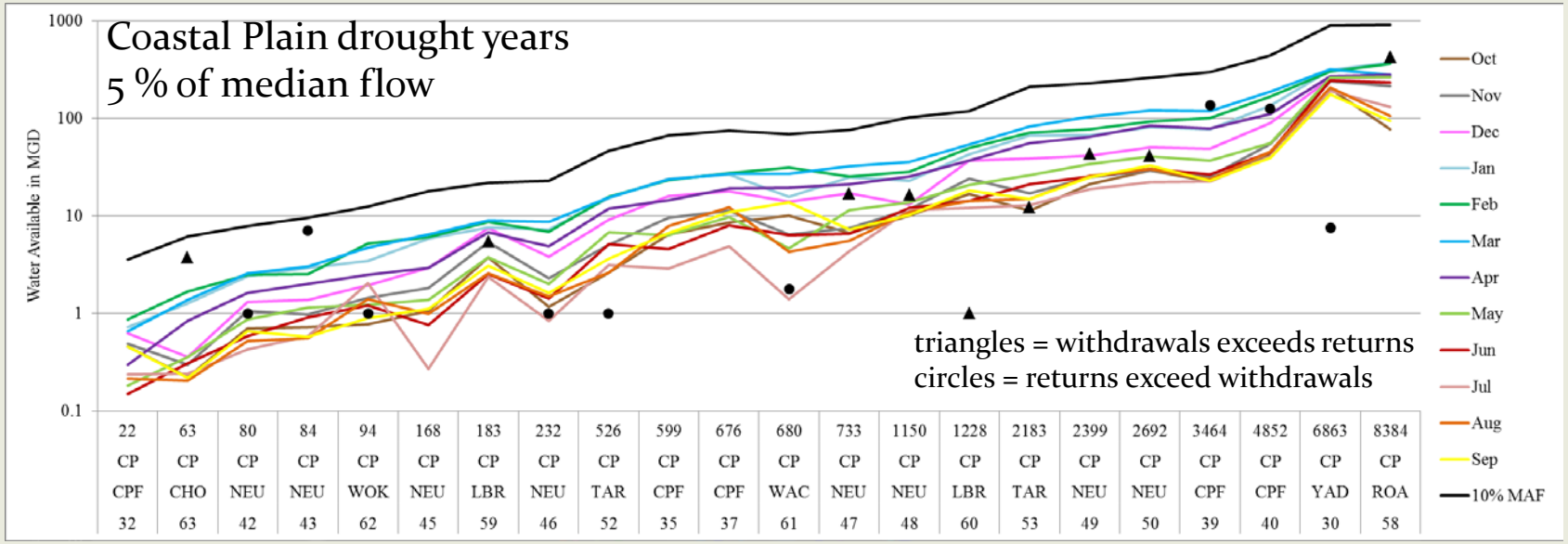




Water available in million gallons per day (MGD)

- Calculated relative to 5 and 10% of the monthly median flow average
- Compared to 10% of the Mean annual flow for reference





Protect Natural Flow Regime

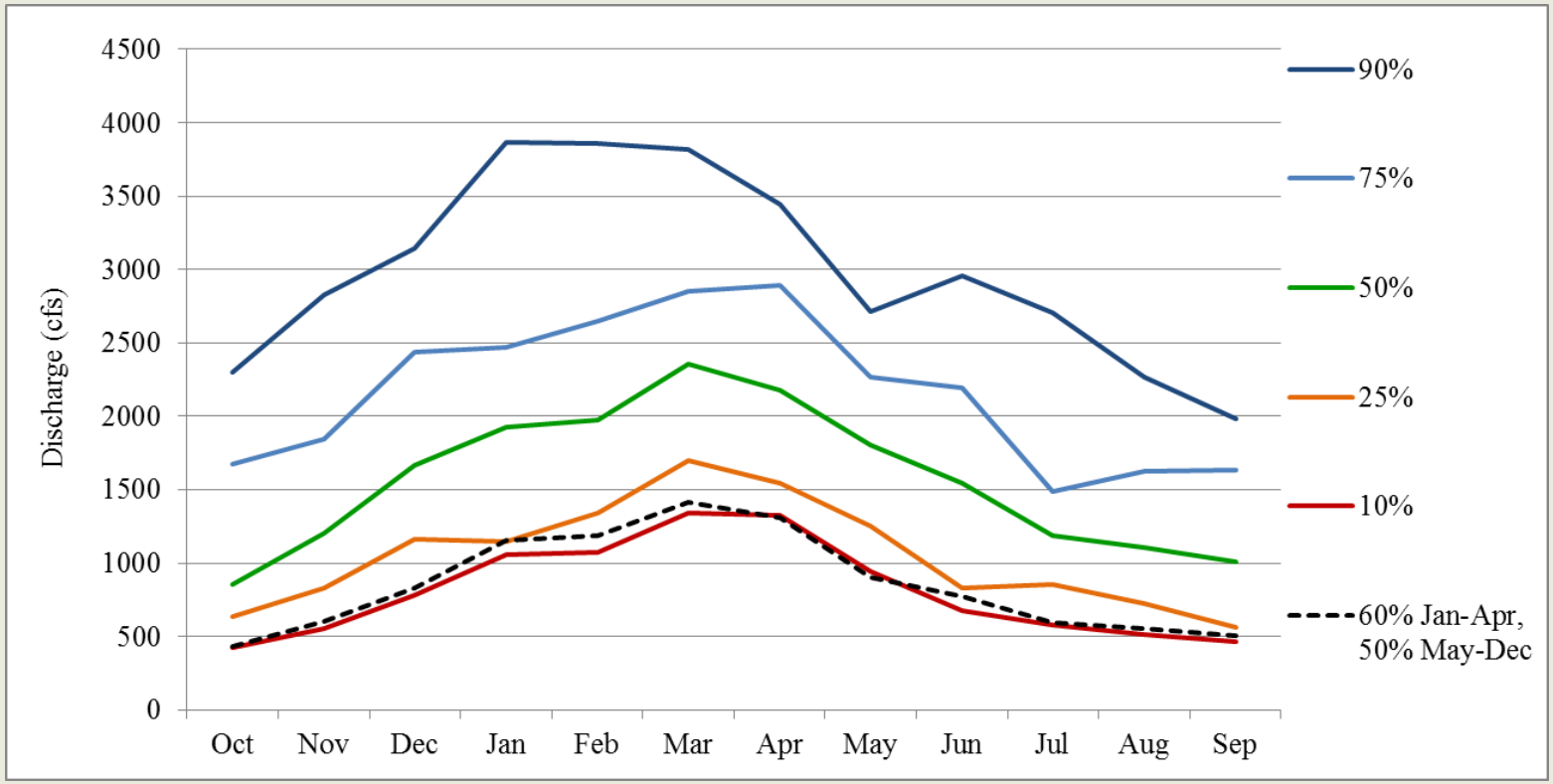
- **Allocate a percent of the monthly median flow to net water use**
  - **10% allowable in normal to wet conditions**
  - **5% allowable in drought conditions**
- Protects range of natural variability
  - Calculated from monthly means, protects seasonal flow patterns
  - Water available for use varies by month, basin area, river basin and eco-region
  - Limits additional water use effects in areas of existing use
  - Limits new water use effects in areas not currently altered
- Calculated from median flow from the current altered record
  - More indicative of prevalent conditions and central flow tendency
  - Consistently results in less impact than 10% of Mean Annual Flow allocation
- Defines allowable daily net water use
  - Amenable to management because it involves a set-amount that does not vary with daily flow, only monthly and annual flow patterns
  - Net of old and "new" allowances on top of existing users
  - Identifies area where no new use is available

Prevent water use related decreases to the 10th percentile flows

- **Pass-by flows when flows decrease below a percent of the median monthly flow**
  - **60% of median Jan-April (50% in drought years)**
  - **50% of median May-Dec (40% in drought years)**
- These flows correspond to the range between the 10-25th percentile flow averages for the period of record and provide protection when flows decrease below this range
- Calculated with same flow record as the P-O-F daily avg. water allocations
- Varies by month, drainage basin area, and ecoregion
- Only implemented during infrequent low-flow episodes and droughts
- Requires daily monitoring of flow conditions

Protecting the 10th percentile low flows

- **Ceasing withdrawals when flows decrease below:**
- **50% of the median monthly flow May-Dec (40% in drought years)**
- **60% of the median monthly flow Jan-April (50% in drought years)**
- Graph is plotted relative to average 10th, 25th, 50th, 75th, and 90th for each month
- Example is from the French Broad River



Environmental Flow Rules

- 1. Protect Natural Flow Regime
  - **5-10% of median flow as net use, variable dependent on drought regimes**

- 2. Prevent further water use-related impacts to the 10th percentile flow by using pass-by flow in times of extreme drought and/or periodic low flow periods. Passby when flow reach:
  - **Normal years 50% of monthly medians May-Dec, 60% of the monthly medians Jan-April**
  - **Drought years: 40% of monthly medians May- Dec, 50% Jan-April of monthly medians**

- 3. Drainage basin area withdrawal cut-off:
  - **< 25 sq. mi. no withdrawals, 25-50 sq. mi. limit to 1-5 MGD**

- 3. Manage use relative to climate conditions
  - **Variable rules for normal/wet years and droughts**

Flow Recommendations Derived from P-O-F Approach Defined by Monthly Flows for a Given Stream Reach of a River Basin Will Protect:

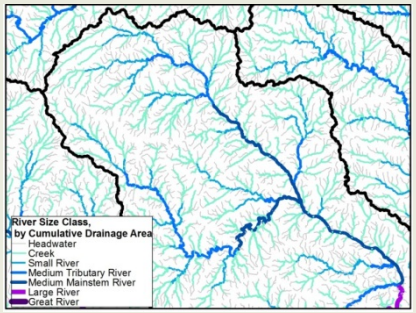
Seasonal variability (inter and intra-annual)

Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug	Sept

Ecological Variability among Eco-regions, Basins, and Drainage Basin Sizes

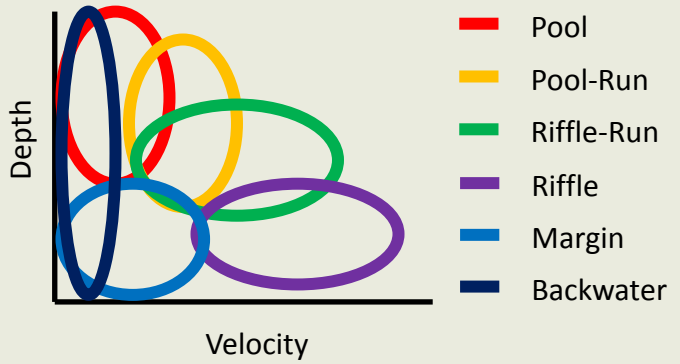
Blue Ridge

Piedmont



Coastal Plain

Life-history, biological cues, behavior strategy, and/or ecological functions of different species, guilds, and other biological and physical processes



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