Advancing The Science: North Carolina Ecological Flows Science Advisory Board

South Carolina State Water Plan Symposium

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N.C. Wildlife Resources Commission

Background

- NC Session Law 2010-143
- Requires NCDEQ to develop basinwide hydrologic models for each of the 17 major river basins in NC
- Simulate flows to determine if adequate water is available to meet all needs, including essential water uses and ecological flows
- Does not:
  - replace site-specific studies
  - vary existing permits/licenses
  - establish regulations

What are Ecological Flows?

- The Session Law defines ecological flow as “the stream flow necessary to protect ecological integrity.”
- Ecological integrity is defined (in S.L.) as “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.”
- “prevailing” not in original definition (Karr and Dudley 1981); sets the current condition as baseline

Ecological Flows Science Advisory Board

- SL 2010-143 directed DEQ to "create a Science Advisory Board to assist the Department in characterizing the natural ecology and identifying the flow requirements."
- Role:
  - water resource planning
  - recommend scientifically-based methods or approaches and ecological flow requirements
- Not a role:
  - water-use permitting
  - recommending how DEQ responds to a water-availability issue
  - advising DEQ on how to use the EFSAB recommendations

Makeup of the EFSAB

1. Academic Research – Duke University
2. Agriculture – NC State University; NC Division of Soil and Water Conservation
3. Electric Public Utilities – Duke Energy Carolinas
4. Environmental NGOs – Environmental Defense Fund; The Nature Conservancy
5. Local Governments – Hazen & Sawyer; Mecklenburg County
6. NC American Water Works Association – CH2M HILL
7. NC Division of Water Resources
8. NC Division of Water Quality
9. NC Environmental Management Commission
10. NC Forestry Association – NC Forest Service; USDA Forest Service
11. NC Natural Heritage Program
12. NC Marine Fisheries Commission – East Carolina University; NC Division of Coastal Management
13. NC Wildlife Resources Commission
14. US Geological Survey
15. US Fish and Wildlife Service
16. US National Marine Fisheries Service

Facilitation provided by N.C. State University's Natural Resources Leadership Institute and NCSU Cooperative Extension

Met 28 times between November 2010 and October 2013

ELOHA (Ecological Limits of Hydrologic Alteration)

- Start with regional hydrologic models
- Identify stream types expected to respond differently to flow alteration
- Model ecological responses to flow alteration for each stream type
- Use ecological models with socially-determined objectives to decide on flow requirements
- Monitor outcomes, improve models, repeat

Advancing the Science: Stream Classification

- DWR worked with a consultant to characterize and classify North Carolina streams based on flow characteristics from USGS gage data
- Resulted in a classification scheme comprised of seven stream classes that generally reflected stream size and flow stability

Class Characteristics – Hydrologic

Descriptive Index	North Carolina Stream Class						
	A	B	C	D	E	F	G
Median Daily Flow (CFS)	Small 126	Small 97	Large 1295	Small 48	Very Large 2470	Medium 490	Very Small 10
Median Daily Variable (%)	Moderate 128	Stable 107	Stable/Low 80	Flashy/High 206	Moderate 118	Stable/Low 91	Flashy/High 239
Percent of Daily Flow Volume Are Very Low Flows	1	4	5	1	2	4	0
Percent of Daily Flow Volume Are Low Flows	3	7	8	3	4	7	1
Percent of Daily Flow Volume Are Average Flows	33	39	42	25	32	40	22
Percent of Daily Flow Volume Are High Flows	26	20	19	19	23	20	19
Percent of Daily Flow Volume Are Very High Flows	40	32	27	53	39	29	57
Predictability (%)	Low 49	Moderate 65	High 75	Low 51	High 74	High 74	Very Low 37
Distribution of Annual Flow Among Five Flow States	4085782 A & H	3408071 A & VH	2883263 L & A	5538508 VH	4127314 A & H	3162172 L & A	5914233 VH

Advancing the Science: Stream Classification

Problems

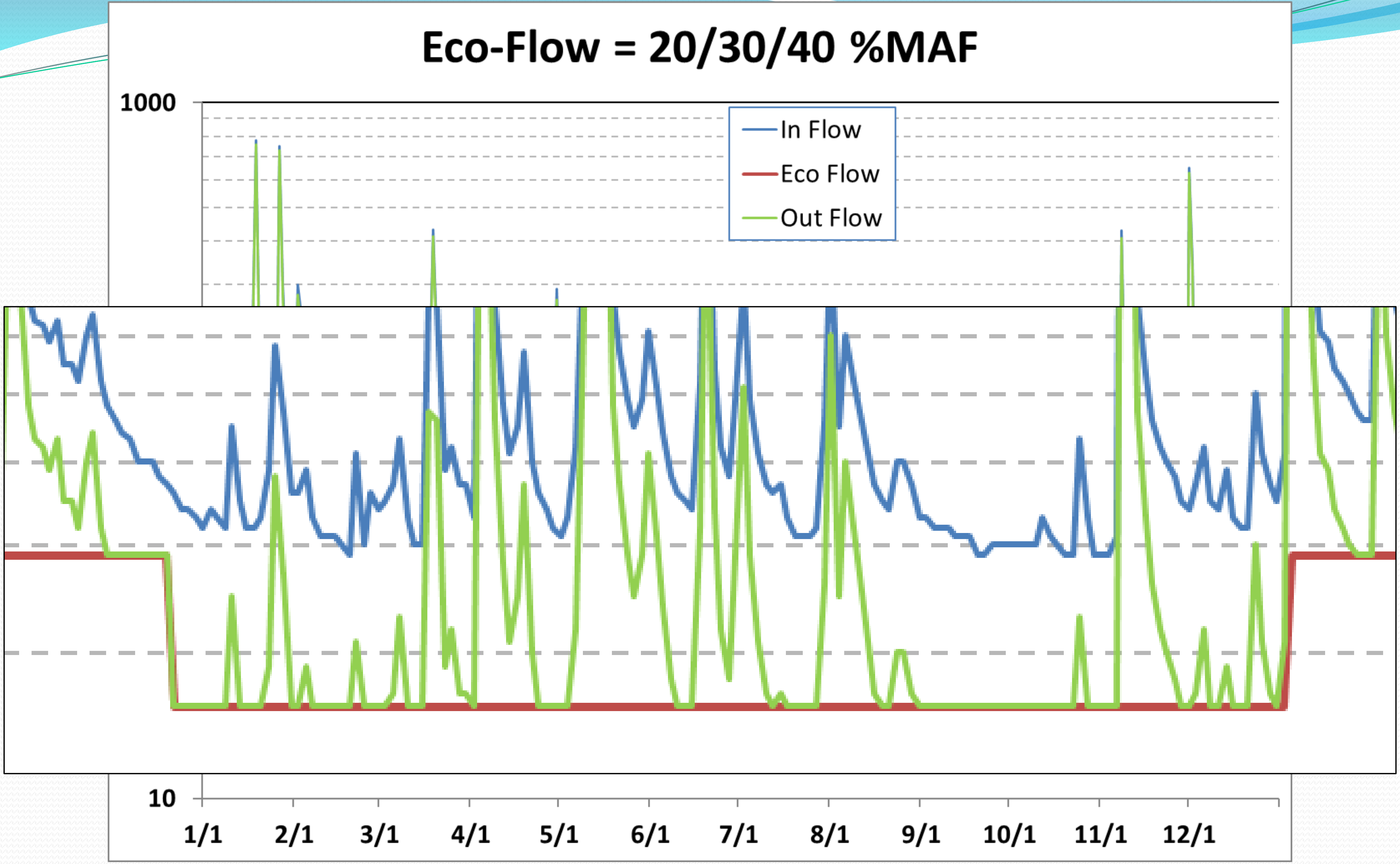
- Classes generated from hydrology derived from USGS gages often differed from hydrology created from the WaterFALL® rain-runoff model
- Stream hydrology classification approach should not be extrapolated beyond the USGS gages to ungaged sites
- Dropped this approach

Types of Eco-flow Recommendations

- Minimum Flow Threshold
- Statistically-based Standard
- Percent of Flow Standard

Minimum Flow Threshold

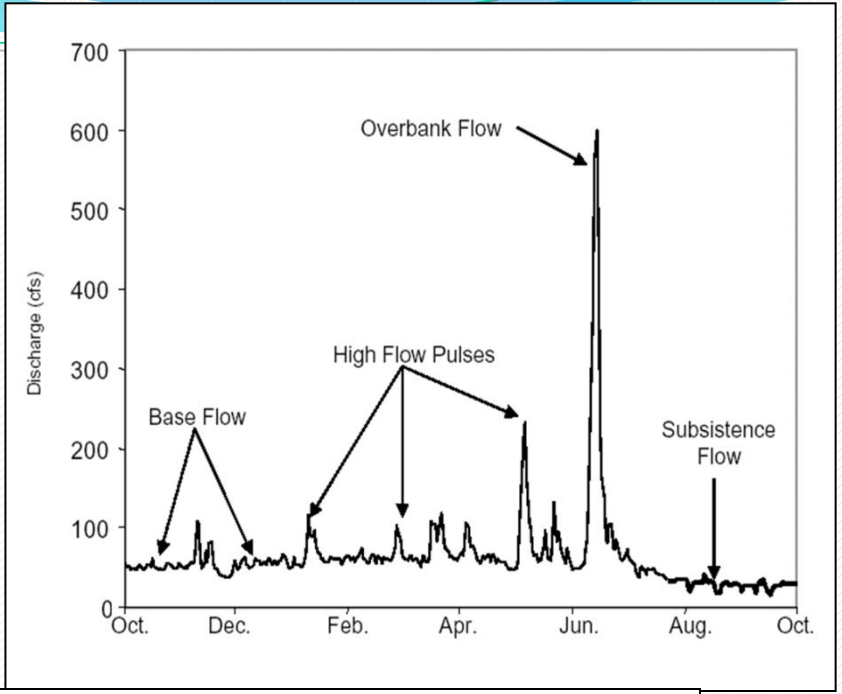
- May be a single value or seasonally adjusted (e.g., South Carolina)
- Can be based on low-flow statistic (e.g., 7Q10) or a percentage of mean annual flow (MAF)
- Reduces inter- and intra-annual variability
- Can “flat-line” the hydrograph if withdrawal is large

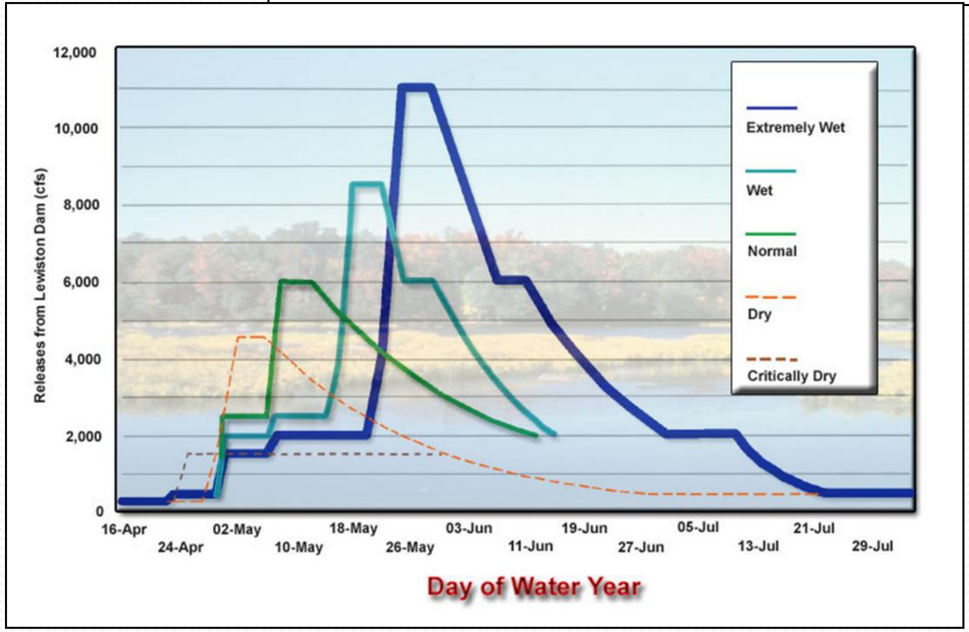


Eco-Flow = 20/30/40 %MAF
1000
10
In Flow
Eco Flow
Out Flow
1/1
2/1
3/1
4/1
5/1
6/1
7/1
8/1
9/1
10/1
11/1
12/1

Statistically-Based Standard

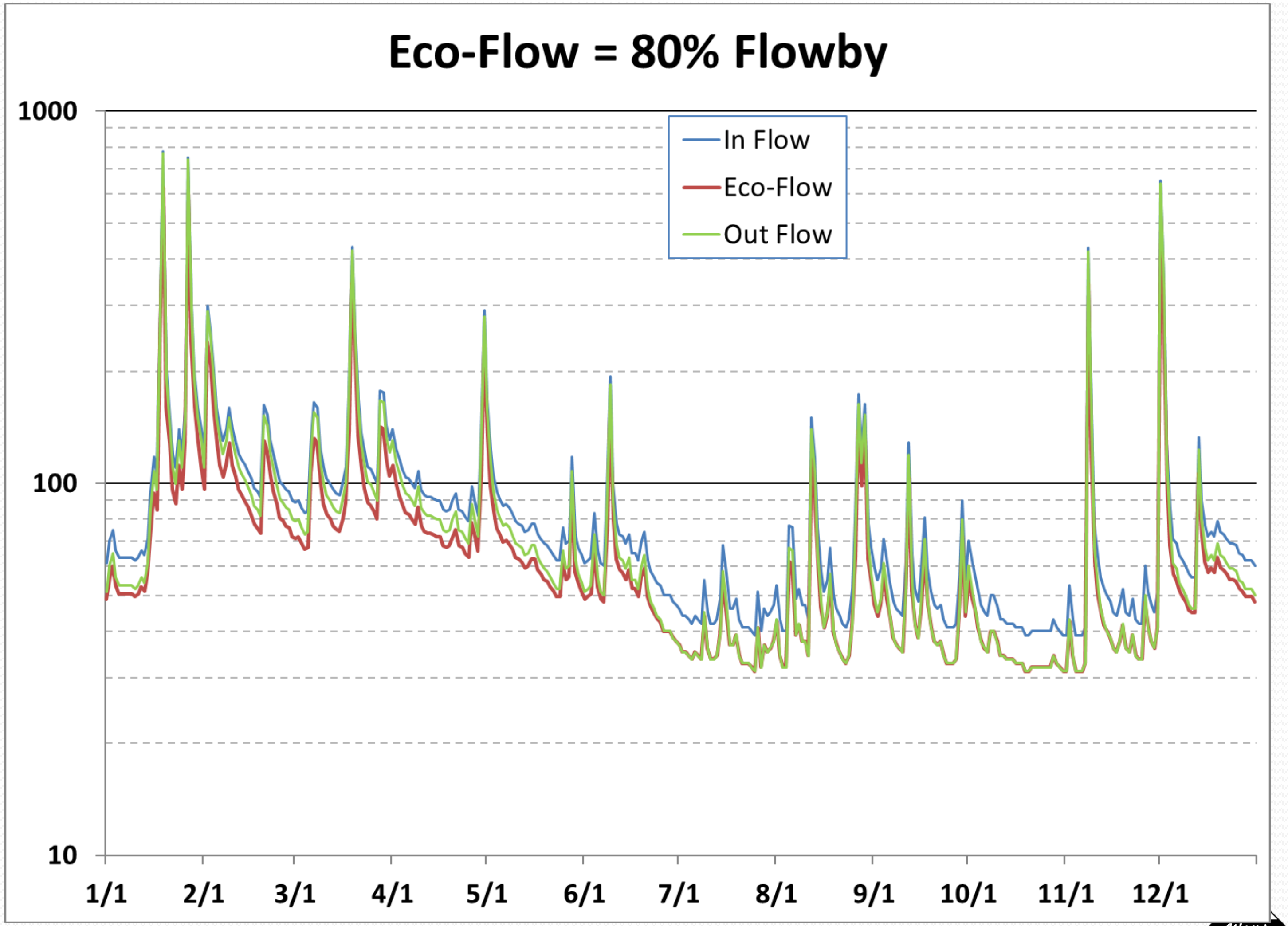
- Flow components include:
  - Critical low, low, high flow pulses, small floods, high floods
  - Wet, normal, dry years
- For each component, includes magnitude, duration, frequency, season
- Tied to ecologically significant events
  - e.g., spawning, floodplain rejuvenation, fry/juvenile growth, migration, sediment movement, channel maintenance
- Hard to implement in a model





Percent of Flow Standard

- Remove X% of water flowing by for a given time step
  - X generally 6 – 20%
  - Time step can be daily, weekly, etc.
  - X can differ by season
- Percent-of-flow is easiest way to maintain all five flow components and variability
- aka “flow-by”



Strategies to Determine Ecological Flows

- Reviewed many other states and regions
- Habitat response models
  - Habitat quantity and quality are measured relative to flow
  - Indirect and intermediate measure of expected biological response
- Biological response models
  - Composition or structure of the biological community is measured relative to flow
  - Can be hard to discern signal from noise, especially in diverse communities

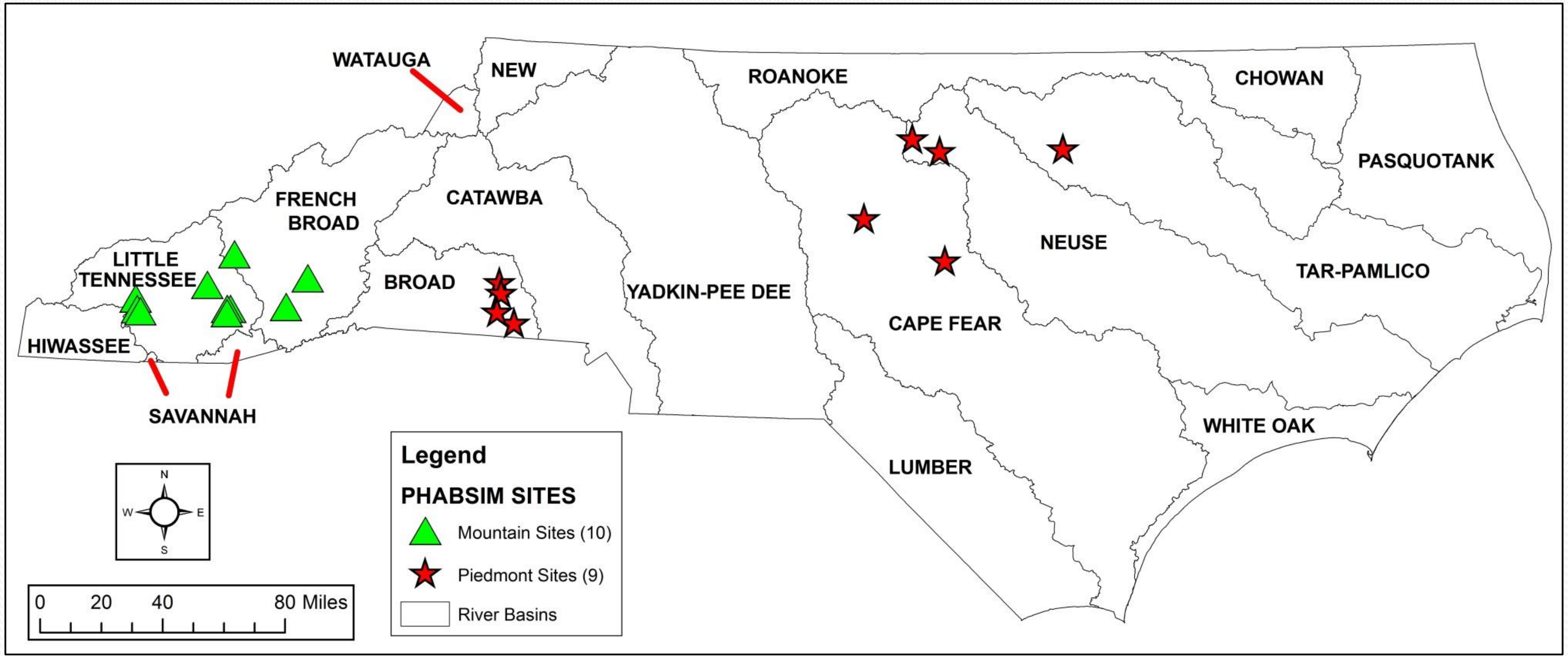
Strategies to Determine Ecological Flows

- Coastal systems
  - Low gradient and tidally-influenced streams function differently from other inland streams
  - Flow may play a secondary role to other factors including tides, salt concentration, and community structure and function
- Approaches
  - Inflow-based – keep flow within prescribed bounds (i.e., statistically-based)
  - Condition-based – set flow to maintain a specified condition (e.g., salinity) at a given point in the estuary (i.e., habitat response)
  - Resource-based – sets flow based on the requirements of specific resources (e.g., shrimp; i.e., biological response)

Advancing the Science: Flow-Habitat Relationships

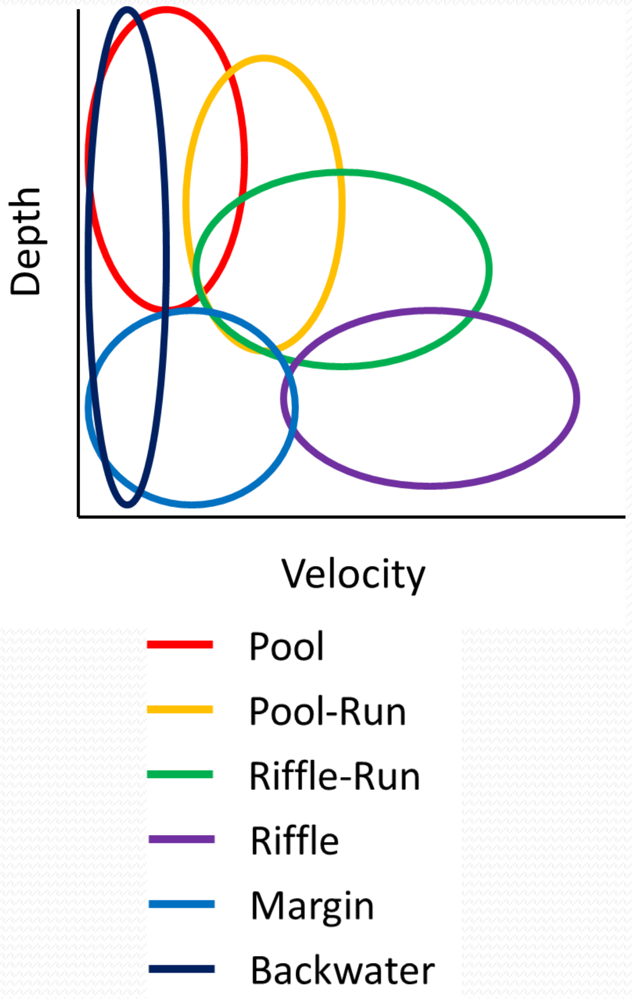
- Habitat response models
  - Uses a suite of biota habitat preference curves to ensure that all types of habitat are represented
  - PHABSIM (Physical Habitat Simulation)
    - Common habitat model
    - Used in NC for hydro relicensing and water withdrawal studies

Flow-Habitat Studies in NC



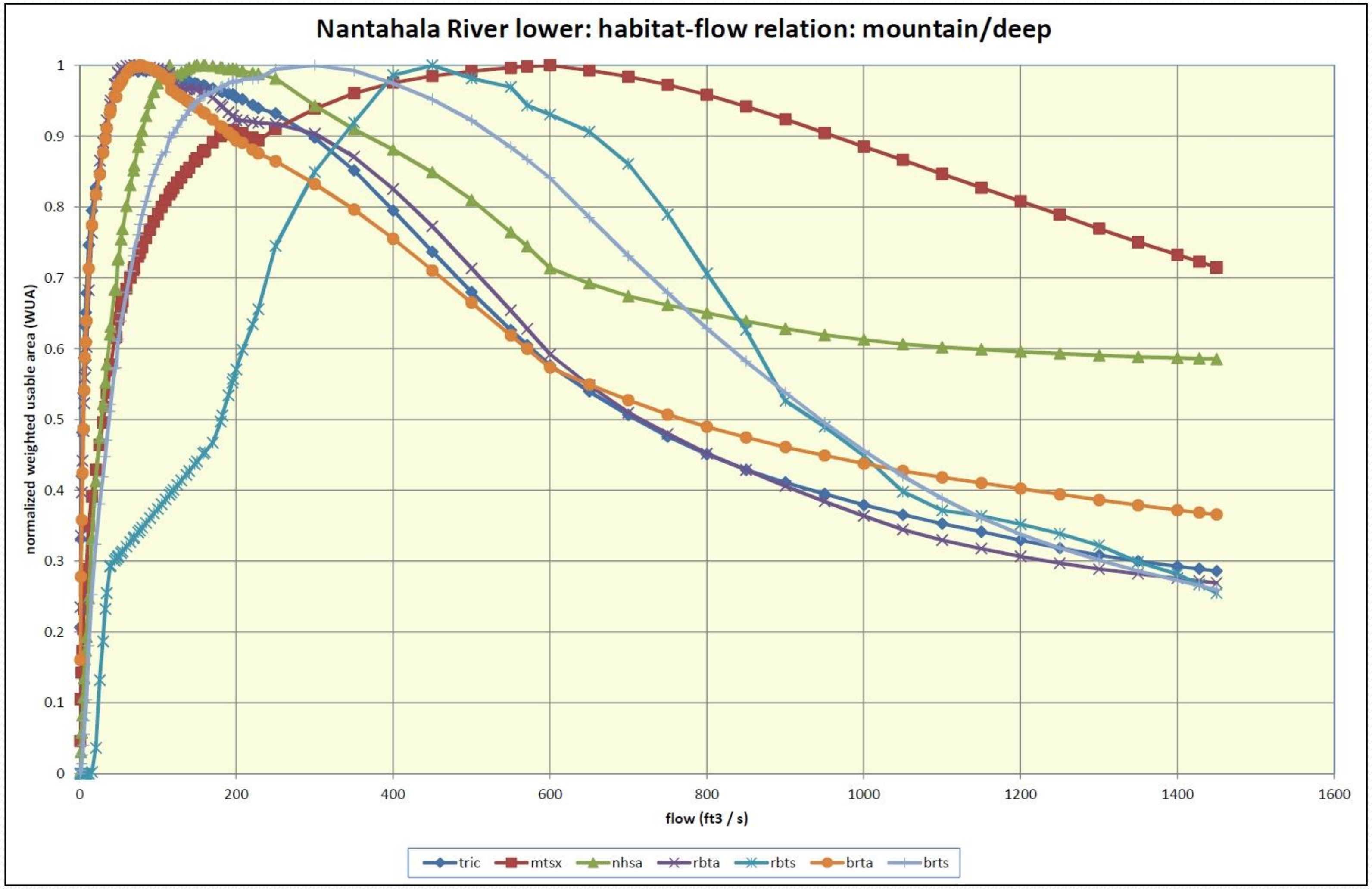
Advancing the Science: Flow-Habitat Relationships

- Consider all biological components

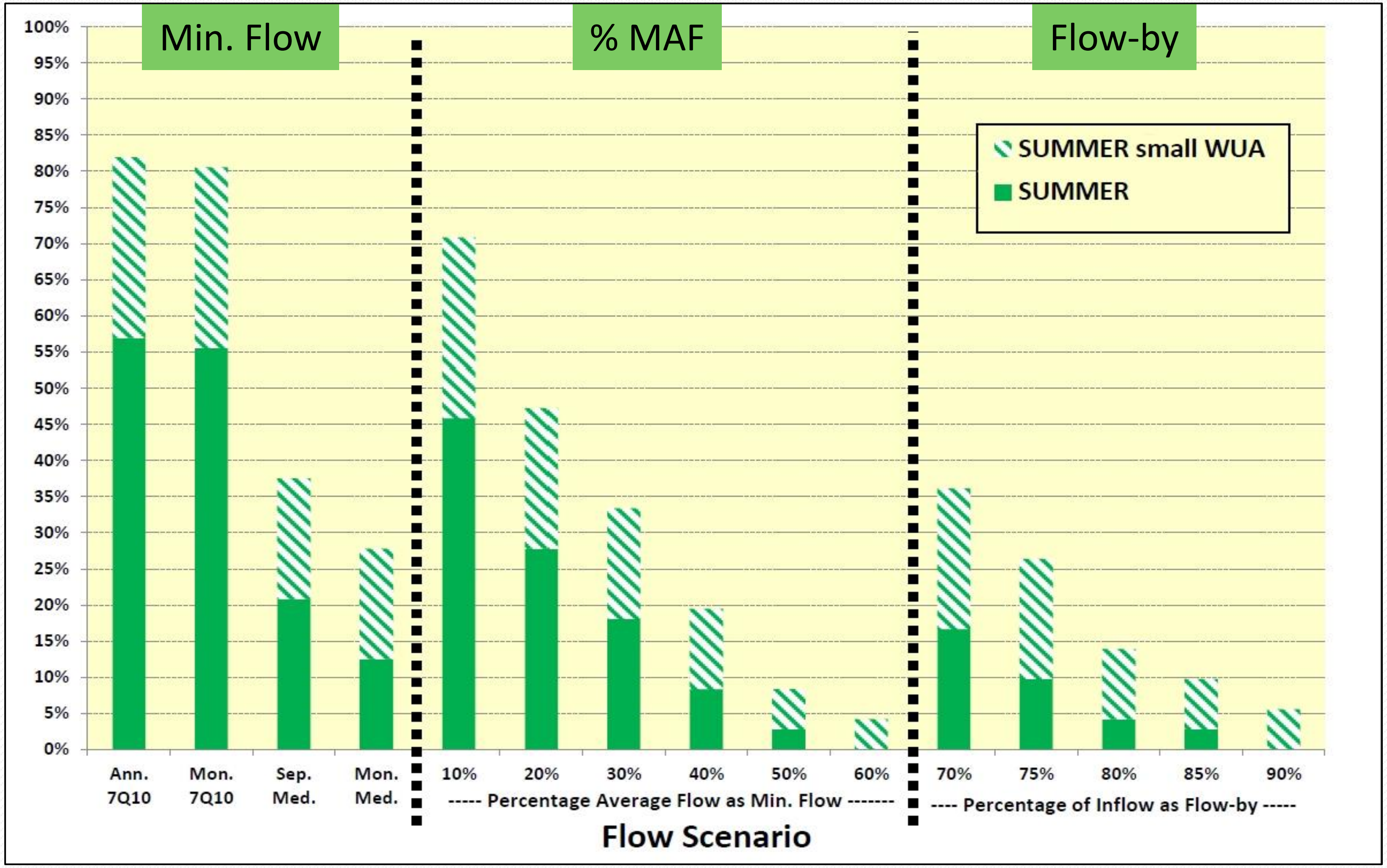


Advancing the Science: Flow-Habitat Relationships

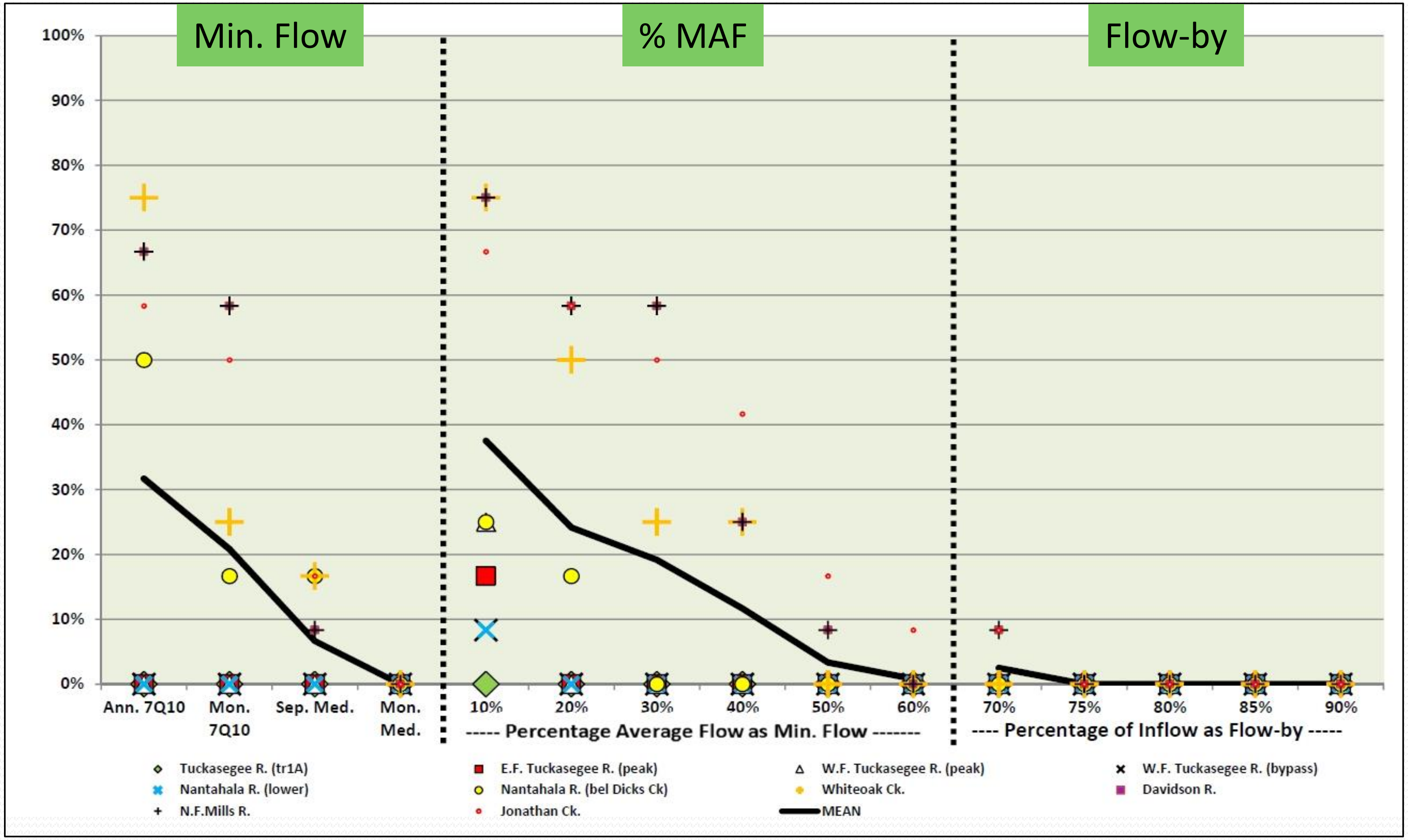
- Model converts depth, velocity and substrate/cover preferences into flow-habitat curves



Percent of Piedmont Sites not Protecting 80% of Habitat for Deep Guild



Percent of Mountain Sites not Protecting 80% of Habitat for Shallow Guild



Advancing the Science: Flow-Habitat Relationships

- Generally, flow scenarios that deviate most from the unaltered condition were least protective of habitat (i.e., more water in stream is better)
- Less clear, which flow scenarios were consistently best when considering all permutations of region, season, guild group
- More could be done to expand the number of sites, but these are intensive efforts; the easiest sites have been done

Advancing the Science: Flow-Ecology Relationships

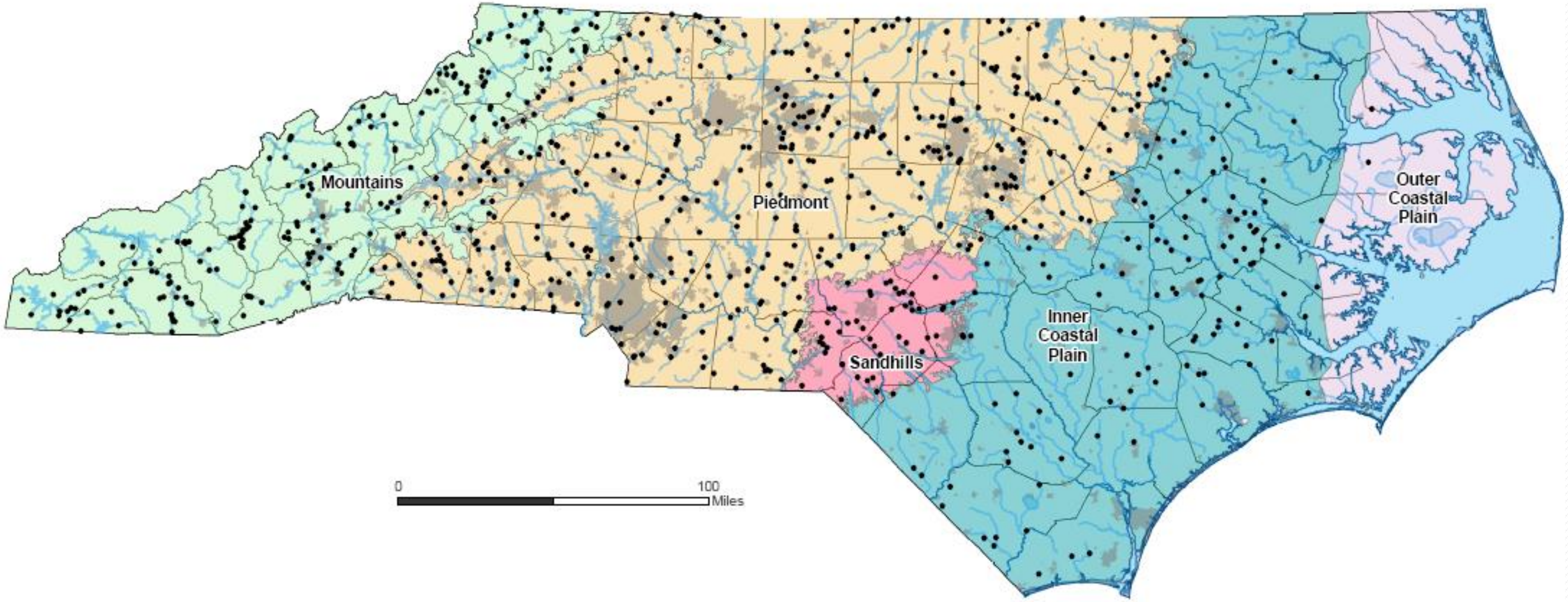
- Ecological integrity inferred from fish or benthic macroinvertebrate community structure metrics
- Two basic approaches
  - Relate biological conditions to flow across a range of flow conditions (space for time)
  - Relate changes in biological condition to flow at a site over time (time series)
- Organizations outside of the EFSAB tried both approaches and reported their results to the Board
  - RTI International (RTI) and USGS – used space for time
  - The Nature Conservancy – used both approaches

Advancing the Science: Flow-Ecology Relationships

- 649 fish and 1,227 benthos “wadeable” sites across NC
- RTI/USGS conducted numerous statistical analyses to find meaningful relationships between fish/benthos and flow metrics
- Significant relationships were found between six flow metrics and:
  - Shannon-Weaver Diversity Index of the riffle-run fish guild
  - EPT taxa richness for benthic invertebrates
- Flow metrics – annual and seasonal ecodeficits and reductions in the average 30-day minimum flow
- Attempted to include other explanatory factors (e.g., stream size and basin characteristics), but these were unsuccessful

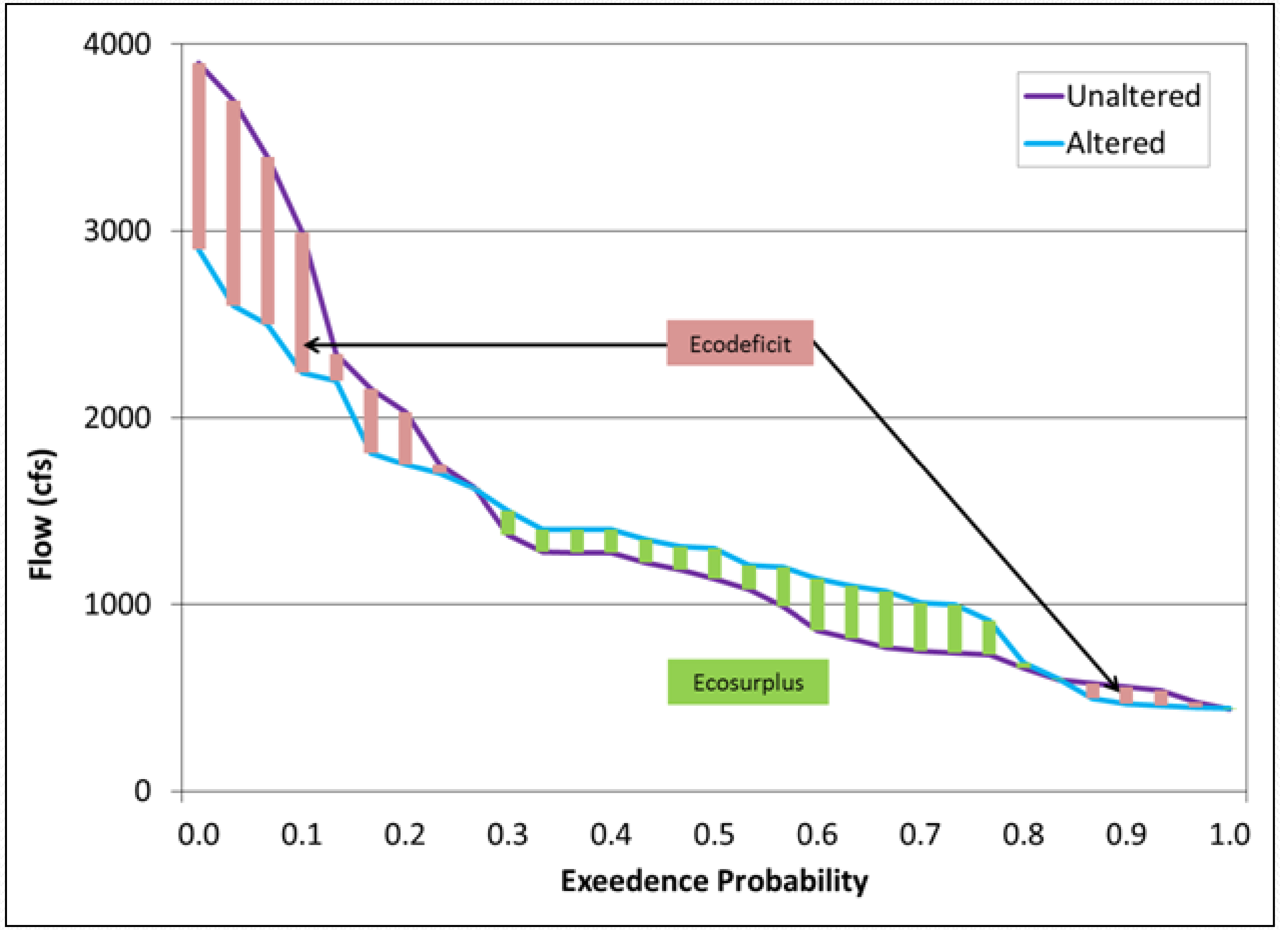
Fish Dataset

- NCDWR wadeable streams data; not trout

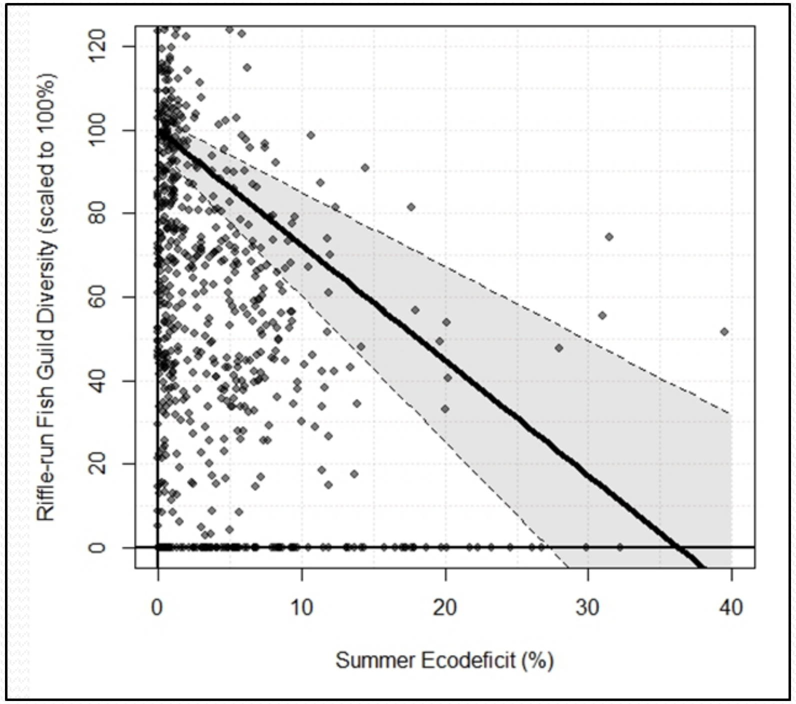


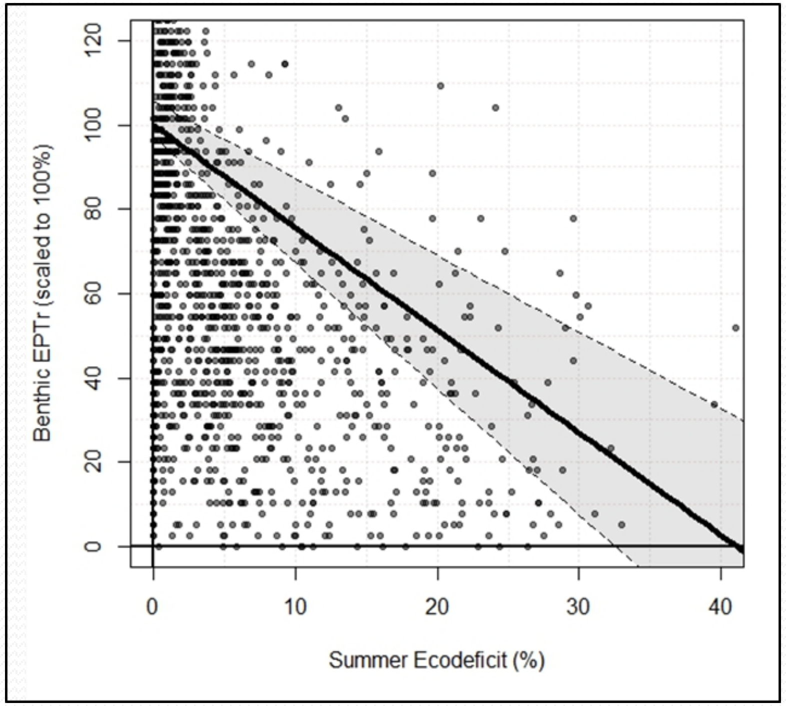
Advancing the Science: Flow-Ecology Relationships

- Ecodeficit – sum of reductions in flow between altered and unaltered flow duration curves (Vogel et al. 2007)
- Avoids auto-correlation among 100+ other flow metrics



Advancing the Science: Flow-Ecology Relationships





Riffle-run Fish Guild: Shannon-Weaver Diversity Index

	Intercept (A)			Slope (B)		
Ecodeficit	Value	SE	p-value	Value	SE	p-value
Annual	100	2.580	<0.001	-1.429	0.429	<0.001
Winter	100	2.383	<0.001	-1.353	0.530	0.011
Spring	100	2.365	<0.001	-1.653	0.332	<0.001
Summer	100	1.797	<0.001	-2.761	0.469	<0.001
Fall	100	2.326	<0.001	-2.093	0.444	<0.001

Benthic macroinvertebrates: EPT richness

	Intercept (A)			Slope (B)		
Ecodeficit	Value	SE	p-value	Value	SE	p-value
Annual	100	2.210	<0.001	-2.344	0.387	<0.001
Winter	100	2.050	<0.001	-2.427	0.334	<0.001
Spring	100	2.009	<0.001	-2.657	0.307	<0.001
Summer	100	2.005	<0.001	-2.433	0.257	<0.001
Fall	100	1.730	<0.001	-2.341	0.166	<0.001

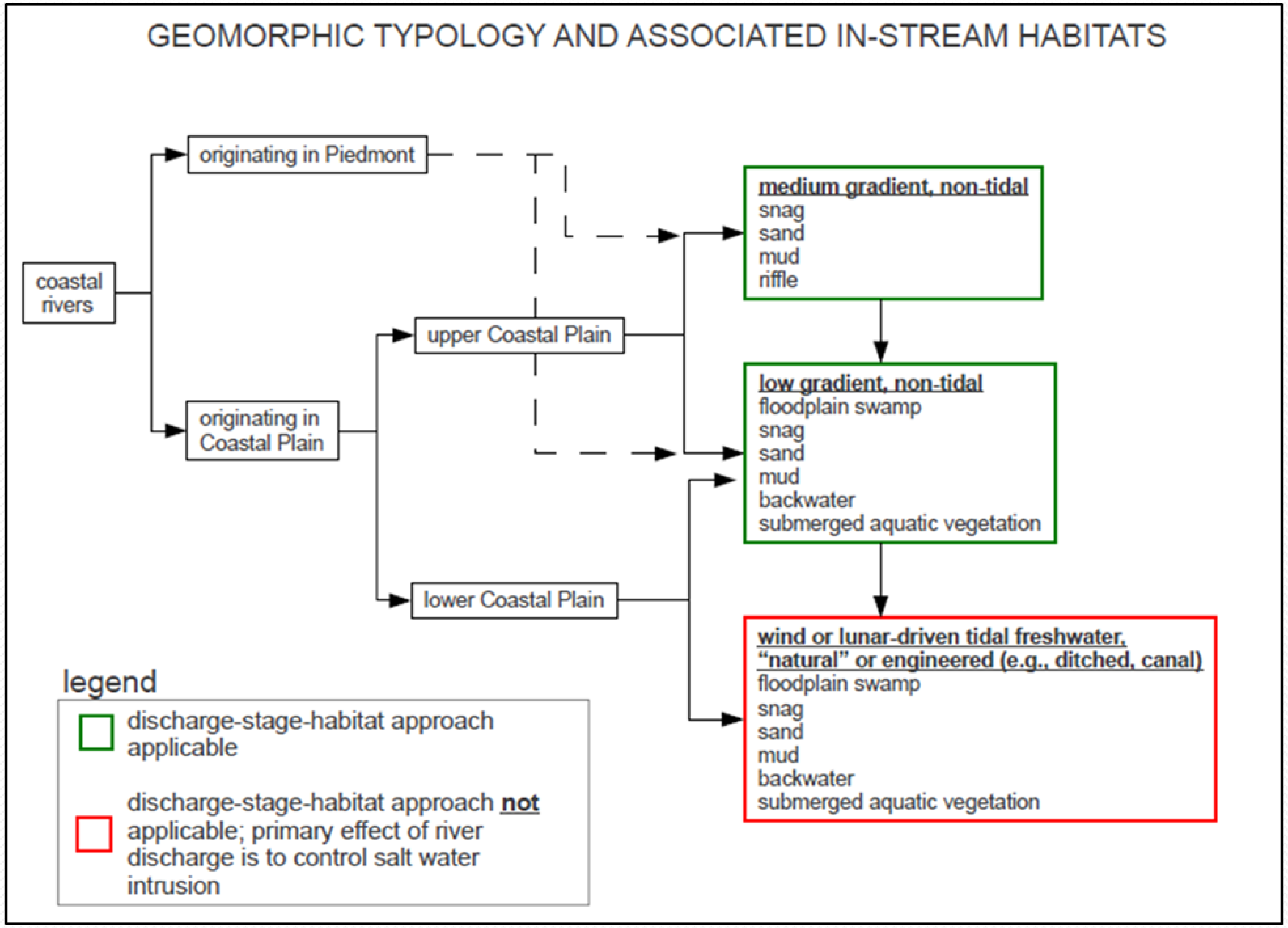
Advancing the Science: Flow-Ecology Relationships

- Published series of papers in Journal of the American Water Resources Association in February 2017 (Vol. 53, No. 1)
  1. Pearsall et al. – Series Introduction
  2. Eddy et al. – Watershed Flow and Allocation Model
  3. Eddy et al. – Evaluating Stream Classification Systems
  4. Phelan et al. – Fish and Invertebrate Relationships
  5. Patterson et al. – Flow-Biology Relationships Based on Fish Habitat Guilds

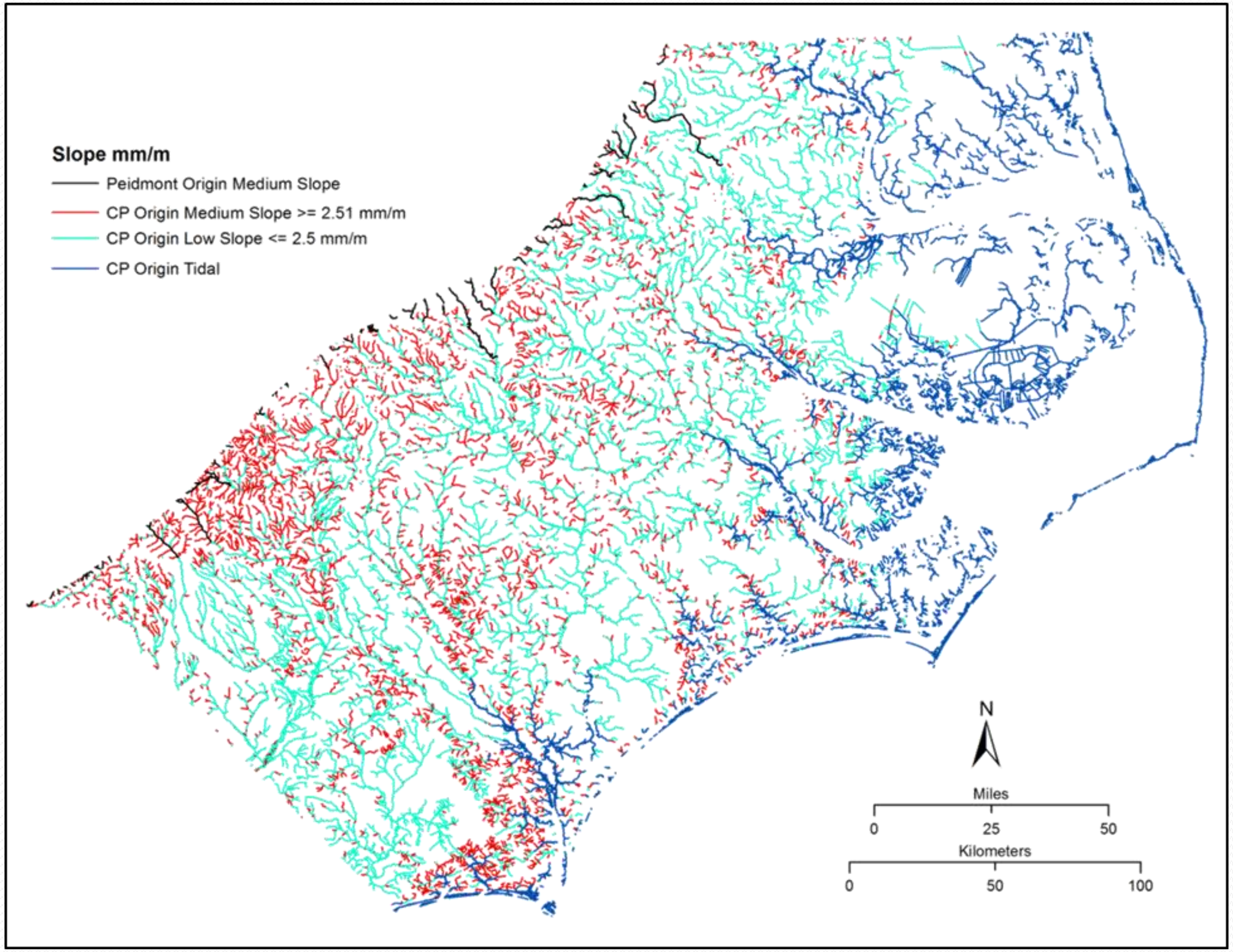
Advancing the Science: Flow-Ecology Relationships

- The Nature Conservancy
  - Fish diversity and abundance
  - 141 wadeable sites in Roanoke, Cape Fear, Tar, and Little Tennessee basins
  - Compared to flow for the period of 1992 – 2009
- Many sites saw little change in fish diversity/abundance over time
  - However, fish abundance and diversity declined in portions of the Cape Fear and Tar basins
- To understand the direct influence of water withdrawals, only sites located downstream of known water withdrawals were analyzed further (N=14)
- Negative relationship between fish diversity and the relative size of the water withdrawal; statistically significant, but low explanatory power
  - 10% ↓in MAF → 5-10% ↓ in species diversity
  - 50% ↓in MAF → 25-30% ↓ in species diversity

Advancing the Science: Coastal Considerations



Advancing the Science: Coastal Considerations



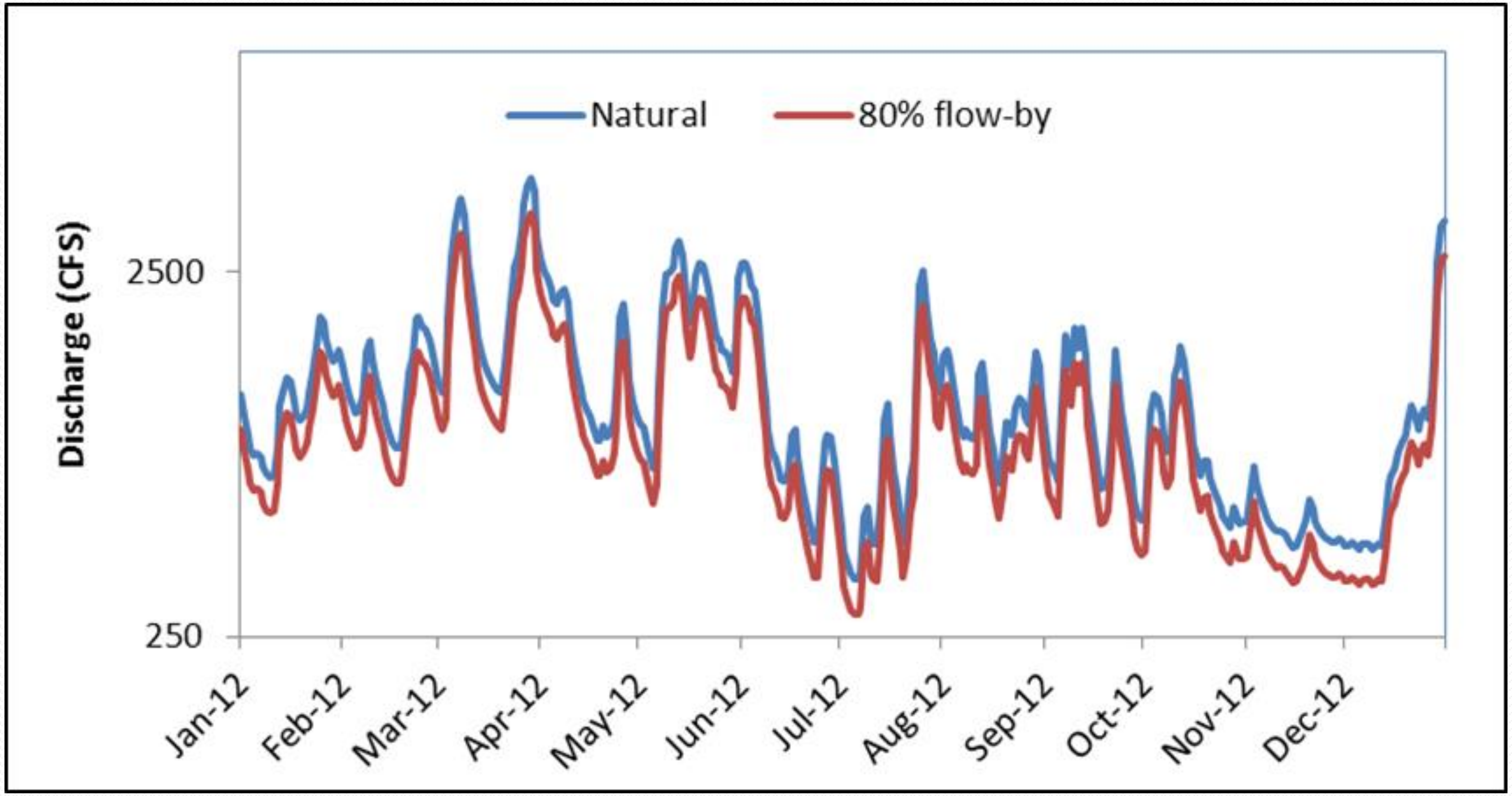
EFSAB Recommendations: Ecological Flow Standard

Percentage of Flow (1)

- Default statewide approach [for modeling/planning scenarios]
- 80-90% of the instantaneous modeled baseline flow
- Why a range?
  - No apparent threshold from habitat response analyses
  - Flow-by percentages >80% were most consistently protective
  - No consensus on a single flow-by percentage by the EFSAB
  - Similar to values from other jurisdictions
- DEQ discretion to select the most appropriate value for planning purposes

EFSAB Recommendations: Ecological Flow Standard

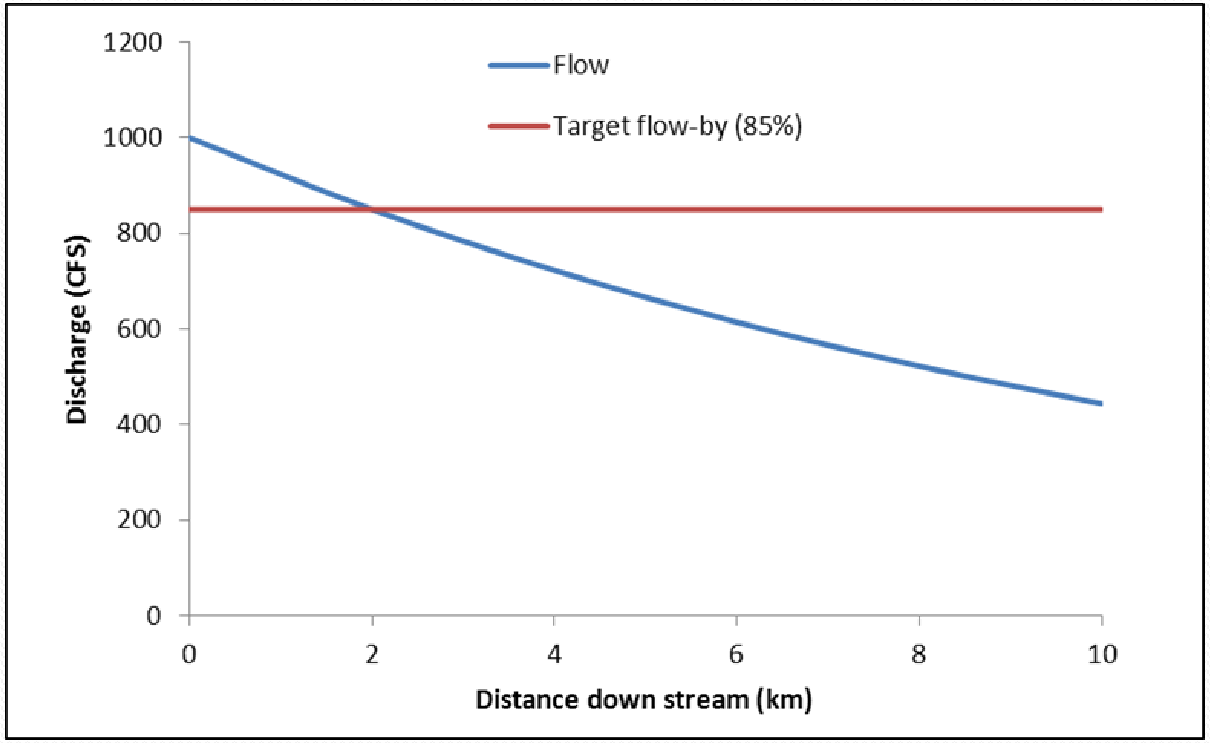
Percentage of Flow (2)



EFSAB Recommendations: Ecological Flow Standard

Percentage of Flow (3)

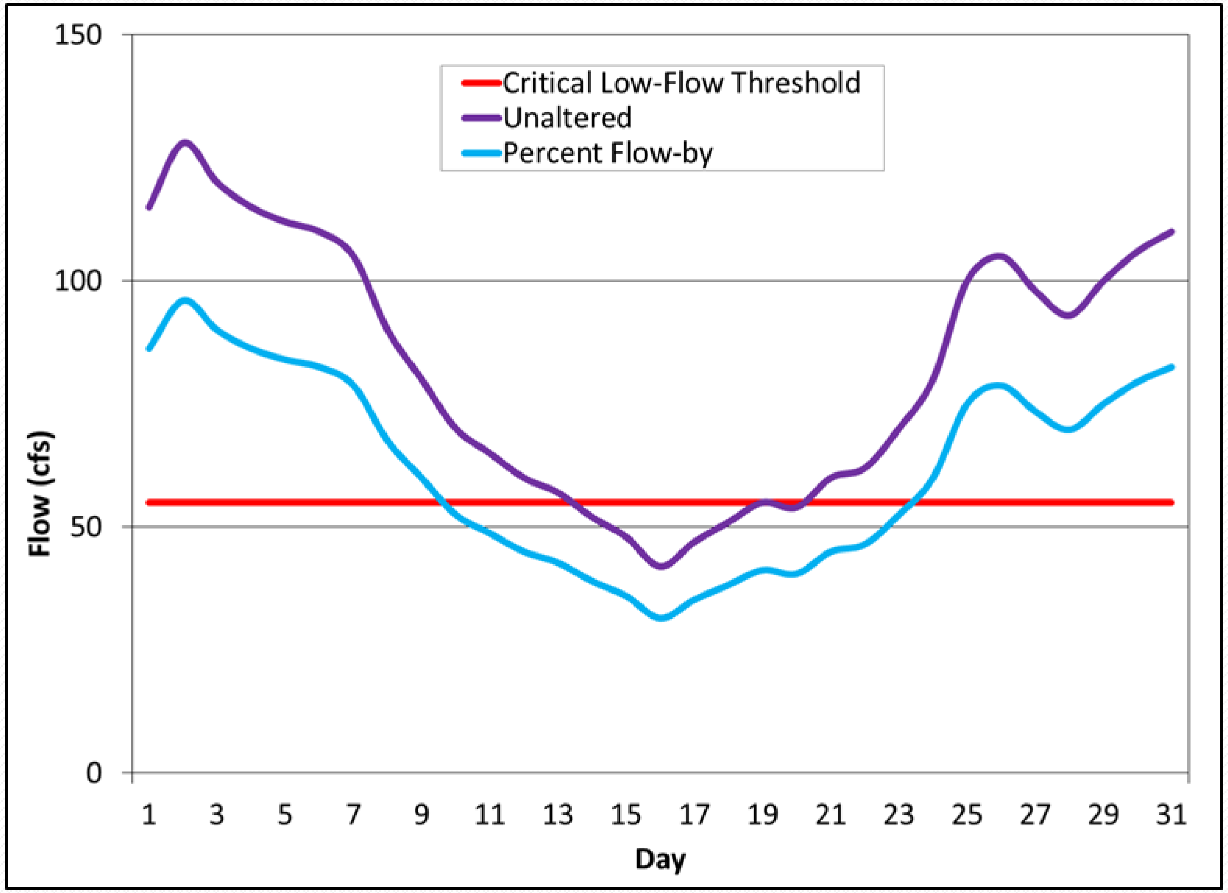
- "Instantaneous" = normal time step of the model (typically daily)
- Model cumulative effects to avoid impacts of a series of withdrawals



EFSAB Recommendations: Ecological Flow Standard

Percentage of Flow (4)

- Combine with a critical low-flow component
  - Protect the aquatic ecosystem during periods of drought
  - Prevent increasing the frequency or duration of extreme low flows that are damaging to ecosystem health
- Use 20th percentile flow as a critical low flow (by month)
- Ecological flow threshold is the larger of the flow-by and critical low-flow values



EFSAB Recommendations: Ecological Flow Standard

Percentage of Flow (5)

- Model should include following flow regimes
  - natural (without any withdrawals or returns)
  - baseline (with current withdrawals and returns)
  - projected (with current and future withdrawals and returns)
- Comparisons
  - baseline:natural = how much hydrology has already been altered
  - baseline:future = effects of future withdrawals and returns
- Model updates should keep baseline as 2010 conditions to avoid comparisons to a continually shifting “current” condition

EFSAB Recommendations: Ecological Flow Standard

Percentage of Flow (6)

- Run basin model with 2 hydrology datasets – full and trimmed (10-90%)

# times threshold exceeded		Condition	DENR Action
Full	Trimmed		
0	0	Green	None
1+	0	Yellow	Begin review of water usage that may be contributing to the deviations. Management tools, including water shortage and drought response plans, should be evaluated for the purpose of maintaining ecological integrity.
1+	1+	Red	Additional review could include actions such as conducting site-specific evaluations or review and modeling of any biological data that are available

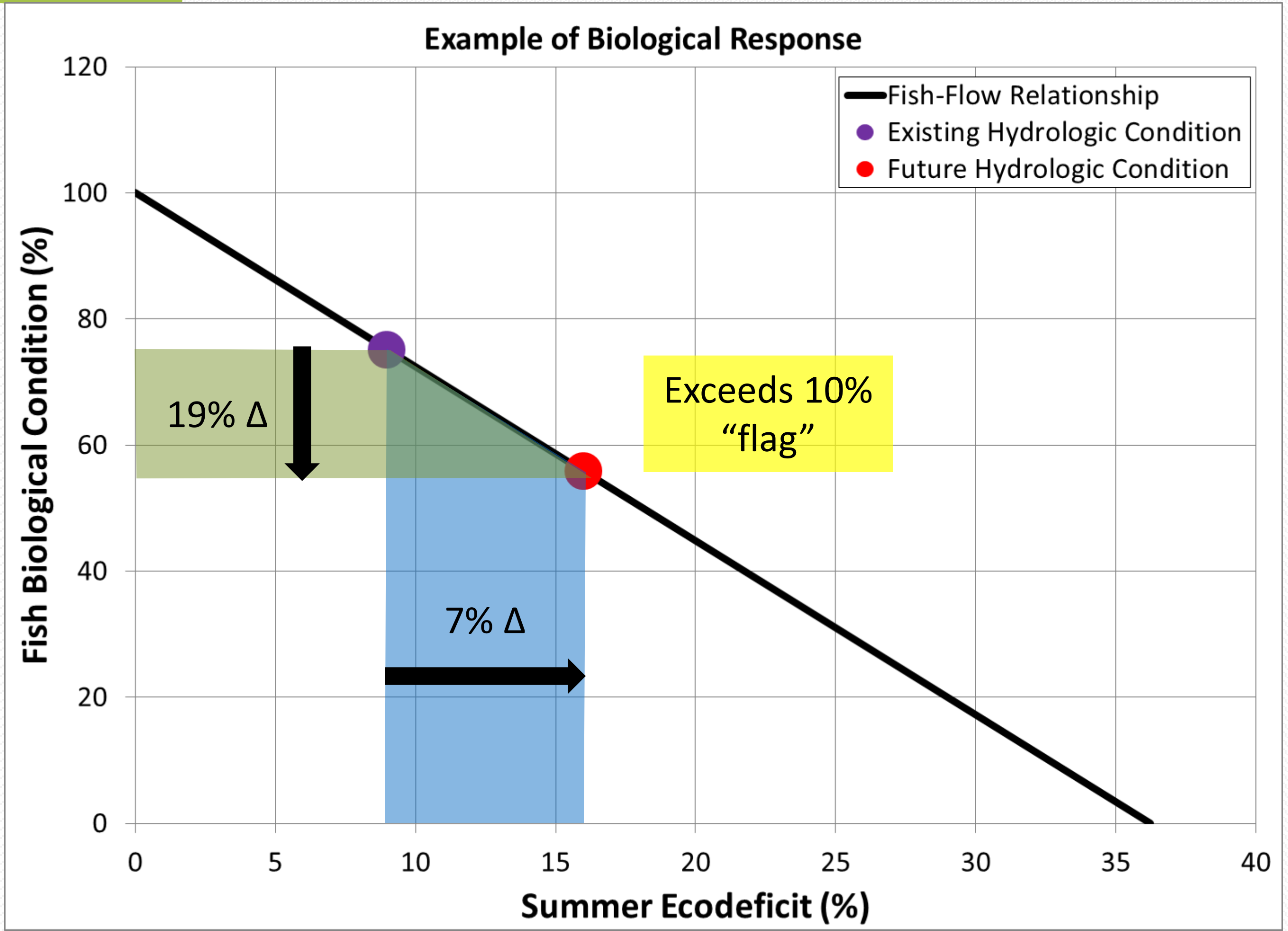
EFSAB Recommendations: Ecological Flow Standard

Biological Response

- DEQ should evaluate the use of these models to assess changes in biological conditions associated with projected changes in flow
- A 5-10% change in biological condition suggested as an initial criterion for further review
  - Based on average range of EPT richness within the invertebrate condition classes (Excellent, Good, Good-Fair, Fair, and Poor) as defined by DEQ
  - The 5-10% criterion represents a change of one-quarter to one-half of the width of a condition class

EFSAB Recommendations: Ecological Flow Standard

Biological Response



EFSAB Recommendations: Ecological Flow Standard

Exceptions – Coastal

- No numerical standards proposed
- Consider the following

Origin	Gradient	Ecological Flow Approach			
		Statewide Recommendation	Habitat Relationship	Downstream Salinity	Overbank Flow
Piedmont	Medium	X	X	X	
Coastal Plain	Medium	X	X	X	
Coastal Plain	Low		X	X	X
Coastal Plain	Wind or tidally driven flow			X	X

EFSAB Recommendations: Ecological Flow Standard

Exceptions – Headwaters

- Streams with drainage basins <10 km^2, DEQ should conduct additional analyses to determine the potential for impact
  - Limited biological and hydrologic data
  - Higher vulnerability to disturbance
  - Statewide approach may not adequately protect

EFSAB Recommendations: Other

- Listed Species
  - For planning purposes, portions of basins (e.g., nodes) that include listed species should be treated by DEQ as needing additional analysis in consultation with WRC, NMFS and USFWS
- Adaptive Management
  - Emphasize new data (hydrologic and biological) collection and evaluation in headwaters, in the coastal plain, and in large rivers
  - Validate ecological thresholds
  - Track impact of flow changes
  - Modify characterizations, target flows, and thresholds based on new data, changing conditions and lessons learned

Thanks!

DWR Website of EFSAB:
http://ncwater.org/?page=366

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