The Science of Ecological Flows

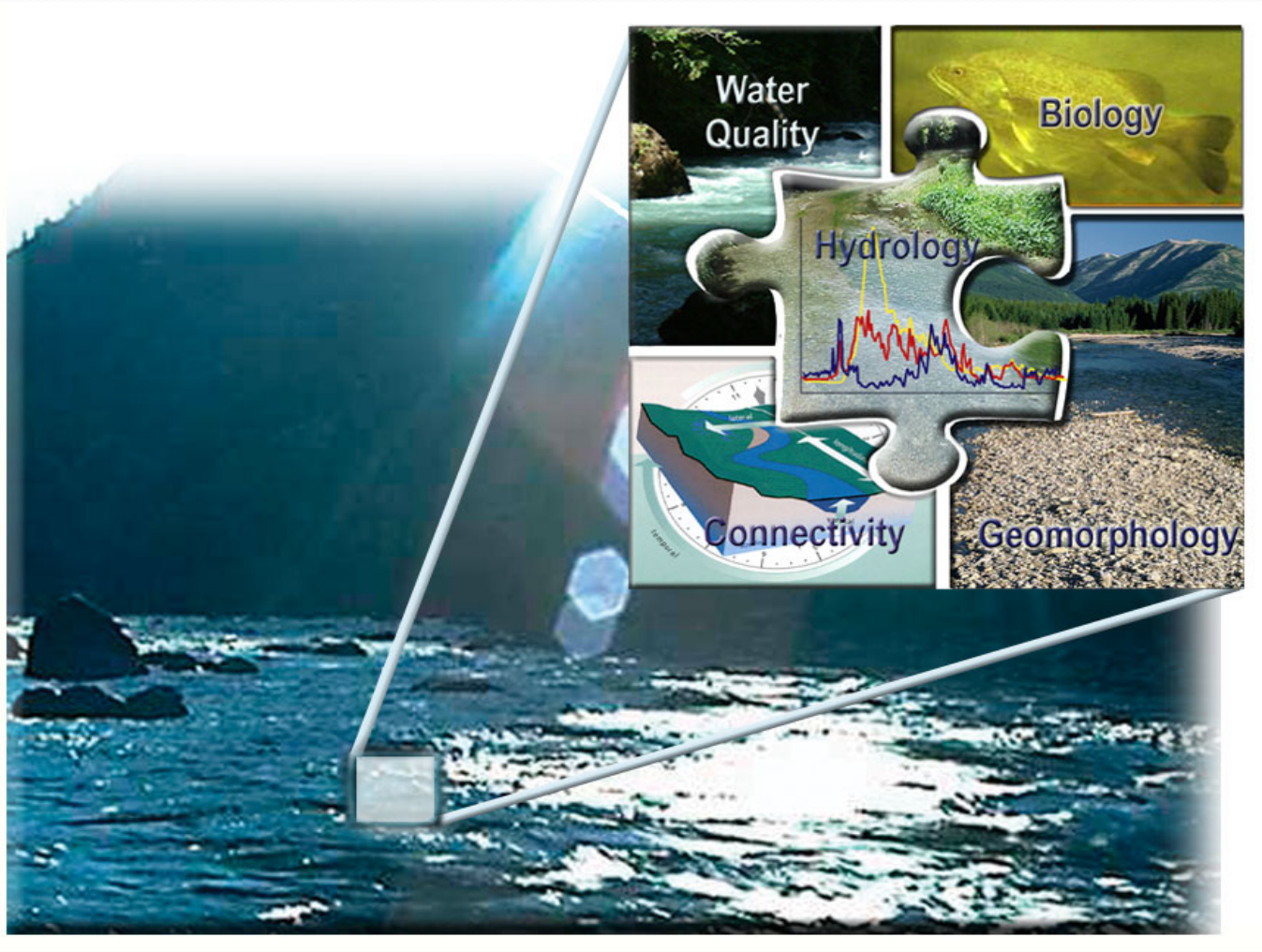
Environmental Management Commission
Water Allocation Committee
November 13, 2019

Chris Goudreau
N.C. Wildlife Resources Commission

How Much Water Do Fish Need?

- This is how some people frame the question – "What is the minimum flow for fish?"
- They assume everything else is available for human use
- It's not quite that simple

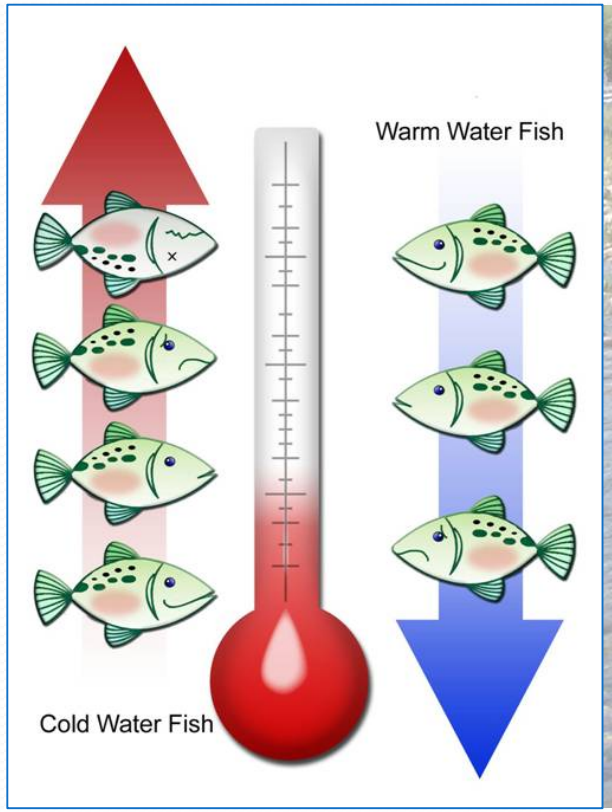
Five Riverine Components

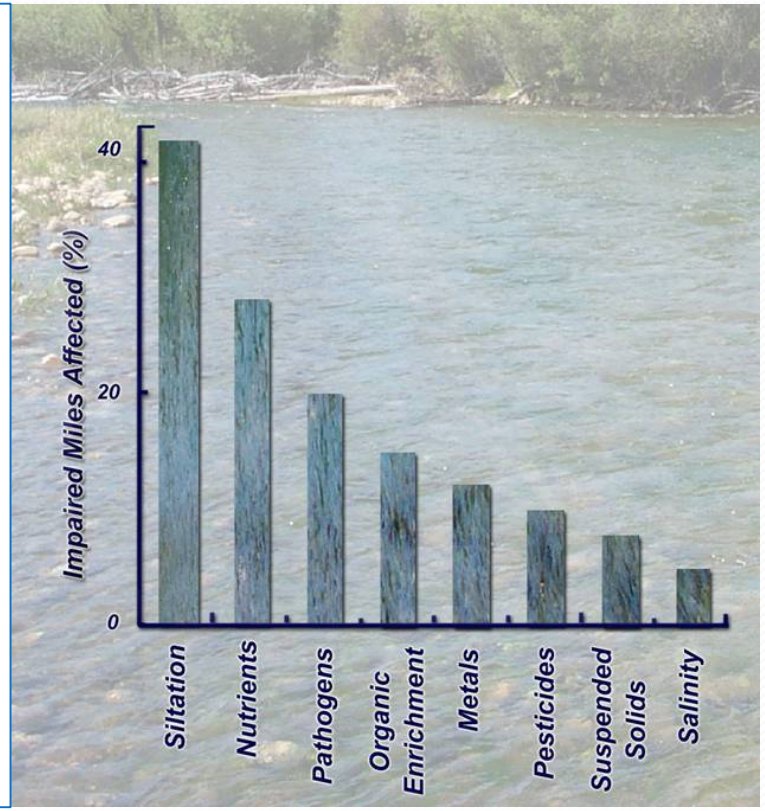


1. Water Quality

Ecological flows:

- maintain good temperature and dissolved oxygen
- handle natural and human loadings (e.g., nutrients, sediment, etc.)
- Minimum “water quality” flow (i.e., 7Q10) isn’t enough!

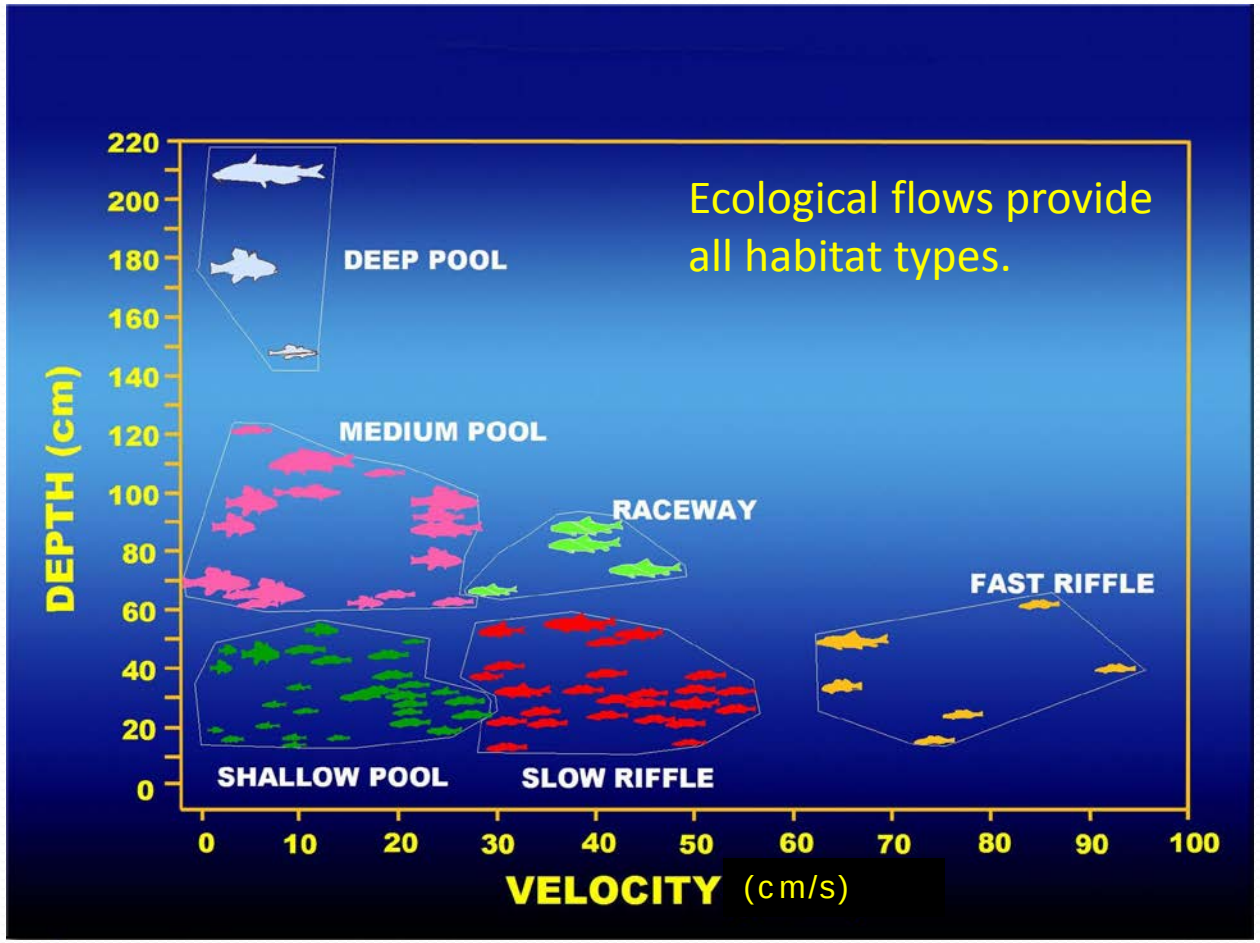




2. Biology

<u>Ecological flows consider:</u>

- All biota – fish, mussels, crayfish, amphibians, insects, plants, trees, etc.
- All lifecycle aspects – feeding, resting, reproduction, dispersal, etc.
- All lifestages – eggs, larvae, juveniles, adults



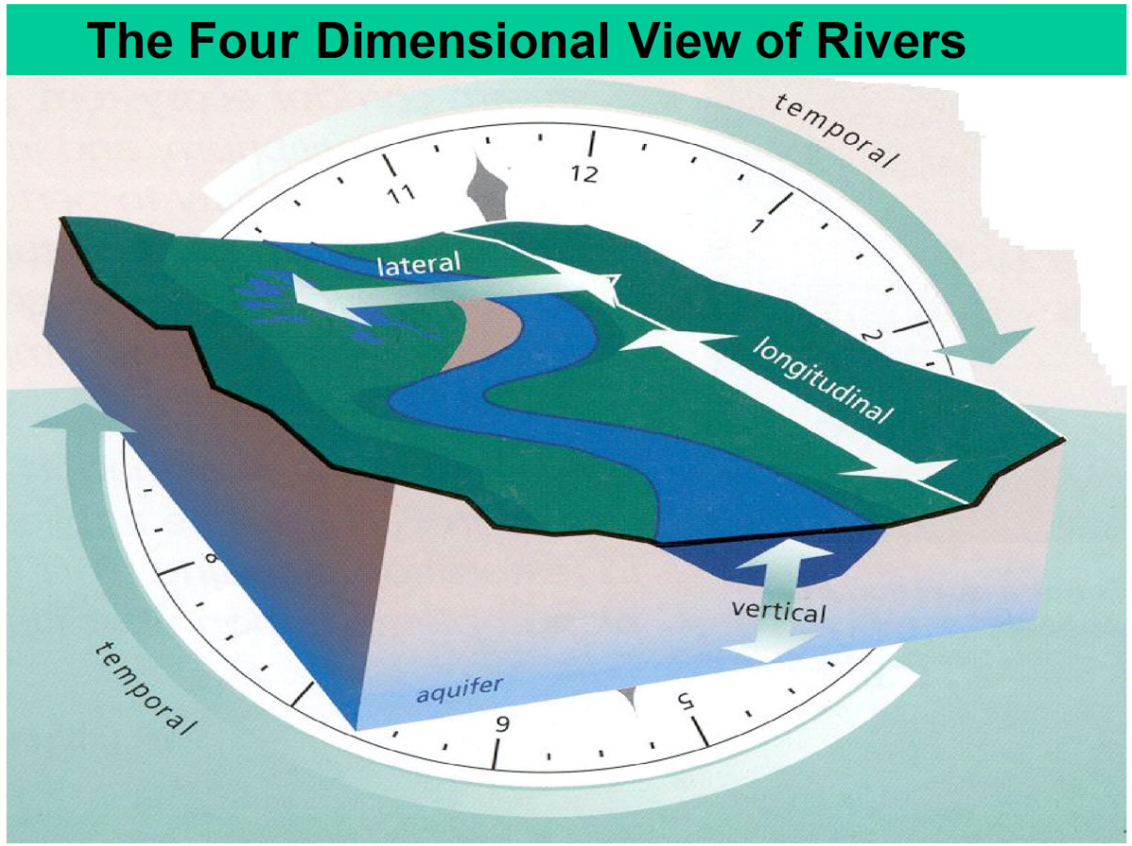
3. Geomorphology

- The relationship between the river and the land
  - Pattern, Profile, Dimension, Substrate
- “Three-River” Concept – Rivers must move:
  - Water
  - Substrate
  - Wood
- Flows must enable the river to move the three materials and maintain its shape over time

4. Connectivity

<u>Ecological flows connect the river:</u>

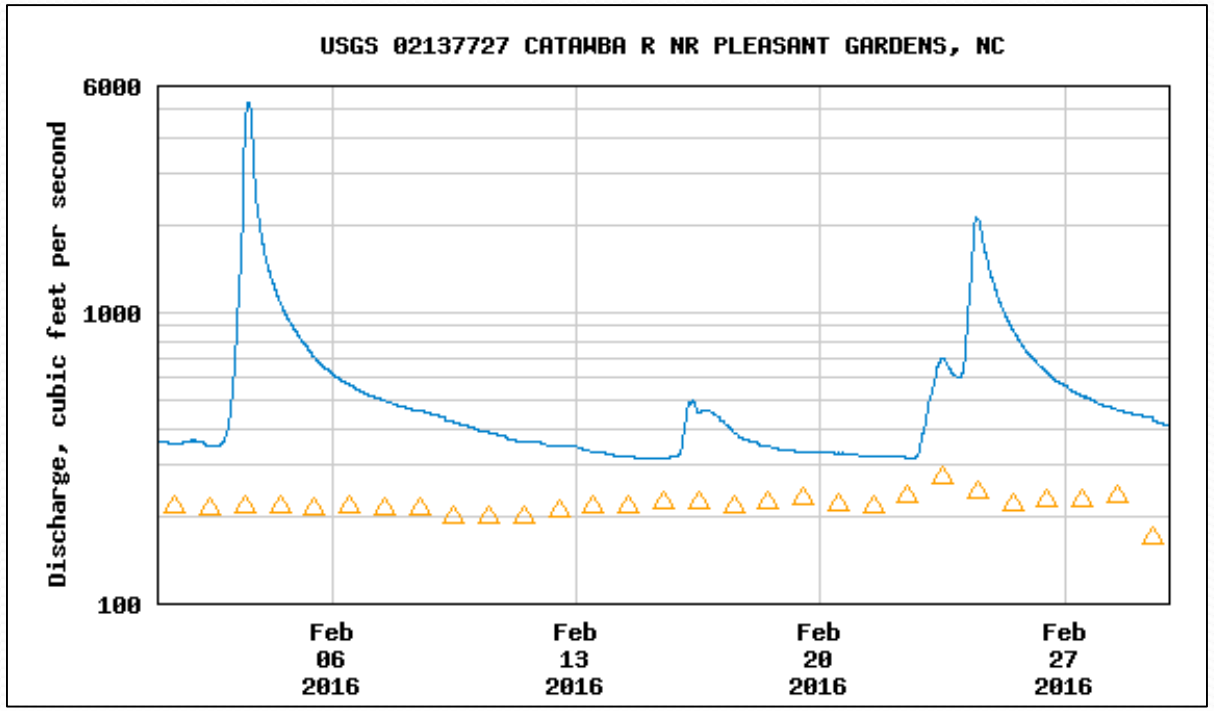
- to the floodplain
- to the groundwater
- upstream/downstream
- over time



5. Hydrology – The Keystone

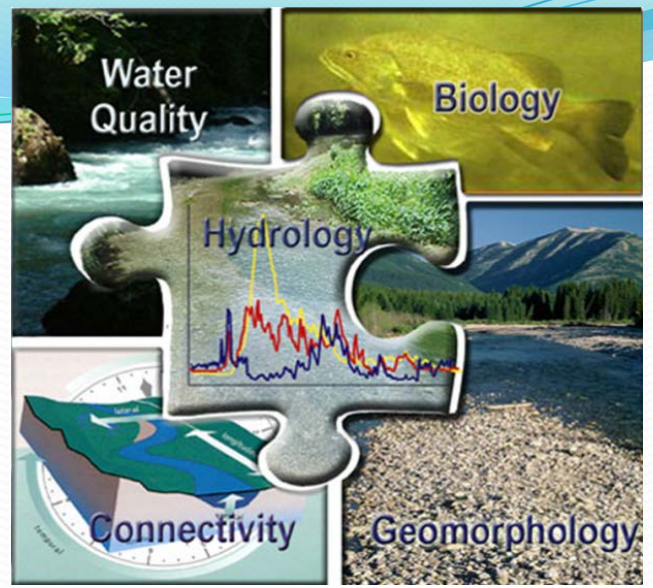
Five Attributes

- Magnitude
- Timing
- Duration
- Frequency
- Rate of Change



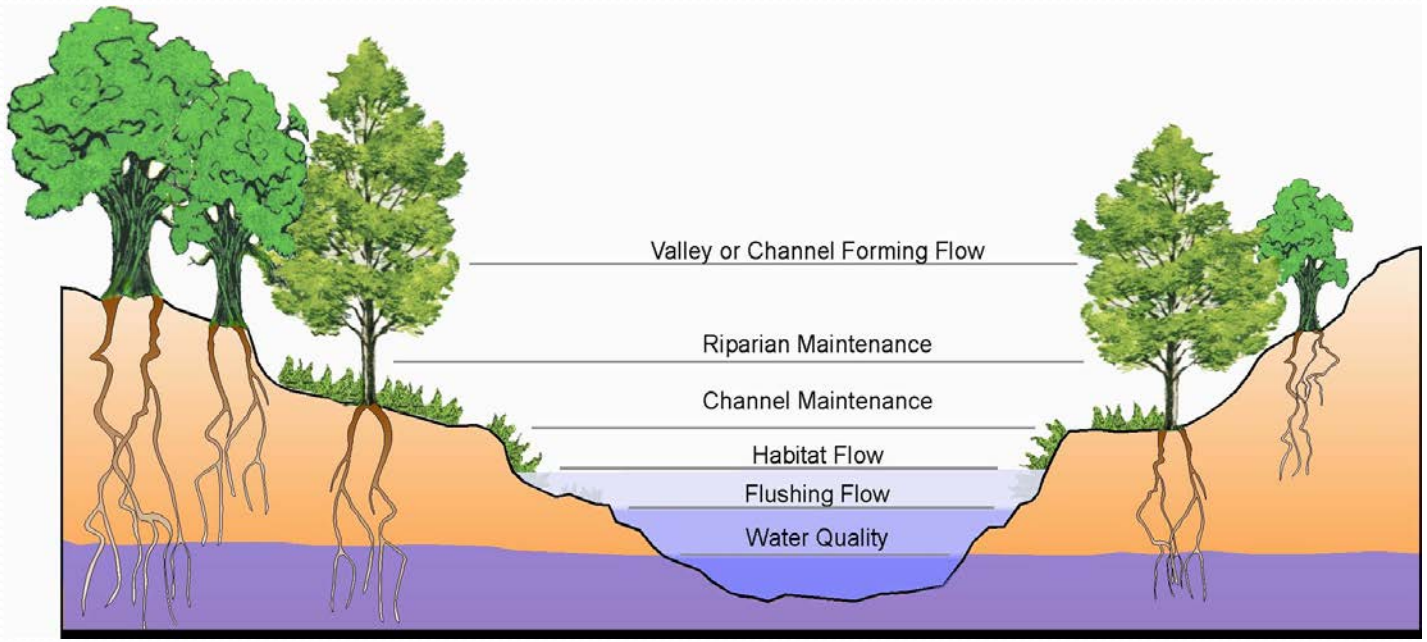
River ecosystems need the right amount of flow at the right time for the right duration and the pattern must have a natural frequency and rate of change.

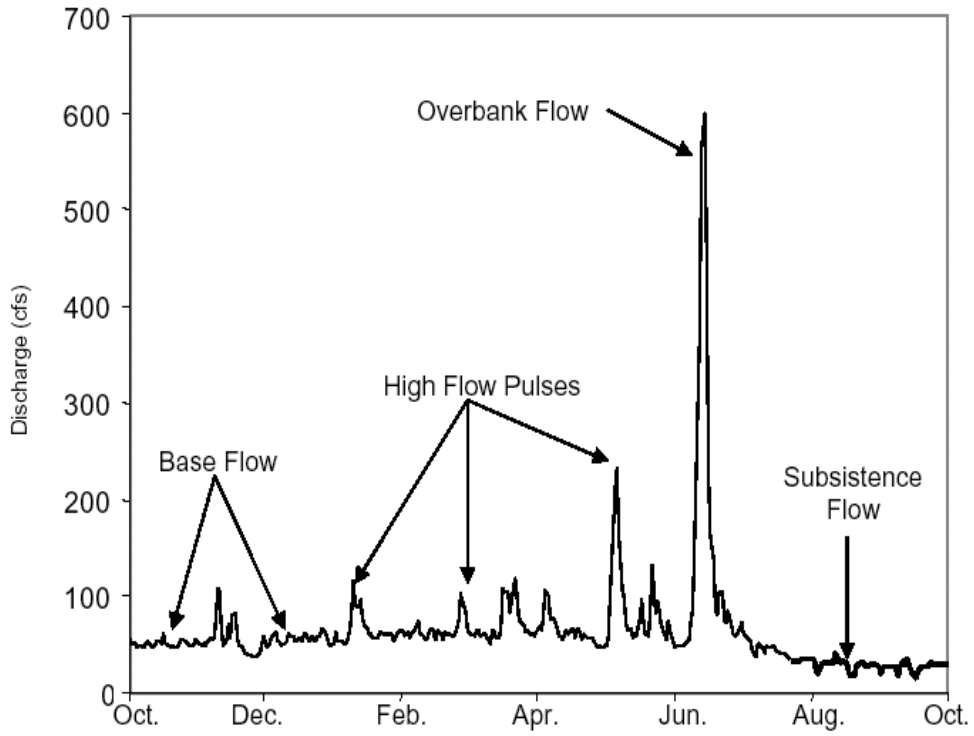
Importance of Flow



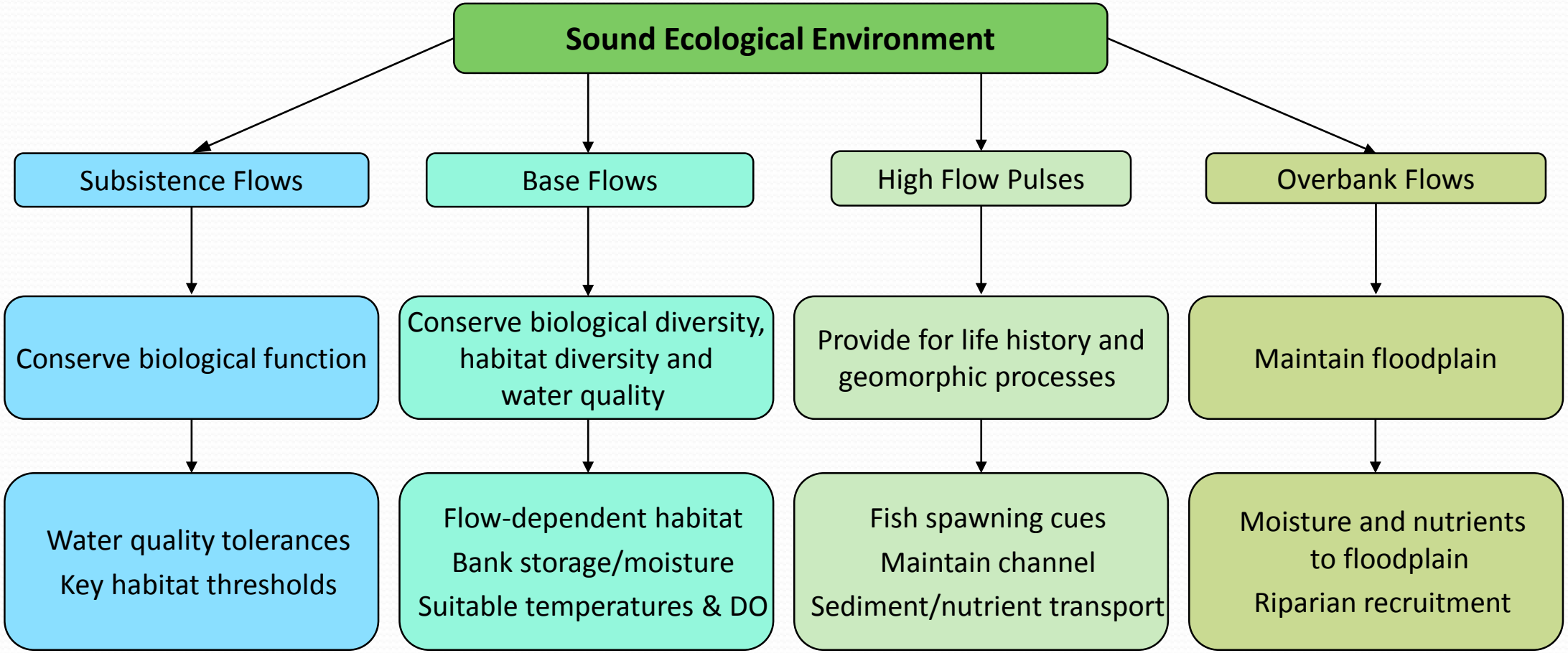
- "Master variable" of riverine systems
- Determines water quality, biology, physical habitat, and energy transfer
- All components of the flow regime (magnitude, duration, frequency, timing, and rate of change), including natural variability, are important to maintaining ecological integrity
- Natural variability of flows includes intra-annual and inter-annual variability and consists of extreme low flows, low flows, high flow pulses, small floods, and large floods
- Collectively, these concepts are known as the "natural flow paradigm"

We need to think in terms of flow regimes, not single flows





Flow Regime Tied to Ecology

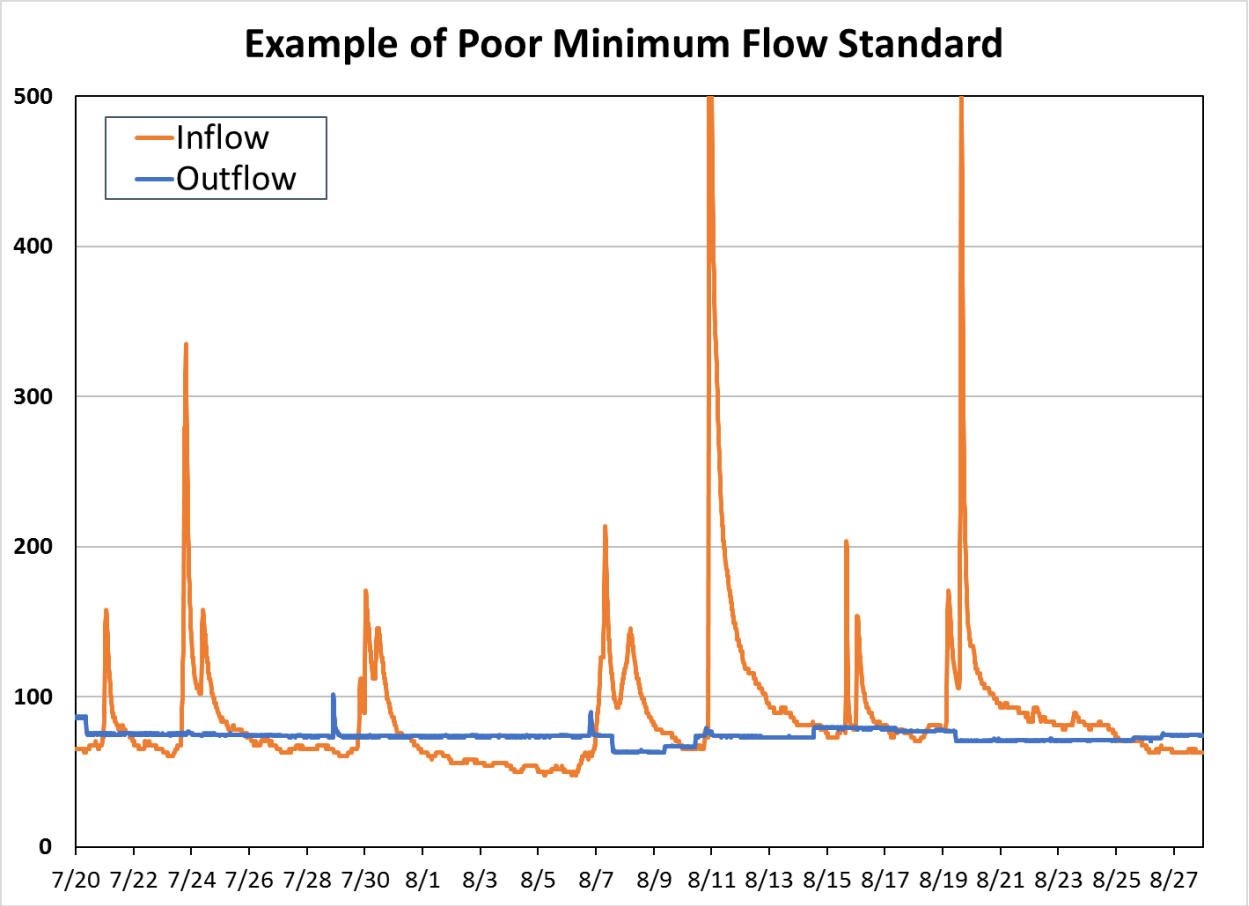


Types of Eco-Flow Recommendations

- Minimum Flow Threshold
- Statistically-based Standard
- Percent of Flow Standard
- Site-specific Study

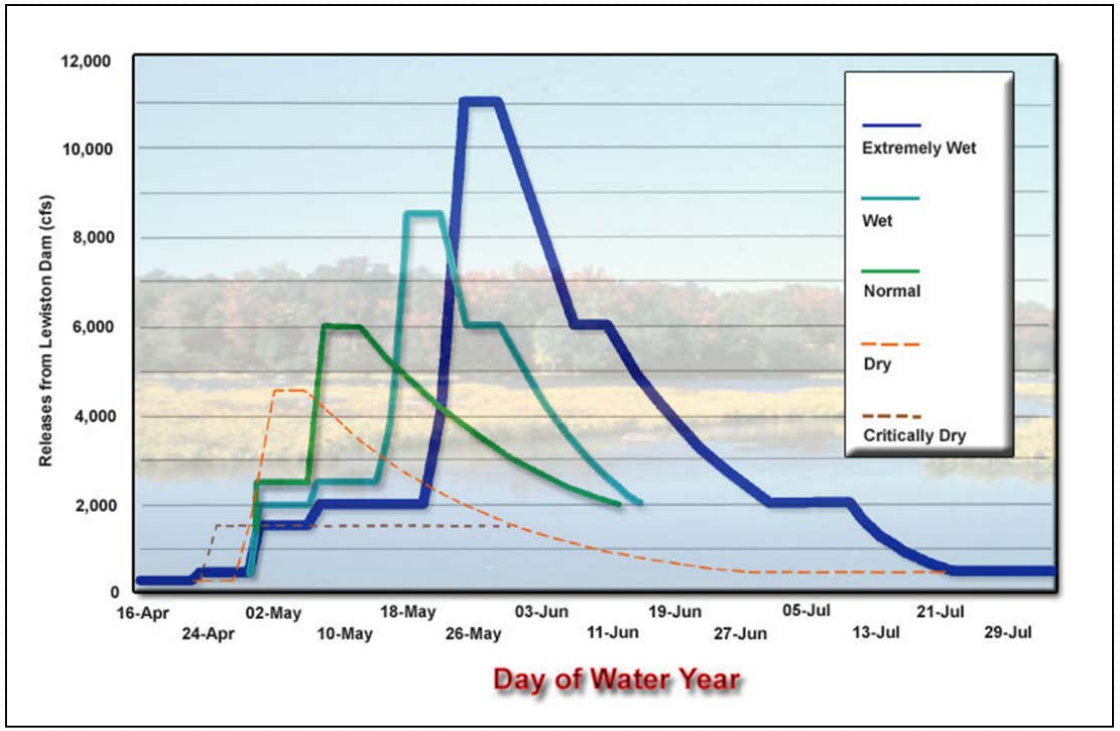
Minimum Flow Threshold

- 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



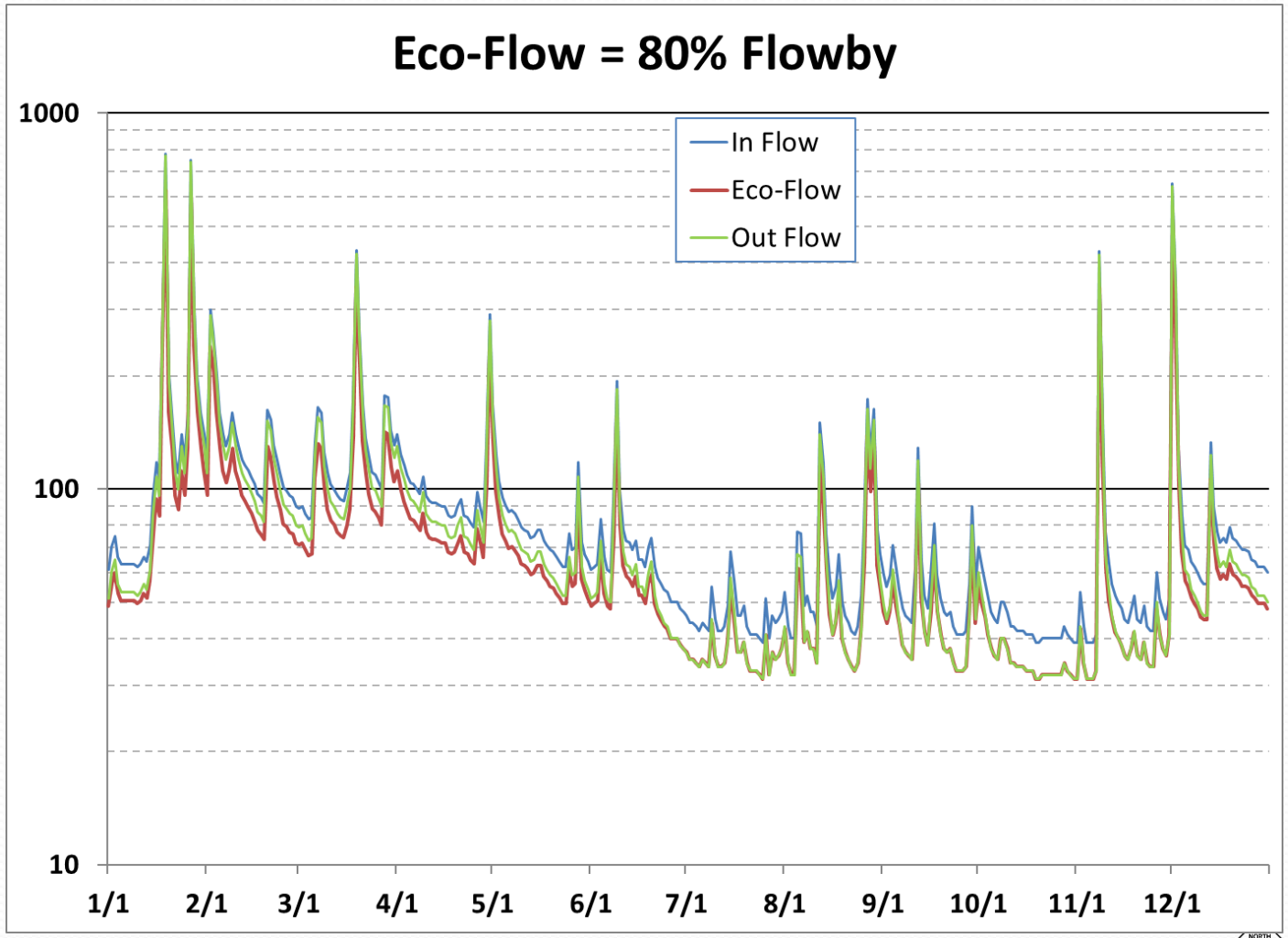
Statistically-Based Standard

- 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



Percent of Flow Standard

- Remove X% of water flowing by for a given time step
  - X generally 6 – 20% in the literature
  - 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
- Inverse is “flow-by”
  - Withdrawal of 20% = Flow-by of 80%
- Relatively easy to model

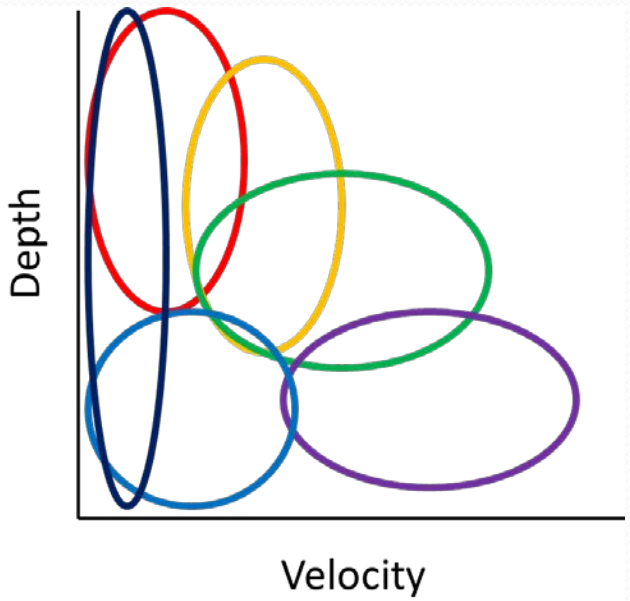


Site-specific Studies

- Can be used with any of the other recommendation types
- Wetted perimeter – Amount of stream bottom that is wet at different flows
- Habitat response models
  - Habitat quantity and quality are measured relative to flow
  - Indirect and intermediate measure of expected biological response
  - Use a suite of biota habitat preference curves to ensure that all types of habitat are represented
- PHABSIM (Physical Habitat Simulation)
  - Common habitat model
  - Has been used in NC for hydro relicensing and water withdrawal studies

Flow-Habitat Relationships

- Consider all biological components



- Pool
- Pool-Run
- Riffle-Run
- Riffle
- Margin
- Backwater

Recommendations of the North Carolina Ecological Flows Science Advisory Board

Environmental Management Commission
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N.C. Wildlife Resources Commission

EFSAB 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

Ecological Flows as Defined in S.L.

- 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)
  - Essentially 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
  - recommend ecological flow requirements
- Not a role:
  - water-use permitting
  - recommending how DEQ responds to a water-availability issue
  - advising DEQ on how to implement 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

Characterizing Stream Ecology

- Did not spend much time with this
- Covered in DENR basin water quality plans
- In light of other findings, EFSAB report gives summary descriptions based on eco-region and stream size

Basic Streams in NC

Mountain

- Less altered
- Steep
- Cold-Cool

Piedmont

- More altered
- Moderate
- Cool-Warm

Coast

- Less altered
- Flat
- Warm
- Tidal / non-tidal

Headwater

- Drainage area <10 km^2
- All parts of the state
- Comprise majority of mileage
- Limited hydrologic and biologic data

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

*Poff et al. 2009

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

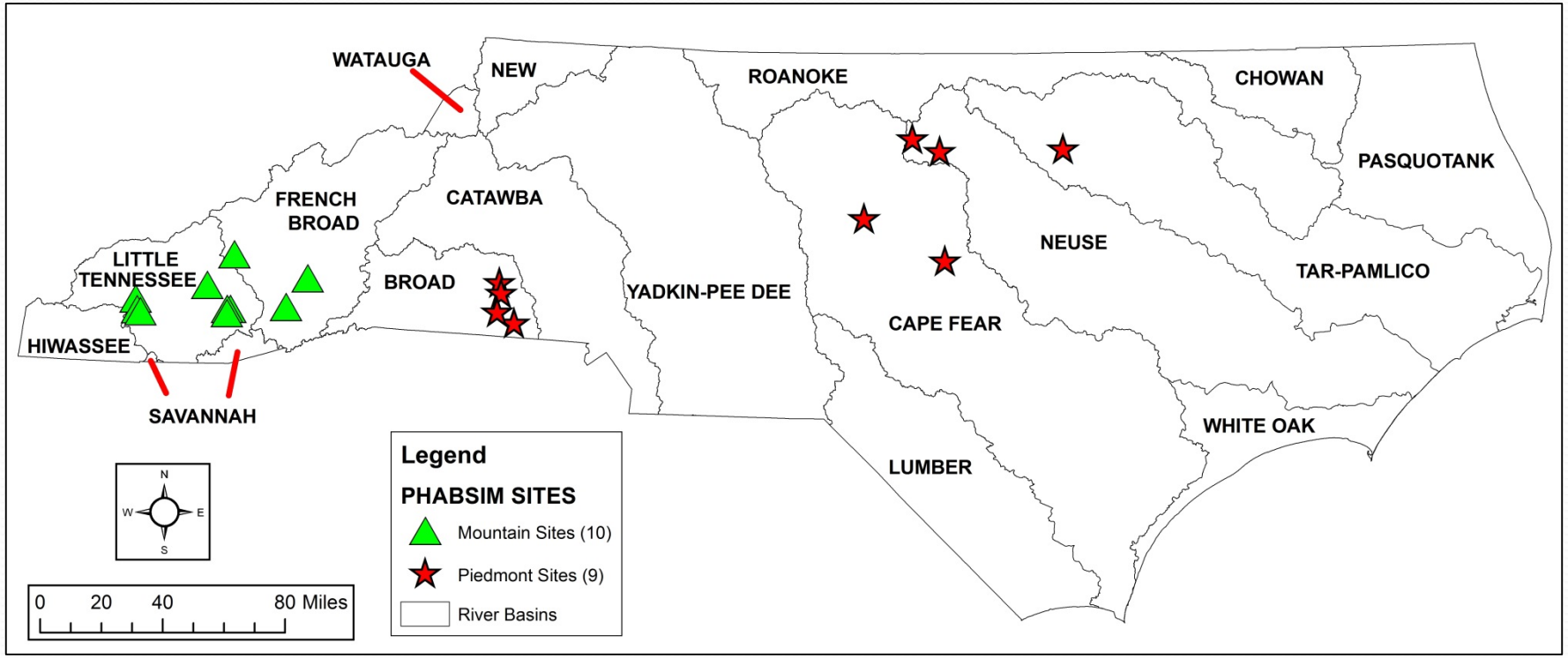
Eco-Flow Approaches Used by EFSAB

- Minimum Flow Threshold – Yes
- Statistically-based Standard – No; too difficult to model
- Percent of Flow Standard – Yes
- Site-specific Study – Used multiple studies to assess trends

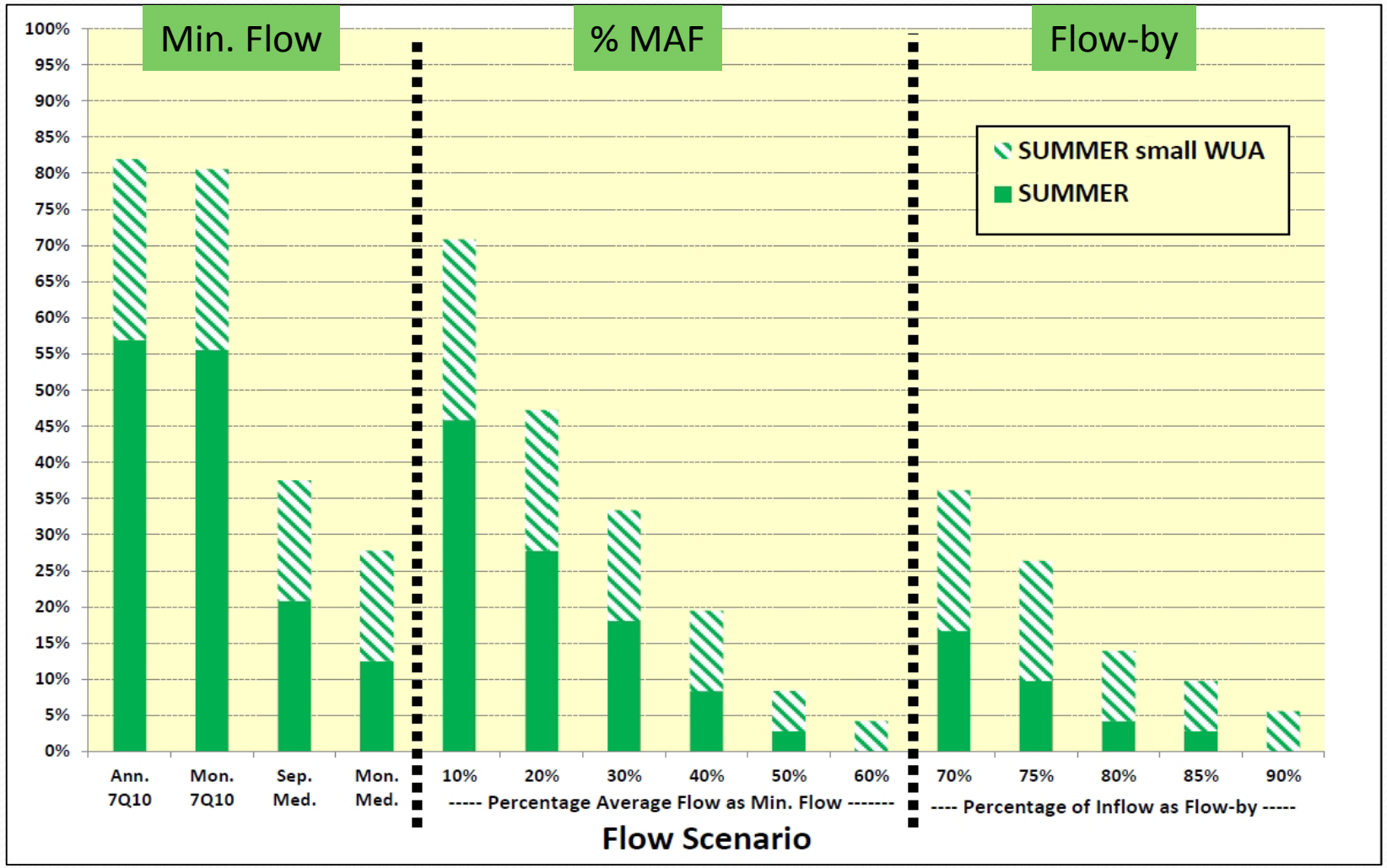
Strategies to Determine Ecological Flows

- 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

Flow-Habitat Studies in NC



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

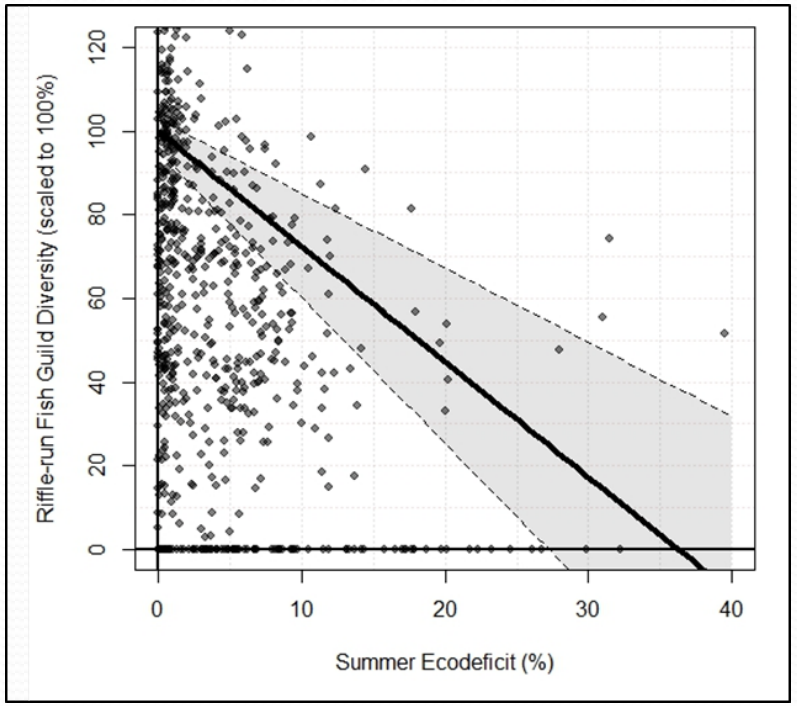
Advancing the Science: Flow-Ecology Relationships

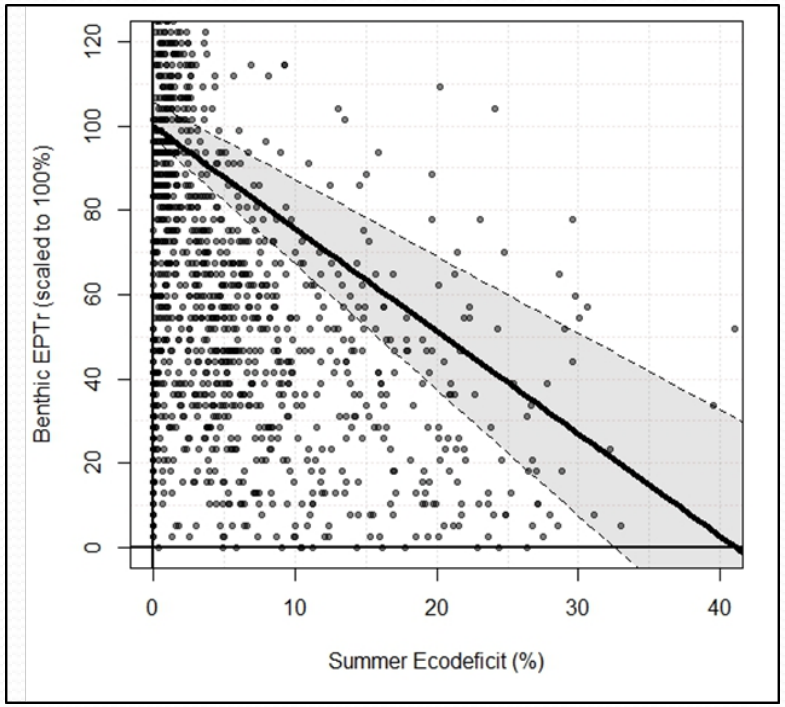
- Ecological integrity inferred from fish or benthic macroinvertebrate community structure metrics
- Two basic approaches
  - Relate biological conditions to flow across a range of flow conditions (space for time)
  - Relate changes in biological condition to flow at a site over time (time series)
- 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 average 30-day minimum flow
- Attempted to include other explanatory factors (e.g., stream size and basin characteristics), but these were unsuccessful

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

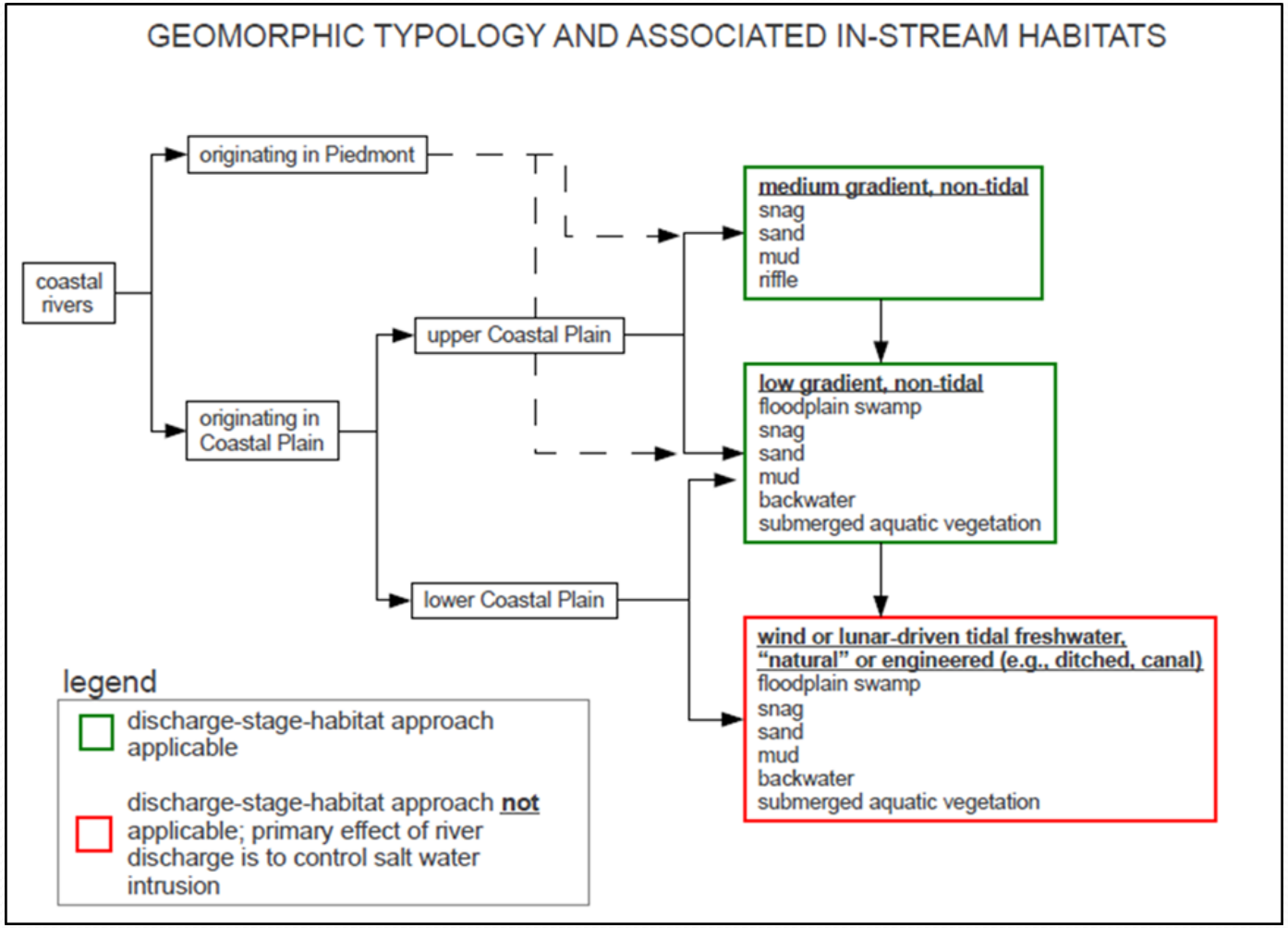
Advancing the Science: Flow-Ecology Relationships

- 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

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: Coastal Considerations



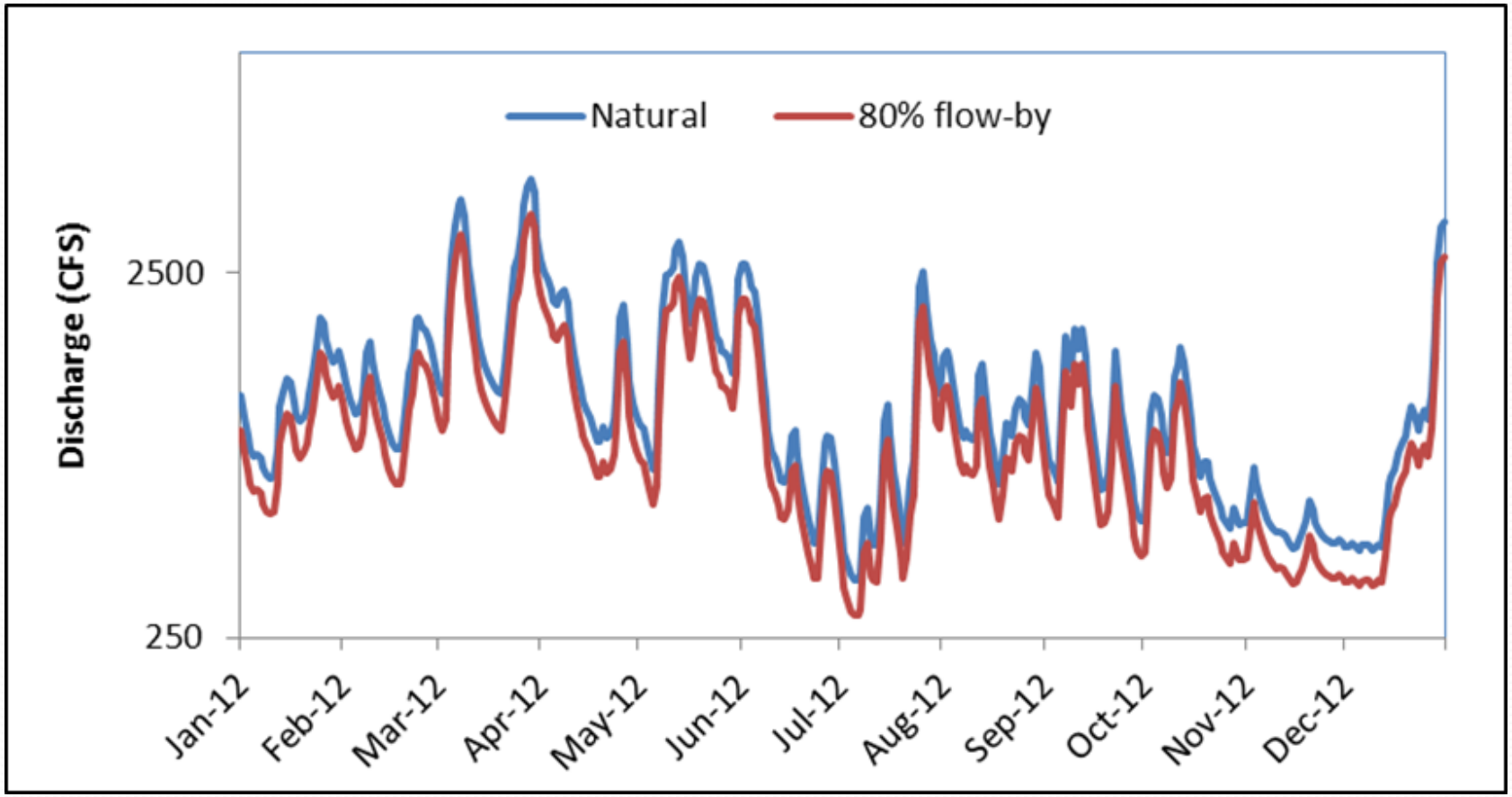
EFSAB Recommendations: Ecological Flow Standard

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

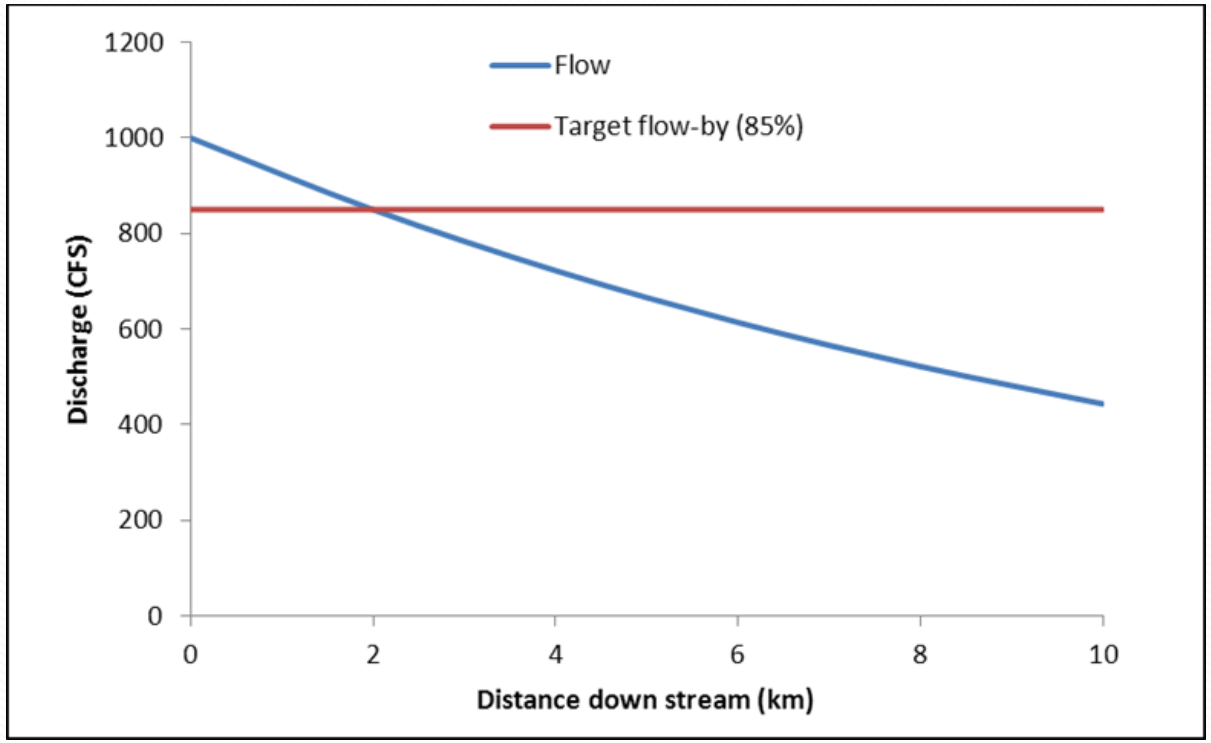
Percentage of Flow (example)



EFSAB Recommendations: Ecological Flow Standard

Percentage of Flow (2)

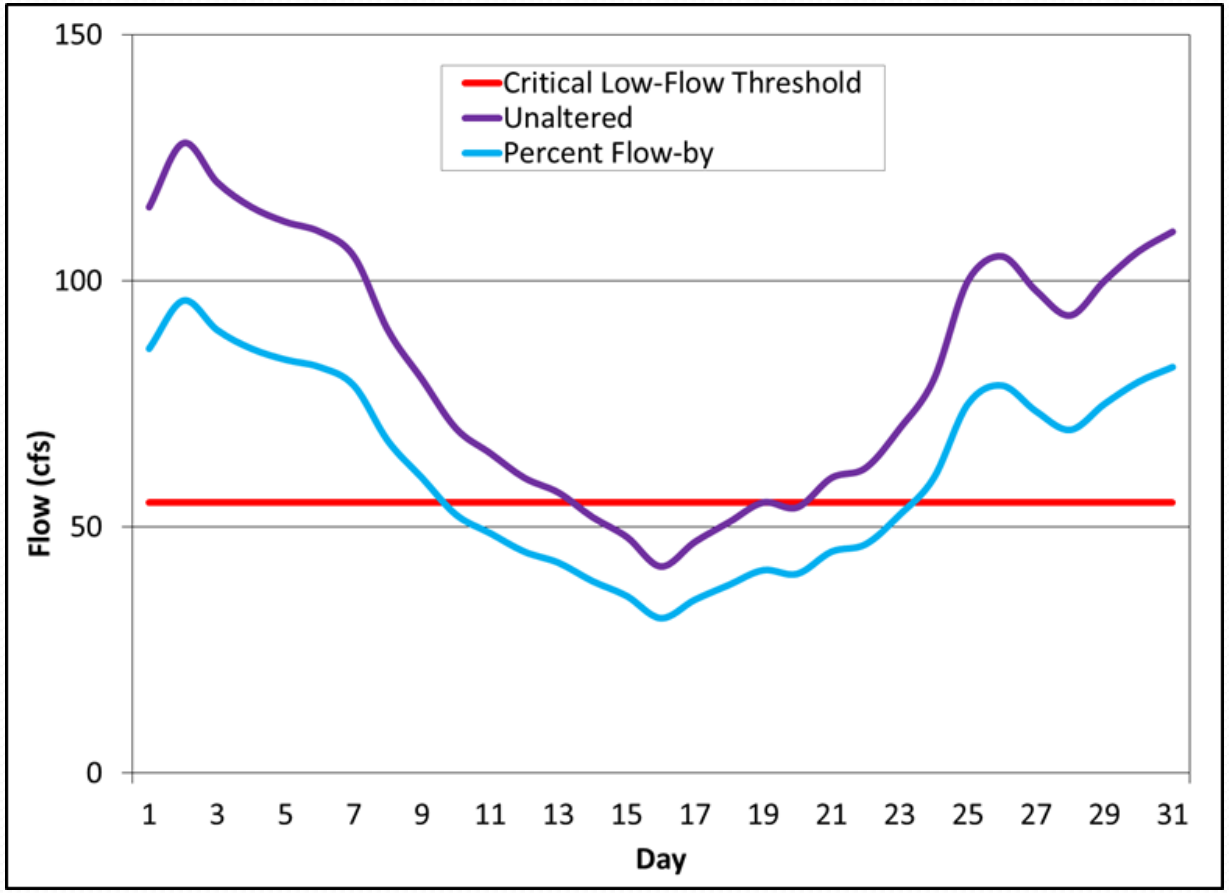
- "Instantaneous" = normal time step of the model (typically daily)
- Model cumulative effects to avoid impacts of a series of withdrawals



EFSAB Recommendations: Ecological Flow Standard

Percentage of Flow (3)

- 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 (4)

- 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 (5)

- 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

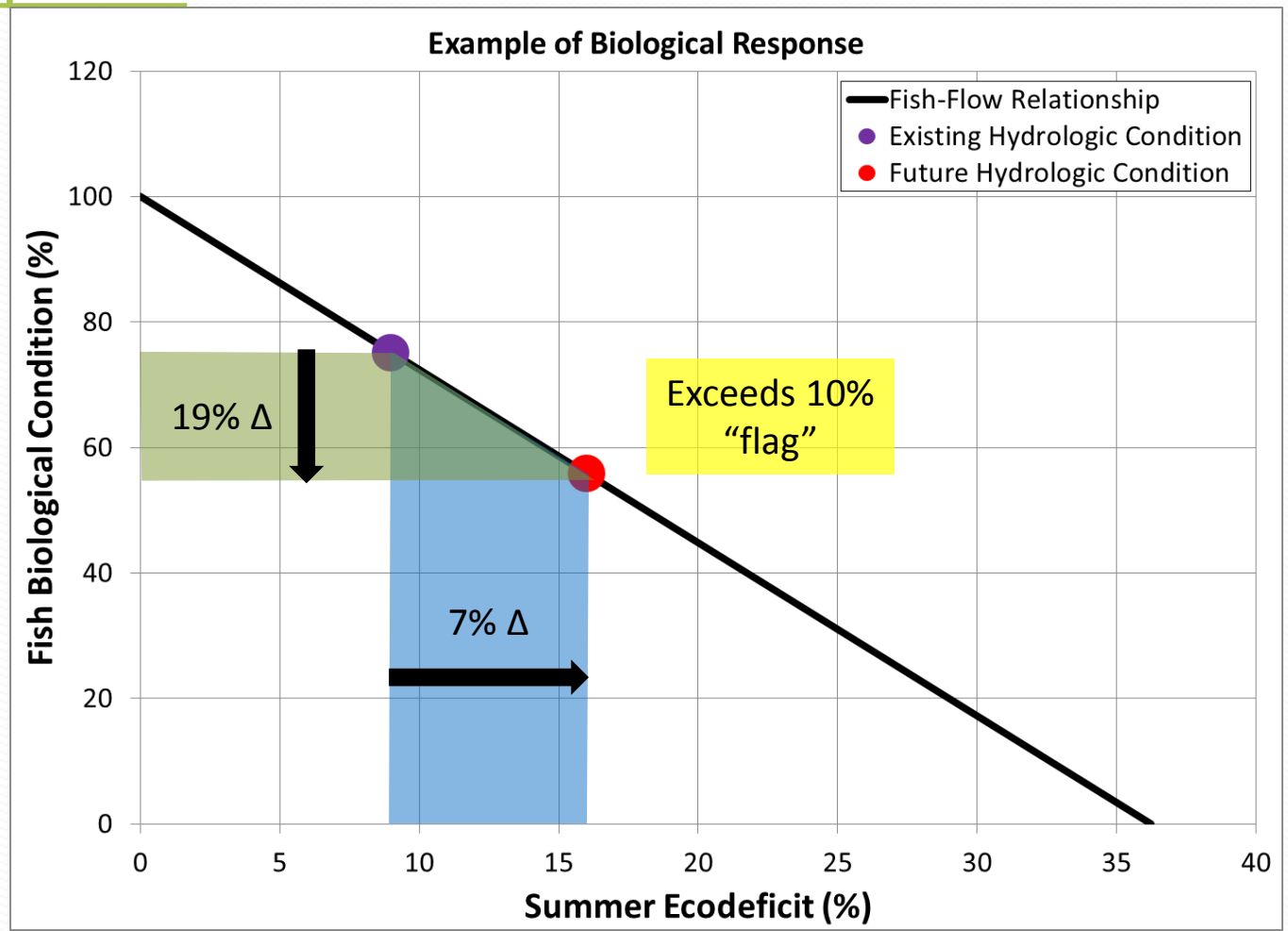
EFSAB Recommendations: Ecological Flow Standard

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

- A separate coastal workgroup continues this work (facilitated by APNEP)

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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