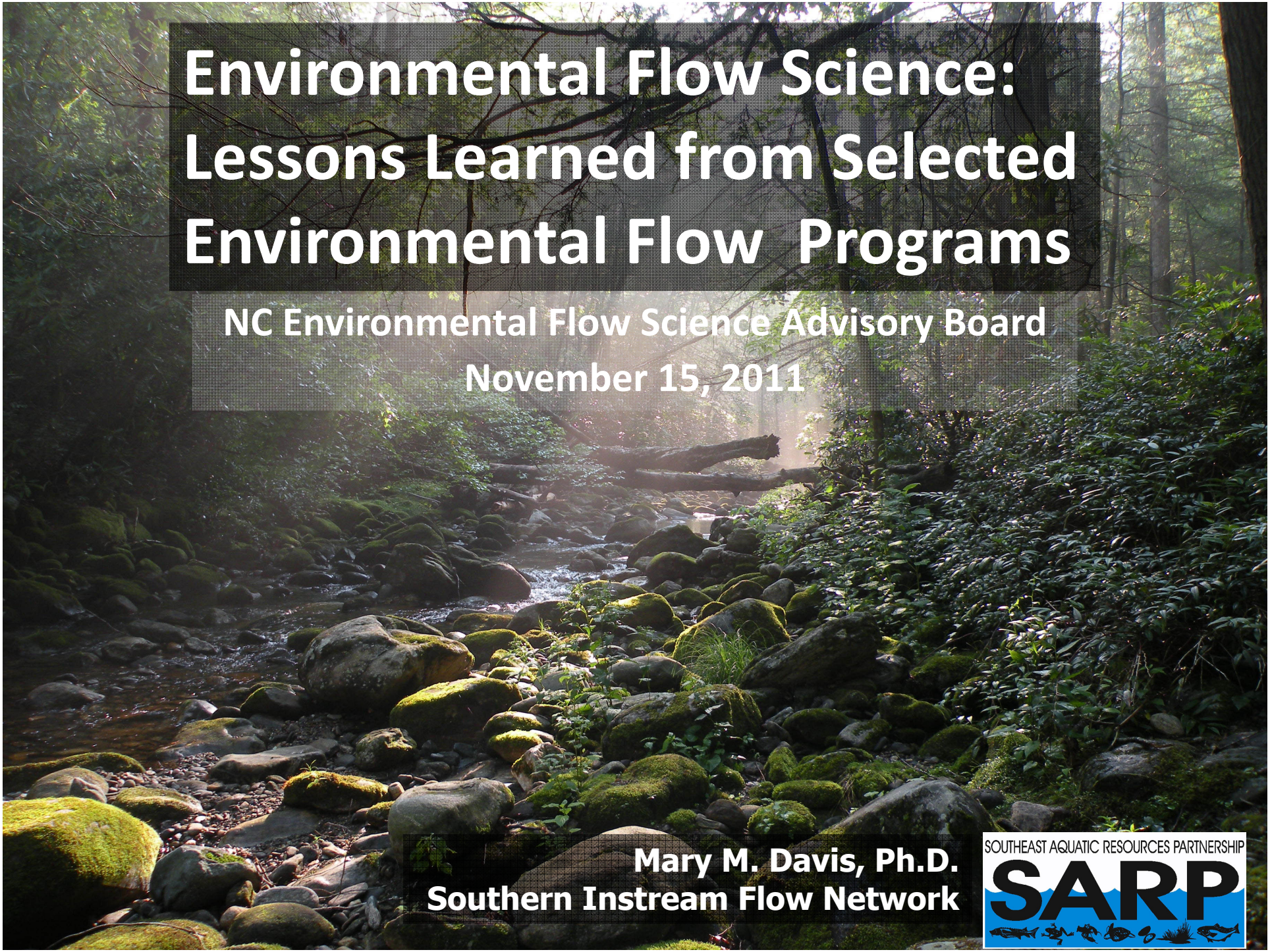


Environmental Flow Science: Lessons Learned from Selected Environmental Flow Programs

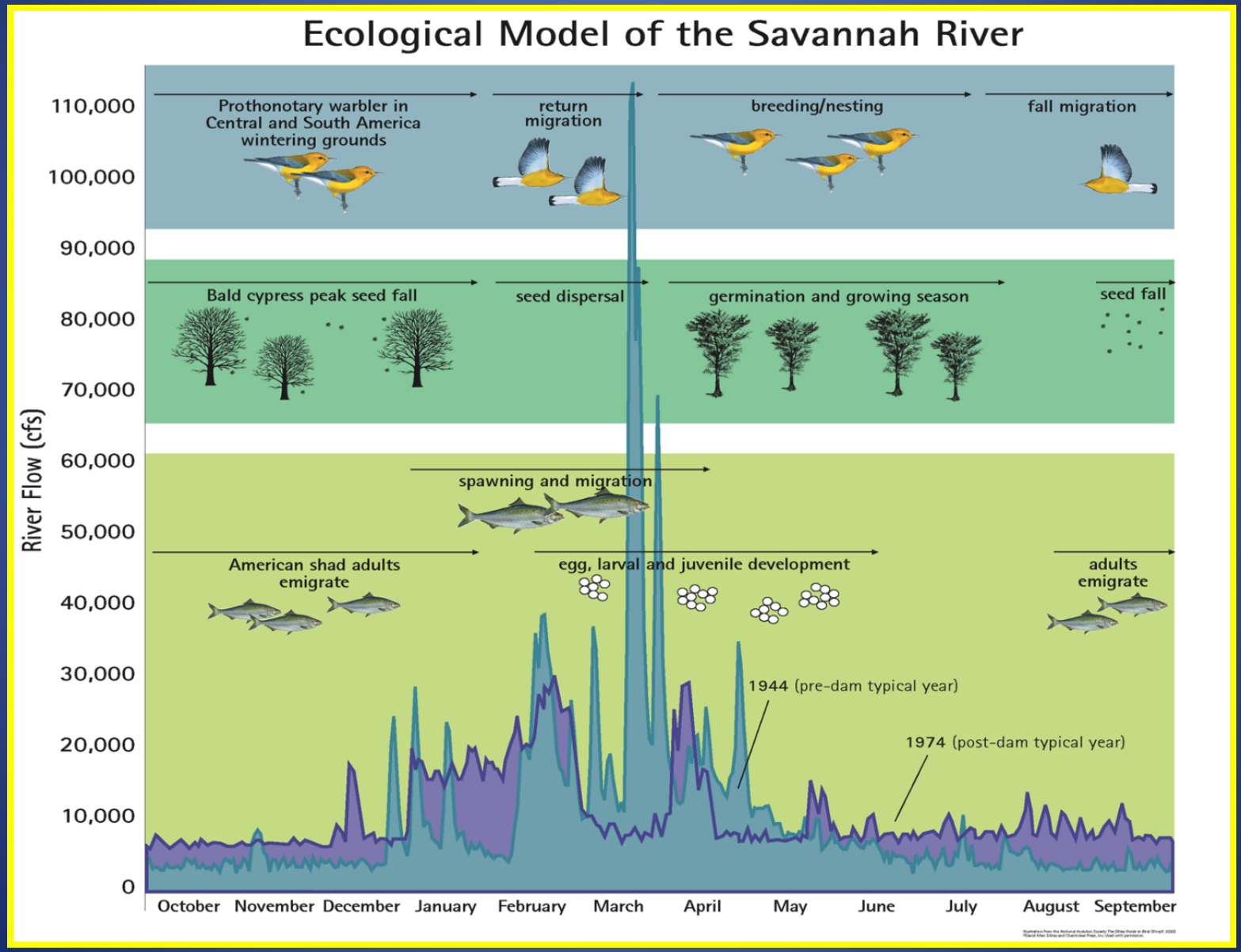
NC Environmental Flow Science Advisory Board

November 15, 2011

Mary M. Davis, Ph.D.
Southern Instream Flow Network

SOUTHEAST AQUATIC RESOURCES PARTNERSHIP
SARP

“Hydrologic regimes are the master variables in aquatic ecosystems.” Poff et al. 1997



Southern Instream Flow Network

Purpose - To facilitate protective instream flow policies and practices in 15 southern states by providing science-based resources and opening lines of communication.

SOUTHEAST AQUATIC RESOURCES PARTNERSHIP
SARP

More information at:
www.southeastaquatics.net/programs/sifn/

Presentation Overview

1. Review of science-based methods to determine IF needs

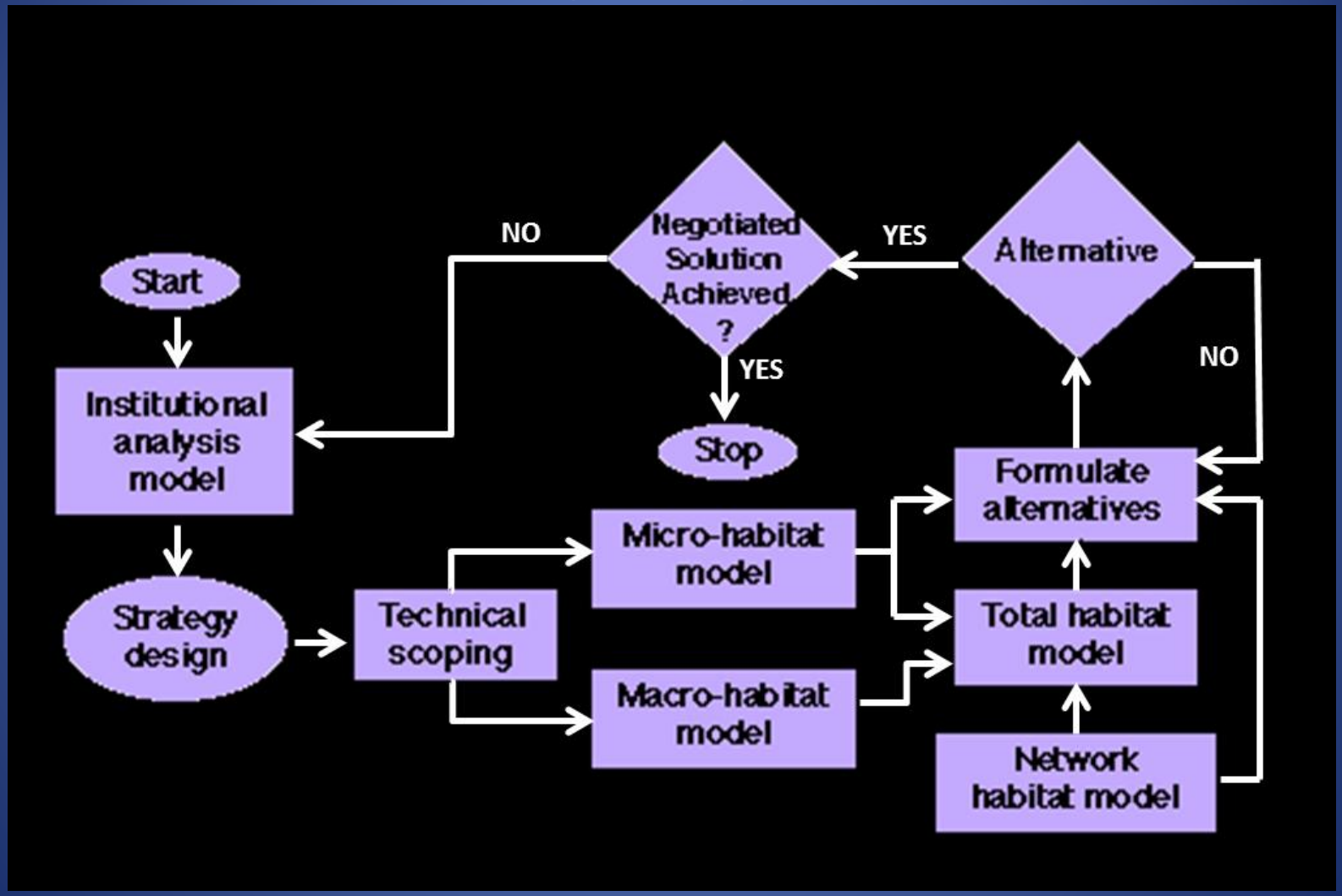
2. Methods used by select states to determine IF needs

3. IF resources for North Carolina

Science-based Methods to Determine Instream Flow Needs

- Instream Flow Incremental Method (IFIM)
- Ecologically Sustainable Water Management (ESWM)
- Ecological Limits of Hydrologic Alteration (ELOHA)

Instream Flow Incremental Method (IFIM)



Source: http://www.fort.usgs.gov/Products/Software/ifim/5phases.asp

IFIM Process: Site- and Project–specific Evaluations

Field Study

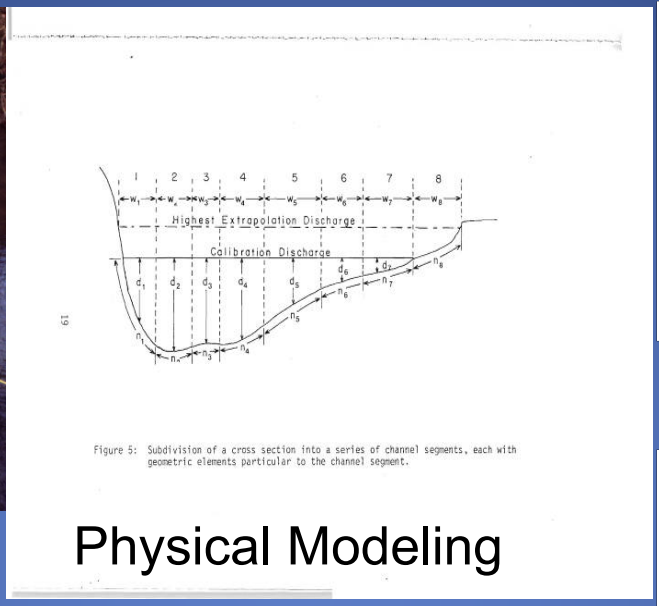
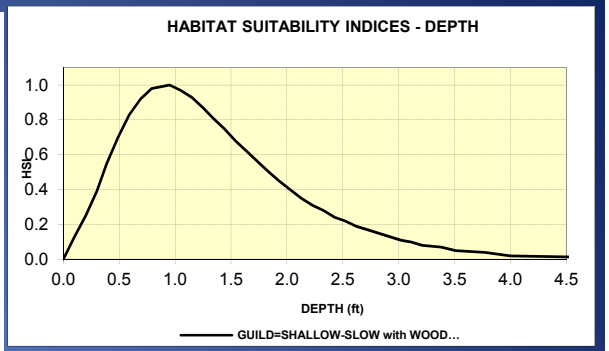
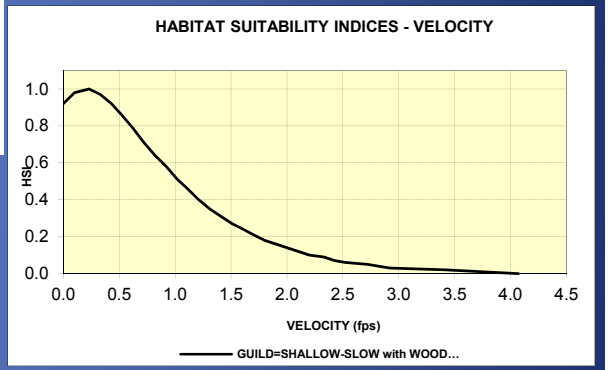


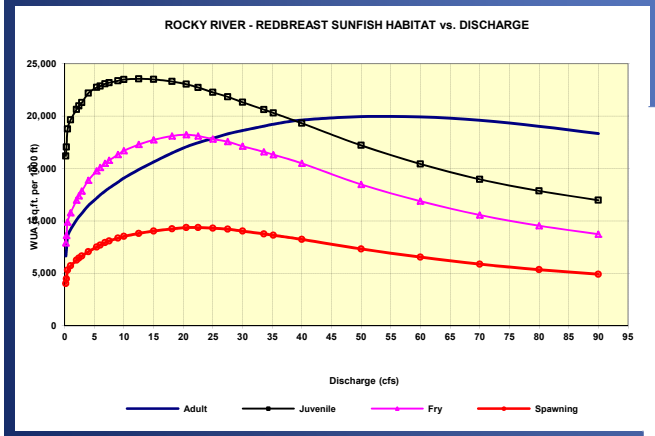
Figure 5: Subdivision of a cross section into a series of channel segments, each with geometric elements particular to the channel segment.

Physical Modeling

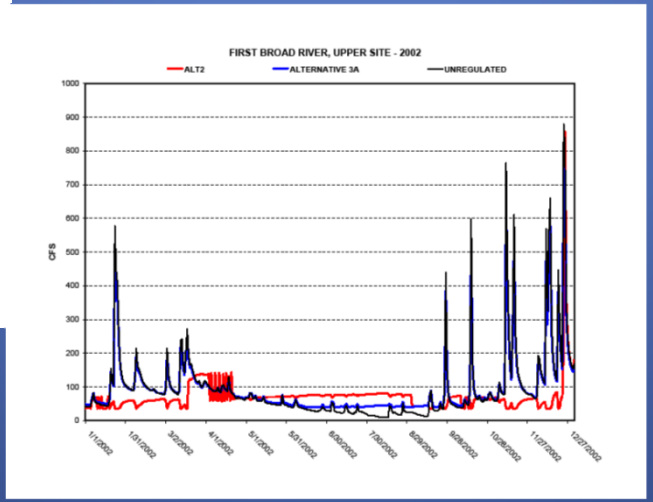


Habitat Modeling





Habitat vs. Flow
for each organism

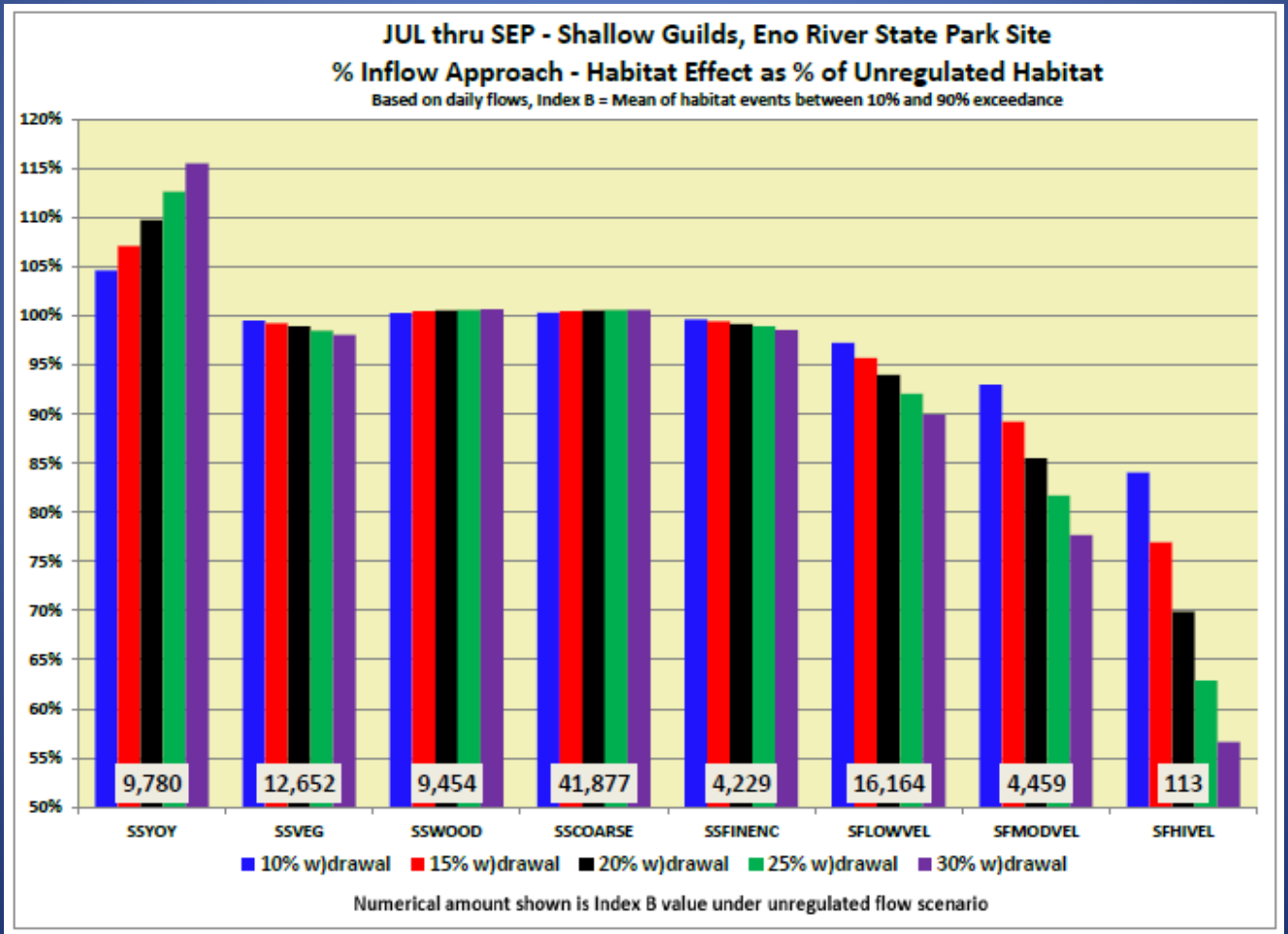


Hydrologic Modeling

- Time Series Analysis
- Flow Alternatives
- Recommendations

Requires time and $

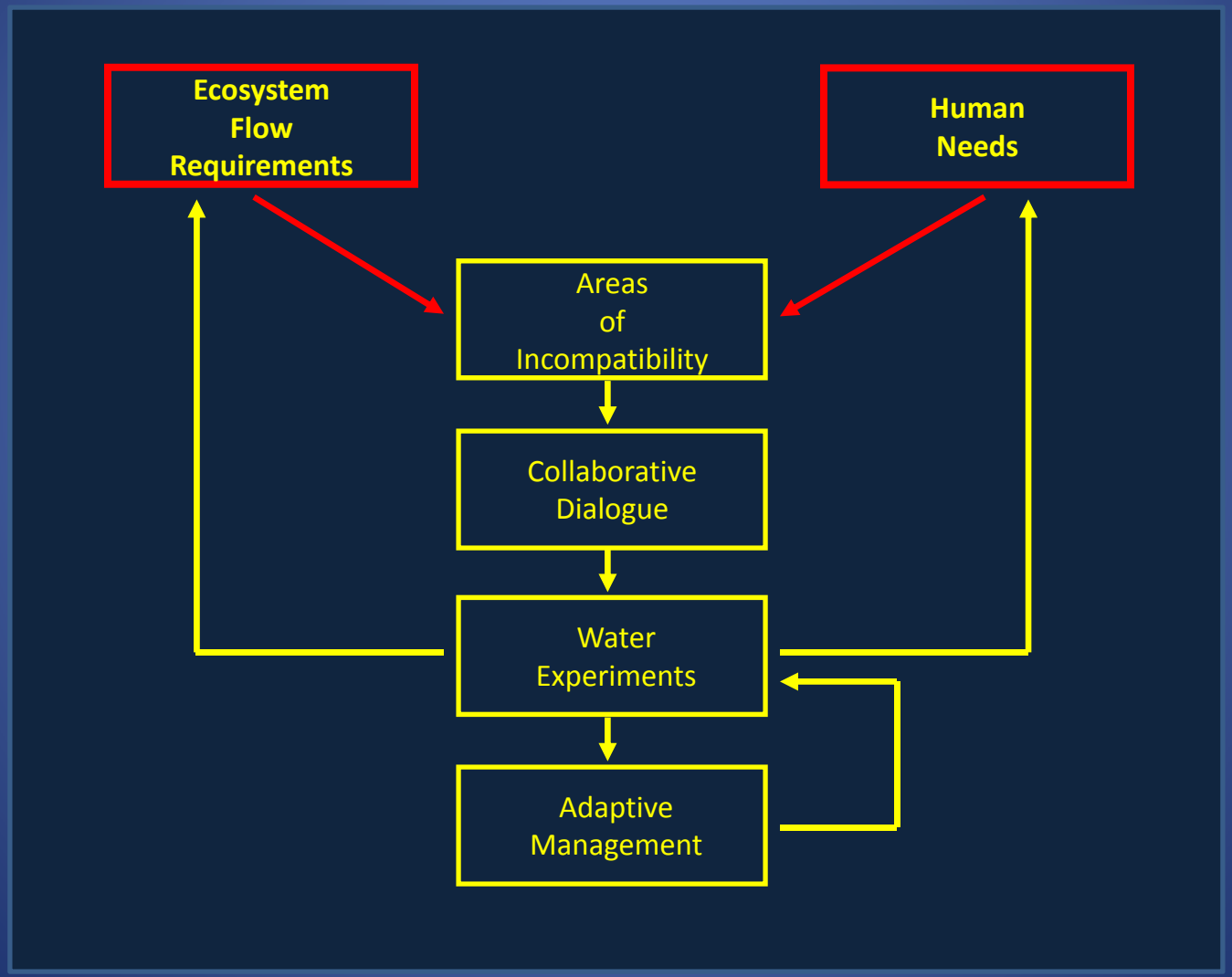
IFIM Process:
Water management alternatives are the basis for a negotiated solution.



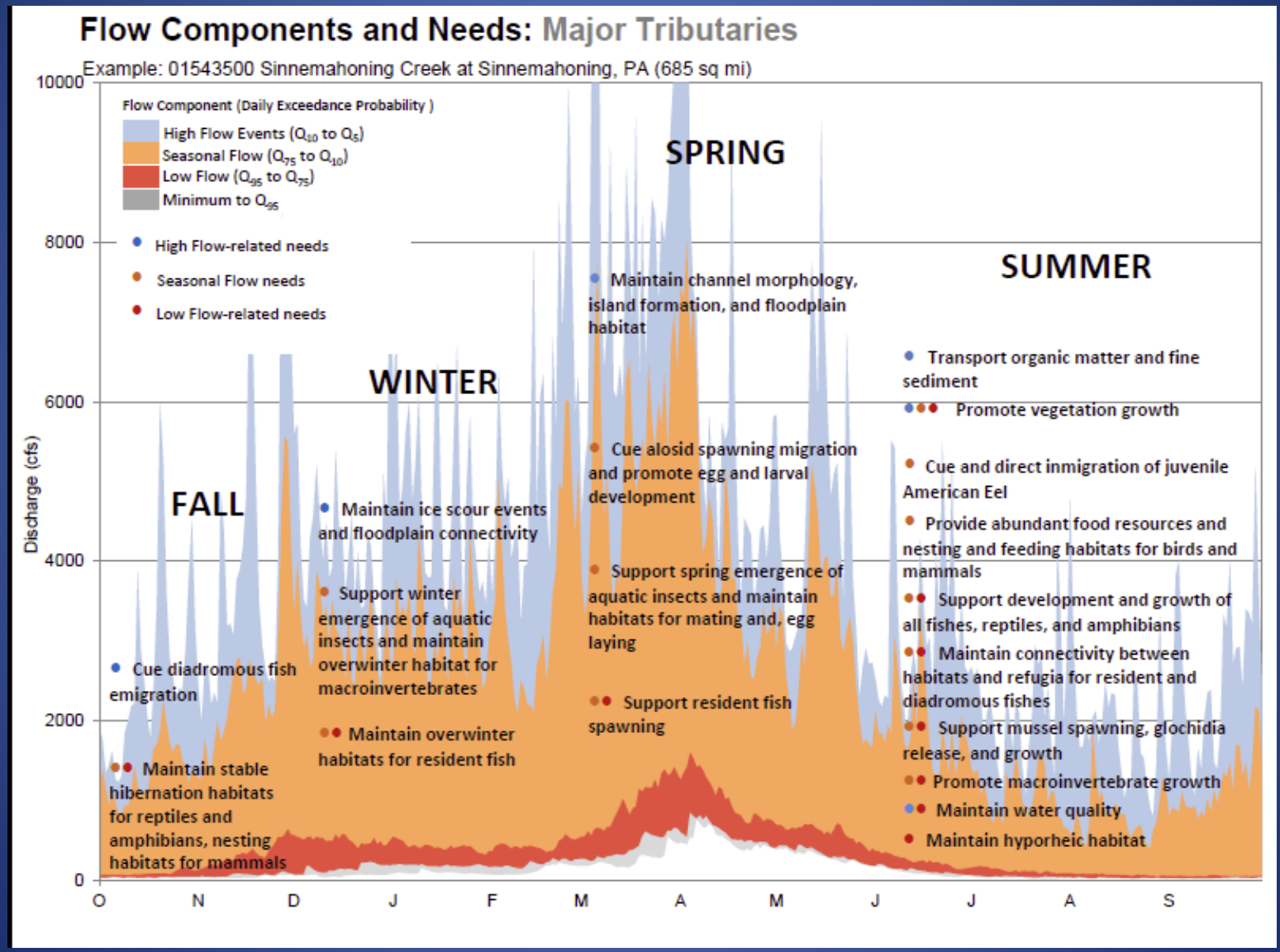
IFIM Essentials

- Well-established methodology developed in the 1980s and 1990s
- Applies (usually) species-specific models at site-specific level
- Based on ***population responses to natural variation*** in velocity, depth, cover, and area
- Negotiated instream flow solutions

Ecologically Sustainable Water Management (ESWM)



Ecological Conceptual Model



Source: Susquehanna River Commission 2011

Savannah River Ecosystem Flow Workshop Participants

Ecosystem Flow Recommendations: Building Block Method

Augusta Shoals on the Savannah River

Floods

No flood flow recommendations provided for the Shoals

High Flow Pulses

20,000-40,000 cfs;
2-3 days, 1/month | 14 days, 1/month
Jan & Feb | Mar & Apr

20,000-40,000 cfs; 2-3 days, 1/month

>16,000 cfs; 1-2 days, 1-2 pulse

- Herring passage over NSBLD
- Morone egg suspension

20,000 cfs;
2-3 days, 1 pulse
- Sturgeon spawning

Low Flows

>5,000 cfs;
- Sturgeon spawning

6,000-10,000 cfs, with 6,000 cfs as baseflow

6,000-10,000 cfs, with 6,000 cfs as baseflow

4,000-6,000 cfs, 4,000 cfs as baseflow

- Shad, striped bass, robust redhouse spawning and habitat

4,000-5,000 cfs;
- Sturgeon spawning

4,000-5,000 cfs;

4,000-5,000 cfs;

- Resident fish habitat
- Juvenile fish out-migration

>2,700 cfs;
- Juvenile Outmigration

>2,700,000 cfs

>2,700 cfs | >2,000 cfs | >2,700 cfs

- protect spider lily from deer grazing

Key

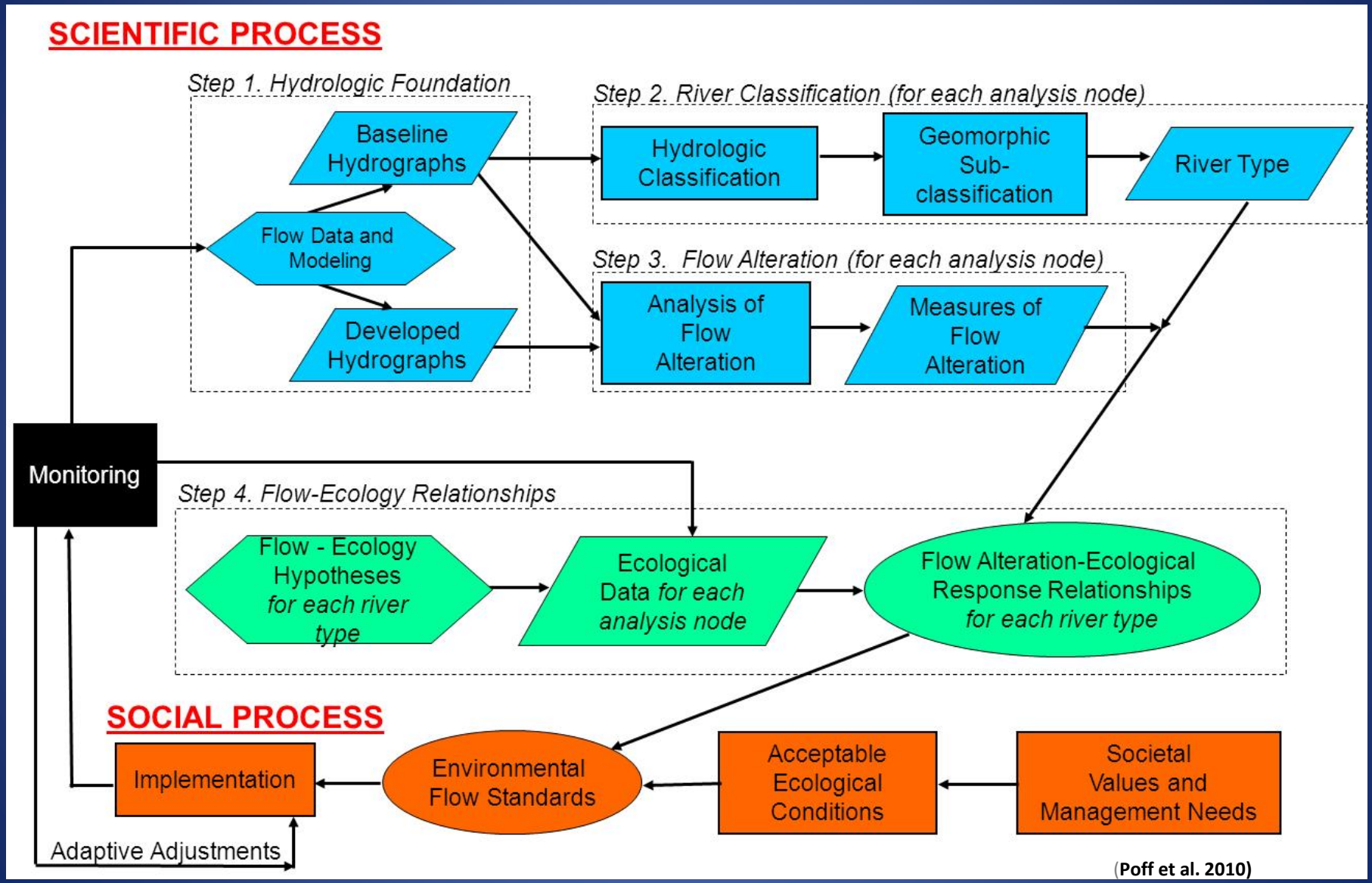
- Wet Year
- Avg Year
- Dry Year

JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC

ESWM Essentials

- Developed in 1990s by The Nature Conservancy
- Applied at watershed level to improve flow regimes and restore ecological function
- Based on existing data and expert knowledge of ecological relationships with natural hydrologic regimes
- Integrates societal values with ecological needs

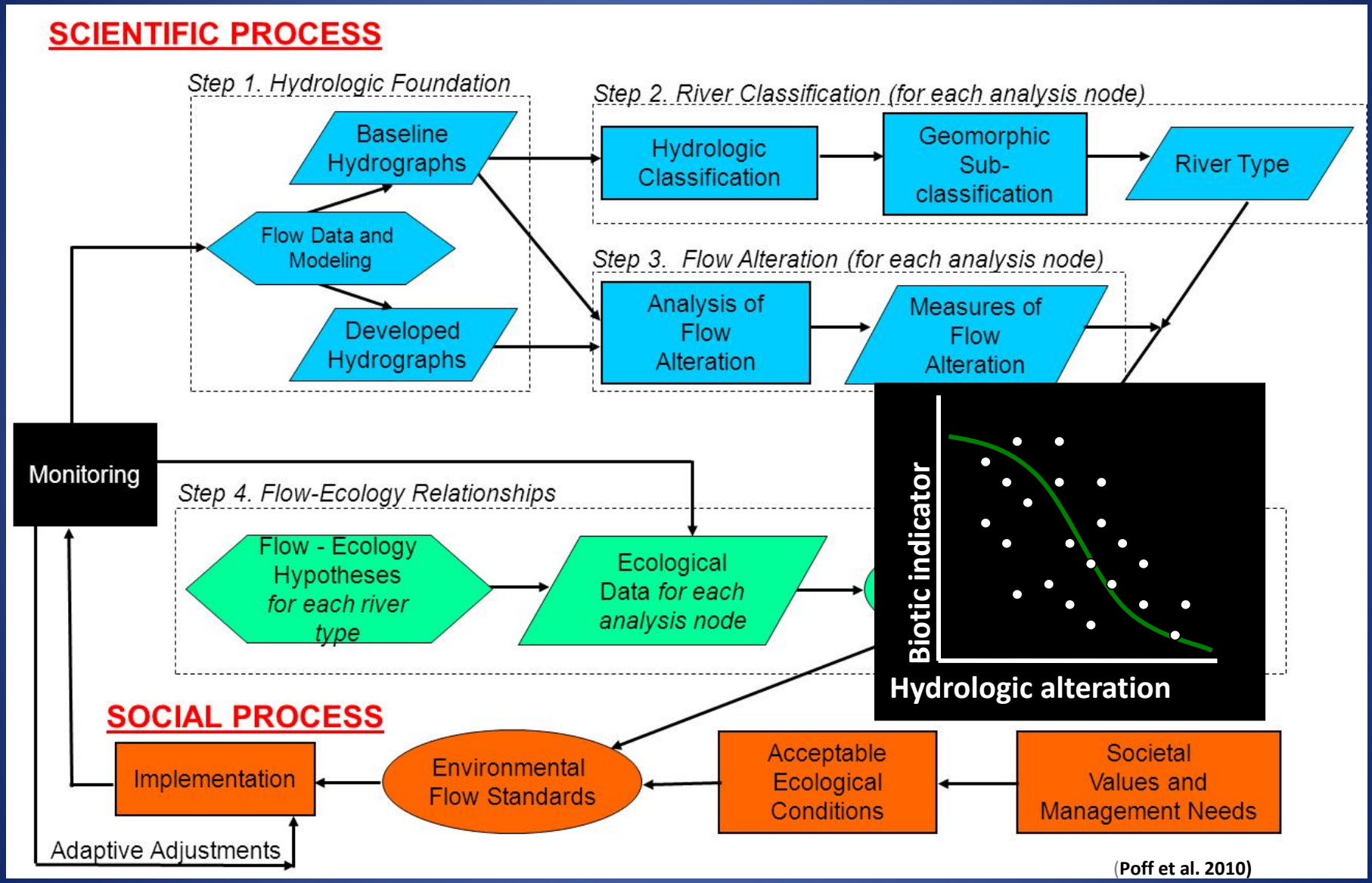
Ecological Limits of Hydrologic Alteration (ELOHA)



(Poff et al. 2010)

http://conserveonline.org/workspaces/eloha

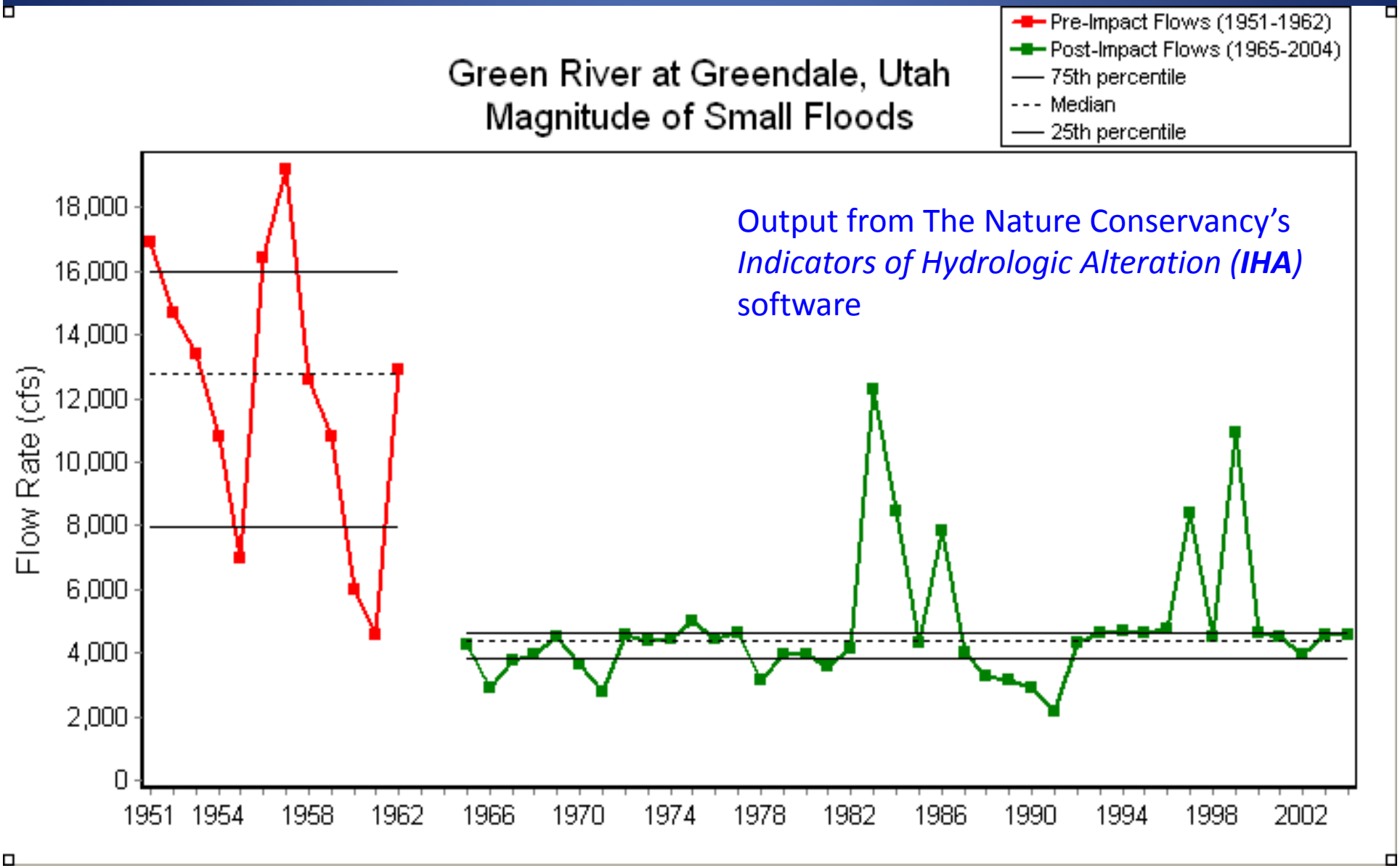
Ecological Limits of Hydrologic Alteration (ELOHA)



(Poff et al. 2010)

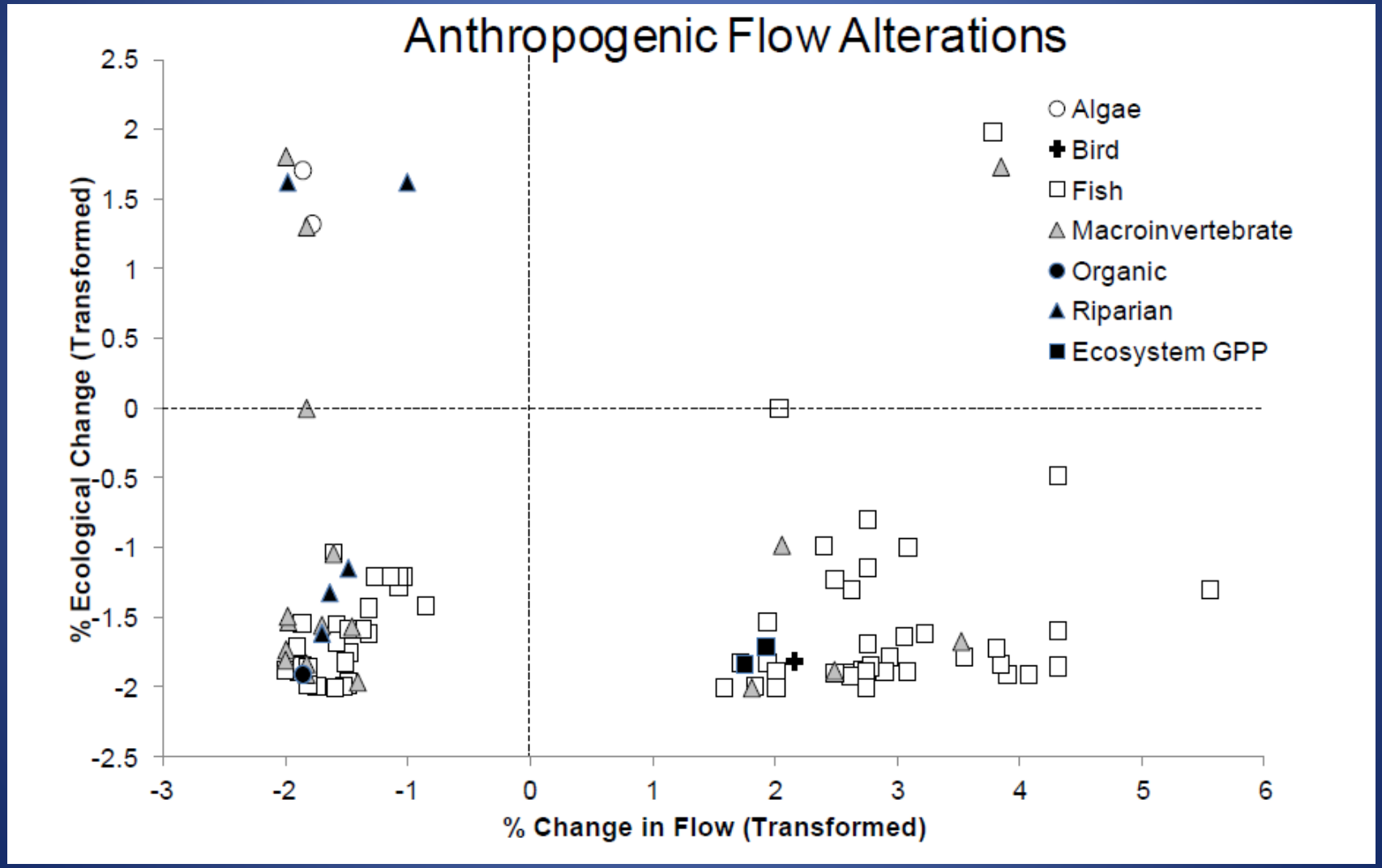
http://conserveonline.org/workspaces/eloha

Calculation of Flow Alteration



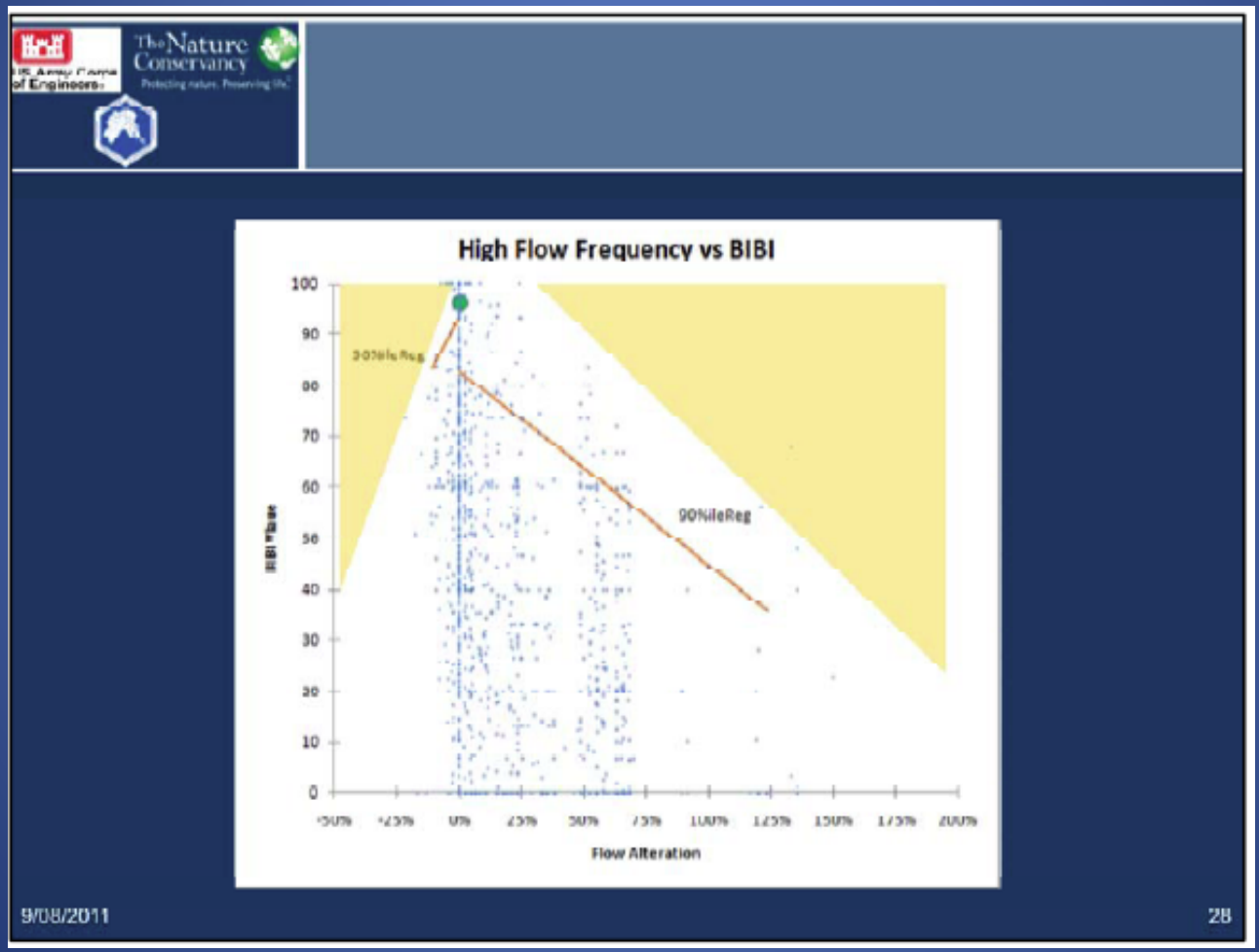
Output from The Nature Conservancy's *Indicators of Hydrologic Alteration (**IHA**)* software

Flow-Ecology Relationships from Literature



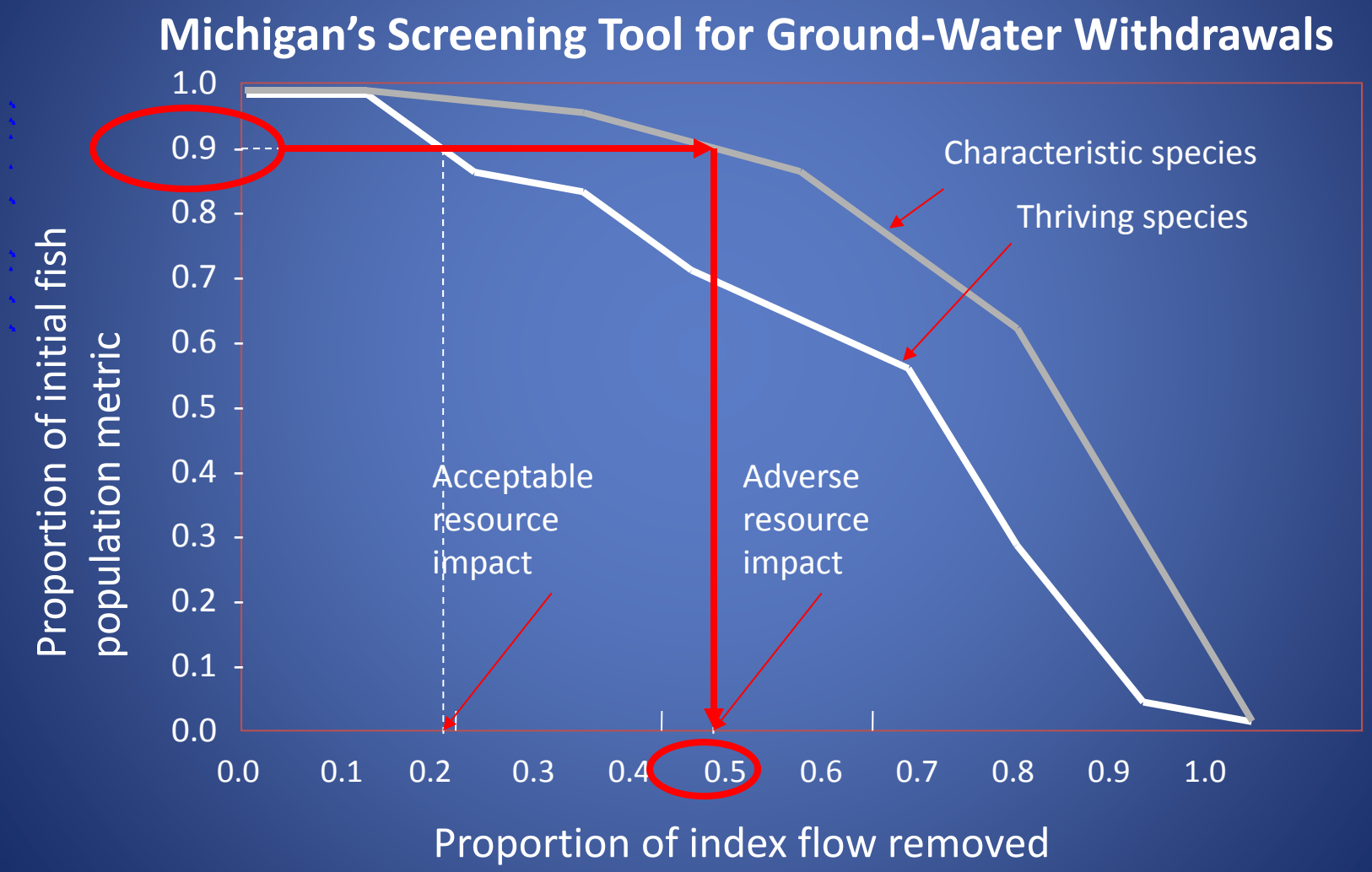
Source: McManamay et al. 2011

Flow-Ecology Relationships from Existing Data



Source: Potomac River Commission Watershed Assessment 2011

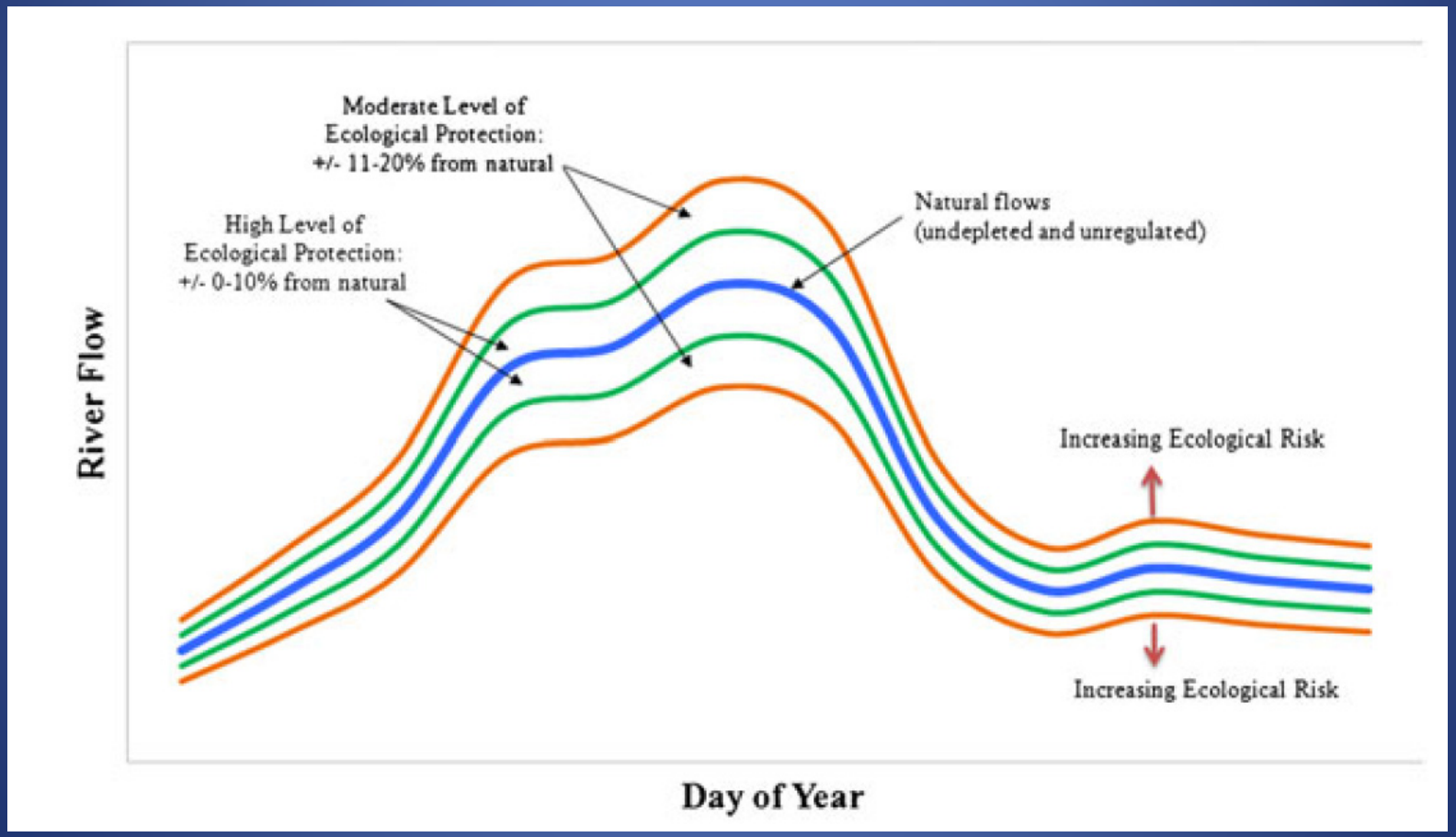
Ecological Response to Flow Alteration



ELOHA Essentials

- Newly established method (Poff et al. 2010)
- Uses existing data to develop flow-ecology relationships for classes of rivers
- Based on ***ecological responses to flow alteration*** of natural hydrologic regime
- Integrates societal values with ecological values

Presumptive Flow Standard for Environmental Flow Protection



(Richter et al. 2011)

Presentation Overview

1. Review of science-based methods to determine IF needs

2. Methods used by selected programs to determine IF needs

3. IF resources for North Carolina

Approaches for Determining IF Standards

- Minimum flow threshold
  - 7Q10 (e.g., AL, LA, MS)
  - Modified Tennant (e.g., AR, GA, SC)
- Statistically based standards

  (e.g., FL St Johns WMD, Potomac River Commission)
- Percent of flow approaches

  (e.g., FL SW Florida and Suwannee River WMDs, TN Presumptive WQ Standard)

  Under development in SE: TX, NC, VA

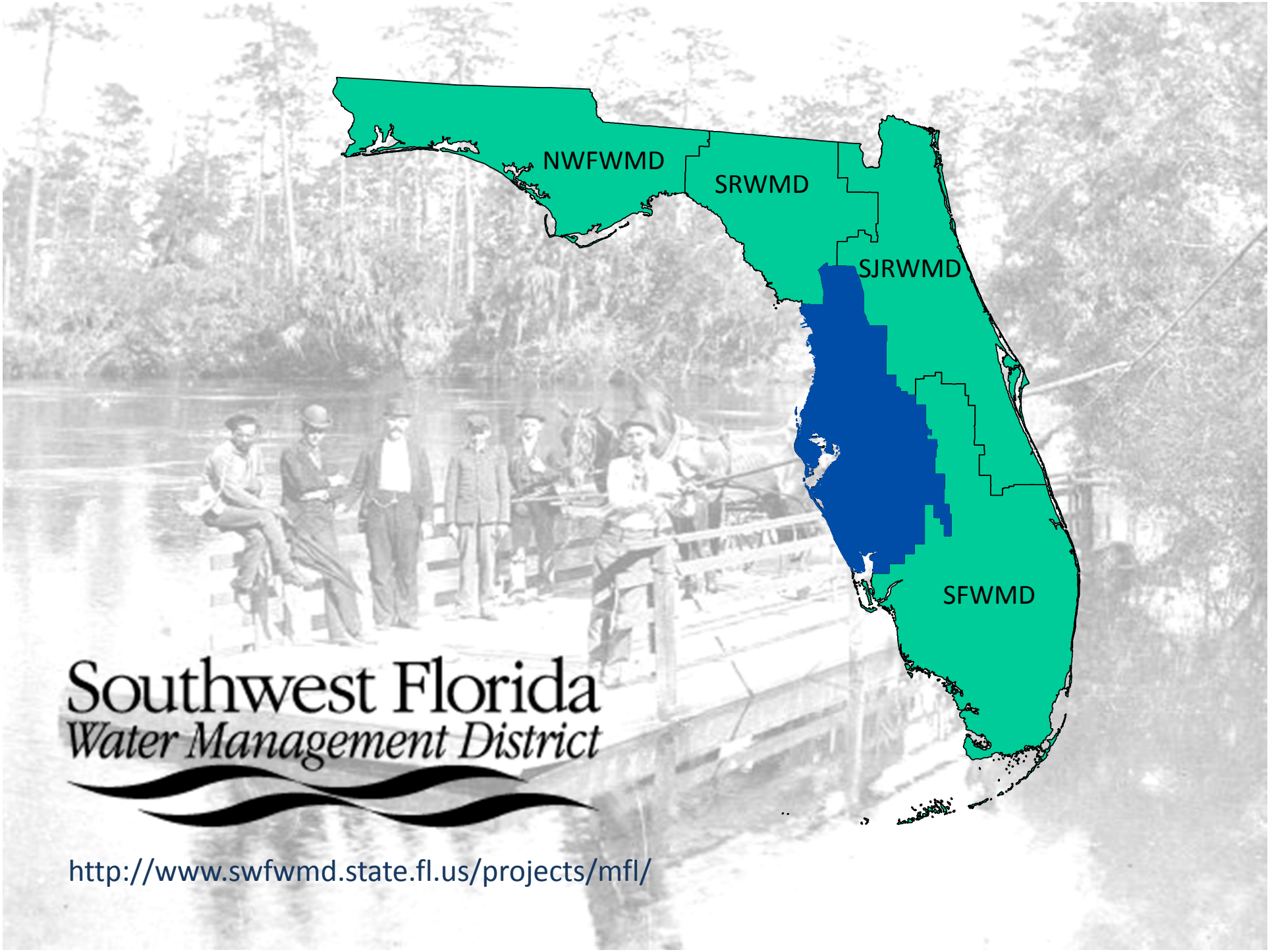
IF Methods Used by Selected Programs

- Florida
- Michigan
- Potomac River Commission

- Texas, if time allows

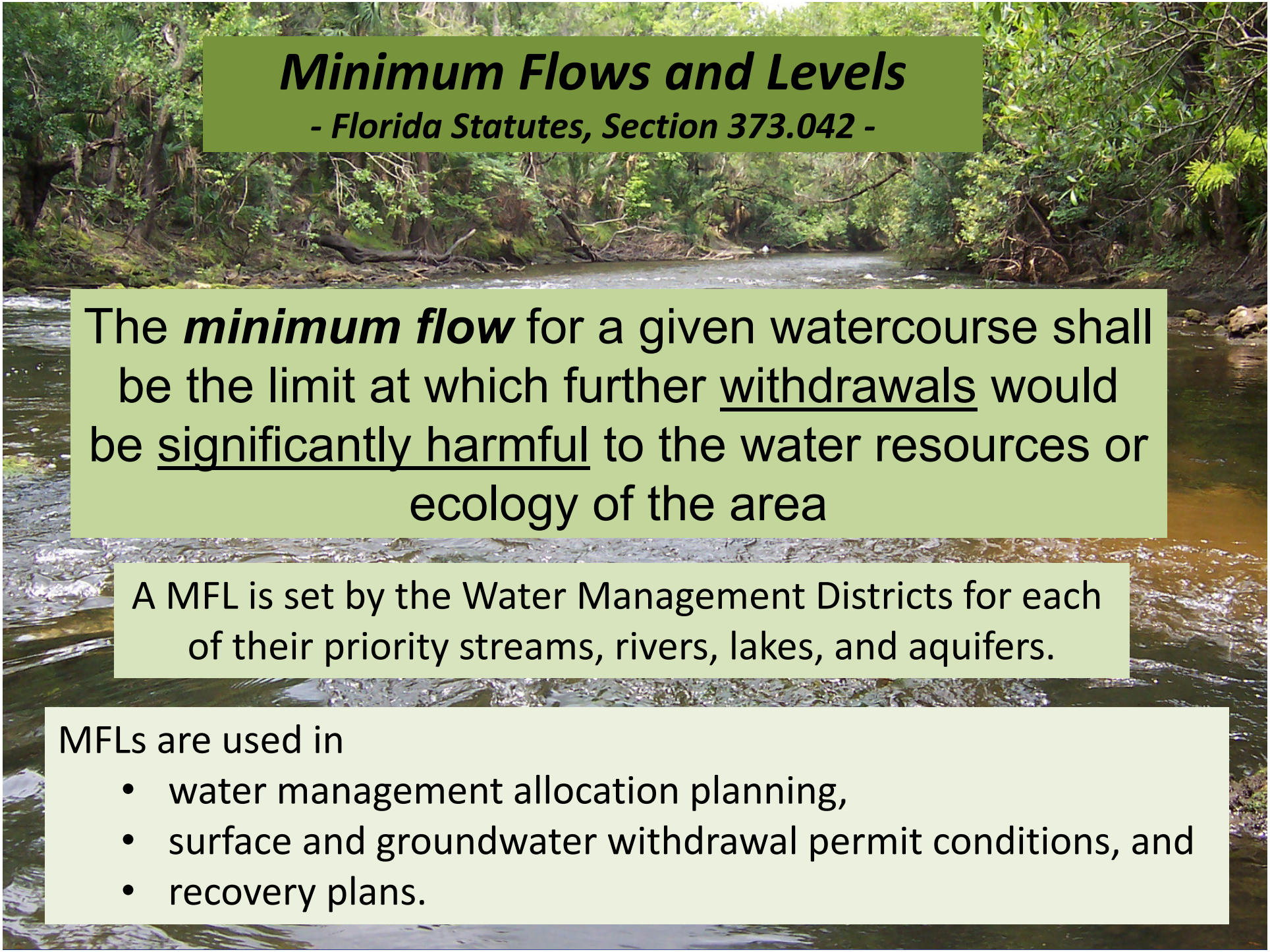
Florida – Instream Flow Protection Policy and Management Programs

Slides courtesy of
Marty Kelly, Director
SWFWMD MFL Program



Southwest Florida Water Management District

http://www.swfwmd.state.fl.us/projects/mfl/



Minimum Flows and Levels

- Florida Statutes, Section 373.042 -

The ***minimum flow*** for a given watercourse shall be the limit at which further withdrawals would be significantly harmful to the water resources or ecology of the area

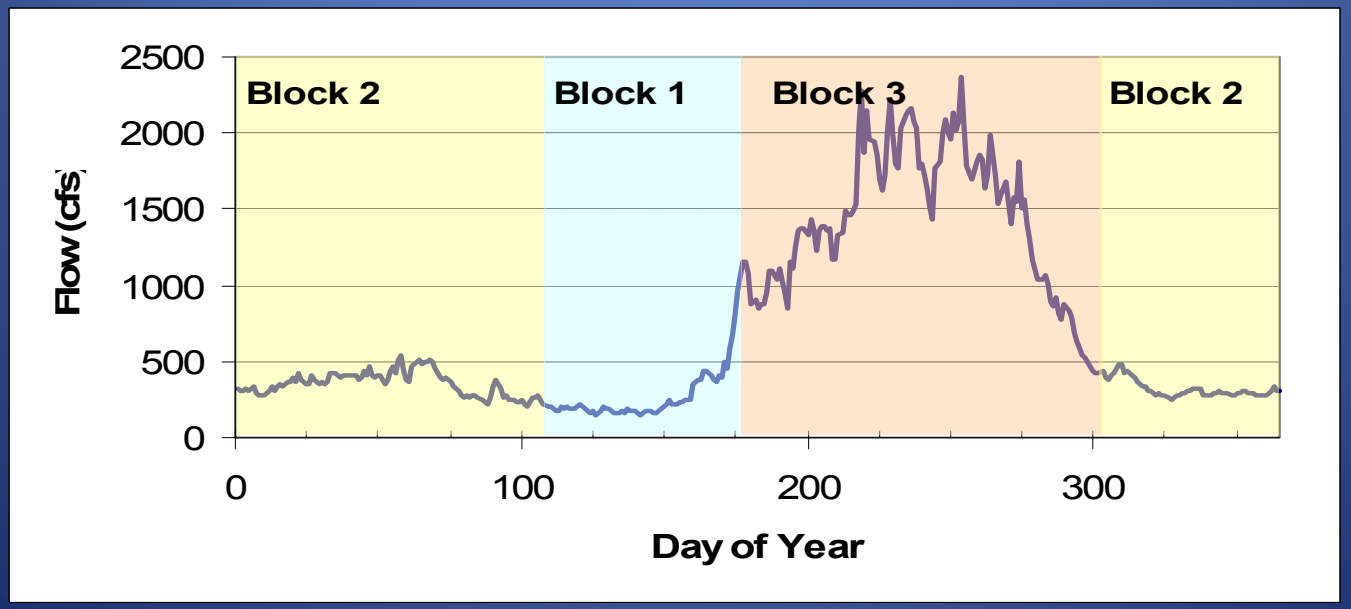
A MFL is set by the Water Management Districts for each of their priority streams, rivers, lakes, and aquifers.

MFLs are used in

- water management allocation planning,
- surface and groundwater withdrawal permit conditions, and
- recovery plans.

SWFWMD Instream Flow Program

- *Building Block Method*
- *PHABSim-style methodology*
- *Percent of Flow Reduction Approach*
- *'Significant Harm' threshold = 15% reduction in available habitat for most conservative target*

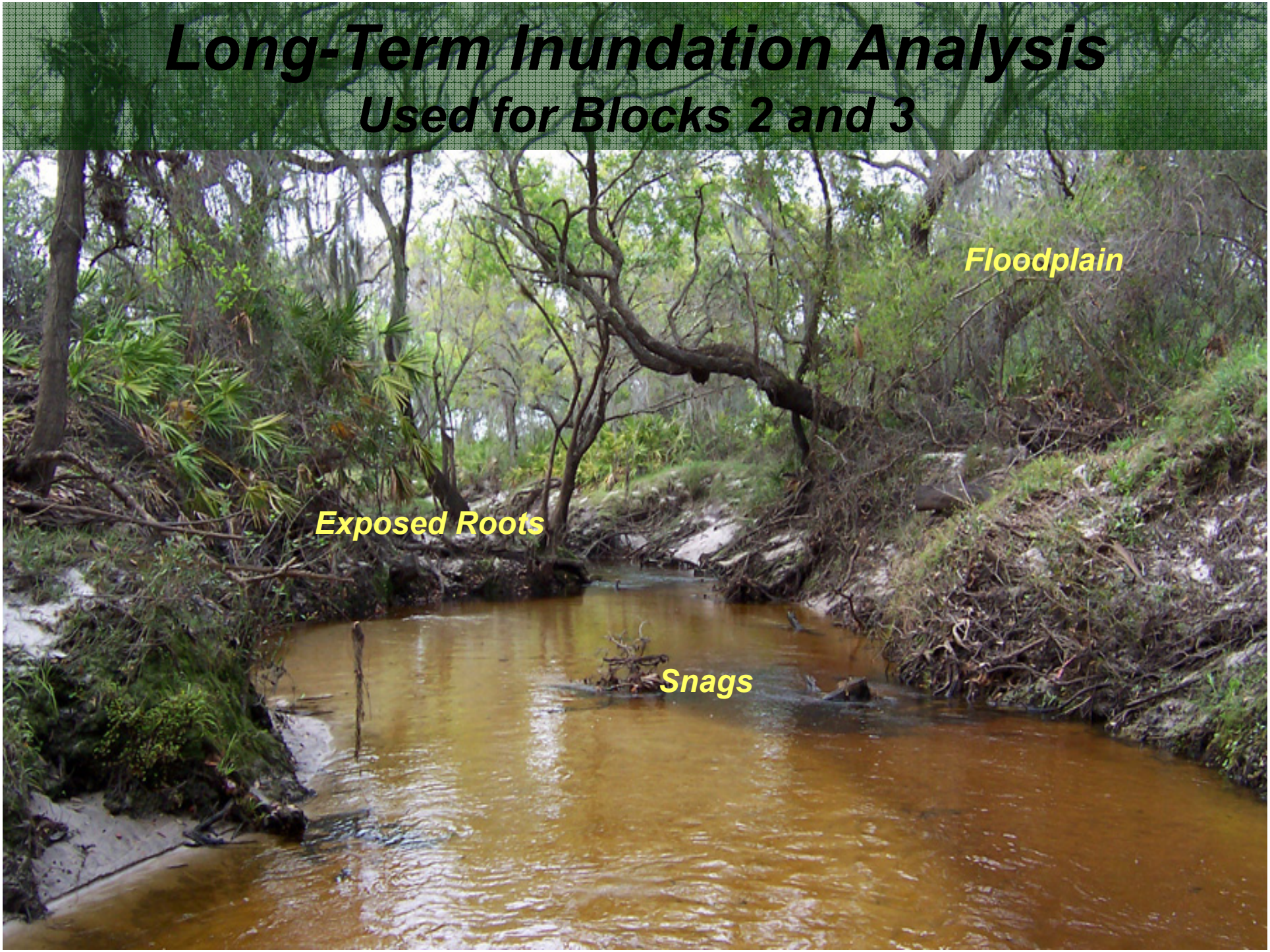


Physical Habitat Simulation System

Used for Blocks 1 and 2

Long-Term Inundation Analysis

Used for Blocks 2 and 3

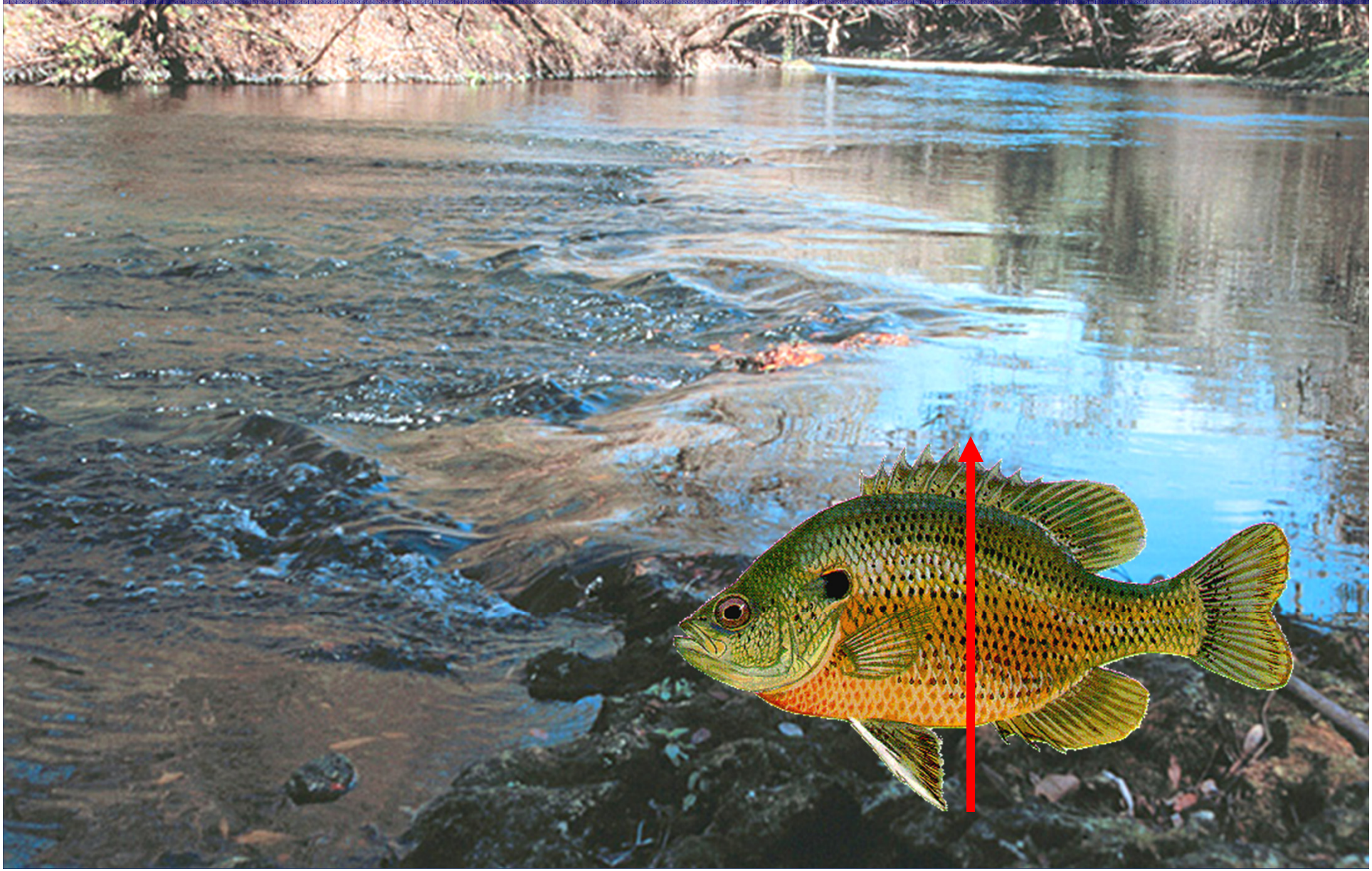


Low Flow Threshold - Wetted Perimeter

Used for All Blocks

Low Flow Threshold - Fish Passage

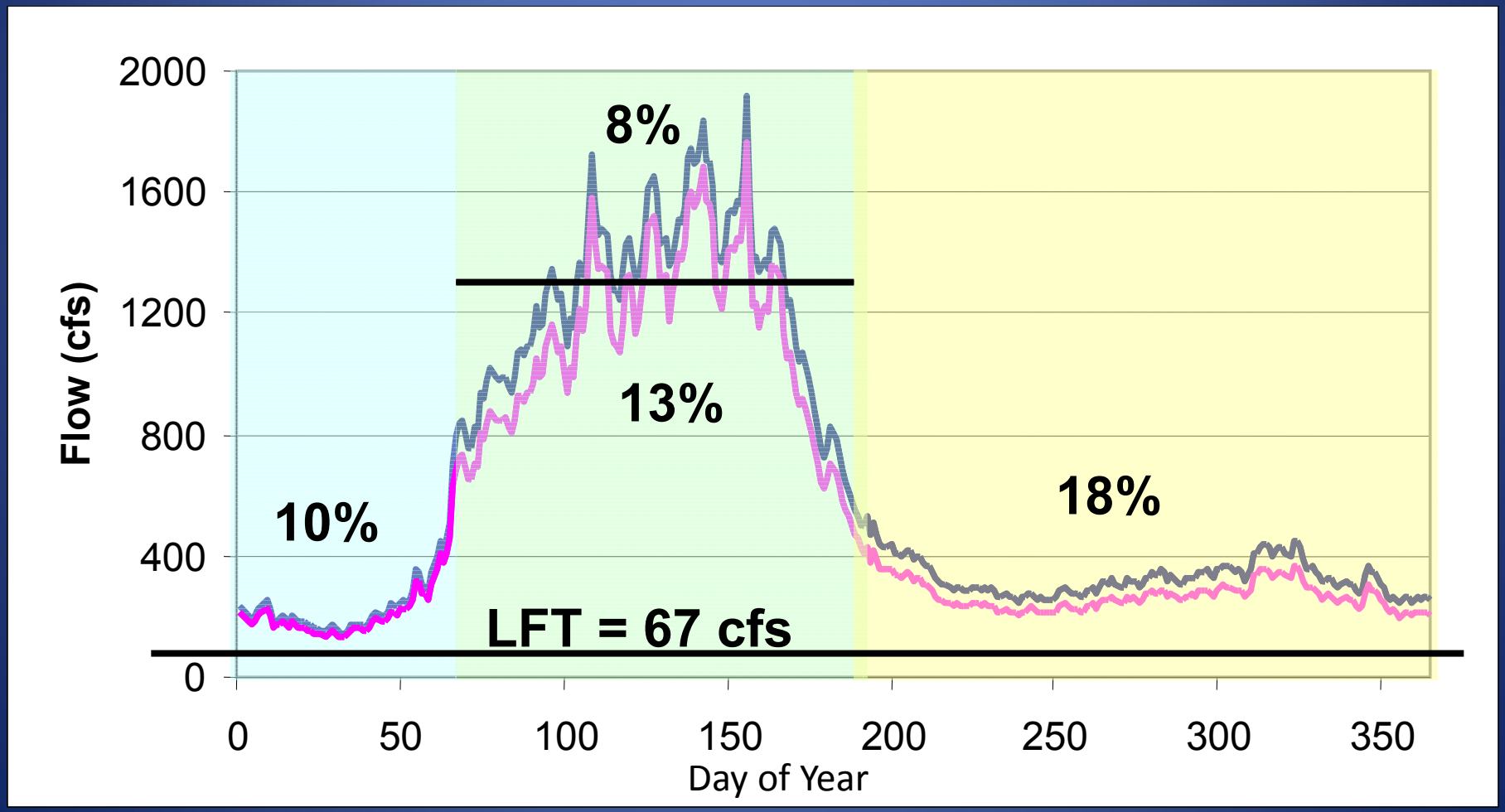
Used for All Blocks



Flow Prescription

Percent of Flow and Seasonality

of allowable cumulative withdrawals



- Best Available Information
- Peer Review Process

SWFWMD MFLs
Range of Percent Allowable Withdrawals
(Significant Harm Threshold < 15% habitat loss)

Block	Rivers									
	Upper Alafia		Braden		Myakka		Peace		Hillsborough	
	Hi	Lo	Hi	Lo	Hi	Lo	Hi	Lo	Hi	Lo
1 (April 20-June 24)	8	10	10	10	15	15	8	10	8	10
2 (Oct 28 – Apr 19)	8	15	10	11	5	5	8	18	8	11
3 (Jun 25 – Oct 27)	8	13	10	19	7	16	8	13	8	13

Source: http://www.swfwmd.state.fl.us/projects/mfl/

SWFWMD MFL Essentials

- MFL set for each water body (i.e., no classification needed)
- Flow requirements based on most sensitive ecological response to flow alteration (i.e., fish, coarse woody debris, floodplains, organic soils, etc.)
- Estimate habitat loss based on cumulative depletion of the natural daily flow regime
- MFLs for medium size, coastal rivers show a small range of allowable depletions.

IF Methods Used by Programs

- Florida – using similar methods as NC; finding similar standards within river class
- Michigan
- Potomac River Commission

Environmental Flow Standards in Michigan

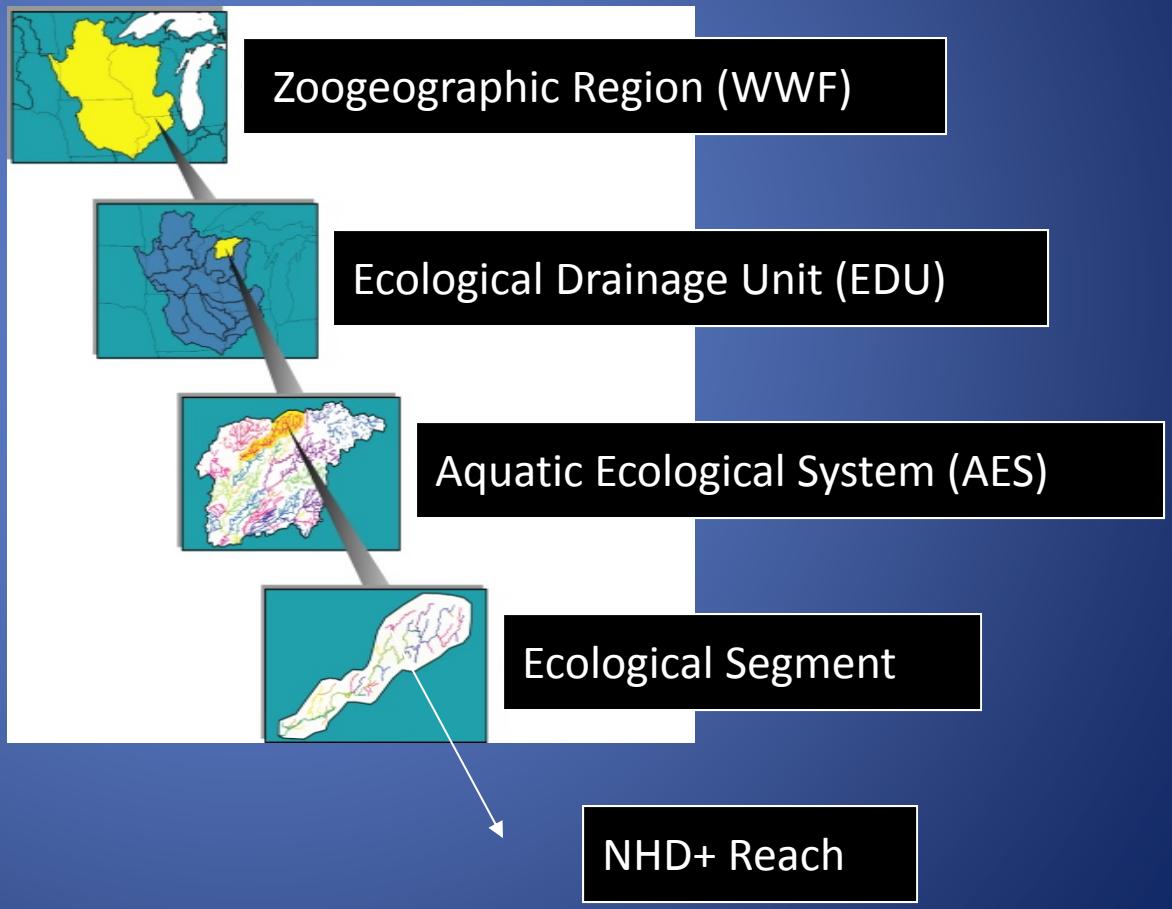
Slides courtesy of Paul Seelbach, USGS
and Richard Bowman, TNC

Michigan River Classification Approach

Spatial framework | Reach attribution | MI fisheries classification | Coordination is good

Well-established conceptual framework tested and implemented over past 15 years by TNC, USGS Regional Aquatic GAP, and a few states.

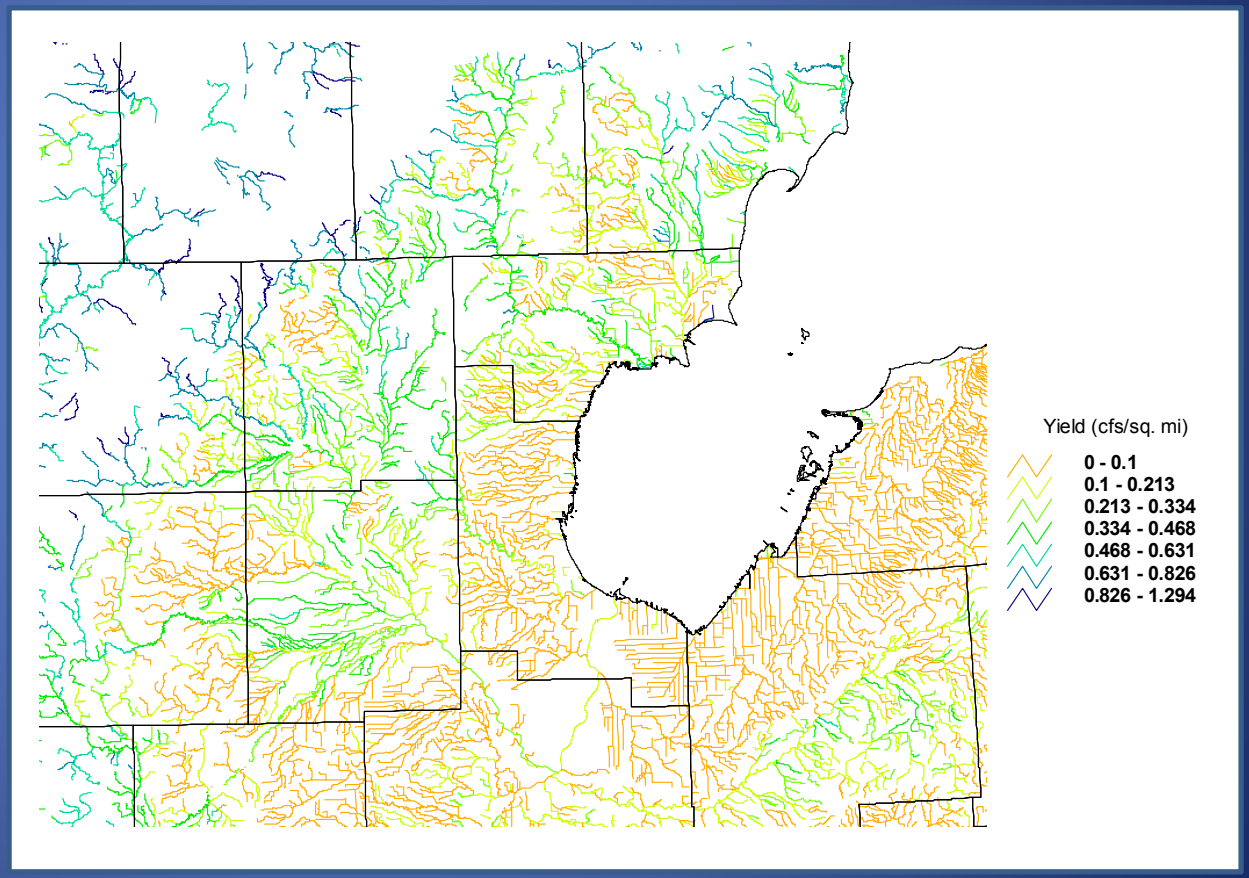
Provides for multi-state coverage.



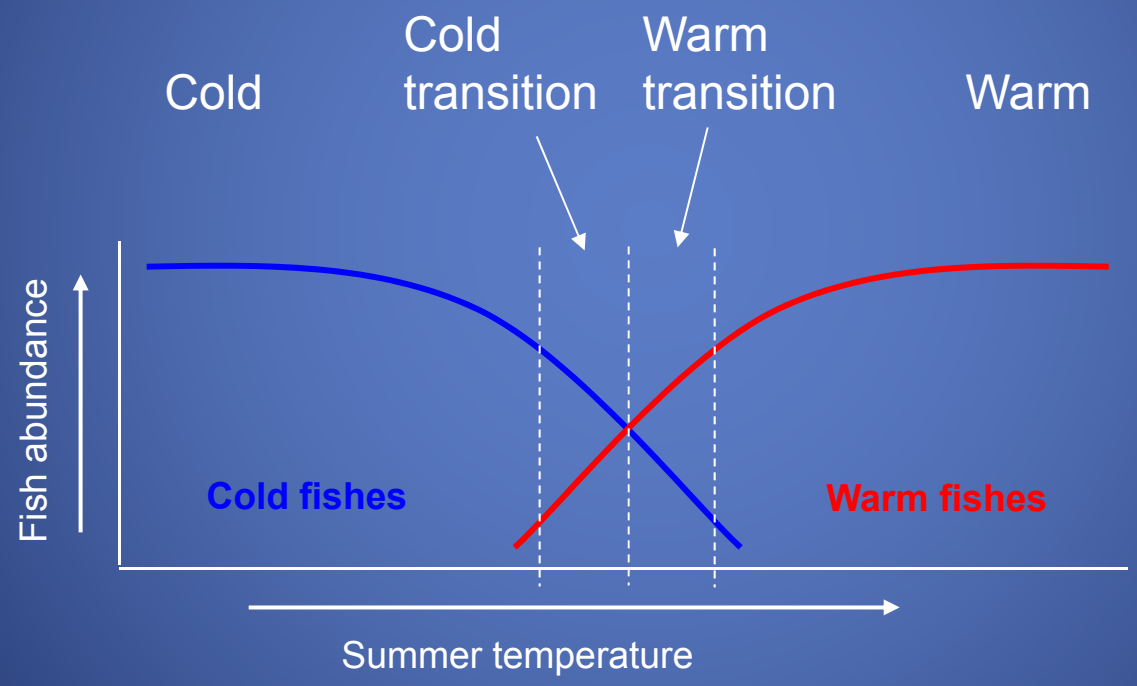
Spatial framework | **Reach attribution** | MI fisheries classification | Coordination is good

Key landscape and riverine attributes for every reach came from existing map-level data and state-level models.

Examples: flow, temperature, slope, and elevation.

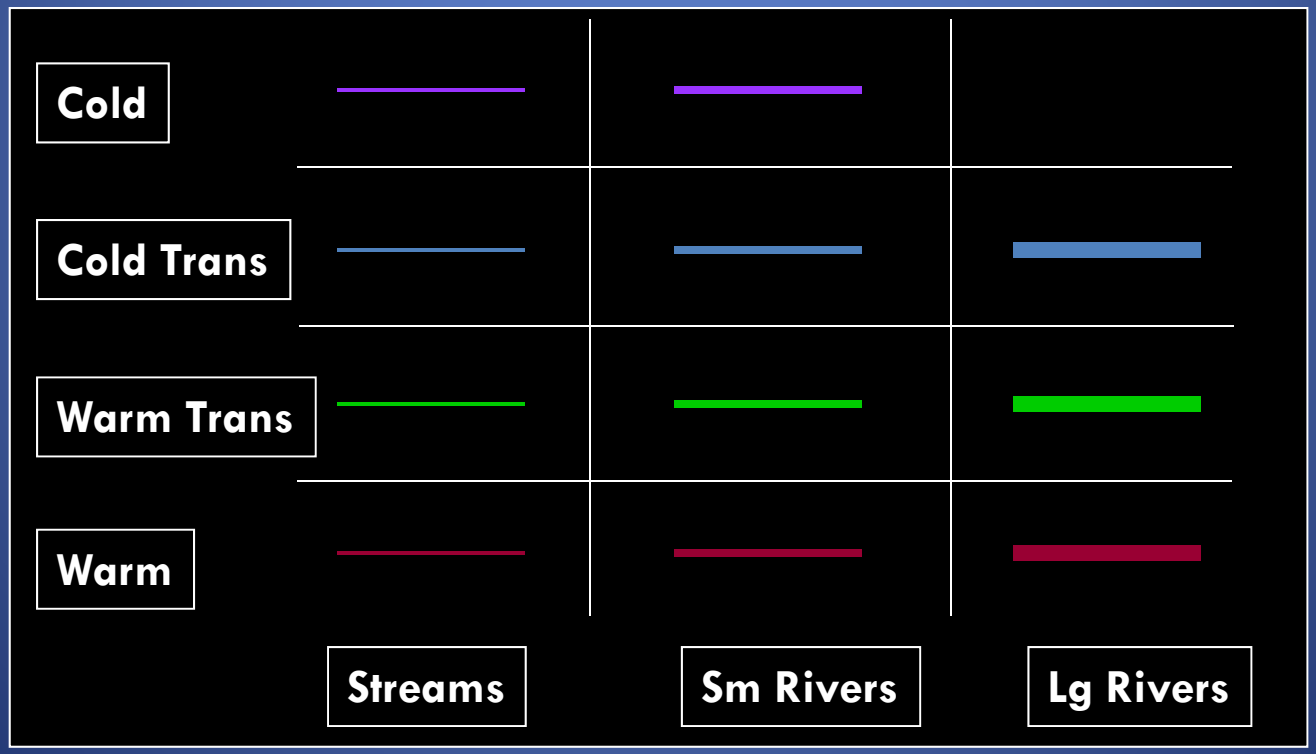


Spatial framework | Reach attribution | **MI fisheries classification** | Coordination is good



Spatial framework | Reach attribution | **MI fisheries classification** | Coordination is good

11 river classes based on flow and temperature

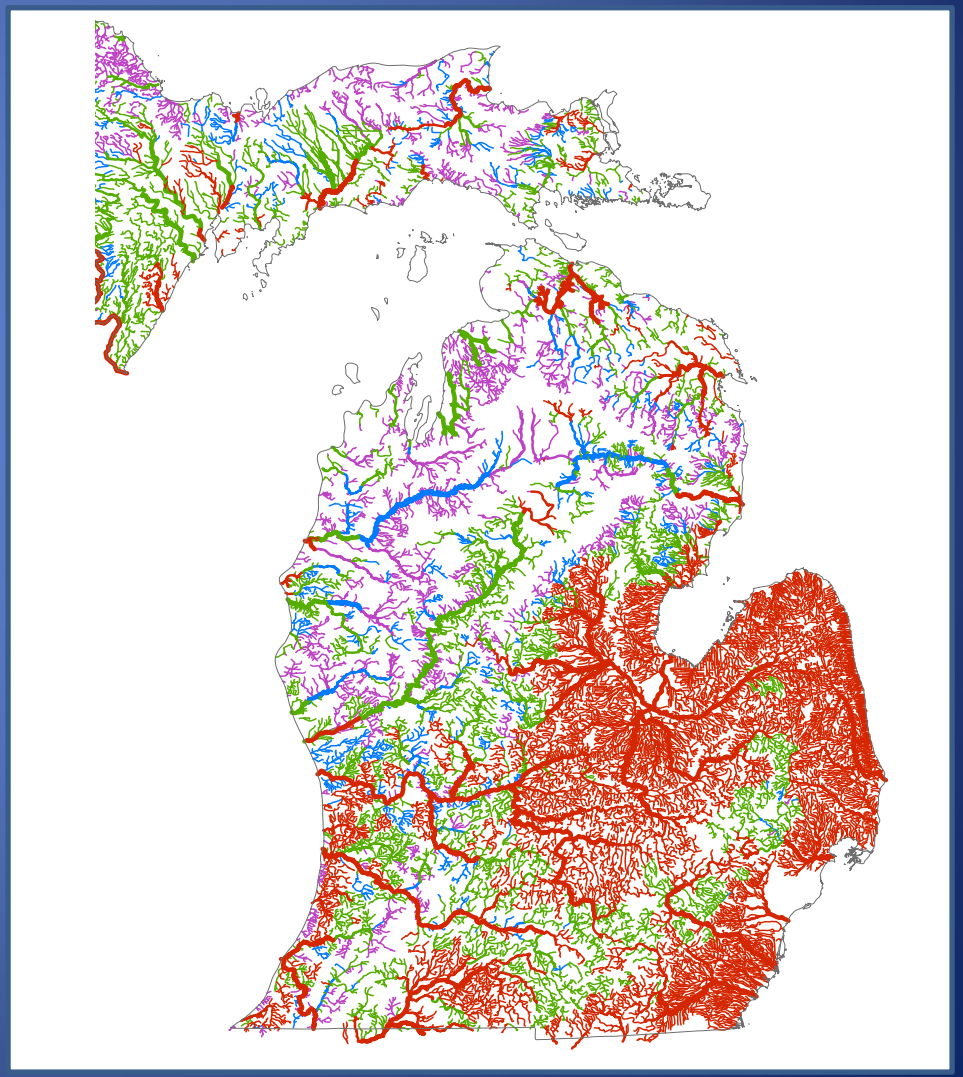


Spatial framework | Reach attribution | **MI fisheries classification** | Coordination is good

Simple. Familiar. Fish values.

Incredibly powerful in policy development. “Map that changed the world.” Map is central to state water law. Is in minds and language of policy leaders and users.

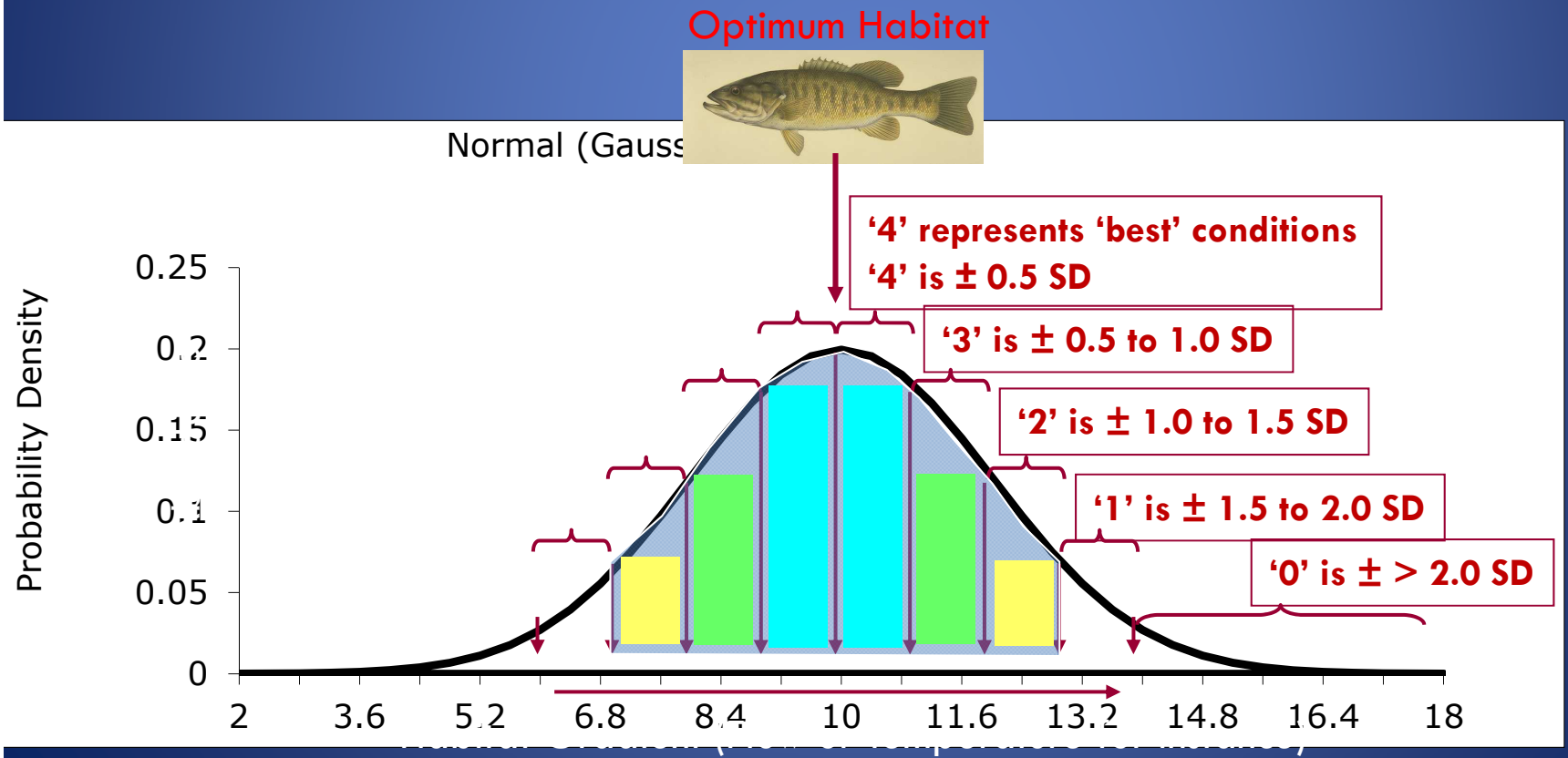
Is useful to many other river management programs. Can drill into database for more details.



Reference flows | River types | Degree flow alteration | **Ecological response curves** | Ecological targets | Enviro. flow targets | Implement program

Statewide habitat suitability info: flow and temperature

Rank scores per normal distribution; 60+ species



Reference flows | River types | Degree flow alteration | **Ecological response curves** | Ecological targets | Enviro. flow targets | Implement program

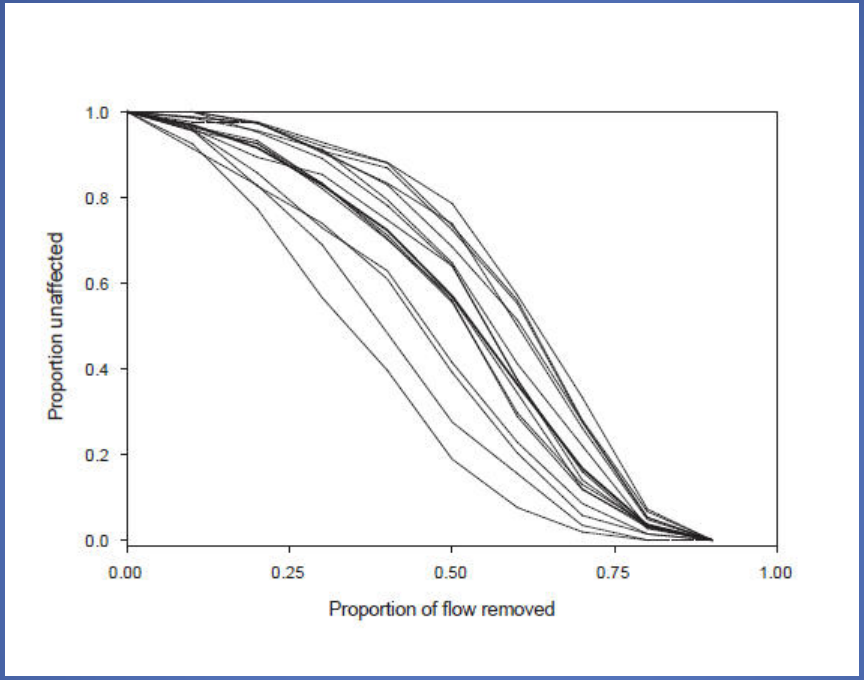
For representative sites per river type:

Considered initial "characteristic" species

Ran withdrawal simulations and followed scores

	Percent flow reduction						
	0	10	20	30	40	50	60
common shiner	4	4	4	3	3	3	2
white sucker	4	3	3	3	2	2	2
longnose dace	3	3	2	2	2	0	0
rainbow darter	2	2	1	0	0	0	0

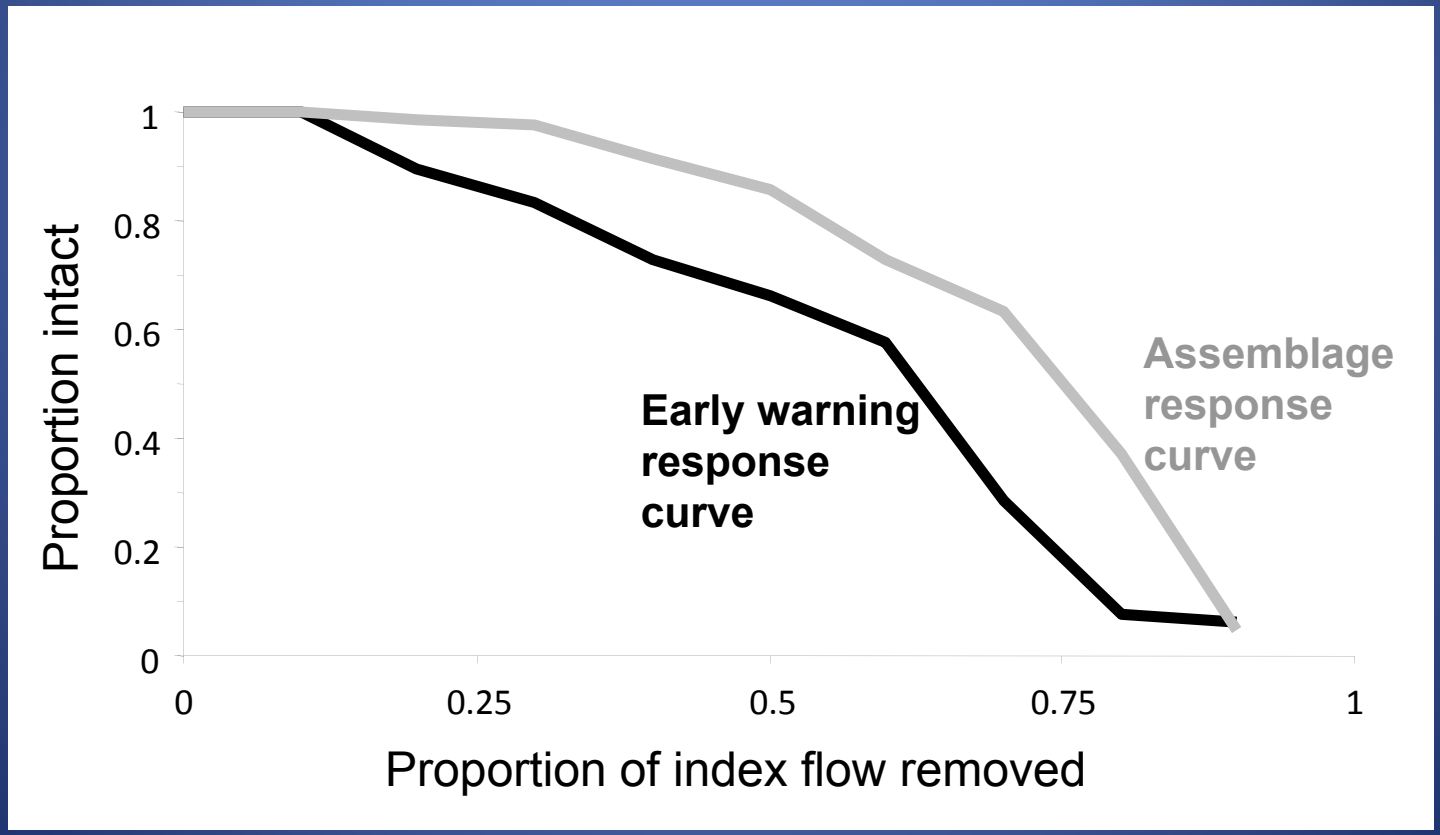
Reference flows | River types | Degree flow alteration | **Ecological response curves** | Ecological targets | Enviro. flow targets | Implement program

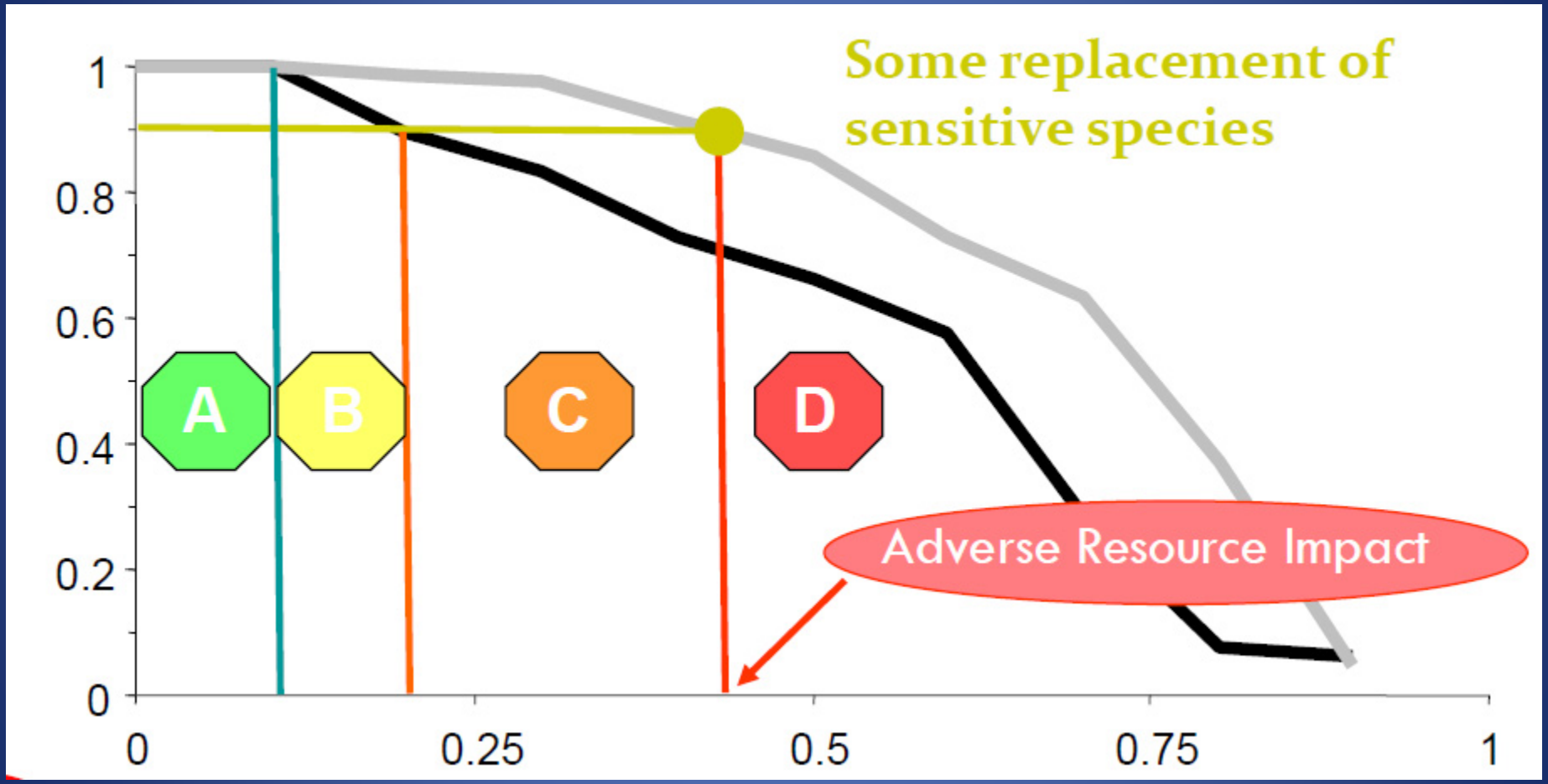


Variation in fish assemblage response curves for each of 15 representative sites within one river type. The mean response (dark line) was used in the water management program, and policy safeguards were used in recognition of the degree of variation.

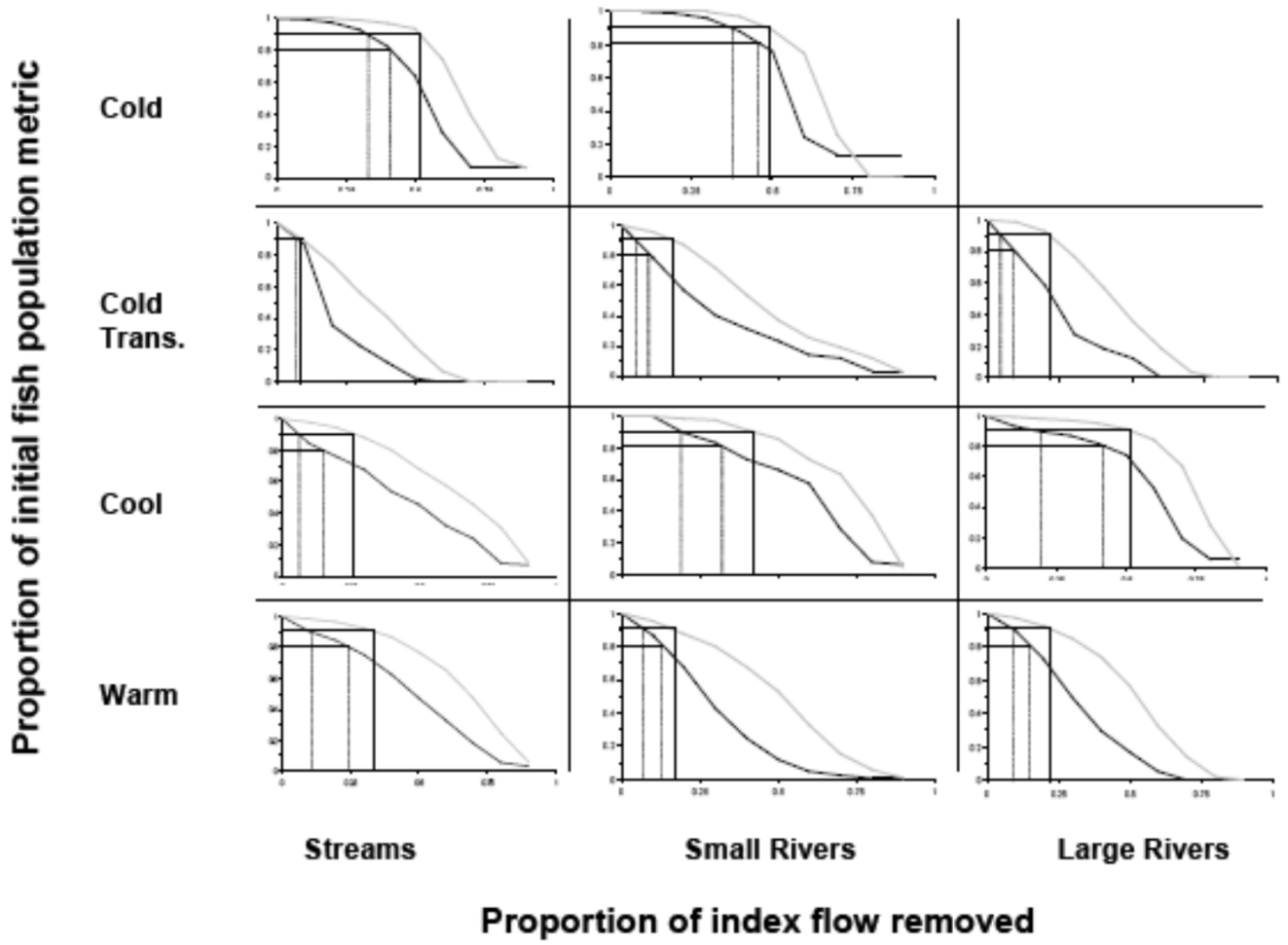
Reference flows | River types | Degree flow alteration | **Ecological response curves** | ological gets | Enviro. flow targets | Implement program

Summaries of simulations create early warning and total impact curves (for assemblage)




Some replacement of sensitive species
1
0.8
0.6
0.4
0.2
0
0
0.25
0.5
0.75
1
A
B
C
D
Adverse Resource Impact

Curves and target zones per each ecological river type.
Geographies of biological response and social values.



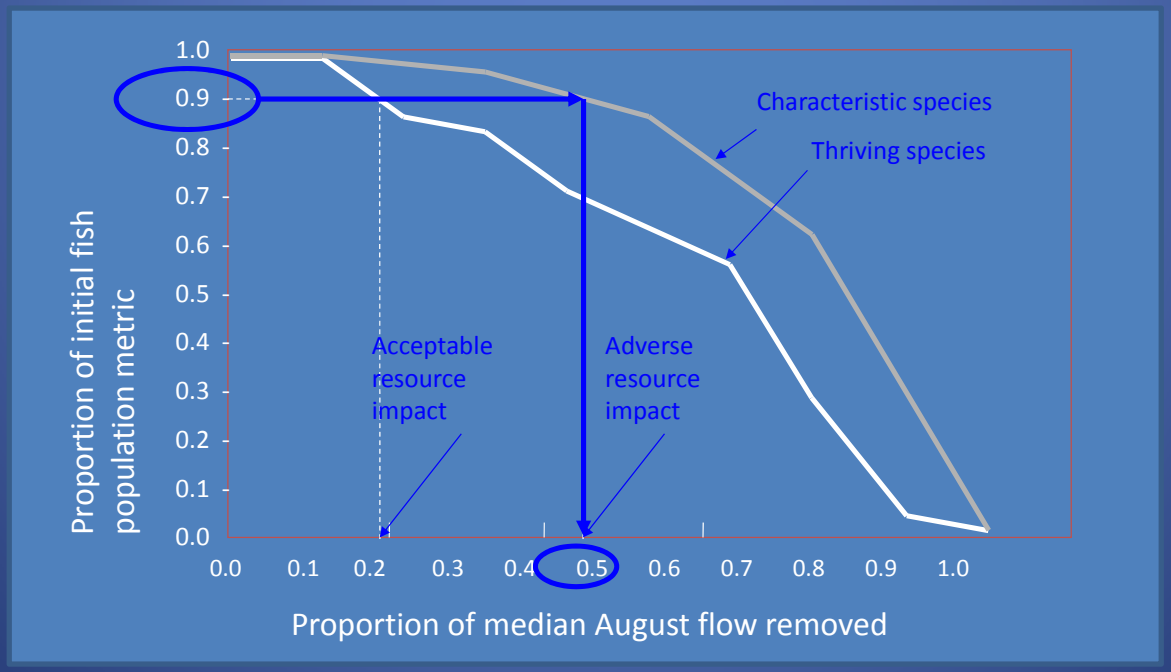
Michigan's Screening Tool for Ground-Water Withdrawals

	A/B	B/C	ARI	A/B	B/C	ARI	A/B	B/C	ARI
COLD	14%	14%	20%	10.5%	10.5%	21%			
TRANS		4%	4%		2%	2%		3%	3%
COOL	6%	15%	25%	15%	19%	25%	14%	19%	25%
WARM	10%	18%	24%	8%	13%	17%	10%	16%	22%
	Stream			Small River			Large River		

Allowable cumulative withdrawal
(% median August)

Michigan Instream Flow Program

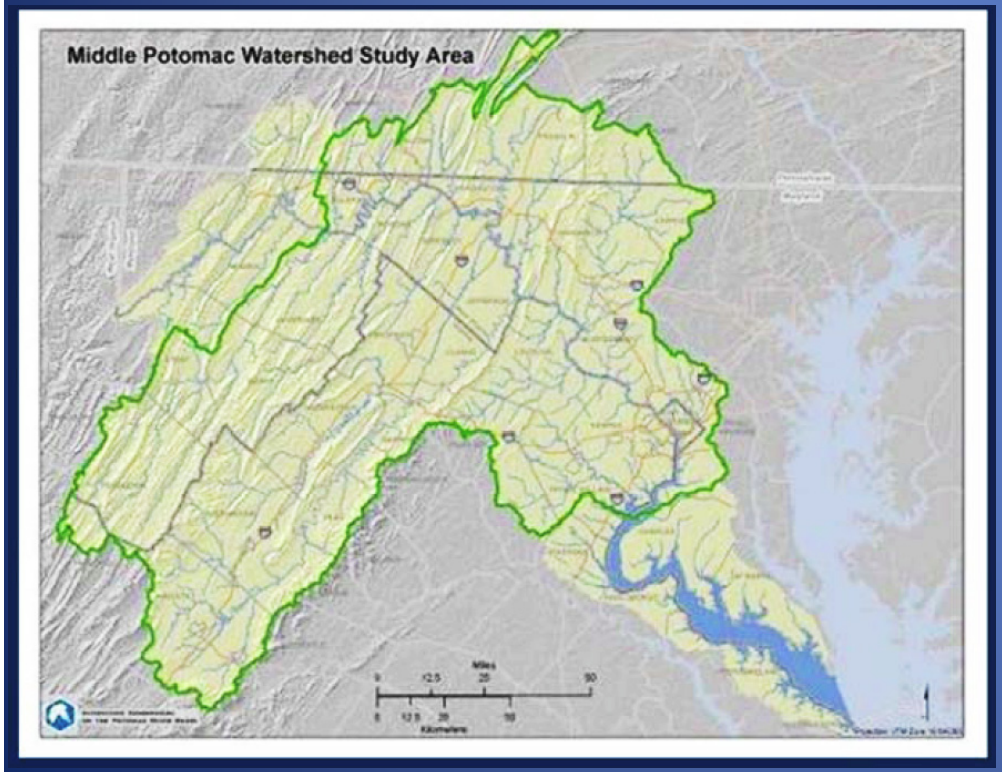
- River classification informed by fish assemblages
- *PHABSim-style methodology*
- *Percent of Flow Reduction Criteria*



IF Methods and Approaches Used by Advanced State Programs

- Florida – similar standards within river class
- Michigan – river classification informed by fish assemblages; similar standards within river class
- Potomac River Commission

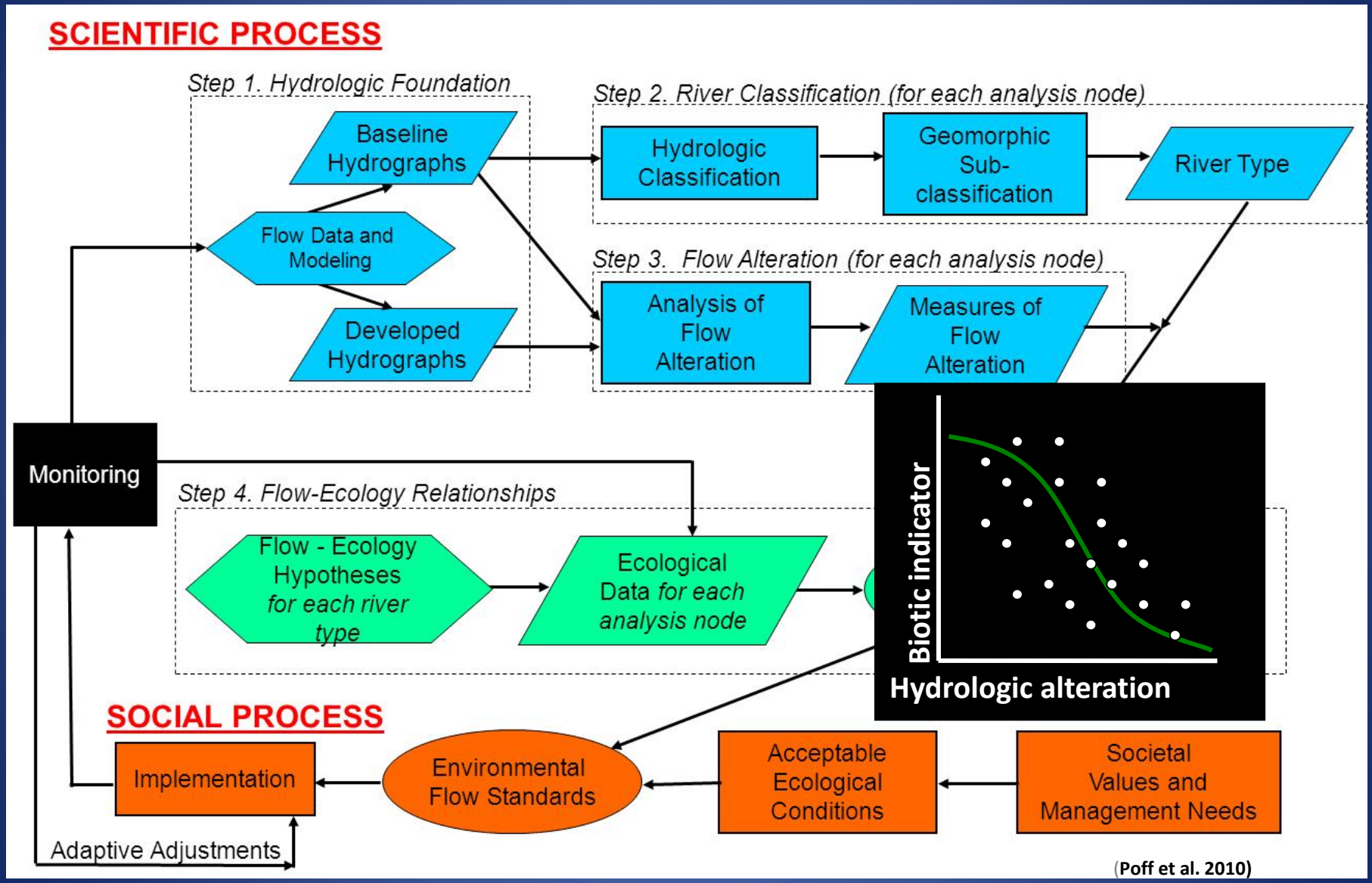
Middle Potomac Watershed Assessment: Environmental Flows



- Follows ELOHA framework
- Multistate watershed
- www.potomacriver.org

Slides courtesy of Carlton Haywood, PRC

Ecological Limits of Hydrologic Alteration (ELOHA)



(Poff et al. 2010)

http://conserveonline.org/workspaces/eloha

Hydrologic Data

- Simulated daily flow time series for a current conditions scenario and for a baseline scenario
  - Current conditions:
    - 2000 land use
    - 2005 withdrawals, discharges, and impoundment volume
    - 1984-2005 hydrology
  - Baseline:
    - Land use modified to 78% forest, 0.35% impervious surface, other land uses adjusted proportionally,
    - Discharges and withdrawals set to zero.
    - No impoundments
- Flows simulated for 747 watersheds

US Army Corps of Engineers

The Nature Conservancy
Protecting nature. Preserving life.

Hydrologic Metrics

- Broad suite of flow metrics are calculated for each flow time series
  - Hydrologic Integrity Tool (HIT). Henriksen et al (2006), *The Hydroecological Integrity Assessment Process*, USGS Open File Report 2006-1093.
  - Indicators of Hydrologic Alteration (IHA). The Nature Conservancy (2007), *Indicators of Hydrologic Alteration, Version 7 User's Manual*.
  - Plus additional metrics commonly used.
  - 256 metrics total
- Selection process to reduce number of metrics
  1. Metrics with high variation between baseline and current scenarios
  2. Metrics with high variation among watersheds
  3. High model efficiency: Medians and inter-quartile range of flow metric for Simulated flows versus for Observed flows are similar
  4. Select only one of highly correlated groups
  5. Represent different aspects of flow regime
  6. Explainable relationship with biota

US Army Corps of Engineers

The Nature Conservancy
Protecting nature. Preserving life.

Hydrologic Metrics

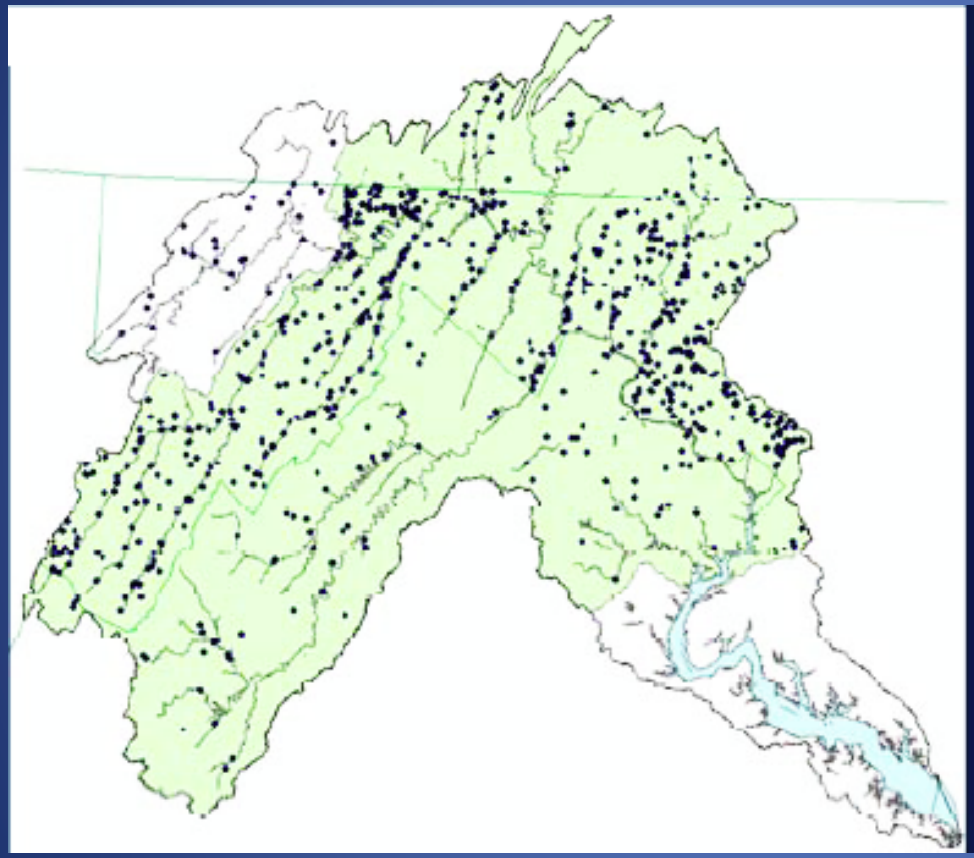
Flow Range	Magnitude	Duration	Frequency	Other
High	Mean high flow volume (MH21)	High Flow Duration (DH17)	High pulse count, High flow freq, Flood freq (FH9)	Skewness in annual max flow(MH19)
Mid	Median Q	Flood free season		Fall rate (RA3), Flashiness
Low	4b3, Seasonal Q85	Low pulse duration, Extreme low duration, Variability in low pulse duration (DL17)	Low pulse count, Extreme low freq.	

*Seasonal flow metrics were evaluated but none of them met the initial screening criteria or were highly correlated with RA3. After further analysis some seasonal metrics may be included.

US Army Corps of Engineers

The Nature Conservancy
Protecting nature. Preserving life.

Middle Potomac – Biological Data



1) Benthic macroinvertebrate data
   a) Only bio data set sufficiently rich for this basinwide, interstate, assessment
   b) Samples rarified to common basis and metrics calculated to family level for consistency
2) Collected in years 2000 – 2008
3) 1,313 samples at 869 locations for 747 watersheds

US Army Corps of Engineers

The Nature Conservancy
Protecting nature. Preserving life.

Biotic Metrics

Candidate Biometric	Description
Diversity	
Family-Level Taxa Richness	Number of taxonomic families
Shannon-Wiener Index	A common measure of taxonomic diversity
Taxonomic Composition	
%EPT	% of individuals belonging to Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies)
EPT Taxa	Number of EPT families
Gold's Index	1 minus % of gastropods (snails), oligochaetes (worms), and Diptera (true flies) individuals; also indicates pollution.
%Chironomidae	% of individuals belonging to Chironomidae family of Diptera
Ephemeroptera Taxa	Number of Ephemeroptera families

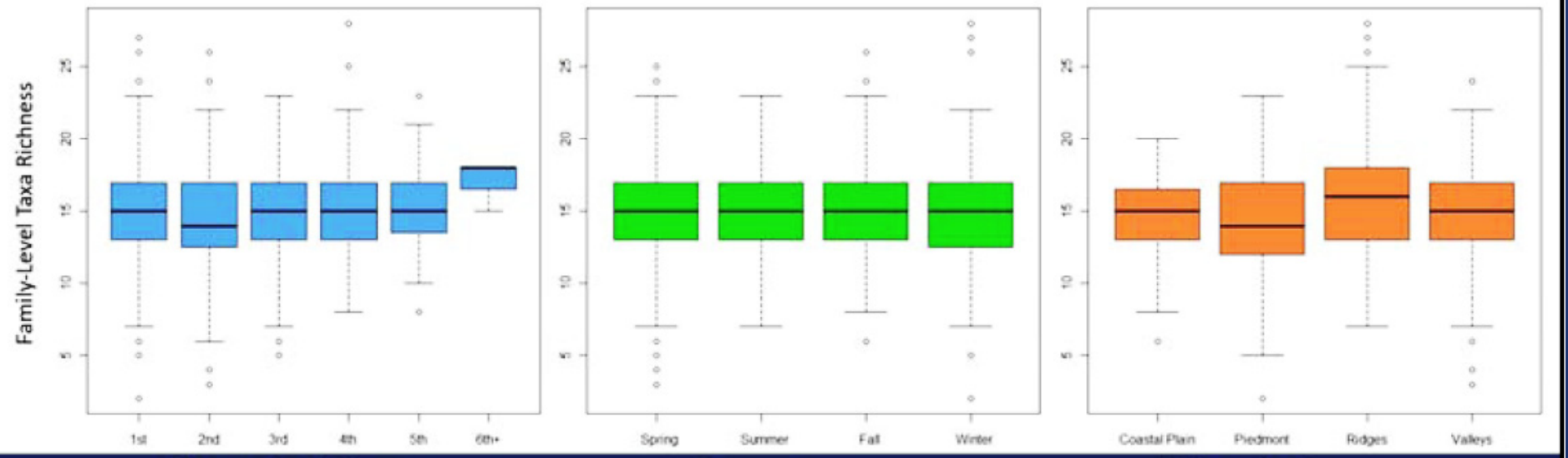
US Army Corps of Engineers

The Nature Conservancy
Protecting nature. Preserving life.

Classification

Some biological metrics appear not to need classification….

Family-Level Taxa Richness



Watershed Size | Season | "Bioregion"

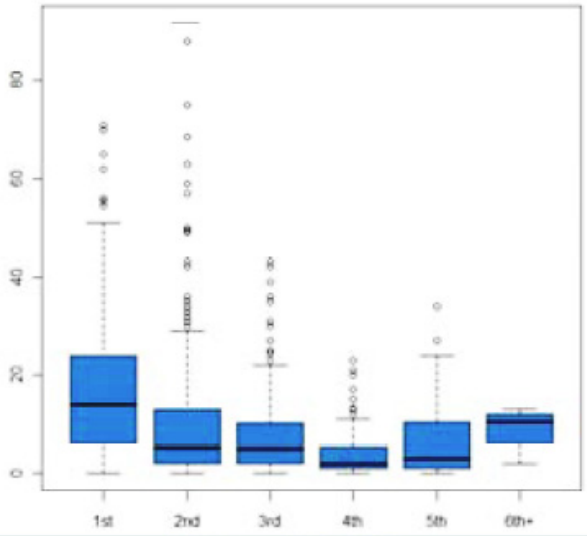
US Army Corps of Engineers

The Nature Conservancy
Protecting nature. Preserving life.

Classification

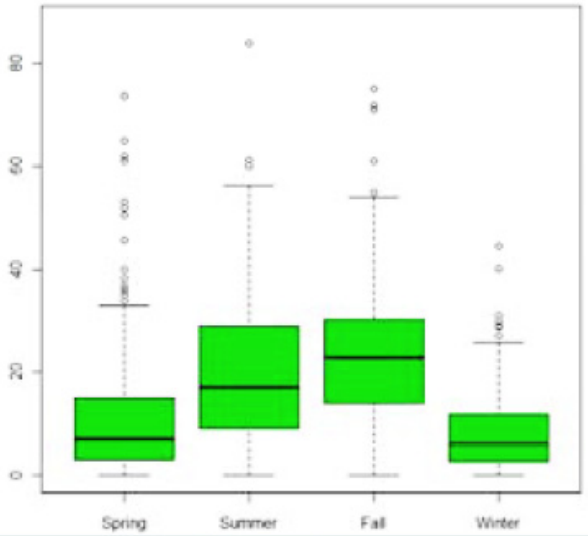
…while others may need classification

%Shredders



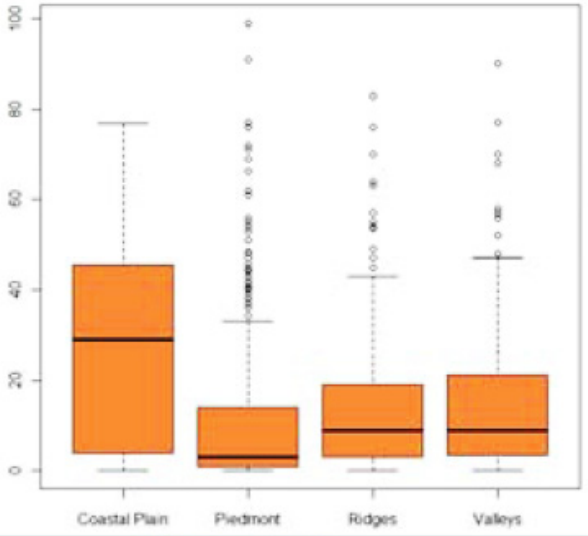
Watershed Size

%Net Caddisfly



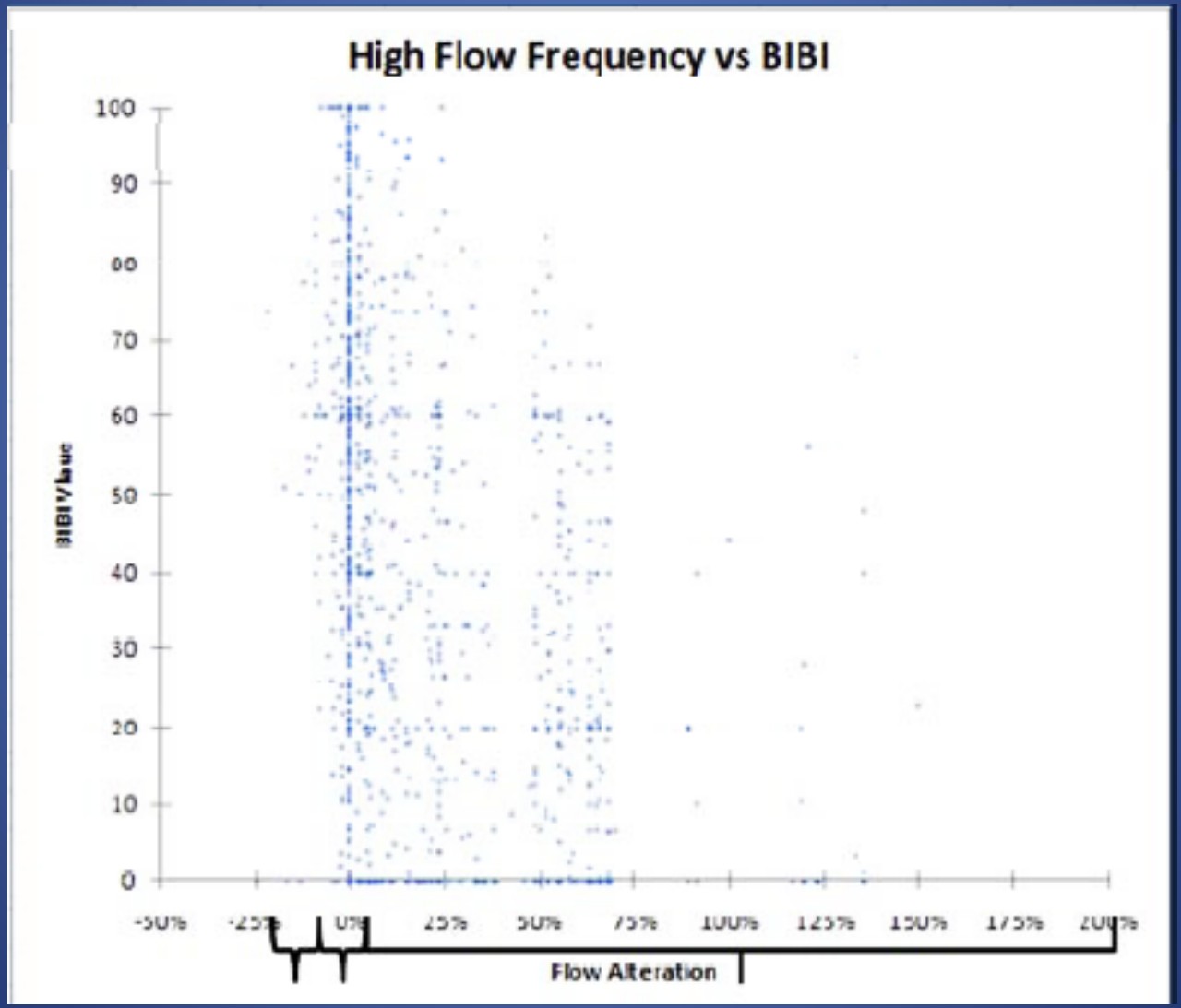
Season

%Chironomidae

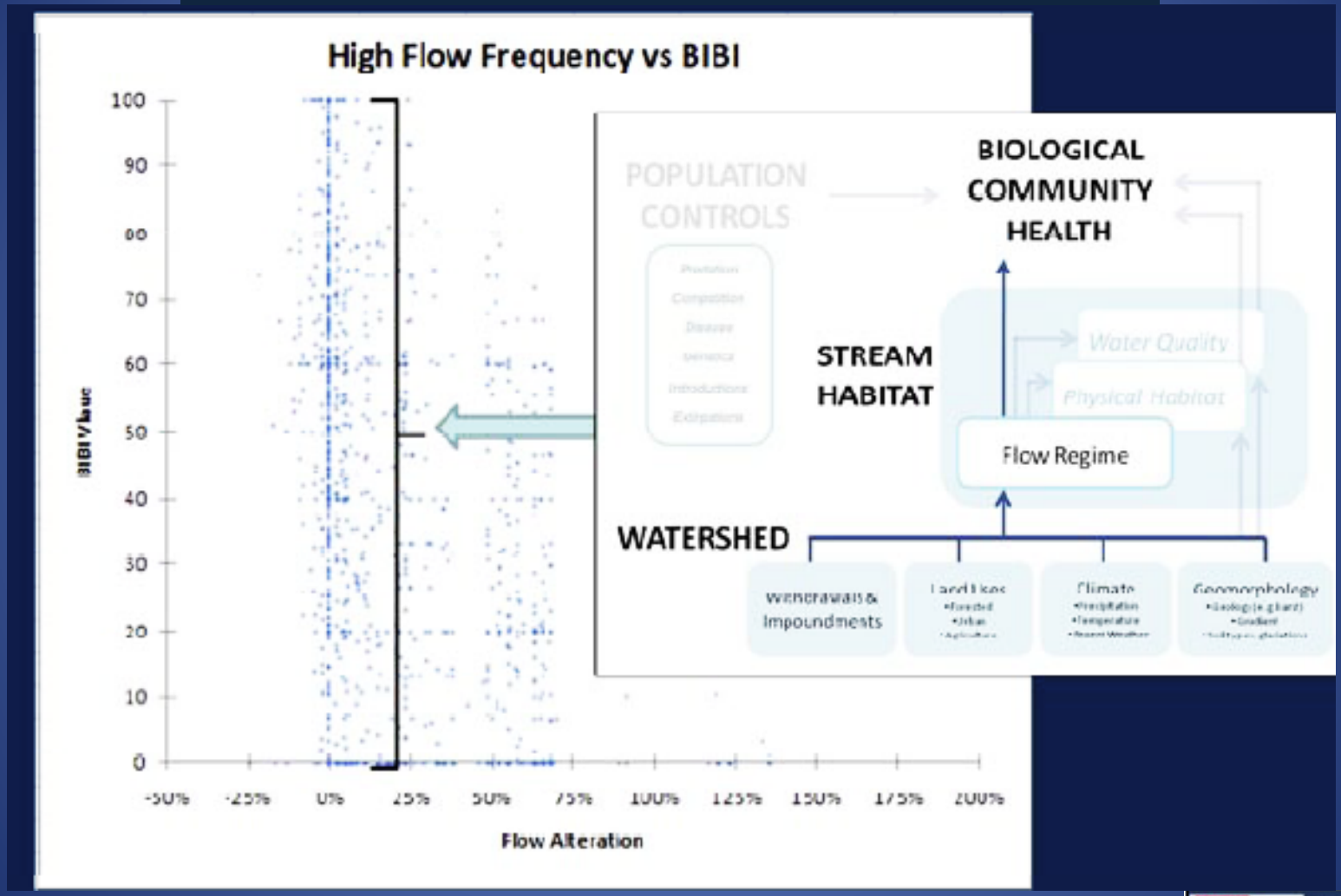


"Bioregion"

Flow-Ecology Relationships



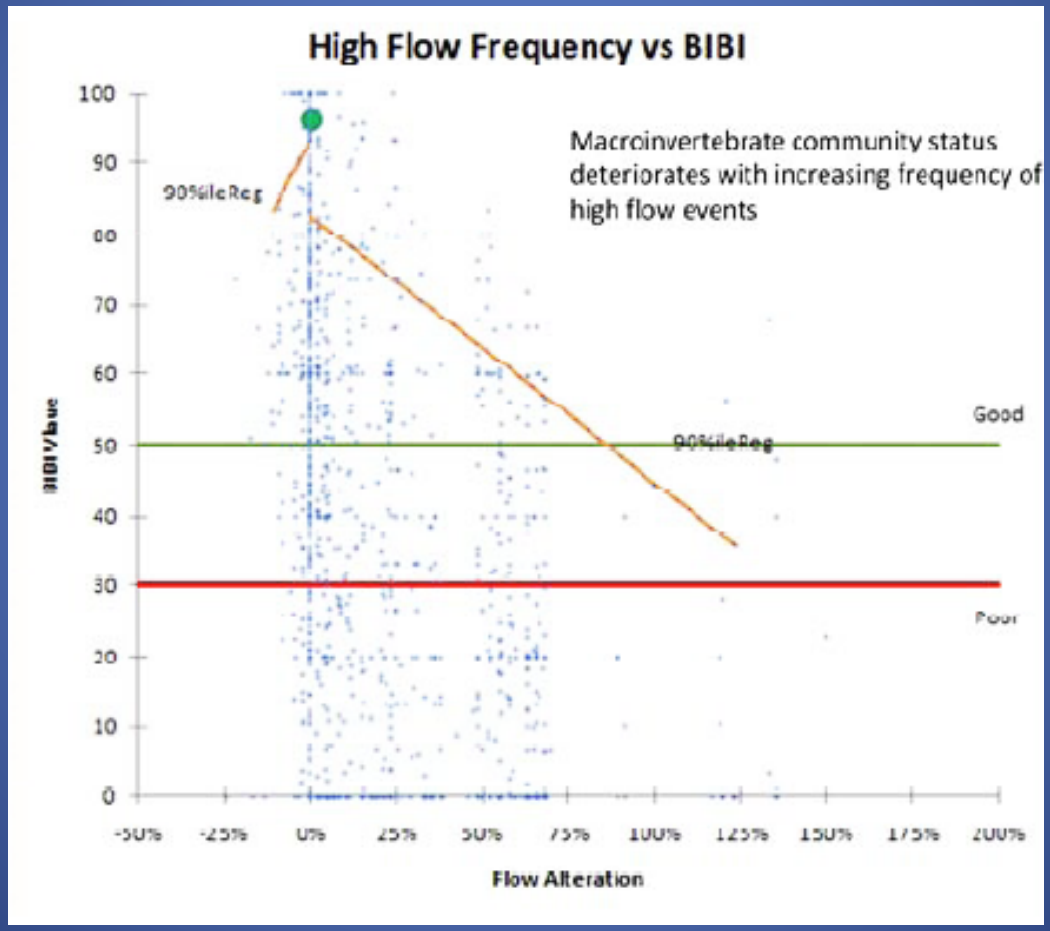
Flow-Ecology Relationships



US Army Corps of Engineers

The Nature Conservancy
Protecting nature. Preserving life.

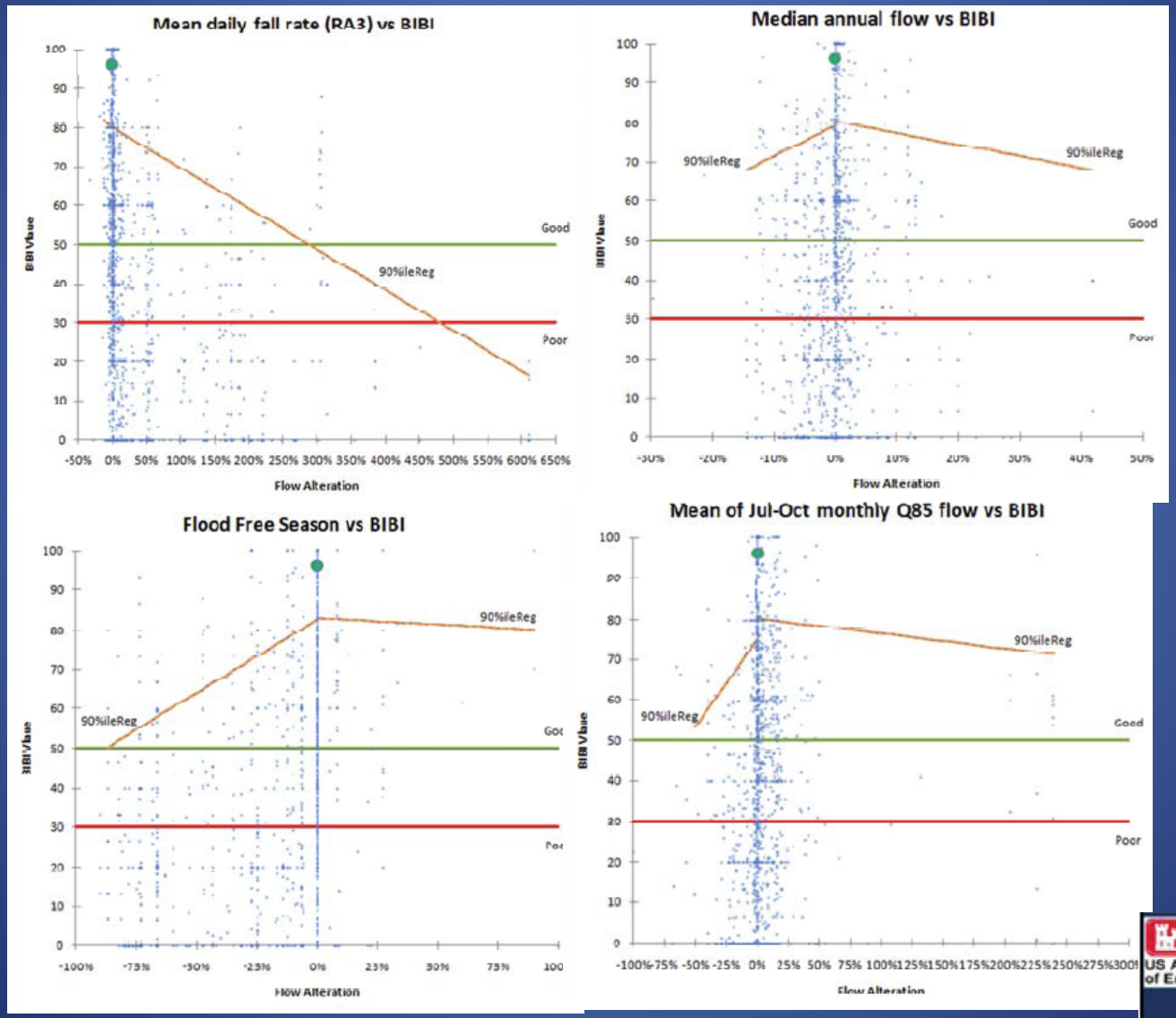
Flow-Ecology Relationships



US Army Corps of Engineers

The Nature Conservancy
Protecting nature. Preserving life.

Flow-Ecology Relationships



US Army Corps of Engineers

The Nature Conservancy
Protecting nature. Preserving life.

IF Methods and Approaches Used by Advanced State Programs

- Florida – similar standards within river class
- Michigan – river classification informed by fish assemblages; similar standards within river class
- Potomac River Commission – demonstrated ecological impairment due to flow alteration in addition to other sources of stress

Presentation Overview

1. Review of science-based methods to determine IF needs

2. Methods used by select states to determine IF needs

3. IF resources for North Carolina and the SE region

Southern Instream Flow Network

Purpose - To facilitate protective instream flow policies and practices in 15 southern states by providing science-based resources and opening lines of communication.

SOUTHEAST AQUATIC RESOURCES PARTNERSHIP
SARP

More information at:
www.southeastaquatics.net/programs/sifn/

Southern Instream Flow Research Agenda

www.southeastaquatics.net/programs/sifn

- **Problem:** The limited focus on research and funding for instream flows has resulted in a lack of science to support protective instream flow standards.
- **Objective:** to highlight research needs and coordinate sources of funding and research to address these needs.
- **Goal:** to ensure that instream flow research is focused on the needs of water resource managers for scientifically credible and protective state instream flow standards and practices.

SOUTHEAST AQUATIC RESOURCES PARTNERSHIP
SARP

Southern Instream Flow Research Agenda

Priority Research Topics

1. **Develop a regional river classification system**

2. **Identify commonalities in ecosystem responses to flow alterations**

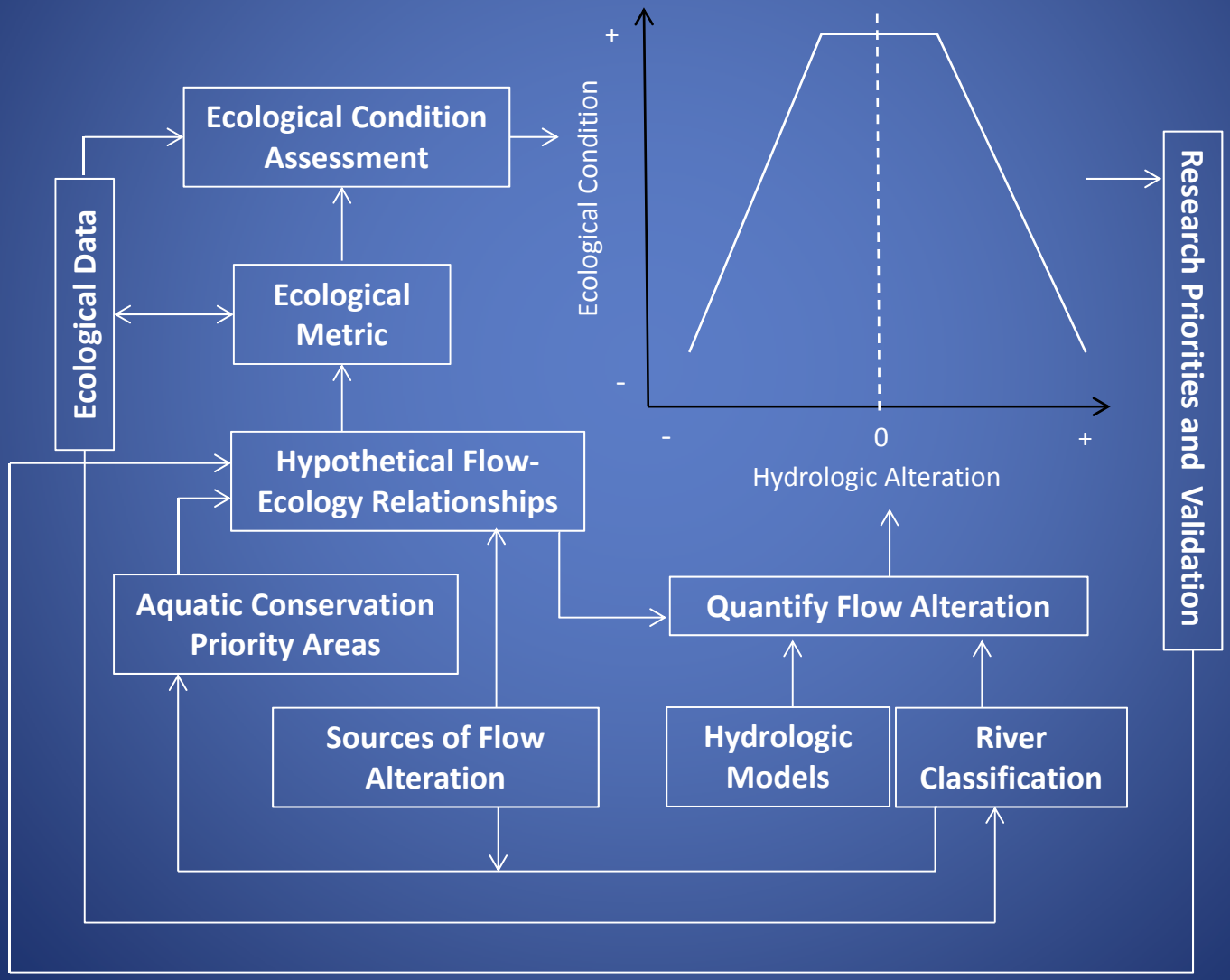
3. **Compile regional aquatic ecology data sets**

4. **Develop hypotheses for regional ecological responses to flow alteration**

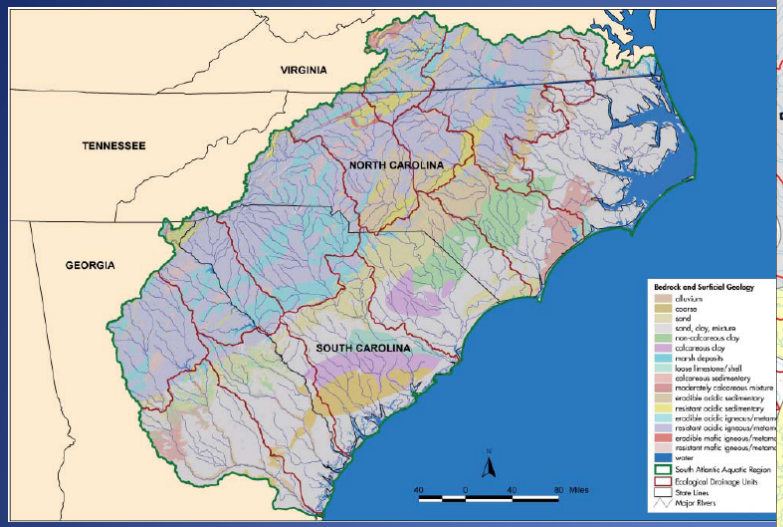
5. **Perform field studies to test ecological responses to altered flow regimes**

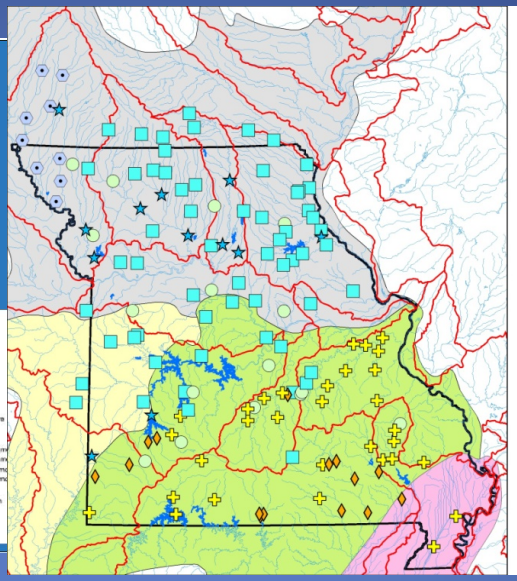
SOUTHEAST AQUATIC RESOURCES PARTNERSHIP
SARP

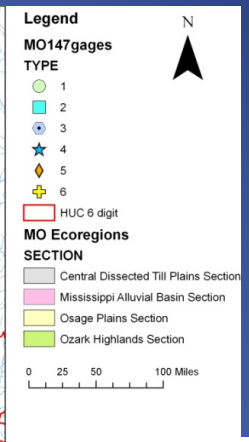
Integration of Instream Research Agenda Products To Develop Flow-Ecology Relationships

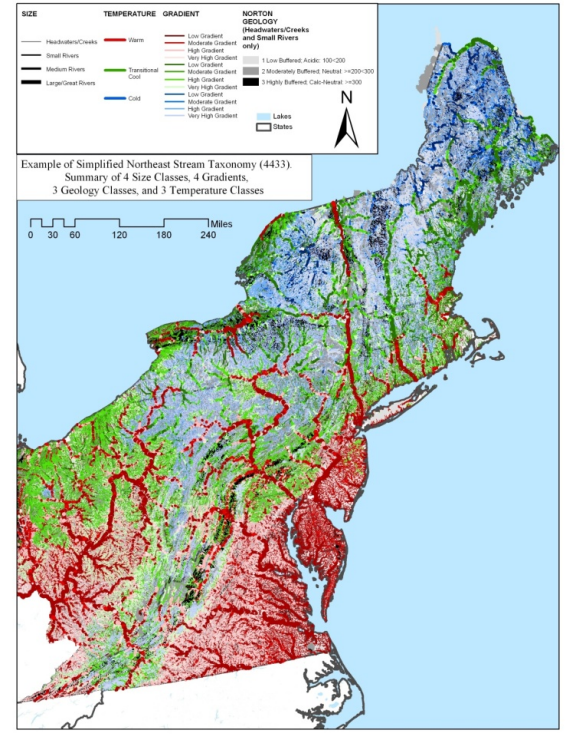


SE River Classification







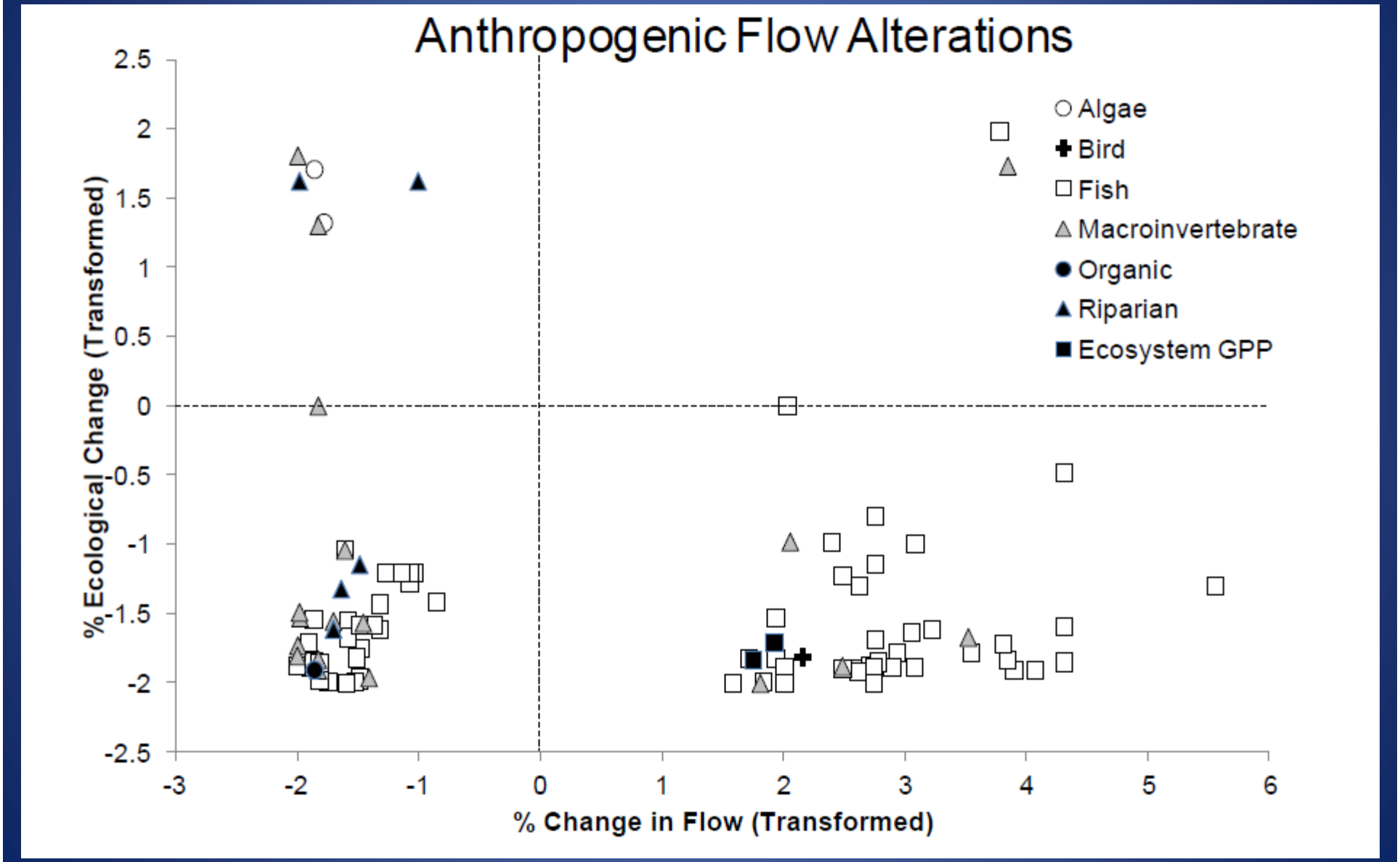


- **Utilizing existing classifications**
- **Hierarchical scales**

  for geomorphology, hydrology, and biota
- **Principals:**

  John Faustini, USFWS and Chris Konrad, USGS

Preliminary SE Flow-Ecology Relationships



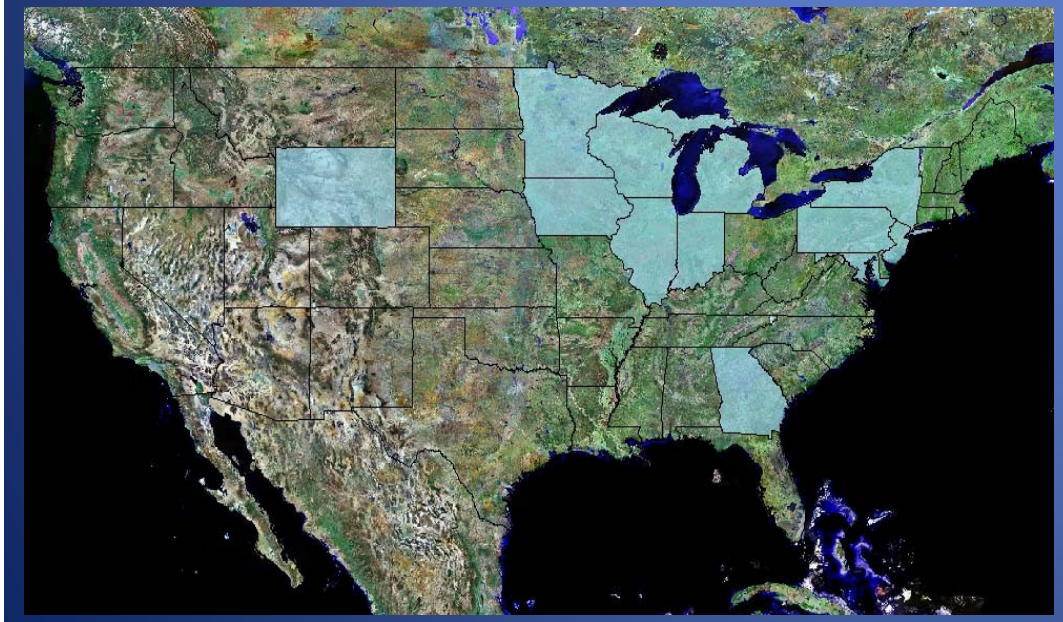
Source: McManamay et al. 2011

Compile regional aquatic ecology data sets

MARIS

Multistate Aquatic Resources Information System

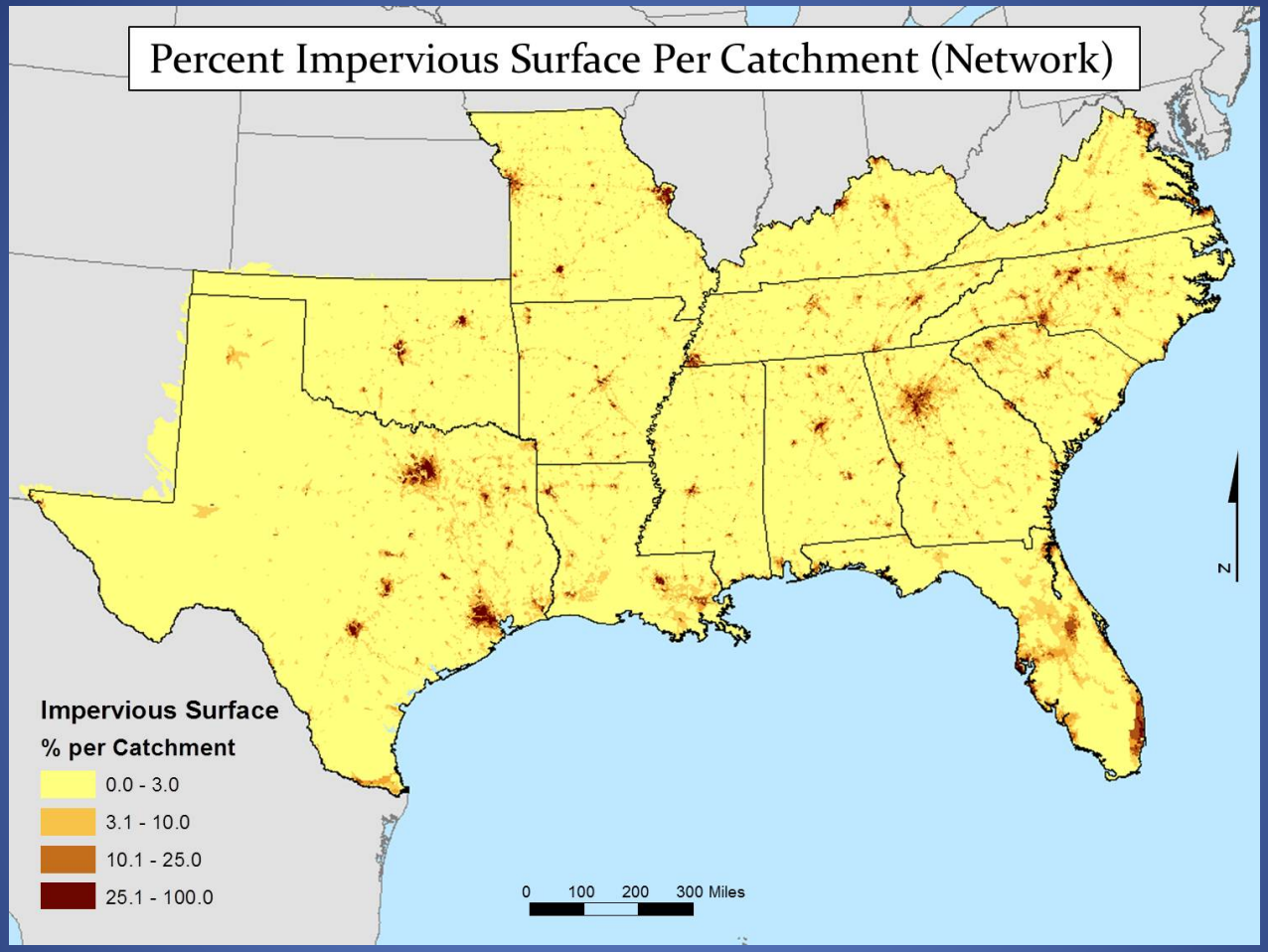
www.marisdata.org



MARIS States (2010)

Integrating State Data into the National Fish Habitat Assessment

SARP Flow Alteration Assessment



Approach – Qualitatively assess sources, spatial distribution, and relative magnitude of hydrologic alteration from water consumption, impervious cover, and dams.

In conclusion:

Generally, instream flow science is progressing and is resulting in more protective policies and management practices.

From the case studies:

- **River classification works well where there is a clear relationship with biota.**
- **'Flow-ecology' relationships help guide selection of hydrologic and biotic metrics**
- **Demonstrated ecological impairment due to flow alteration provides a strong basis for instream flow criteria.**

If we had more time:

- **Scientific certainty should be balanced with policy development.**
- **Presumptive standards may provide a protective option until more studies can be completed.**

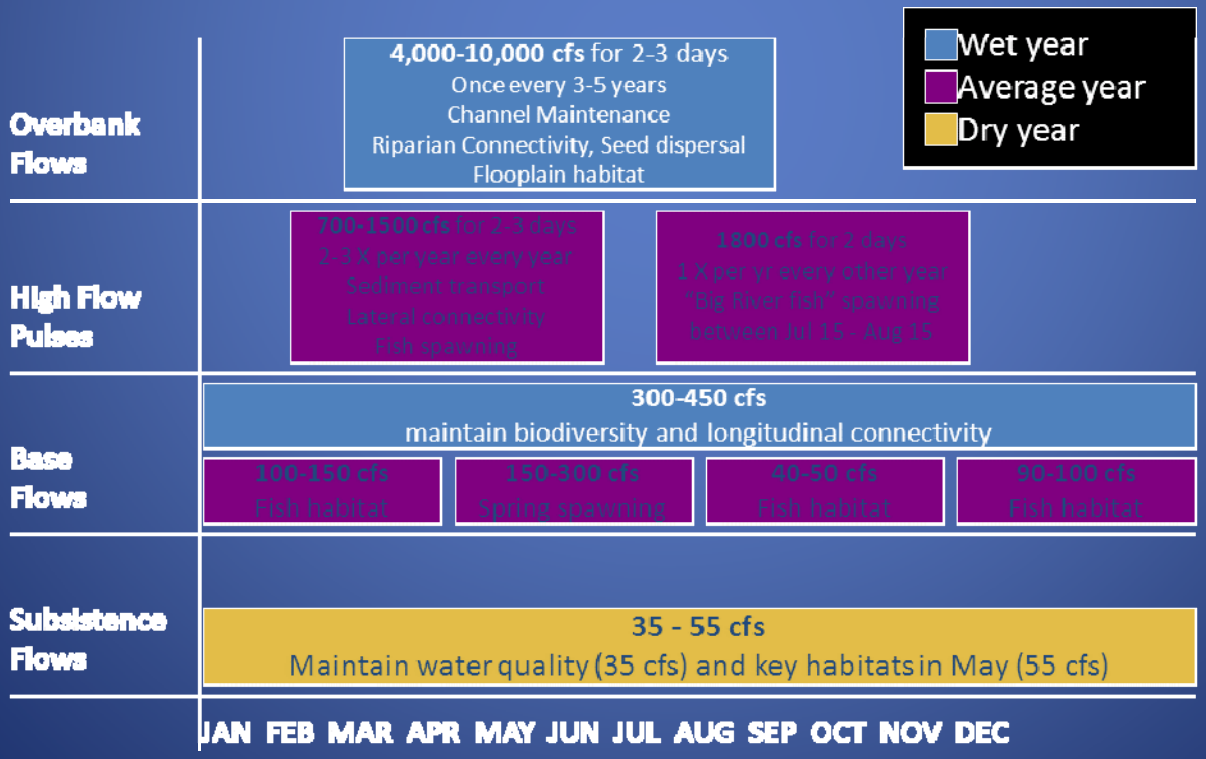
Environmental Flows Allocation Process in Texas

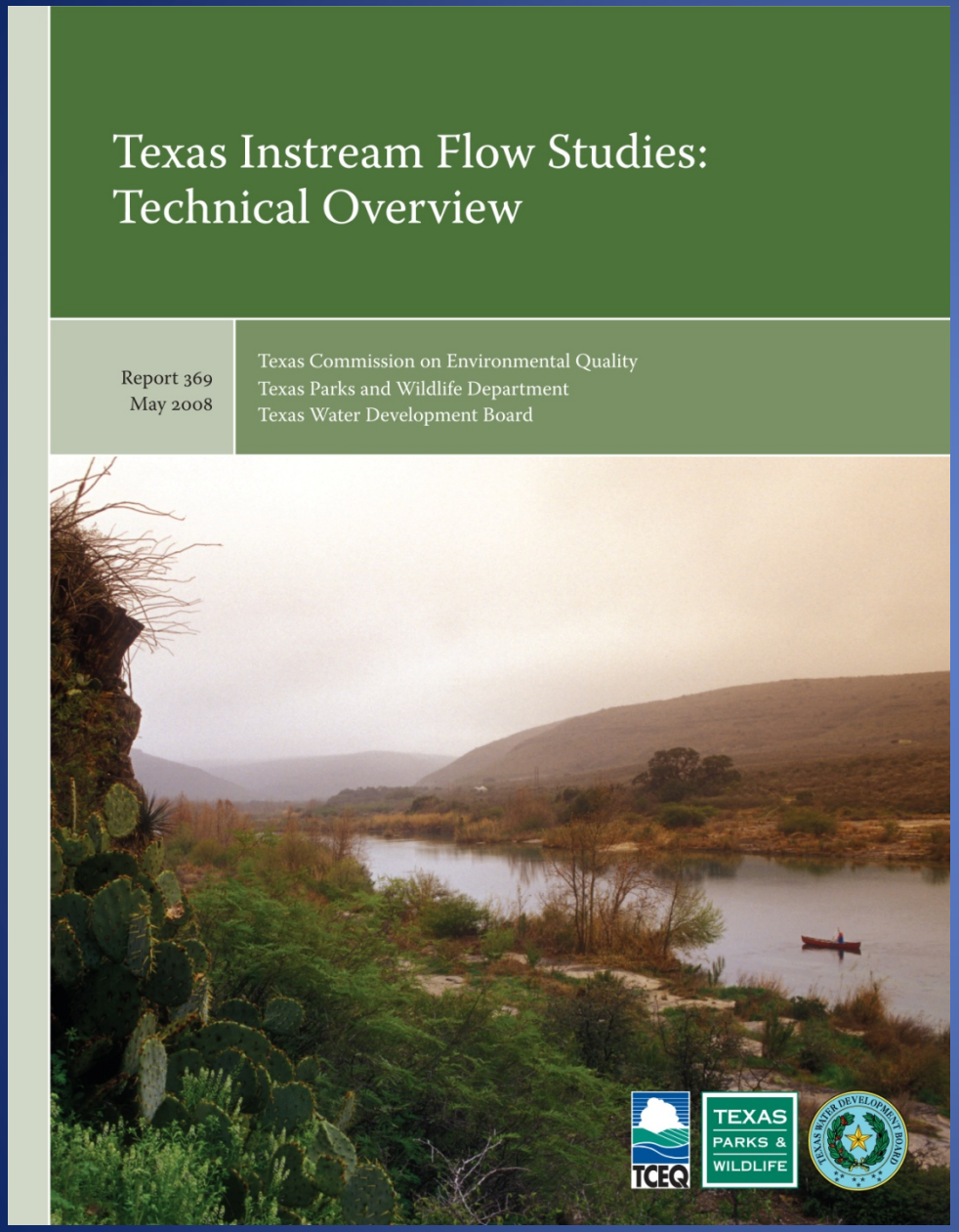
Slides Courtesy of
Kevin Mayes
Director, EF Program

TEXAS PARKS & WILDLIFE

Texas EF Program

- *Flow Regime* – Integration of Ecological Flow Components
- *IFIM-style methodology*
- *Statistically-based approach for recommendations*
- *Sound ecological management target*

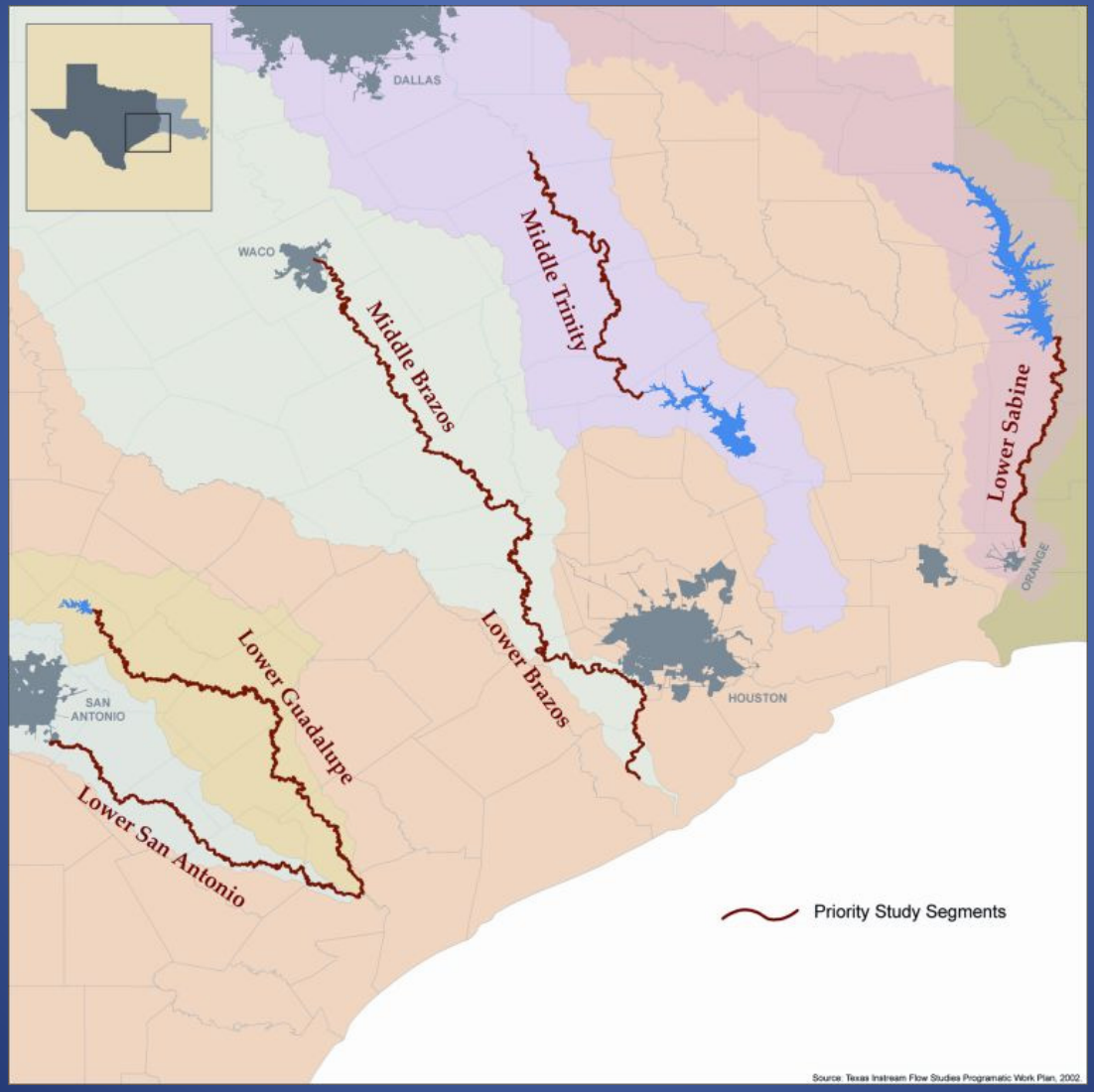




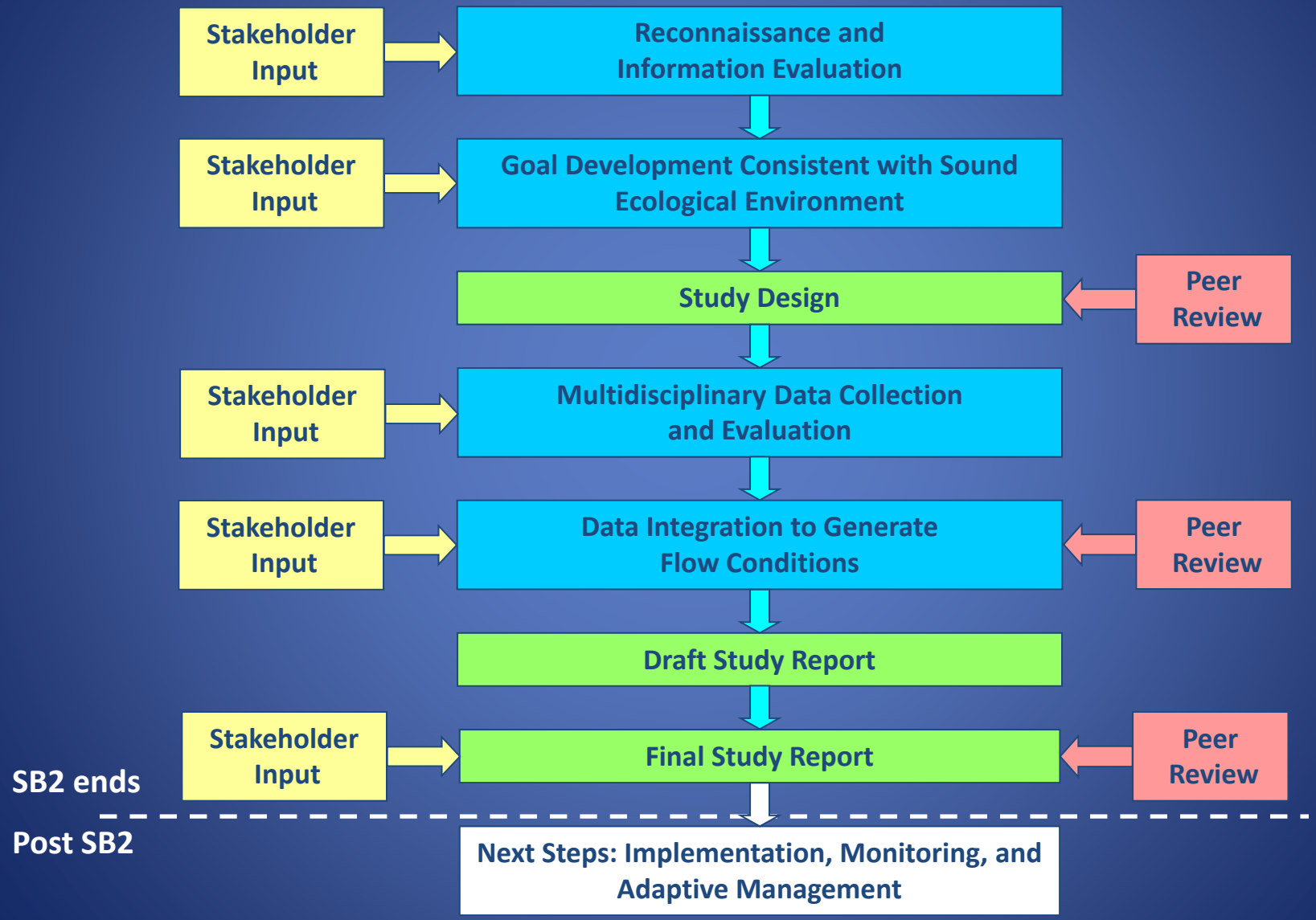
- Clear definitions and process
- Well-defined stakeholder/public involvement process
- Integration framework ties flow components and disciplines
- Approved by National Research Council

Texas Environmental Flow Program

Priority Study River Segments

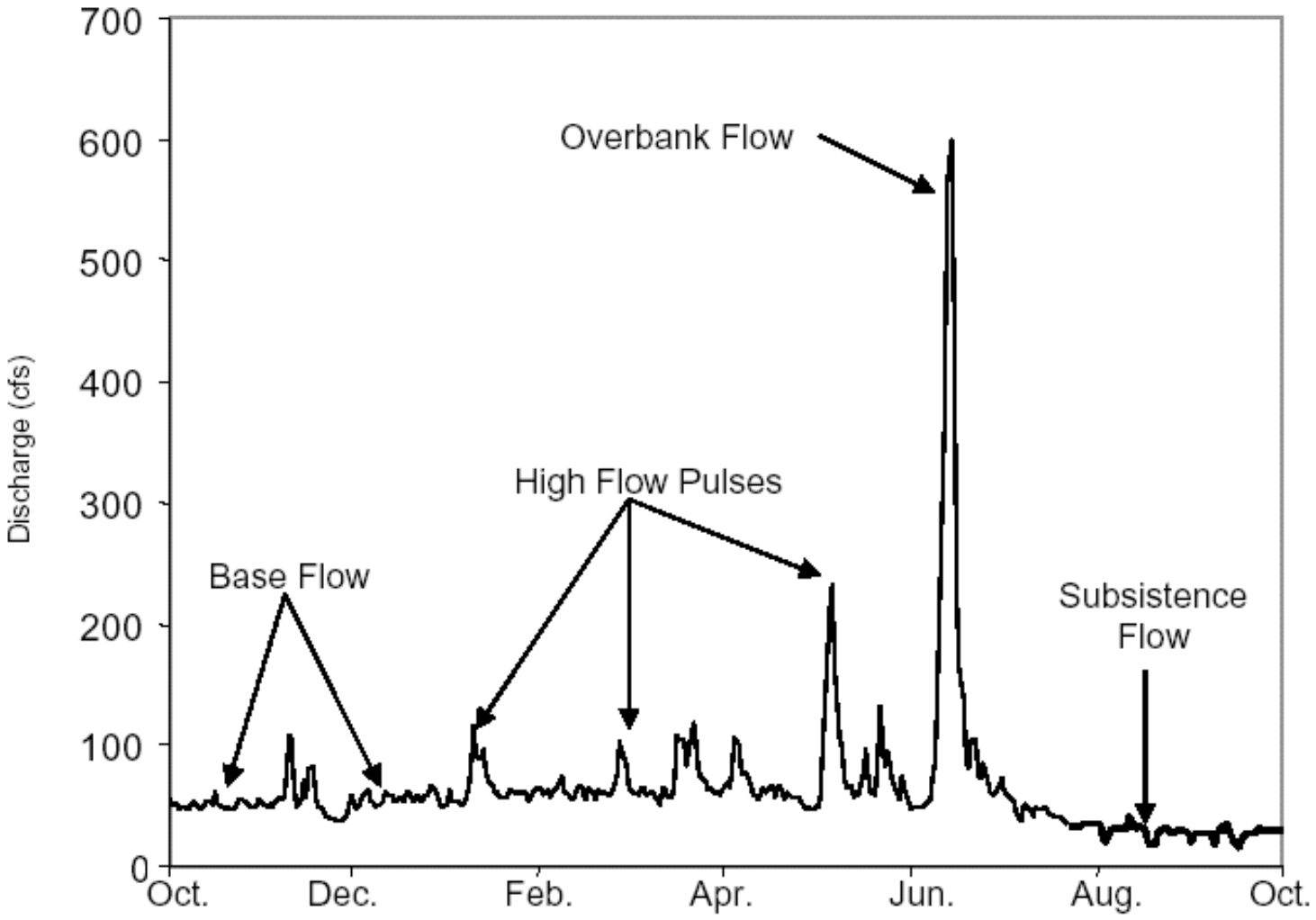


TIFP Process

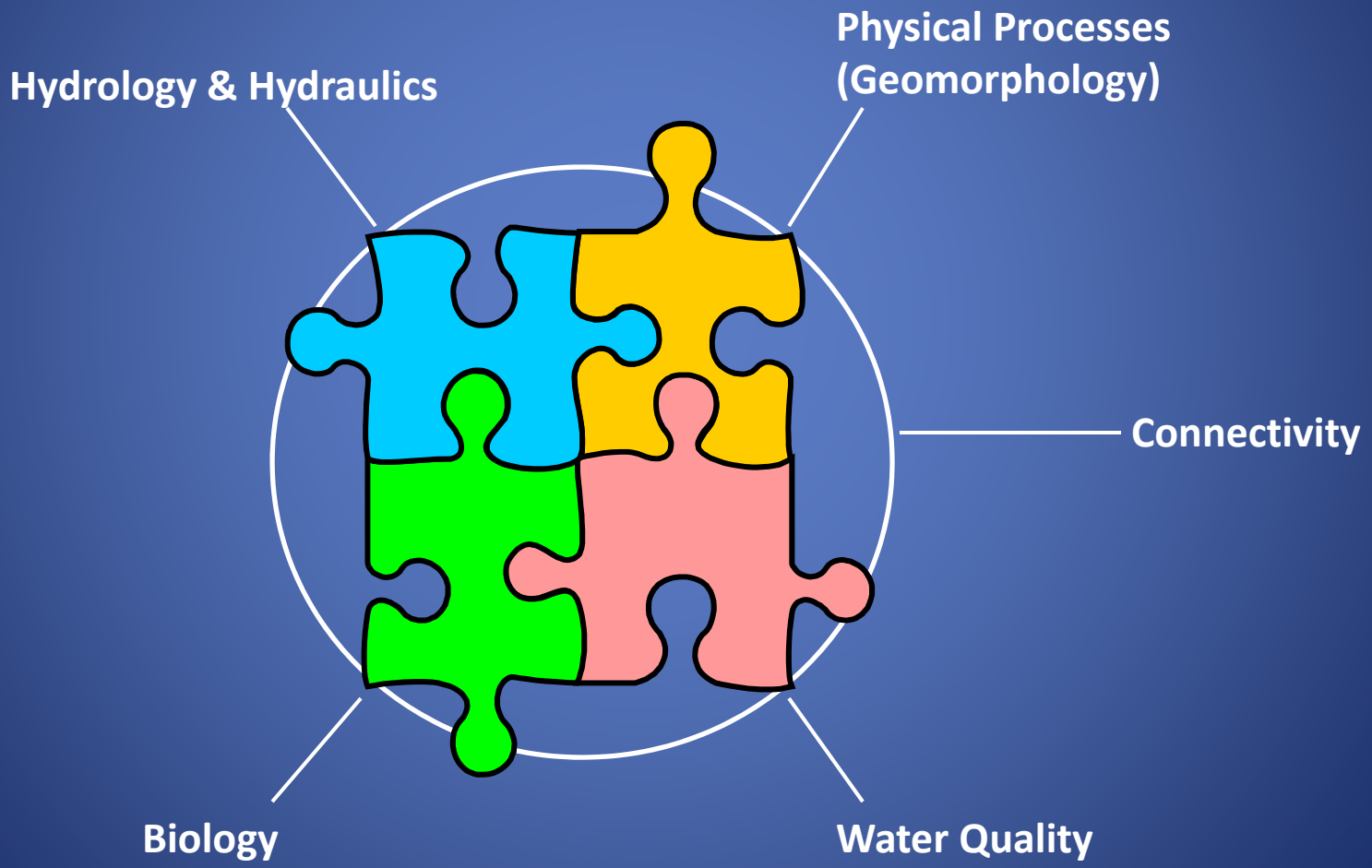


Instream Flow Components

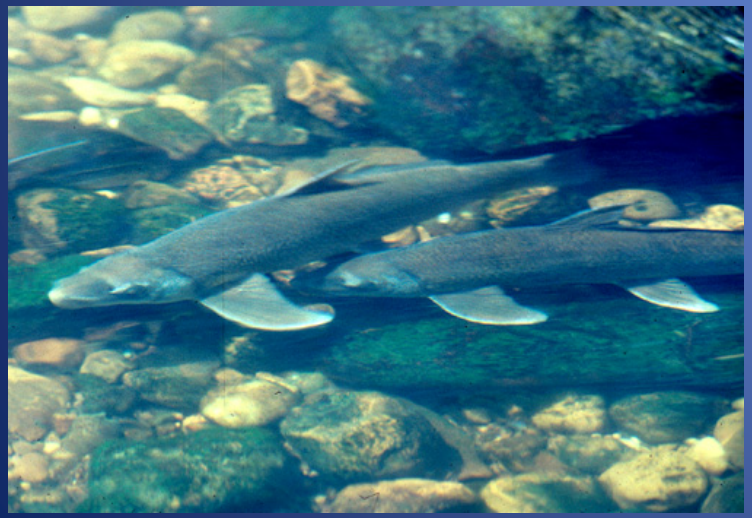
(National Research Council 2005)

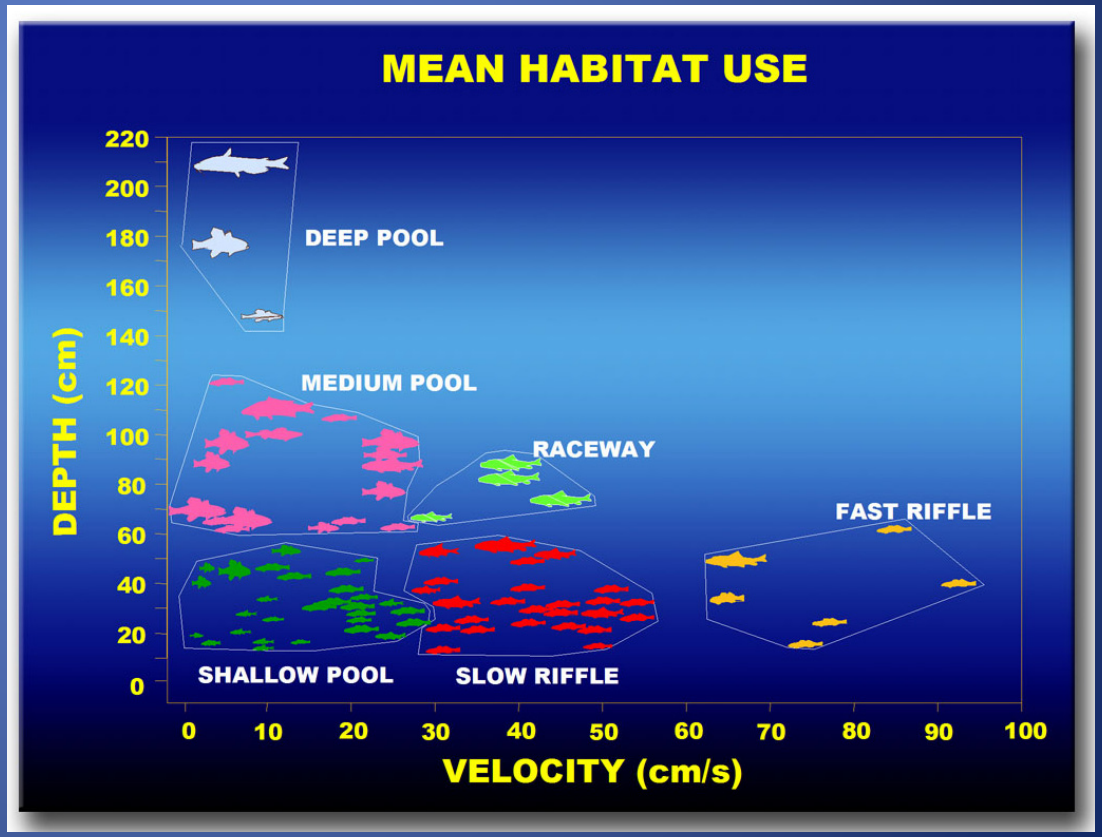


Primary Disciplines



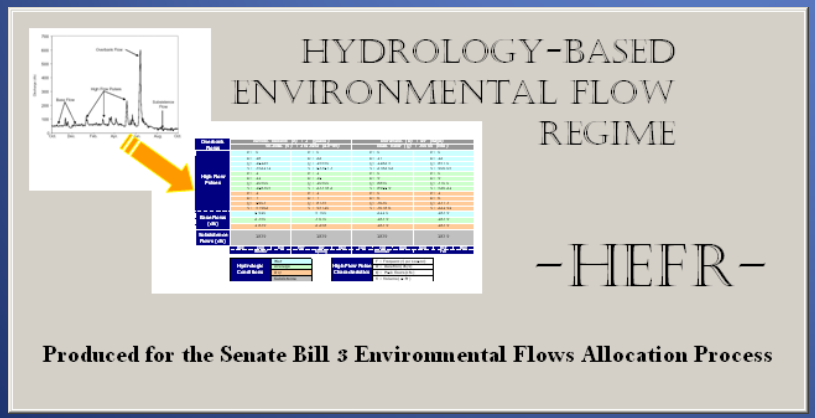
Key Species and/or Habitat Diversity





Hydrology-Based Environmental Flow Regime (HEFR) Basics

- Uses hydrologic data
- Computations are rapid
- Populates a flow regime matrix



(1) Select Flow Gage

↓

(2) Select Period of Record

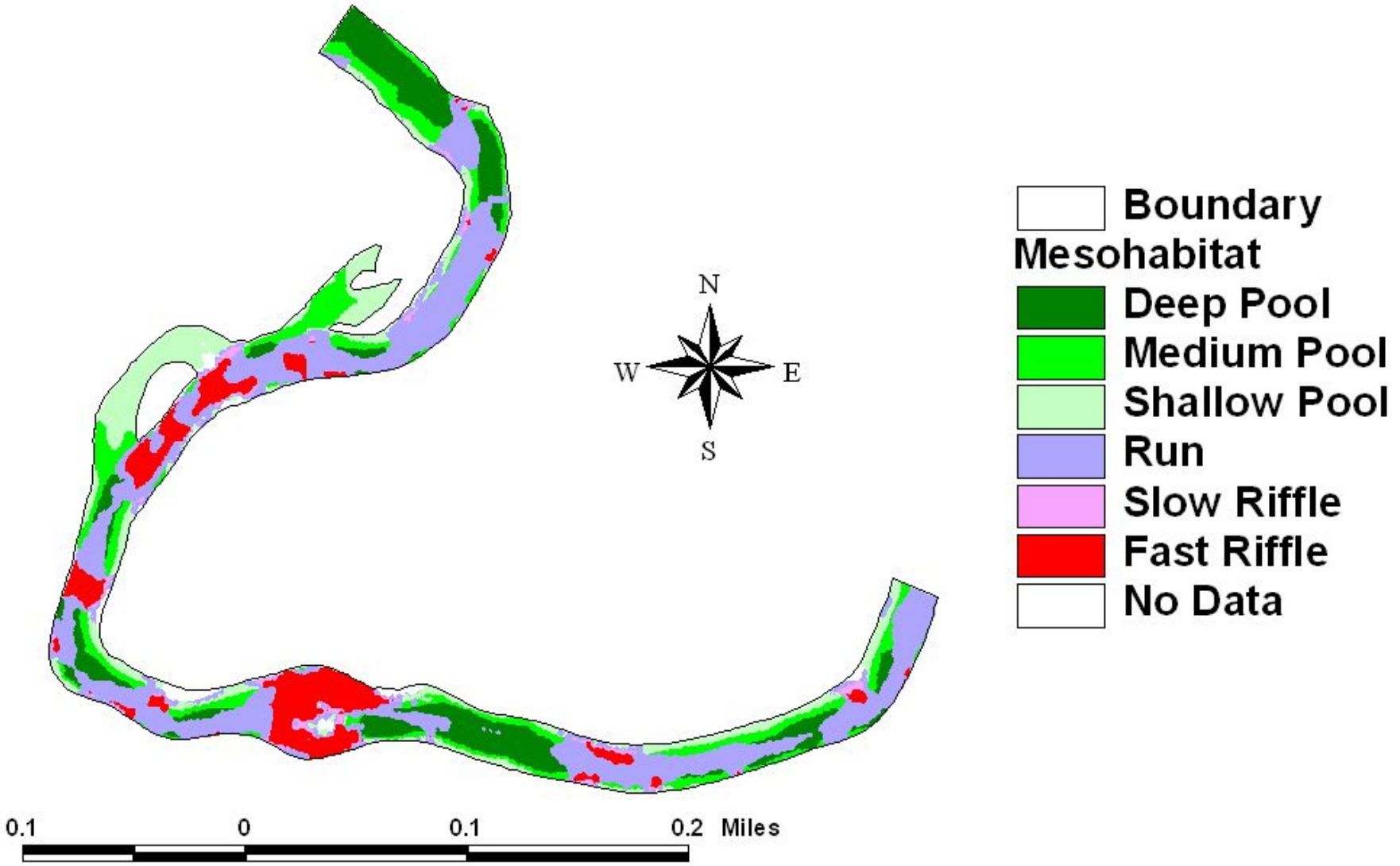
↓

(3) Separate (parse) Hydrograph into Flow Components

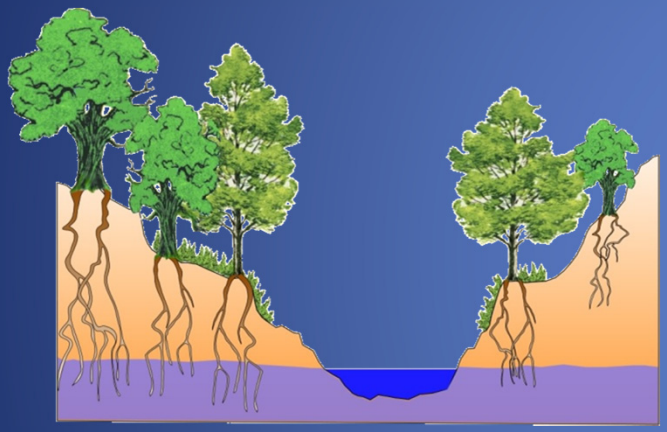
↓

(4) Generate Statistical Summaries in Excel

Mesohabitat for Rainwater Ranch at Q=1000cfs



Subsistence Flows



Identify Biological Considerations

Identify Water Quality Constituents of Concern

Calculate Low Flow Statistics

Conduct Water Quality Modeling Studies

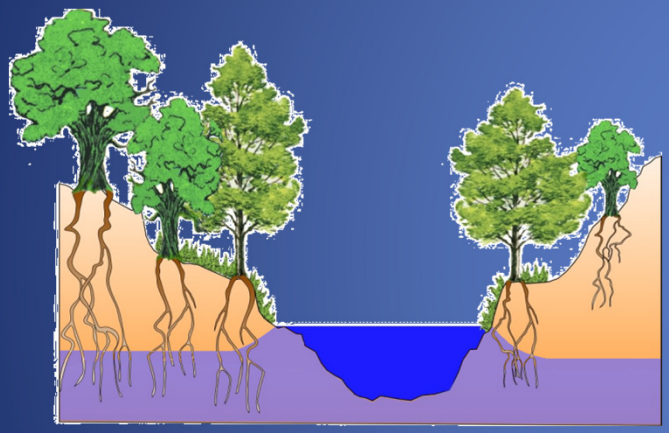
Assess Low Flow - Water Quality Relationship

Other Biological Considerations

Subsistence Flows

Primary Discipline
- Hydrology/Hydraulics
- Biology
- Geomorphology
- Water Quality

Base Flows



Assess Bedform and Banks

Identify Biological Issues and Key Species

Calculate Base Flow Statistics

Collect Biological Data

Model Hydraulic Characteristics in Relation to Flow

Determine Habitat Criteria

Assess Habitat-Flow Relationships, including Diversity

Describe Wet, Normal, and Dry Years

Consider Biological and Riparian Issues

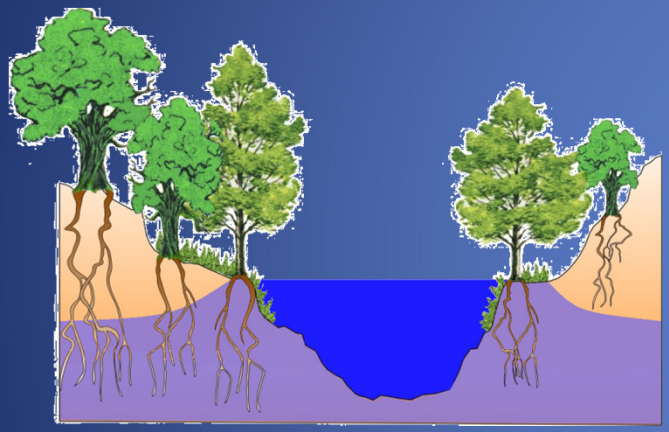
Consider Water Quality Issues

Base Flows

Primary Discipline

- Hydrology/Hydraulics
- Biology
- Geomorphology
- Water Quality

High Flow Pulses



Assess Active Channel Processes

Develop Sediment Budgets

Assess Channel Adjusting Flow Behavior

Describe Significant Habitat Conditions

Consider Biological Issues

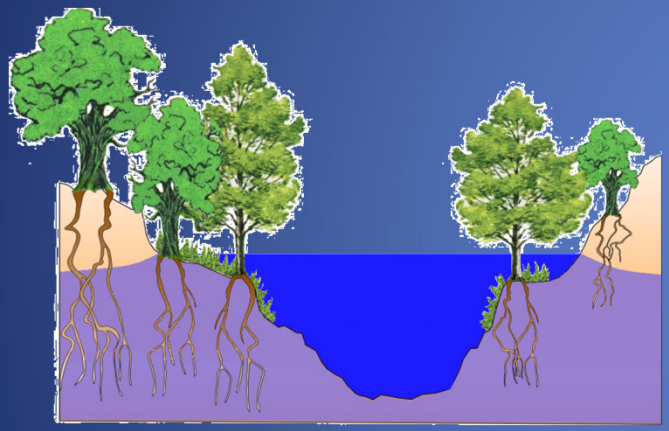
Calculate High Flow Statistics

Consider Water Quality Issues

High Flow Pulses

Primary Discipline
- Hydrology/Hydraulics
- Biology
- Geomorphology
- Water Quality

Overbank Flows



Calculate Flood Frequency Statistics

Model Extent of Flood Events

Assess Active Floodplain and Channel Processes

Assess Overbank Flow Behavior

Consider Biological Issues

Conduct Riparian Studies

Consider Water Quality Issues

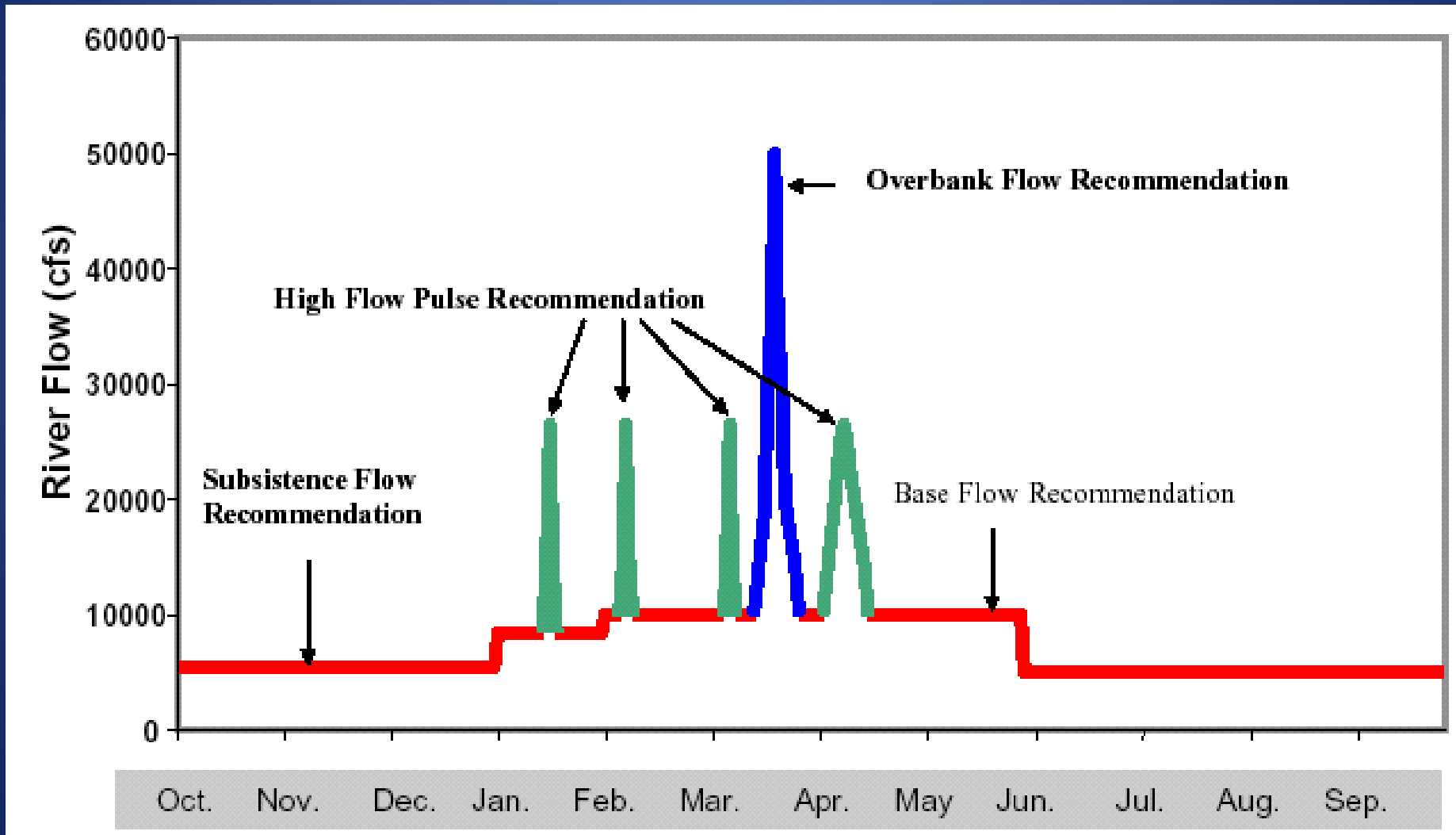
Estimate Riparian Requirements

Overbank Flows

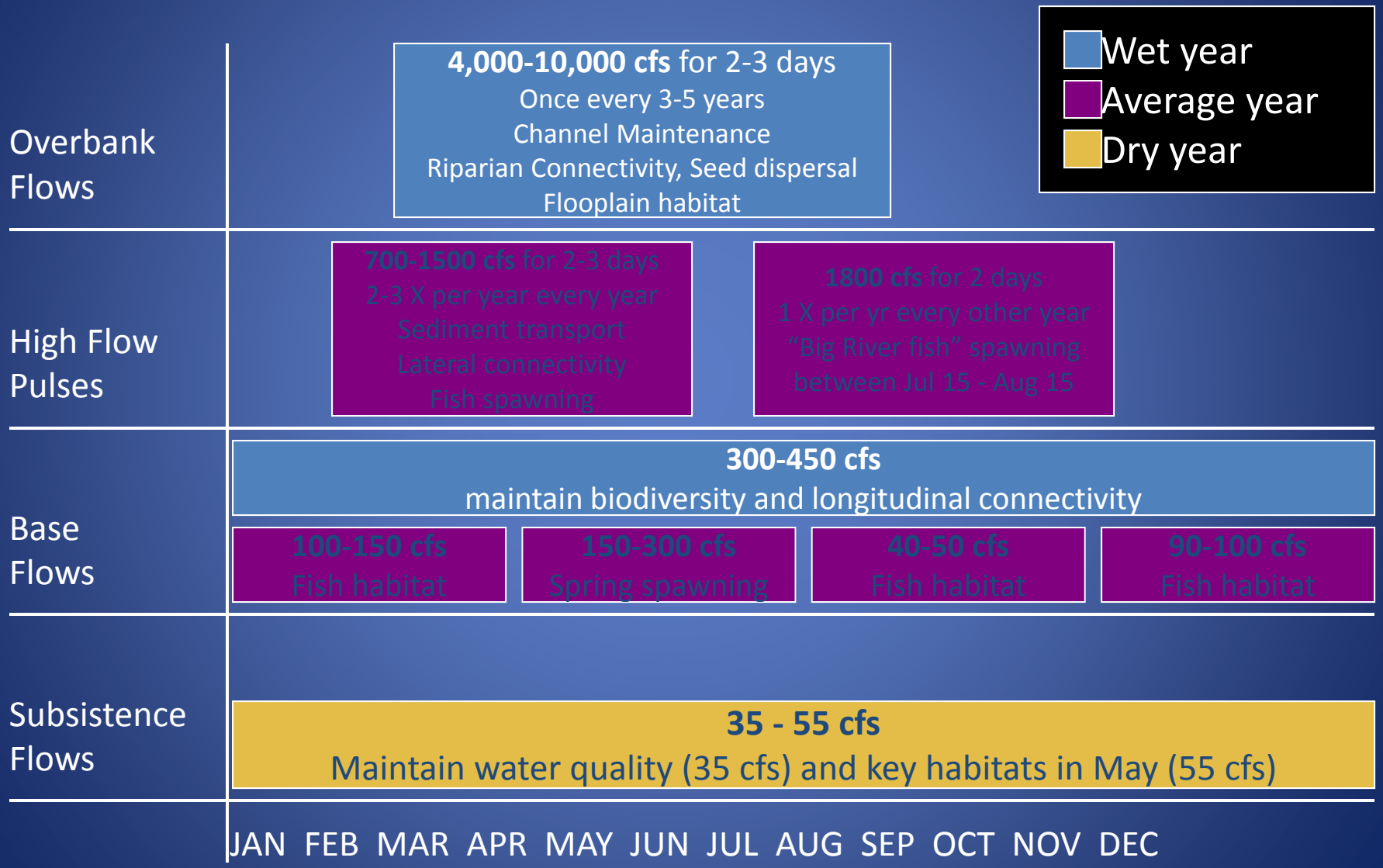
Primary Discipline

- Hydrology/Hydraulics
- Biology
- Geomorphology
- Water Quality

Integration to Generate a Flow Regime



Integration of Flow Components



Status of Texas Environmental Flow Process

Texas Environmental Flows Process (Stakeholder process under SB3)

Stakeholder environmental flow recommendations (instream flows and freshwater inflows to bays and estuaries):

1. Sabine-Neches-Sabine Lake
2. Trinity-San Jacinto-Galveston Bay
3. Colorado and Lavaca Rivers and Matagorda and Lavaca Bays Basin and Bay
4. Guadalupe, San Antonio, Mission, and Aransas Rivers
5. Mission, Copano, Aransas, and San Antonio Bays Basin and Bay

Analyses and draft reports in prep:

- Rio Grande, Rio Grande Estuary, and Lower Laguna Madre
- Brazos River and Associated Bay and Estuary System
- Nueces River and Corpus Christi and Baffin Bays.

Texas Instream Flow Program (Environmental studies under SB2)

Interim report:

1. Lower San Antonio River

Multidisciplinary studies underway in:

- lower San Antonio River
- middle and lower Brazos River
- lower Sabine River

- Parts 3 and 4 – this is the most important part. Take care to focus on the science as much as possible, and if talking about the approach a state settled on, point out changes that were made based on other factors (economics, politics etc.)
- With regards to the science and what other states are doing, here are some questions:
  - Are they classifying/sorting streams? How?
  - How are they coming up with ecological response relationships? What metrics are they evaluating? If working with biological databases, how are they isolating flow effects from water quality effects and effects downstream of big dams not related to flow?
  - How are they evaluating degree of hydrologic alteration against which biological data is being contrasted? What metrics for flow alteration?
-

Develop testable ideas about flow-ecology relations

- many possible ecological responses
- multiple plausible hydrologic drivers

Freeman and Marcinek 2006

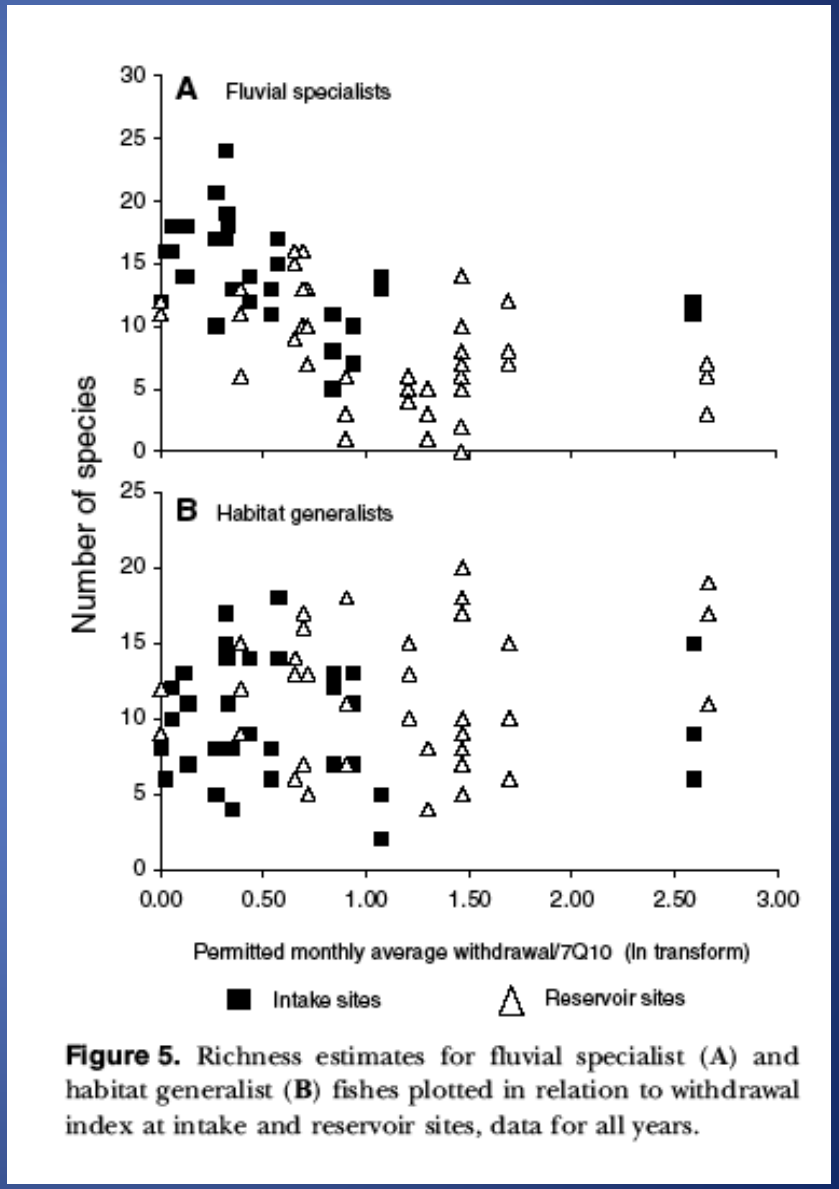


Figure 5. Richness estimates for fluvial specialist (**A**) and habitat generalist (**B**) fishes plotted in relation to withdrawal index at intake and reservoir sites, data for all years.

USGS science for a changing world