Functions Lost, Functions Gained: Can Stream Mitigation Work?

Will Harman, PG
Stream Mechanics

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Overview of Presentation

- Functions Lost – Our war against the river.
- Functions Gained – Our attempts at restoration.
- Understanding and working with stream functions.
- Developing stream mitigation debits and credits.

Love of Channelization

- From 1820 to 1970, more than 200,000 miles of streams and rivers were channelized to reduce flooding, provide drainage for agriculture, and improve navigation

Wohl, E.E., 2004. Disconnected Rivers, Linking Rivers to Landscapes. Yale University, New Haven, Connecticut.

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Functions Lost from Channelization

- Less water and sediment storage on previous floodplain
- Loss of bed form diversity (habitat)
- Increased incision and widening (erosion)
- Loss of fish species and biomass

Darby, S.E. and C.R. Thornes, 1992. Impact of Channelization on the Mimmshall Brook, Hertfordshire, UK. Regulated Rivers 7:193-204.

Hupp, C.R., 1992. Riparian Vegetation Recovery Patterns Following Stream Channelization: A Geomorphic Perspective. Ecology 73:1209-1226.

Kroes, D.E. and C.R. Hupp, 2010. The Effect of Channelization on Floodplain Sediment Deposition and Subsidence Along the Pocomoke River, Maryland. Journal of the American Water Resources Association 46(4):686-699.

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Incised Versus Non-Incised Channels

- Incised channel had turbidity and suspended solids levels that were 2 to 3 times higher than the non-incised channel.
- Total Phosphorus, total Kjeldahl nitrogen, and chlorophyll a concentrations were significantly higher in the incised channel.
- Twice as many fish species with four times the amount of biomass in the non-incised stream.

Shields, Jr., F.D., R.E. Lizotte, Jr., S.S. Knight, C.M. Cooper, and D. Wilcox, 2010. The Stream Channel Incision Syndrome and Water Quality. Ecological Engineering 36:78-90.

Incised Versus Non-Incised Channels

- Correlation analysis showed that hydrologic problems were associated with water quality degradation
- Ecological engineering (restoration) should focus as much attention on mediating hydrologic problems and habitat as on pollutant loading.

Shields, Jr., F.D., R.E. Lizotte, Jr., S.S. Knight, C.M. Cooper, and D. Wilcox, 2010. The Stream Channel Incision Syndrome and Water Quality. Ecological Engineering 36:78-90.

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Lots of Issues?

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Direct and Indirect Impacts

Direct

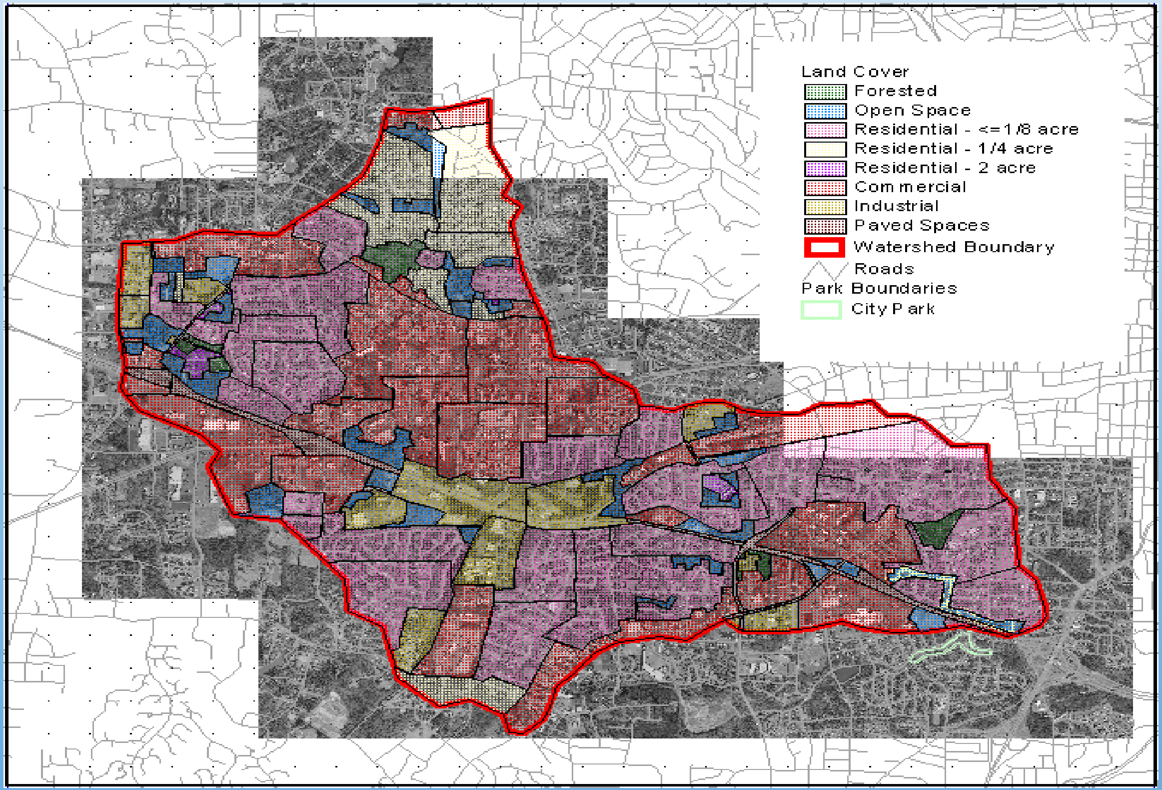
- Flow Regulation
- Channelization and levees
- In-channel mining
- Beaver trapping
- Wastewater effluent
- Floodplain encroachment
- Snagging and removal of wood

Indirect

- Timber harvest
- Agriculture
- Urbanization
- Mining (I added)

Wohl, E.E. 2004. *Disconnected Rivers*. Yale University Press, New Haven & London

How do we match problems (Issues) with restoration approaches?



What is restoration?

"Stream restoration is a catchall term used to describe a wide range of management actions and as such is difficult to define. The definition of stream restoration can vary with the perspective or discipline of the practitioner or with the temporal and spatial scale under consideration."

Simon et al,. 2011. *Stream Restoration in Dynamic Fluvial Systems: Scientific Approaches, Analyses, and Tools*. American Geophysical Union, Washington, DC.

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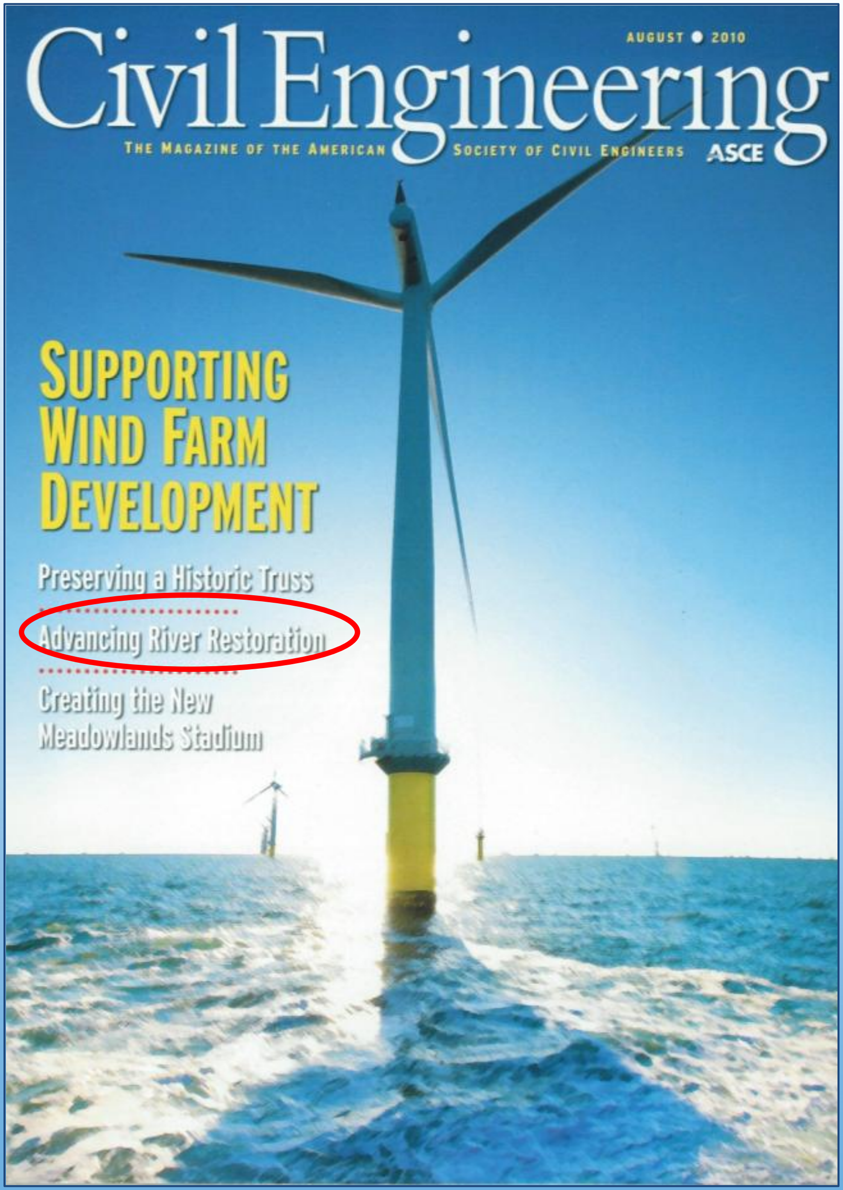

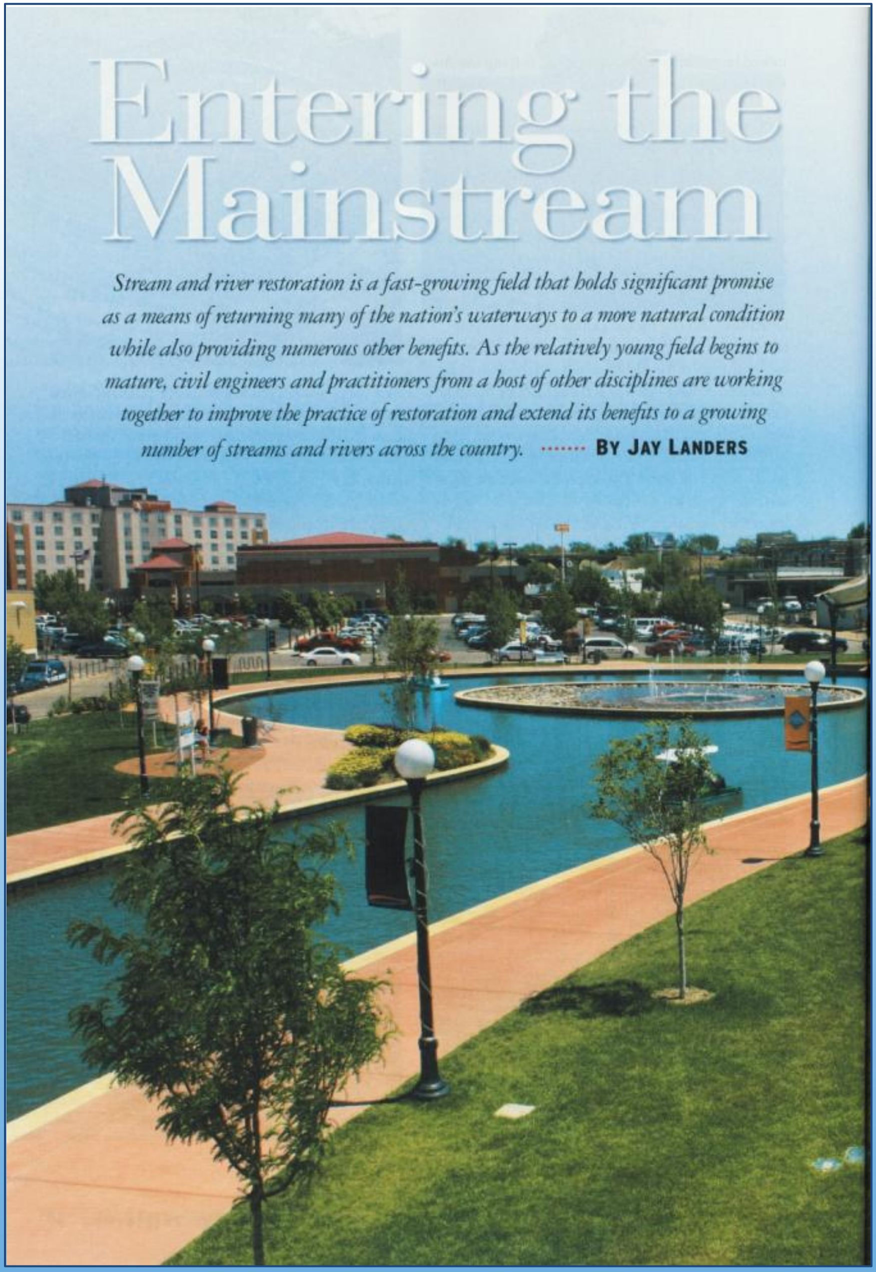

Entering the Mainstream

Stream and river restoration is a fast-growing field that holds significant promise as a means of returning many of the nation's waterways to a more natural condition while also providing numerous other benefits. As the relatively young field begins to mature, civil engineers and practitioners from a host of other disciplines are working together to improve the practice of restoration and extend its benefits to a growing number of streams and rivers across the country. ······· **BY JAY LANDERS**

Stream Function Perspectives

Engineers

Geologists

Ecologists

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"Restoration means the manipulation of the physical, chemical, or biological characteristics of a site with the goal of returning **natural/historic functions** to a former or degraded aquatic resource."

- Re-establishment
- Rehabilitation

2008 Federal Mitigation Rule: 33 C.F.R. § 332/40 C.F.R. § 230

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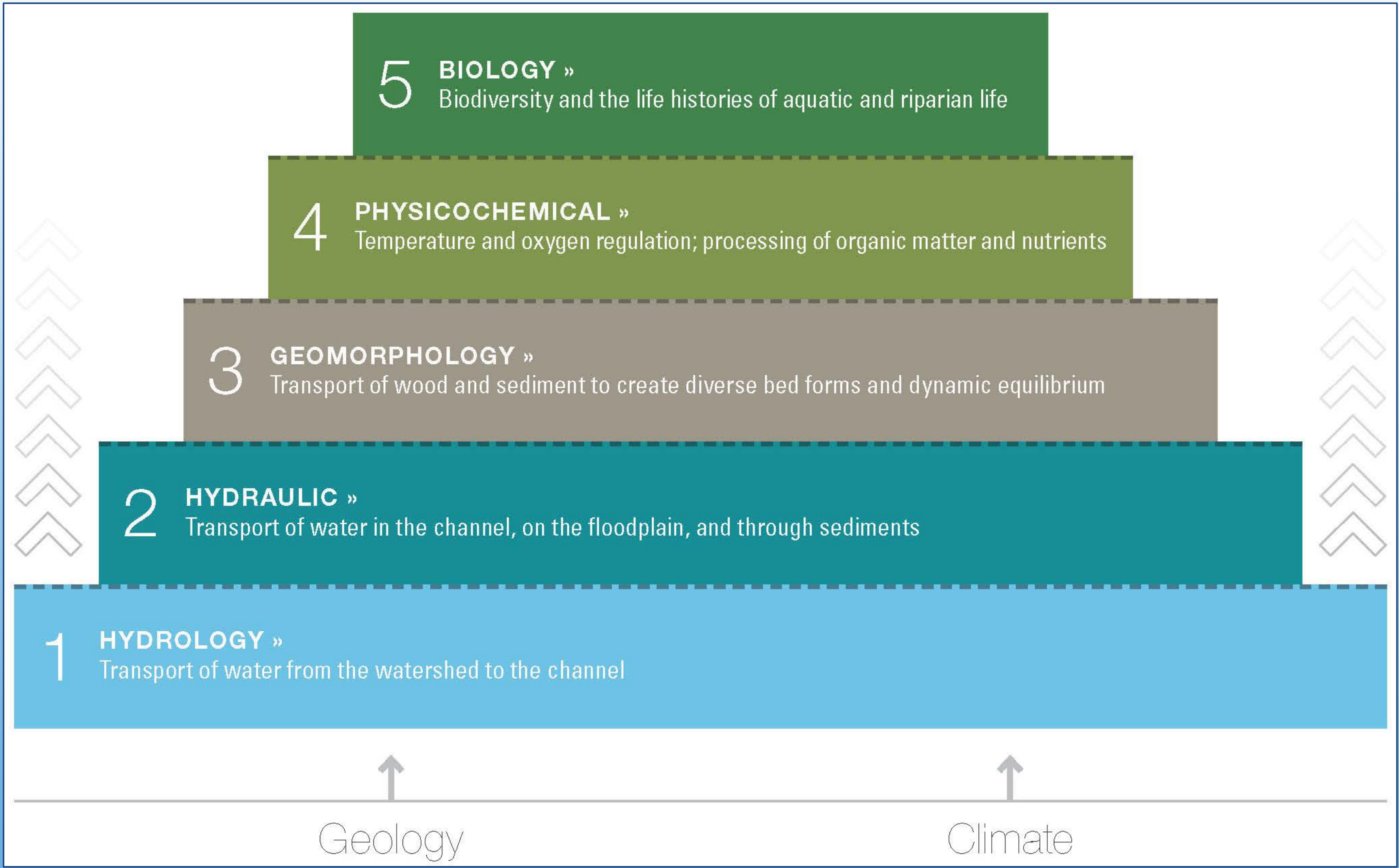
What is restoration?

- Restoring lost functions

OR

- Restoring to a pre-disturbed condition

Stream Functions Pyramid



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Stream Functions Pyramid Framework

Broad Level View (Stream Functions Pyramid)

Functional Categories

Functional Statements

↓

Function-Based Parameters

Describes/Supports Functional Statement

↓

Measurement Methods

Quantifies Function-Based Parameter

↓

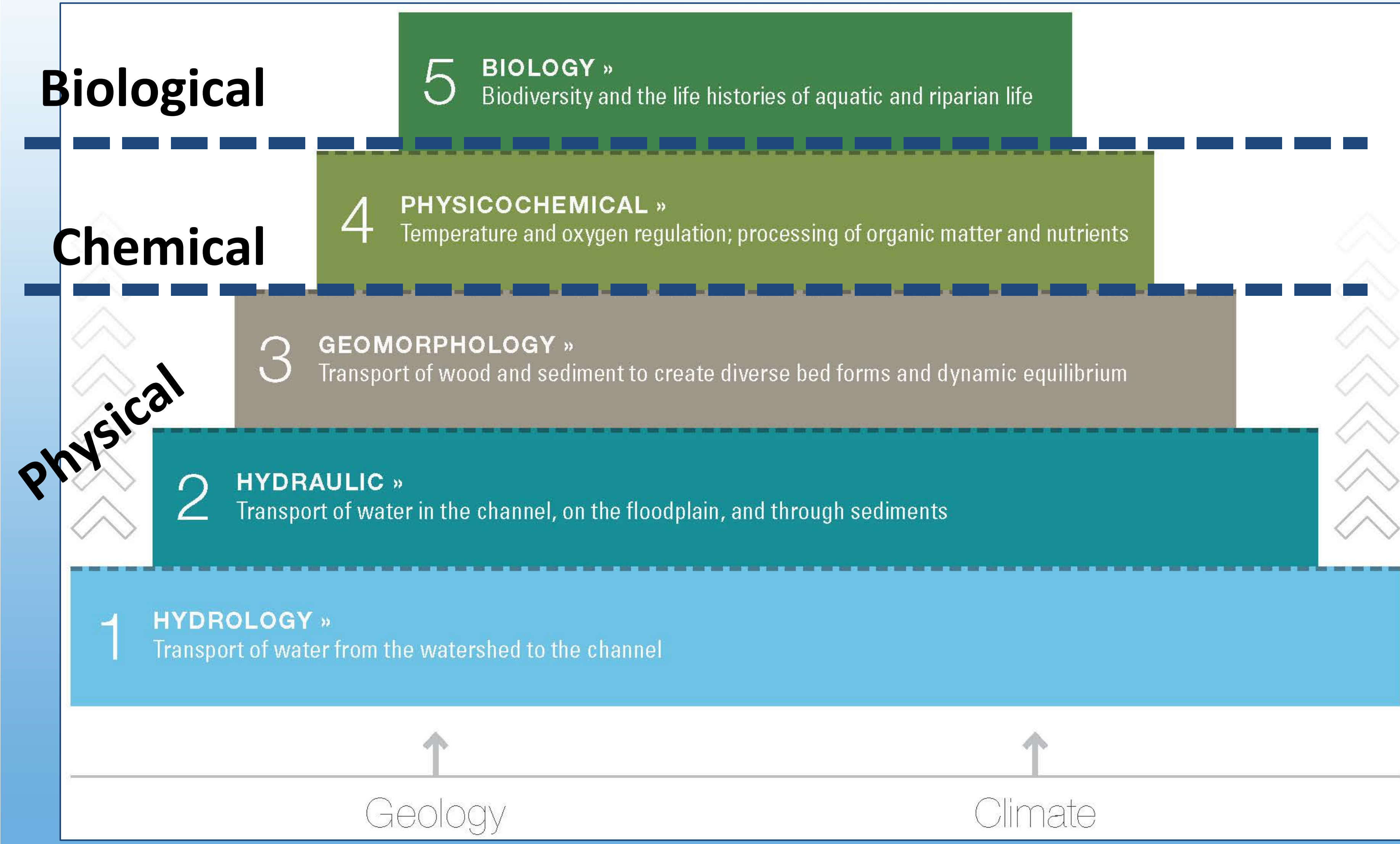
Performance Standards

Functioning

Functioning-At-Risk

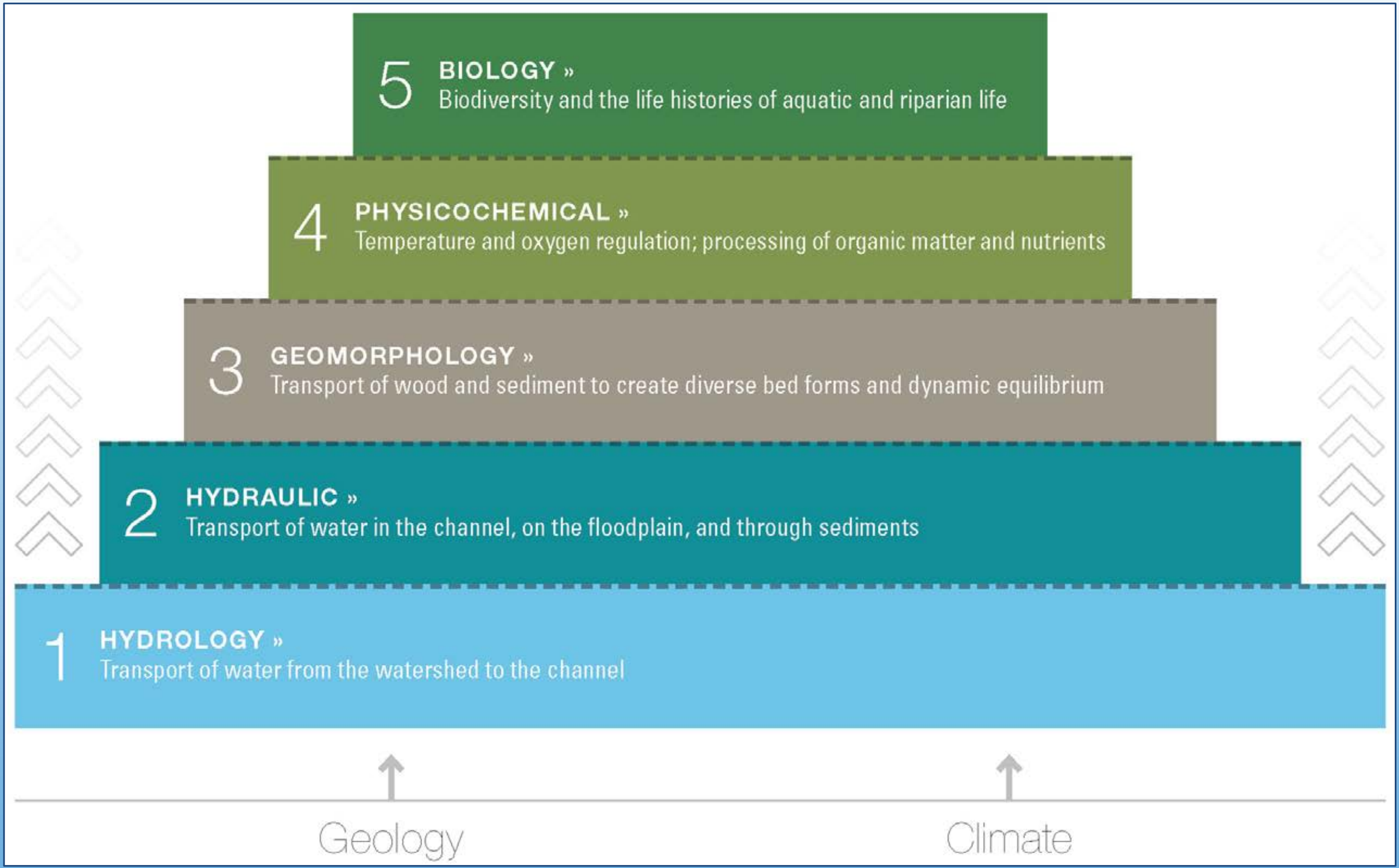
Not Functioning

Function - The physical, chemical, and biological processes that occur in ecosystems.



Effect

Cause



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Pyramid and Parameters

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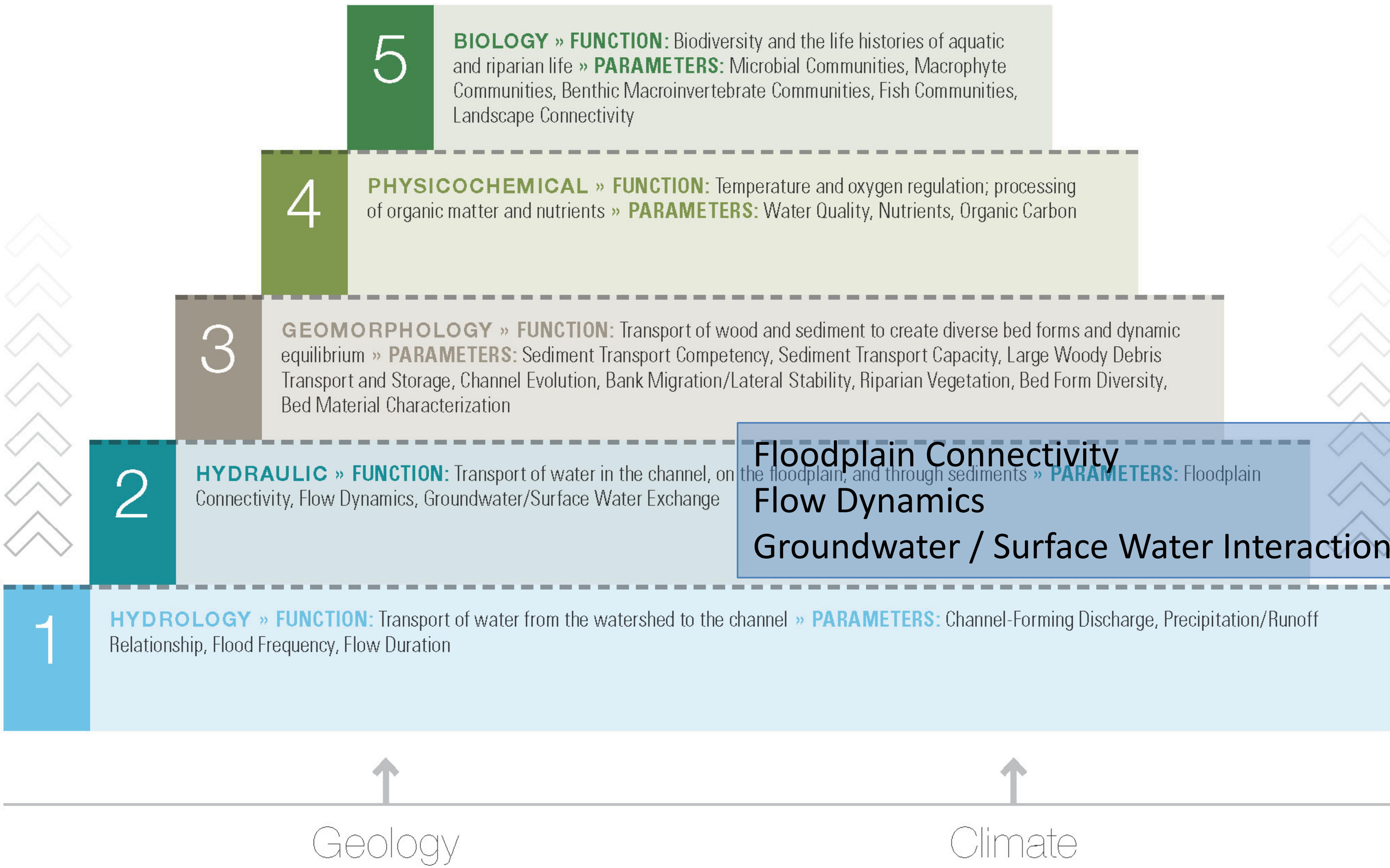
Pyramid and Parameters



Floodplain Connectivity
Flow Dynamics
Groundwater / Surface Water Interaction

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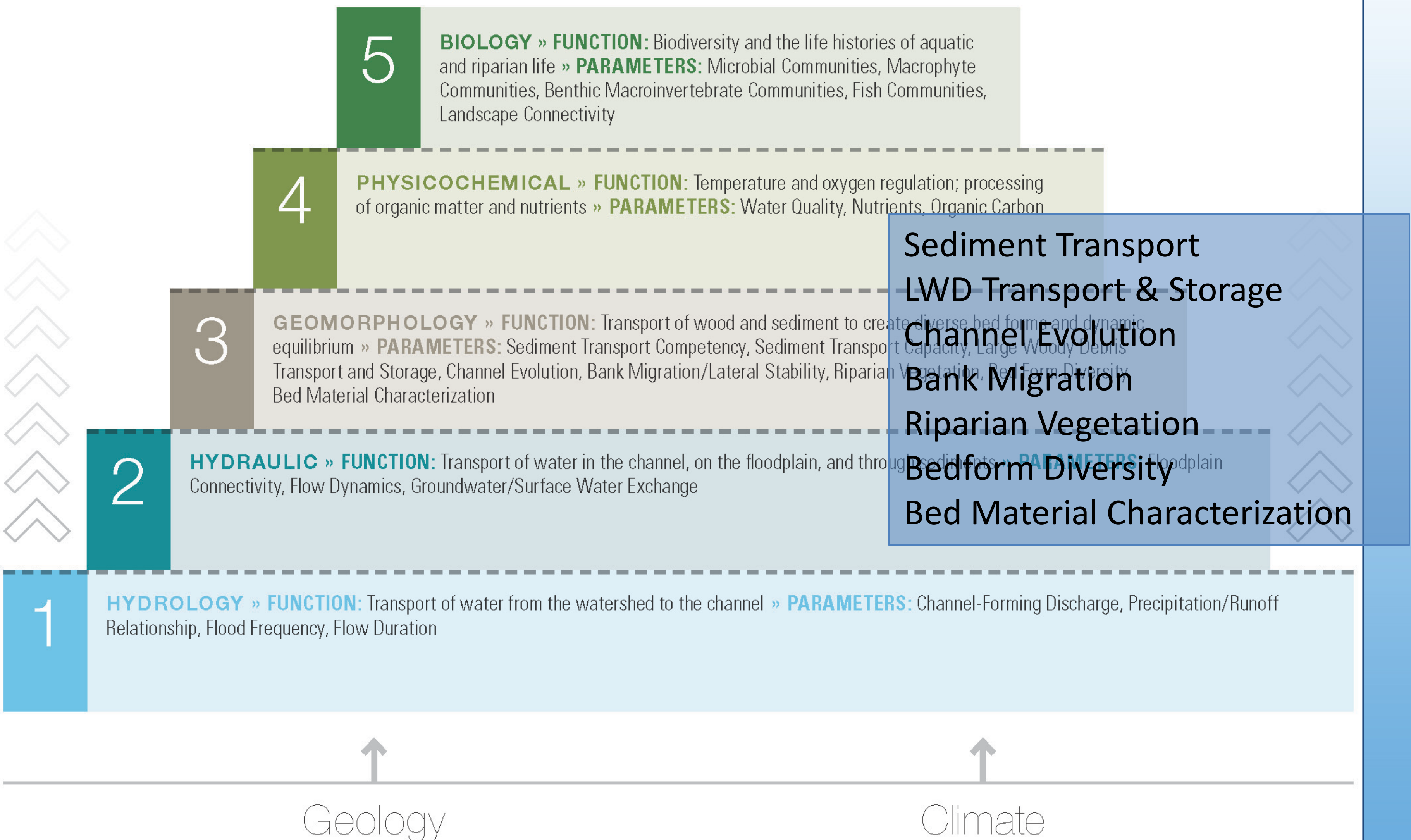
Pyramid and Parameters



Pyramid and Parameters

Pyramid and Parameters

Macroinvertebrate Communities
Fish Communities
Microbial Communities
Landscape Connectivity

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Parameters and Measurement Methods

APPENDIX A.c. Parameters and Measurement Methods

HYDROLOGY	
Parameter	**Measurement Method**
Channel-Forming Discharge	1. Regional Curves
Precipitation/Runoff Relationship	1. Rational Method 2. HEC-HMS 3. USGS Regional Regression Equations
Flood Frequency	1. Bulletin 17b
Flow Duration	1. Flow Duration C 2. Crest Gage 3. Monitoring Devi 4. Rapid Indicators

HYDRAULICS	
Parameter	**Measurement Meth**
Floodplain Connectivity	1. Bank ht Rati 2. Entre ment R 3. Stag versus Dis
Flow Dynamics	1. Stream Velocity 2. Shear Stress 3. Stream Power
Groundwater/Surface Water Exchange	1. Piezometers 2. Tracers 3. Seepage Meters

BIOLOGY	
Parameter	**Measurement Method**
Microbial Communities	1. Taxonomic Methods 2. Non-Taxonomic Methods 3. Biological Indices
Macrophyte Communities	1. Taxonomic Methods 2. Non-Taxonomic Methods 3. Biological Indices
Benthic Macroinvertebrate Communities	1. Taxonomic Methods 2. Non-Taxonomic Methods 3. Biological Indices
Fish Communities	1. Taxonomic Methods 2. Non-Taxonomic Methods 3. Biological Indices
Landscape Connectivity	1. Spatial Analysis 2. Species Tracking 3. Habitat Models

GEOMORPHOLOGY	
Parameter	**Measurement Method**
Sediment Transport Competency	1. Shear Stress Curve 2. Required Depth and Slope 3. Spreadsheets and Computer Models
Sediment Transport Capacity	1. Computer Models 2. FLOWSED and POWERSED
	2. Buffer Density 3. Buffer Composition 4. Buffer Growth 5. Canopy Density 6. Proper Functioning Condition (PFC)
Bed Form Diversity	1. Percent Riffle and Pool 2. Facet Slope 3. Pool-to-Pool Spacing 4. Depth Variability
Bed Material Characterization	1. Bevenger and King (1995) 2. Riffle Stability Index (RSI)

PHYSIOCHEMICAL	
Parameter	**Measurement Method**
Basic Water Chemistry	1. Temperature 2. Dissolved Oxygen 3. Conductivity 4. pH 5. Turbidity
Nutrients	1. Field test kits using reagents reactions 2. Laboratory analysis
Organic Carbon	1. Laboratory analysis

Parameter	Measurement Method
Floodplain Connectivity	1. Bank Height Ratio 2. Entrenchment Ratio 3. Stage/Q Relationships

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Performance Standards
Floodplain Connectivity Example

Measurement Method	Functioning	Functioning-At-Risk	Not Functioning
Bank Height Ratio (BHR)	1.0 to 1.2	1.3 to 1.5	> 1.5
Entrenchment Ratio (ER) for C and E Stream Types	> 2.2	2.0 to 2.2	< 2.0
Entrenchment Ratio (ER) for B and Bc Stream Types	> 1.4	1.2 to 1.4	< 1.2
Dimensionless rating curve	Project site Q/Q_{bkf} plots on the curve	Project site Q/Q_{bkf} plots above the curve	Project site Q/Q_{bkf} of 2.0 plots above 1.6 for $d/_{dbkf}$

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Why use the Stream Functions Pyramid

- Shifts the conversation from dimension, pattern and profile to functions (processes).
  - Improves goal setting.
- Provides a framework for showing functional lift.
- Food for thought for credit determination

This is a Framework

- Users can add Function-Based Parameters, Measurement Methods, and Performance Standards to fit their region and project goals.
- Function-Based Parameter
  - Helps to describe/understand the functional statement
- Measurement Method
  - A measure of the Function-Based Parameter
- Performance Standards
  - Functional Capacity
  - Tied to Measurement Method

Applications

Function-Based Assessments

Goals and Objectives

Debit and Credit Determination

And Beyond

Goals and Objectives

- **Well articulated goals help lead to project success**.
- Goals
  - Should help identify **why** the project is proposed.
  - Can be intangible.
  - Should relate to a function.
- Objectives
  - More specific, tangible. Describes **what** or **how**.
  - Tied to a function-based parameter, measurement method and performance standard.

Bad Goal

The goal of this project is to improve habitat

Better Habitat Goals

The goal of this project is to improve native brook trout habitat (Levels 1-3).

Even better – The goal of this project is to increase the biomass of native brook trout populations (Levels 1-5).

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Quantitative Brook Trout Objectives

- Determine that pH is between 6.5 to 8.0 (Level 4)
- Create water temperature of 11 to 16^{o} C (Level 4)
- Create pool habitat of 40 to 60 percent (Level 3)
- Create 3 to 80 mm diameter substrate for spawning (Level 3)
- Create velocities of 2.8 to 4.3 ft/sec (Level 2)

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Source: Michael Baker Corporation

Source: Michael Baker Corporation

Restoring native trout in suburban / urban environments??

Bad Goal

~~The goal of this project is to improve water quality.~~

Temperature
Dissolved Oxygen

pH
Conductivity

Nitrate-Nitrogen
Phosphorus

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Better Water Quality Goal

The goal addresses a functional problem

- The goal of this project is to reduce NO_3-N concentrations from adjacent land uses (Level 4).

The objective tells what will be done to improve the function

- The objectives are to:
  - Provide floodplain connectivity (Level 2)
  - Establish a 100 foot riparian buffer (Level 3)
  - Improve bedform diversity (Level 3)
  - Increase sinuosity to reduce velocities (Level 2 and 3)

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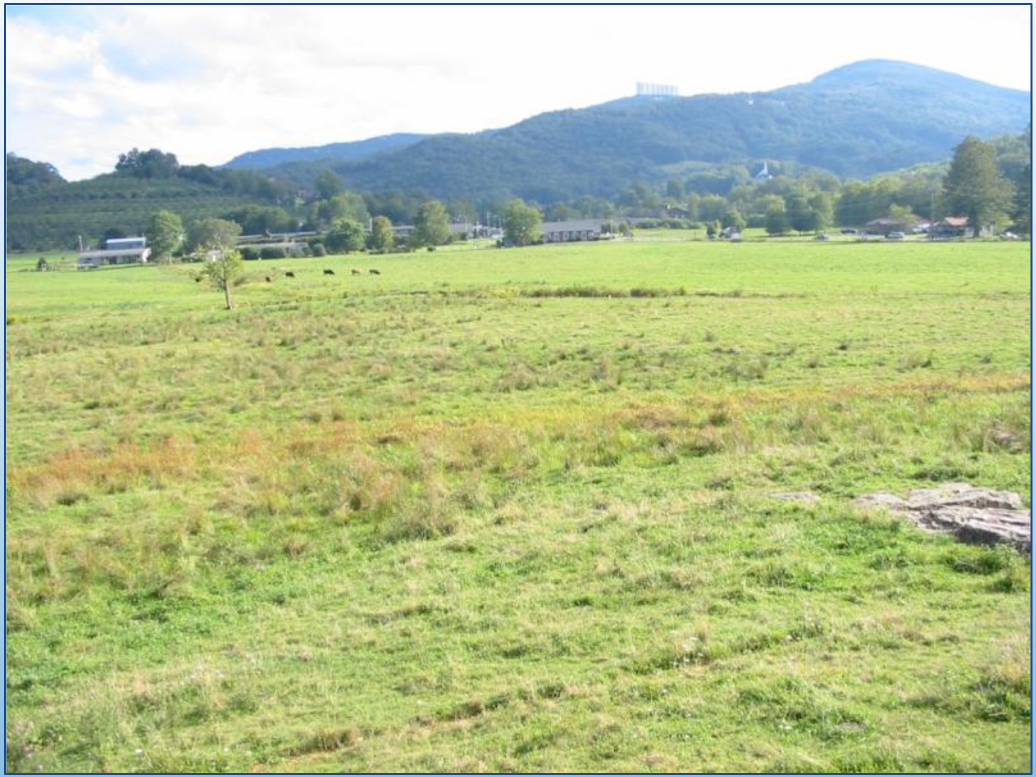

Source: Michael Baker Corporation

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Functional Lift

Source: Michael Baker Corp

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Functional Lift

Level and Category	Parameter	Measurement Method	Pre-Restoration Condition		Post-Restoration Condition	
			Value	Rating	Value	Rating
1 - Hydrology						
2 - Hydraulics						
3 – Geomorphology						
4- Physicochemical						
5 – Biology						

Showing Functional Lift

Existing Condition

Source: Michael Baker Corp

Restored Condition

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Level and Category	Parameter	Measurement Method	Pre-Restoration Condition		Post-Restoration Condition	
			Value	Rating	Value	Rating
1 - Hydrology	N/A					
2 - Hydraulics	**Floodplain Connectivity**	Bank Height Ratio	3.0	**Not Functioning**	1.0	**Functioning**
		Entrenchment Ratio	1.1	**Not Functioning**	20	**Functioning**
3 – Geomorphology	**Bed Form Diversity**	Pool-to-pool spacing	>6.0	**Not Functioning**	4 to 5	**Functioning**
		Depth Variability	<1.1	**Not Functioning**	>1.2	**Functioning**
	Lateral Stability	BEHI/NBS	High/High	**Not Functioning**	Low/Low	**Functioning**
	Riparian Vegetation	USFWS SAR	No zones of vegetation represented	**Not Functioning**	All three zones represented	**Functioning**

Level and Category	Parameter	Measurement Method	Pre-Restoration Condition		Post-Restoration Condition	
			Value	Rating	Value	Rating
4 - Physicochemical	**Water Quality**	Temperature	Meets WQ stds. Not rep of ref cond.	**Functioning-At-Risk**	Meets WQ stds. Meets ref condition	**Functioning**
		Dissolved Oxygen	Meets WQ stds. Not rep of ref cond.	**Functioning-At-Risk**	Meets WQ stds. Meets ref condition	**Functioning**
5 – Biology	**Fish Communities**	Upstream / downstream monitoring	Does not meet upstream reference condition	**Not Functioning**	Does meet upstream reference condition	**Functioning**

Included with all Functional Lift Assessments

- Floodplain Connectivity
- Bedform Diversity
- Lateral Stability
- Riparian Buffer
- Water Quality Screening
  - pH
  - Conductivity

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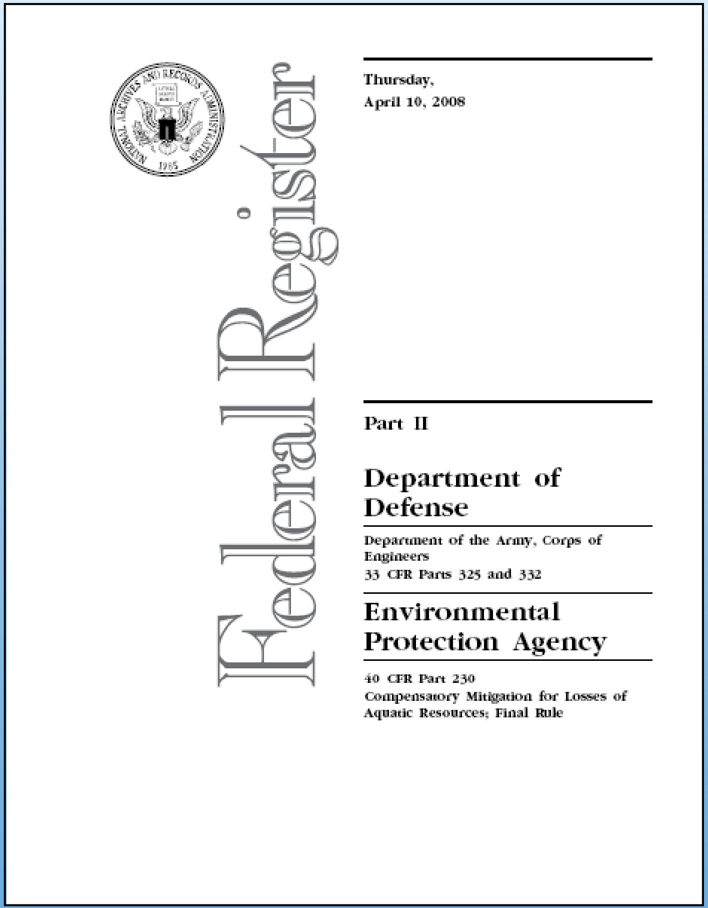
Fun with Mitigation Debits and Credits


Federal Register

Thursday,
April 10, 2008

Part II

Department of Defense

Department of the Army, Corps of Engineers
33 CFR Parts 325 and 332

Environmental Protection Agency

40 CFR Part 230
Compensatory Mitigation for Losses of Aquatic Resources; Final Rule

Credit Production

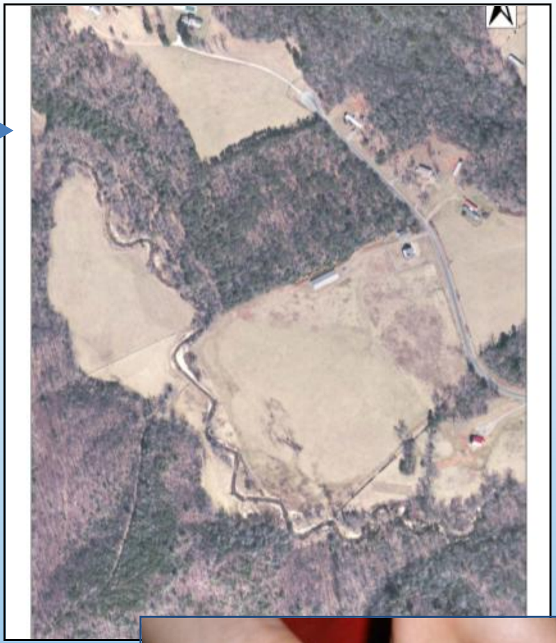
- The number of credits should reflect the difference between pre- and post-compensatory mitigation project site conditions, as determined by a functional or condition assessment or other suitable metric.

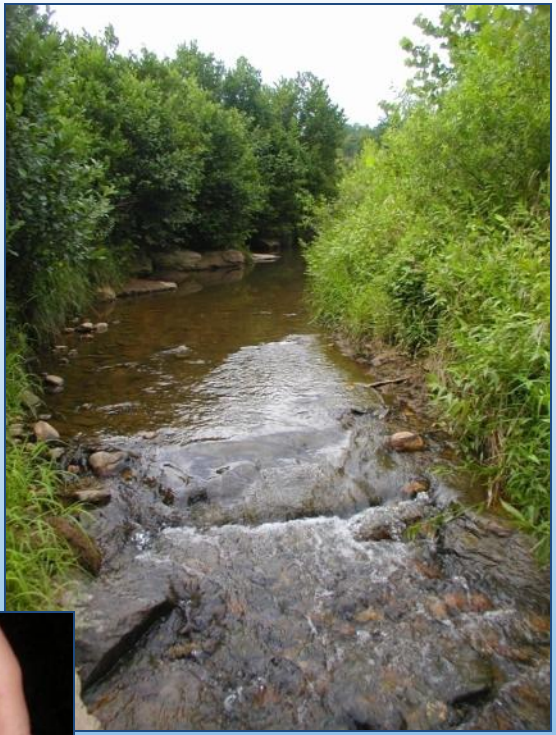
Source: Michael Baker Corp

Restoration 1

Healthy Watershed

Reach Scale Restoration





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Restoration 2

Impaired Watershed

Reach Scale Restoration

Restoration 1 Credits

- Reach scale restoration downstream of healthy watershed.
- High probability of restoring **Level 5** functions.
- Maximum credits. I like 1.0 credit/ft

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Restoration 2 Credits

- Reach scale restoration downstream of impaired watershed.
- High probability of restoring **Level 3** functions.
- Maximum credits < Restoration 1, maybe 0.8 credits/ft

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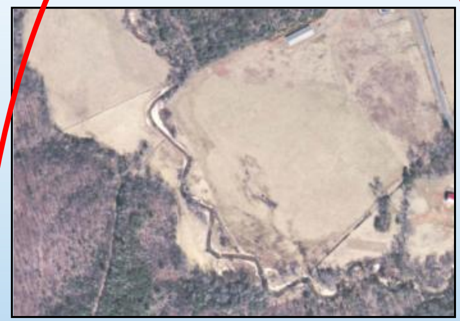
Healthy Watershed + Reach Scale Restoration = Restoration 1

+



Levels 2 - 3

=

Levels 4 - 5

Impaired Watershed + Reach Scale Restoration = Restoration 2

+

Levels 2 - 3

=

Levels 2 - 3

Key Function-Based Parameters Restored with Restoration 1 and 2

- For restoring channelized streams in alluvial valleys. Restoration 1 and 2
  - Floodplain Connectivity
  - Bed form diversity
  - Riparian Vegetation
  - Lateral Stability
- Restoration 1 – Add Level 4 and 5 Function-Based Parameters

= Functional Loss

= More Functional Loss

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Restoration 2

Restoration 1

Debit and Credit Template Structure

- Debits
  - Debit Template 1: Functional **Loss** Determination
  - Debit Template 2: Pre- and Post-**Disturbance** Condition and Rationale
  - Debit Template 3: **Debit** Determination
- Credits
  - Credit Template 1: Functional **Lift** Determination
  - Debit Template 2: Pre- and Post-**Restoration** Condition and Rationale
  - Debit Template 3: **Credit** Determination

Debit Template 3

Pre-Disturbance Condition	**Post-Disturbance Condition**			
	No Functional Loss	**Low to Moderate Functional Loss**	**Moderate to High Functional Loss**	**Debit Adjustment (+/-)**
Low (Mix of FAR and NF)	(Post-disturbance condition matches pre-disturbance condition)	Greater number of FAR and NF scores. **1.1 to 1.2**	Mostly NF scores **1.2 to 1.3**	**0.1**
Moderate (Mix F, FAR, NF)	No Mitigation Required	Loss of F scores and/or greater number of FAR and NF scores. **1.3 to 1.5**	Mix of FAR and NF scores **1.5 to 1.7**	**0.1**
High (F)		Mix of F, FAR, and NF **1.7 to 1.9**	Mix of FAR and NF scores **2.0**	**0.2**

Credit Template 3

Restoration 1

Credit Categories	Pre-Restoration Condition	Post-Restoration Condition	Credits Per Foot
Maximum Lift	All parameters in Levels 2 and 3 have NF scores. Parameters in Levels 4 and 5 are NF or FAR.	Functioning scores for Levels 1-5.	0.8 to 1.0
Moderate Lift	Mix of NF and FAR scores for parameter Levels 2 through 5.	Functioning scores for Levels 1-5.	0.6 to 0.8
Low Lift	Mostly F and FAR scores for parameters in Levels 2 through 3. May include small number of NF scores.	Functioning scores for Levels 1-5.	0.4 to 0.6

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Can stream mitigation achieve no-net loss goals?

- Yes, but maybe not for all functions.
- Requires reach scale restoration and proper site selection criteria
- We need two levels of restoration
  - Restoration 1 = Restoration of all five levels
  - Restoration 2 = Restoration through level 3

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Wilson Creek, KY

- Restoration using Natural Channel Design
- Undisturbed upstream control reach
- 2 year post restoration study
- Temperature was higher in restored reach
- NO_3-N decreased from 0.63 to 0.3 mg/l from control to restored reach
- Velocity reduction in restored reach
- LWD recruitment in restored reach

Andrews, Danielle M., Christopher D. Barton, Randall K. Kolka, Charles C. Rhoades, and Adam J. Dattilo, 2011. Soil and Water Characteristics in Restored Canebrake and Forest Riparian Zones. Journal of the American Water Resources Association (JAWRA) 47(4):772-784. DOI: 10.1111/j.1752-1688.2011.00555.x

Stream Restoration at Duke University

- Stream restoration and BMPs in urban watershed.
- NO_2+NO_3 loads were reduced by 64%.
- Phosphorus loads were reduced by 28%.
- Sediment retention in riparian wetlands showed accretion rate 1.1cm/ yr.

Richardson, C.J., N.E. Flanagan, M.Ho, J.W. Pahl, 2010. Integrated stream and wetland restoration: A watershed approach to improved water quality on the landscape. Ecological Engineering.

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The Future

- Restoration approaches are improving and becoming more refined.
- Doing a better of job of matching an approach with the problem.
- Innovation is happening.

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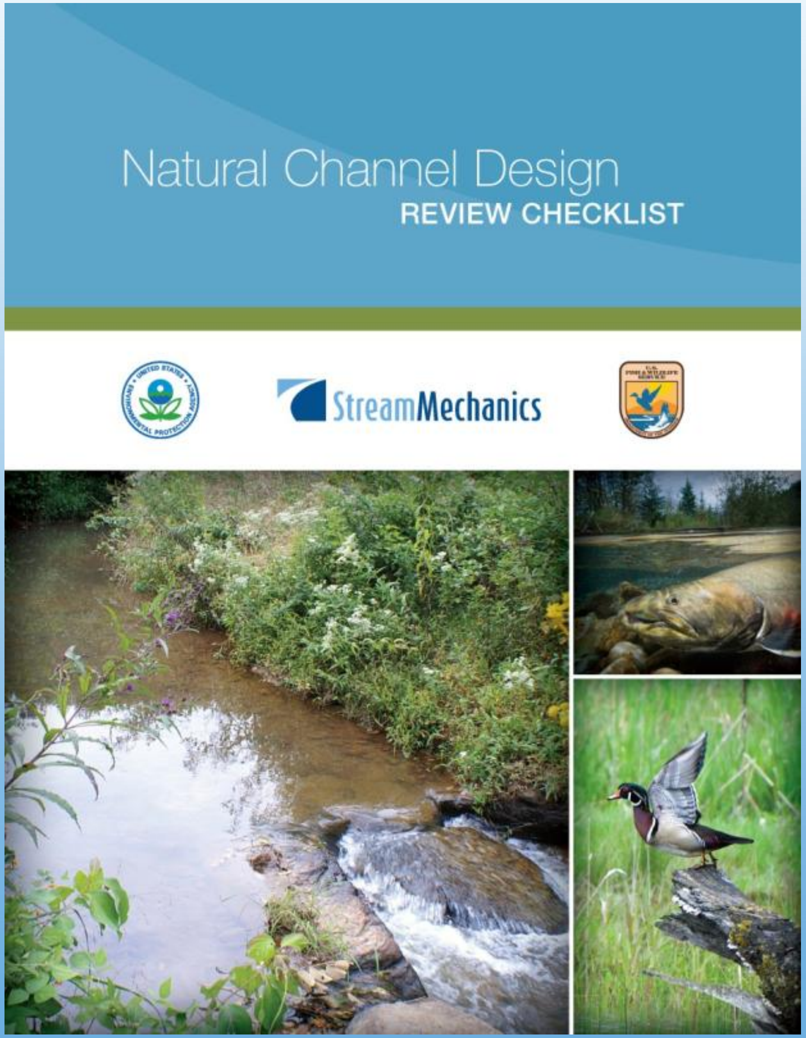
Potential Next Steps

- Natural Channel Design
- Natural Channel Design Review Checklist



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For More Information

- **Download Document**
  - www.stream-mechanics.com
  - http://water.epa.gov/lawsregs/guidance/wetlands/wetlandsmitigation_index.cfm
  - http://www.fws.gov/chesapeakebay/stream.html
- **Workshop**
  - December 4-7, 2012. Raleigh, NC. Register at www.stream-mechanics.com

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  - Rich Starr, FWS