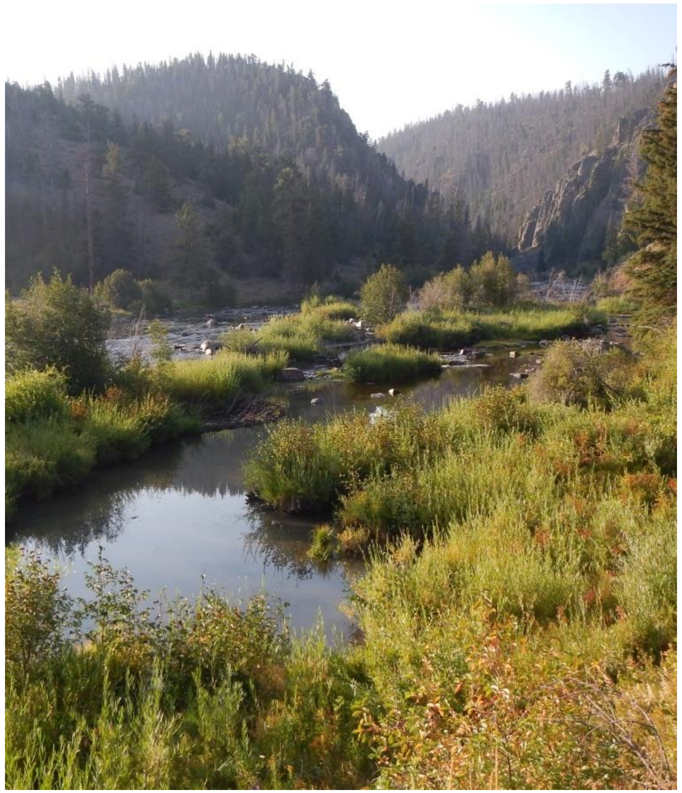


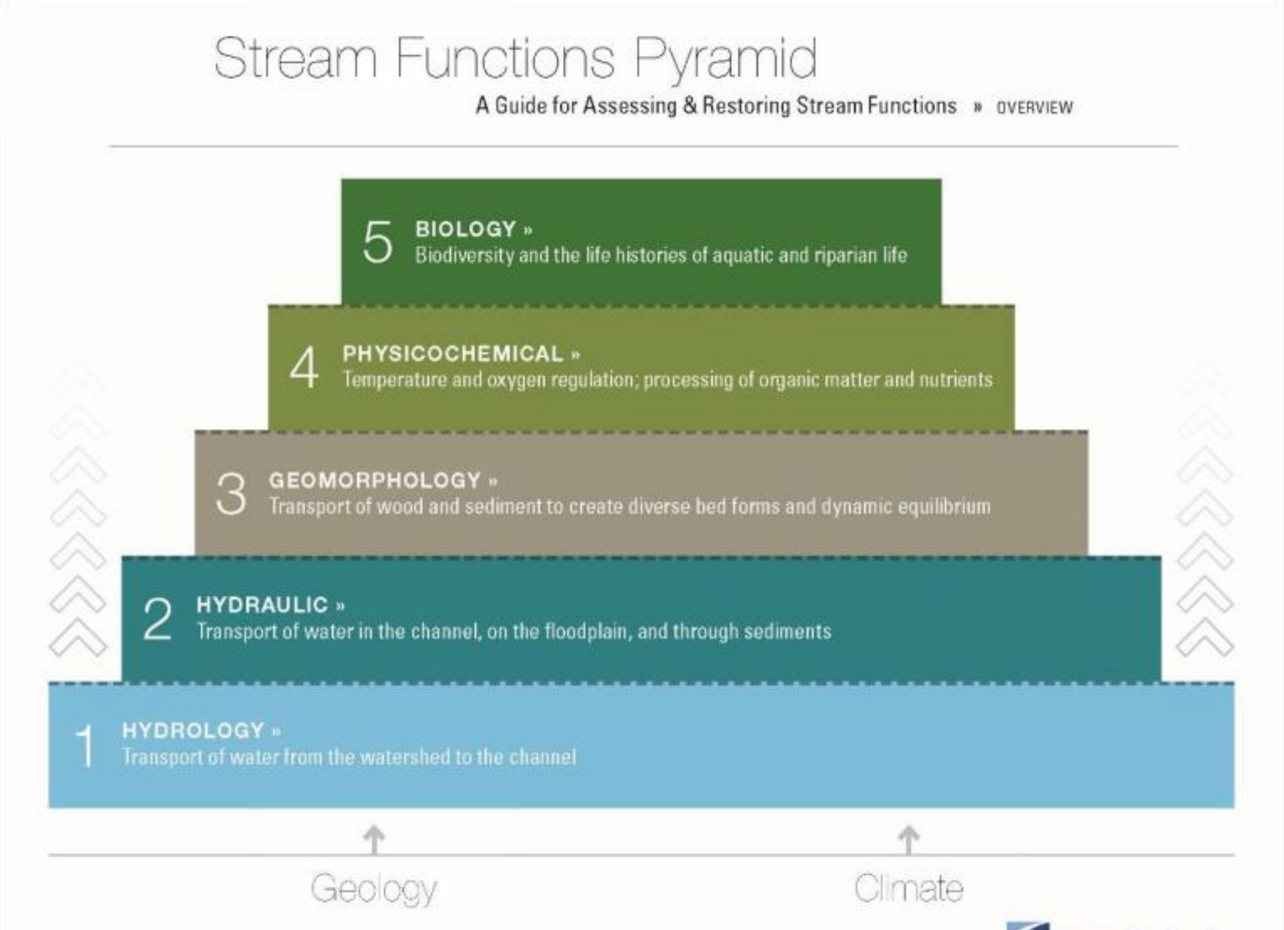


Rethinking The Stream Functions Pyramid

Sustaining Colorado Watersheds Conference
"The Human Element"
October 9th, 2019

Brian Clarke and Brian Murphy

Stream Functions Pyramid Framework



Harman, 2012

Developed to meet the needs for:

- Streamlined compensatory mitigation/regulation tool to assess lift/loss (debits/credit)
- Simplified/standardized assessment framework
- Easily communicated to public, private, and non-profit organizations and agencies

Conceptual Principals:

- Stream functions are a nested "hierarchy that occur and should be addressed in a particular order"
- Lower functions support secondary higher functions – (predominantly) as a one-way influence
- Successful Physicochemical/Biologic restoration starts by assessing/addressing lower functions

Stream Functions Pyramid Framework

Functional Category	Parameter from the Function-Based Framework	Included in WSQT (Yes/No)
Hydrology	Channel Forming Discharge	No
	Precipitation/Runoff Relationship	No
	Flood Frequency	No
	Flow Duration	No
	Reach Runoff**	Yes
	Baseflow Alteration**	Yes
Hydraulics	Flow Dynamics	No
	Groundwater/Surface Water Exchange	No
	Floodplain Connectivity	Yes
Geomorphology	Channel Evolution	No
	Sediment Transport Competency and Capacity	No
	Large Woody Debris	Yes
	Bank Migration/Lateral Stability	Yes
	Bed Material Characterization	Yes
	Bed Form Diversity	Yes
	Plan Form**	Yes
	Riparian Vegetation	Yes
Physicochemical	Organic Carbon	No
	Bacteria**	No
	Water Quality (Dissolved Oxygen, pH, and Conductivity)	No
	Water Quality (Temperature)	Yes
	Nutrients	Yes
Biology	Macrophyte Communities	No
	Microbial Communities	No
	Landscape Connectivity	No
	Macroinvertebrate Communities	Yes
	Fish Communities	Yes

Harman, 2012

The SFPF is being implemented and used through the WSQT, CSQT, and others areas across the US as a regulatory, assessment, and design tool

- Provides simplified functions-based parameters to quantify lift/loss (debit/credit)
- Parameters can be scored based on performance standards set by reference reaches (functioning, functioning at risk, not functioning)

Challenges

- Many key parameters are not commonly used for assessments
- Functional parameters are assessed on a 1:1 basis without capturing the links and feedbacks between functions (can be interpreted but not specifically utilized)
- Developed for and applicable to limited stream types - (primarily) single thread, low response potential channels. In more complex systems the assessment framework "falls apart"
- Function-based parameters assessed based on existing conditions/form – capturing a snapshot in time. Does not capture changing, modified, or urbanized systems
- Scoring of stream systems is relative to natural reference reaches or streams…is that appropriate?

Step Back to *"Functional Objectives for Stream Restoration"* (Fischenich, 2006)

The inspiration for the Stream Functions Pyramid

System Dynamics	Hydrologic Balance	Sediment Processes and Character	Biological Support	Chemical Processes and Pathways
Stream Evolution Processes	Surface Water Storage Processes	Sediment Continuity	Biological Communities and Processes	Water and Soil Quality
Energy Management	Surface / Subsurface Water Exchange	Substrate and Structural Processes	Necessary Habitats for all Life Cycles	Chemical Processes and Nutrient Cycles
Riparian Succession	Hydrodynamic Character	Quality and Quantity of Sediments	Trophic Structures and Processes	Landscape Pathways

5 Functional Categories

15 Primary Functions

Summary of Primary Function Interactions

Rank	Function	Functions Directly Affected[1]	Functions Indirectly Affected[1]
1	Hydrodynamic Character	2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 14, 15	13
2	Stream Evolution Processes	1, 3, 4, 5, 6, 7, 8, 10, 11, 12, 14, 15	9, 13
3	Surface Water Storage Processes	1, 4, 6, 10, 11, 12, 14, 15	2, 5, 7, 8, 9, 13
4	Sediment Continuity	3, 5, 6, 7, 8, 9, 11, 15	1, 13, 14
5	Riparian Succession	1, 2, 3, 4, 6, 12, 14, 15	9, 13
6	Energy Management	1, 2, 3, 4, 5, 7, 8, 15	-
7	Substrate and Structural Processes	1, 2, 4, 6, 7, 10, 15	5, 9, 11, 13
8	Quality and Quantity of Sediments	2, 4, 5, 6, 7, 10, 15	1, 9, 11, 14
9	Biological Communities and Processes	5, 11, 13, 14, 15	1, 2, 3, 7, 8, 10, 12
10	Surface / Subsurface Water Exchange	1, 5, 11, 15	3, 9, 12, 13
11	Water and Soil Quality	8, 9, 13, 14	5
12	Landscape Pathways	9, 13, 14, 15	6
13	Trophic Structures and Processes	9, 11, 14	8
14	Chemical Processes and Nutrient Cycles	8, 9, 13	6
15	Necessary Habitats for all Life Cycles	9, 12, 13	-

- Fischenich's key suggestion is that that there are strong interrelated feedbacks between the primary functions, such that no primary function can be impacted without affecting other functions
- Although some functions are more predominant than others, no function can be impacted without "reverberating" through the system

Links Between Functional Frameworks

Primary Functions

System Dynamics	Hydrologic Balance	Sediment Processes and Character	Biological Support	Chemical Processes and Pathways
Stream Evolution Processes	Surface Water Storage Processes	Sediment Continuity	Biological Communities and Processes	Water and Soil Quality
Energy Management	Surface / Subsurface Water Exchange	Substrate and Structural Processes	Necessary Habitats for all Life Cycles	Chemical Processes and Nutrient Cycles
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Pyramid Functions:

- Hydrology
- Hydraulics
- Geomorphology
- Physicochemical
- Biology

Primary Functions:

- System Dynamics
- Hydrologic Balance
- Sediment Processes and Character
- Biological Support
- Chemical Processes and Pathways

Loss of System Dynamics Functions:

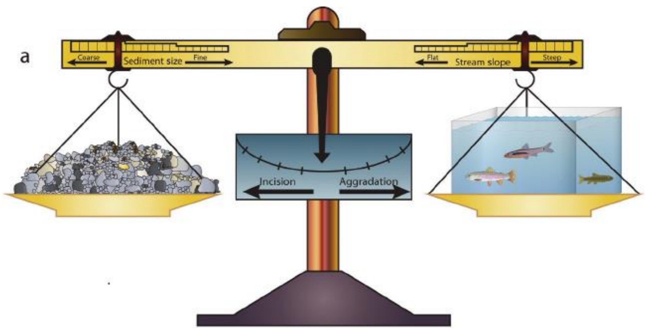
1) Stream Evolution Processes
2) Energy Management Processes
3) Riparian Succession

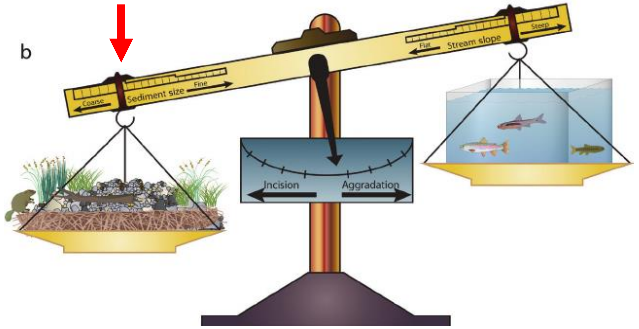
Consequences of Loosing System Dynamics Function

Fundamental Difference

Stream Functions Pyramid Objective:
Natural channels seek to create a stable stream channel that balances its flow of water and sediment so that the channel does not aggrade or degrade.

Primary Functions Objective:
Streams and watersheds interact in complex ways to contribute to the continual restructuring of its associated elements and features. Sediment continuity provides for appropriate erosion, transport, and deposition (response) processes.





Static Equillibrium

Dynamic Equilibrium

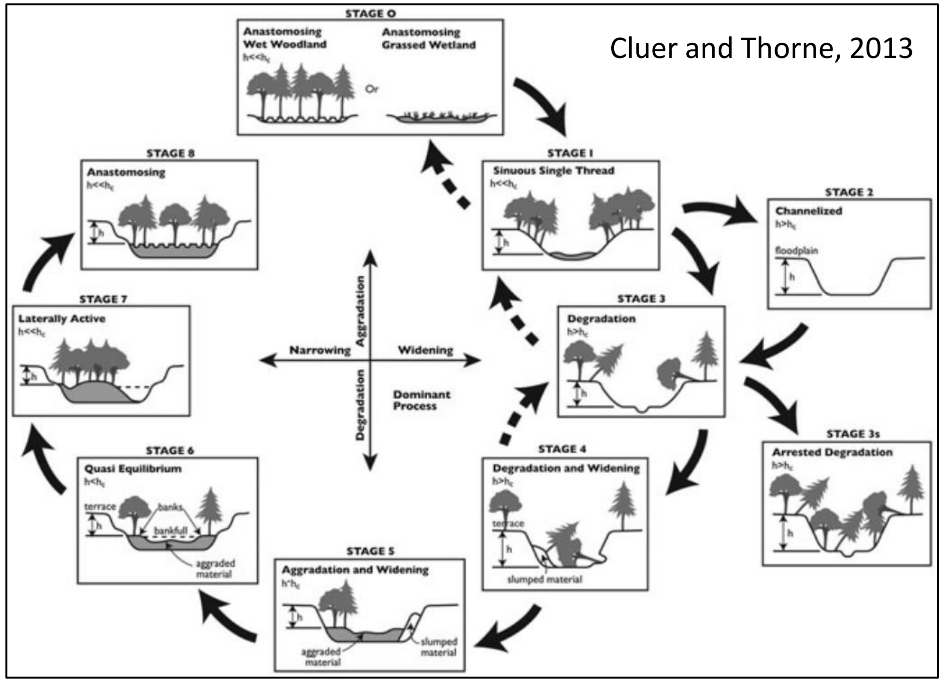
Engineered vs. geomorphic spectrum by Travis Stroth

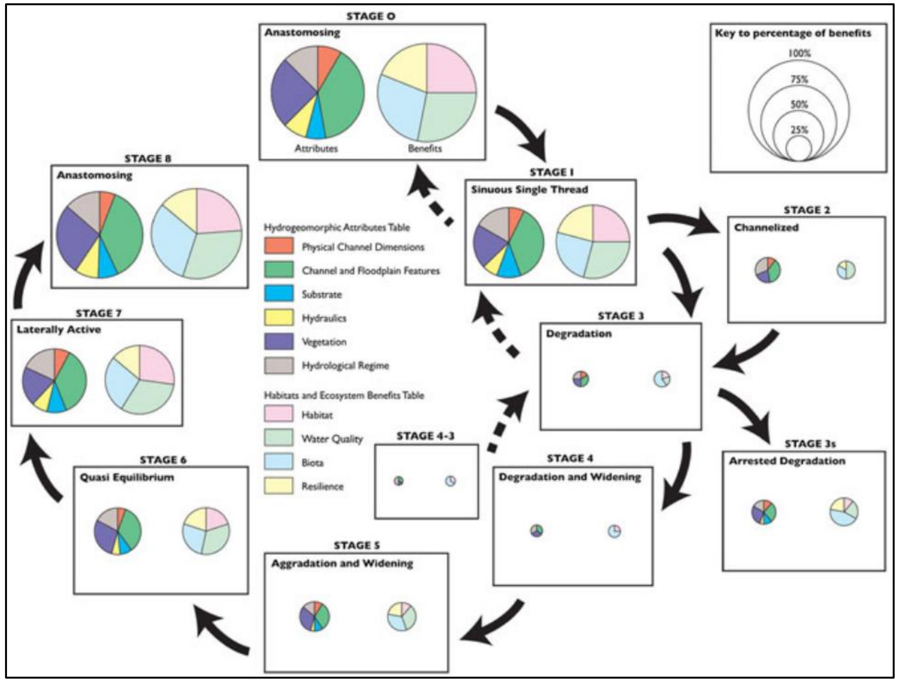
Advances in Science and Application

- Long recognize that stream processes and forms are not in a static state reflecting fixed conditions
- But rather, stream systems fluctuate in response to changes in the driving conditions
- Conceptual models reflect the spectrum of stream responses to changing driving conditions and provide predictive tools for assessment of expected evolutionally trajectories
- But do they meet the needs/mandates of regulatory/mitigation assessments and fit within project constraints?

Stream Evolution Model (SEM) and Habitat and Ecosystem Benefits

CEM and SEM provide alternative to static stream systems perspective





- CEM linear progression of channel evolution
- SEM cyclical evolutionary response to changes in driving conditions and how stream system adjustments
  - Identify existing and predicted responses to hydrologic and sediment regimes
  - Links evolutionary stages to habitat and ecosystem health/benefits
  - Identify issues of concern – what are the driving imbalances or stressors?
  - Forecasts evolutionary trends and helps identify targeted functional improvement goals

Qualitative SEM Scoring

Hydrogeomorphic Attributes Table

Stage	0	1	2	3	3s	4	4-3	5	6	7	8
Physical Channel Dimensions											
Wetted Area Relative to Flow	3	2	1	1	1	0	0	1	1	2	2
Shoreline Length and Complexity	3	2	1	1	1	0	0	1	1	2	2
Channel and Floodplain Features											
Bedforms and bars	2	3	1	0	0	1	0	2	3	3	2
Islands	3	1	0	0	0	0	0	0	0	1	3
Local Confluence/Diffluences	3	1	0	0	0	0	0	0	0	1	3
Stable banks	3	2	2	2	2	0	0	1	2	2	3
River cliffs	2	2	0	1	2	2	2	2	1	2	2
Riparian Margins	3	2	1	1	1	0	0	1	2	2	3
Floodplain Extent and Connectivity	3	3	1	0	0	0	0	1	2	2	2
Side channels	3	2	0	0	0	0	0	0	1	2	2
sediment storage	3	2	1	0	0	0	0	0	1	2	3
Connected Wetlands	3	2	1	0	0	0	0	0	0	1	2
Substrate											
Substrate Sorting	2	3	0	0	1	0	0	1	1	2	2
Substrate Patchiness	3	3	0	0	1	0	0	1	2	3	3
Hydraulics											
Hydraulic Diversity	3	2	0	0	1	0	0	1	1	2	3
Marginal Deadwater	3	2	0	0	0	0	0	0	1	2	3
Vegetation											
Aquatic plants	3	2	1	0	0	0	0	1	2	2	3
Emergent Plants	3	1	1	1	1	1	0	2	2	1	3
Riparian plants	3	2	0	0	1	0	0	1	1	2	3
Floodplain plants	3	3	2	0	0	0	0	0	1	2	3
Woody debris	3	1	0	1	1	2	1	2	2	1	3
Leaf litter	3	2	0	1	2	0	0	1	2	2	3
Hydrological Regime											
Flood pulse	1	1	2	3	3	3	3	2	2	1	1
Flood attenuation	3	2	1	0	0	0	0	0	1	2	3
Base flow	2	3	1	0	0	0	0	0	1	3	2
Hyporheic connectivity	3	3	2	0	0	0	0	1	2	3	3
Results											
possible	78	78	78	78	78	78	78	78	78	78	78
sum	72	54	19	12	18	9	6	22	35	50	67
ratio	92%	69%	24%	15%	23%	12%	8%	28%	45%	64%	86%

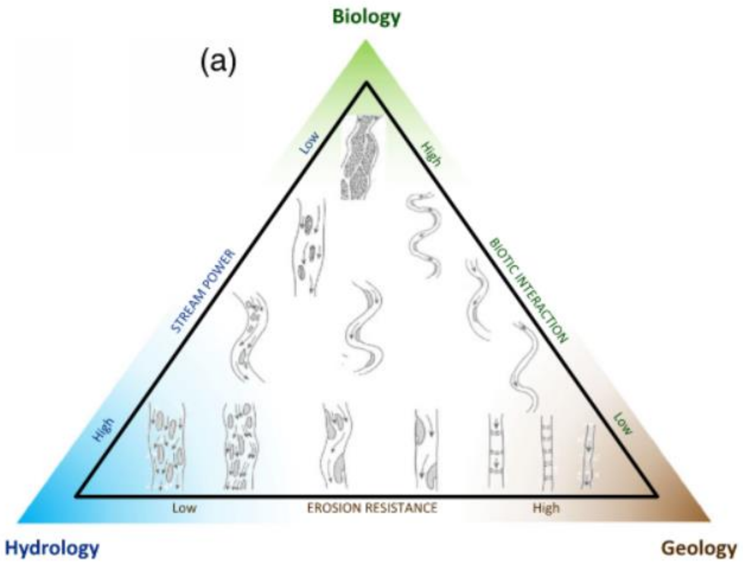
- SEM does provide a system of qualitative scoring that could be applied to debit/credit calculations for existing and predicted stages
- Could be applied or included in regulatory assessment frameworks

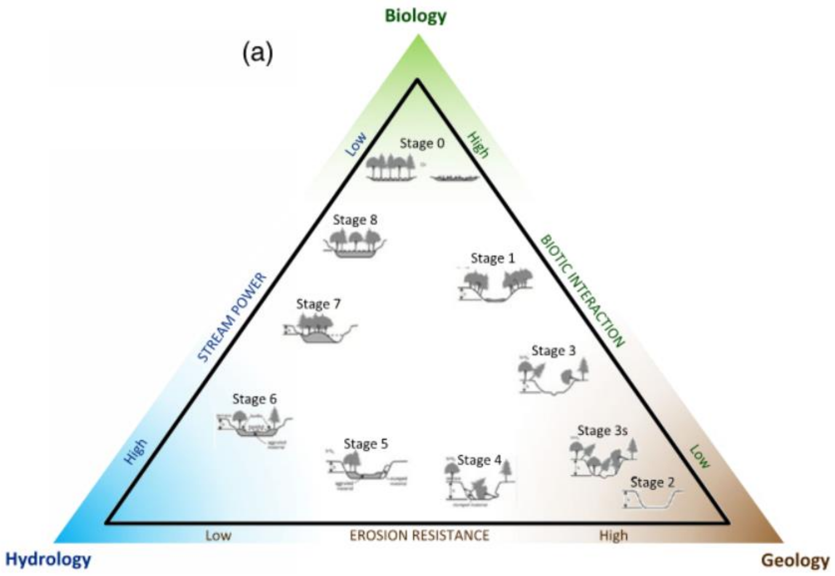
Qualitative SEM "Scoring"

- 3 = Abundant and fully functional
- 2 = Present and functional
- 1 = Scarce and partially functional
- 0 = Absent or dysfunctional

**Similar matrix and scoring available for corresponding habitat and ecosystem benefits

Stream Evolution Triangle





- Conceptual model relating the relative balance between Geologic, Hydrologic, and Biologic drivers on stream systems
- Provides a broad "thinking space" for qualitative interpretation, evaluation, and forecasting of stream systems and their response to perturbations in driving forces
- Assesses stream systems and processes across a full spectrum of conditions…not tied to fixed stages, stream types, or classifications

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- Does not provide a quantitative/qualitative scoring metrics for individual processes…Do we want it to?

Spectrum Of Assessment Tools

- Where are tools appropriate, where are they not, what are the data gaps?

Rigid ⟷ **Flexible**

Stream Functions Pyramid

- Simplified Framework
- Defined and scorable metrics
- Form-based assessment of existing and proposed conditions

- Predominantly applicable to single-thread, low response systems
- Not applicable across diverse stream types
- Isolated functions with limited feedbacks and biologic input
- Only captures a snapshot in time - does not assess changing or modified systems

Stream Evolution Model

- Identifies how the existing conditions reflect hydrologic and sediment regimes (and changing conditions)
- Links evolutionary stage to biotic function/health
- Predictive response to changing hydrologic and sediment conditions
- Qualitative scoring of stream processes

- Under represents the impacts and feedbacks of biologic controls
- Categorizes distinct stages rather than a continuum

Stream Evolution Triangle

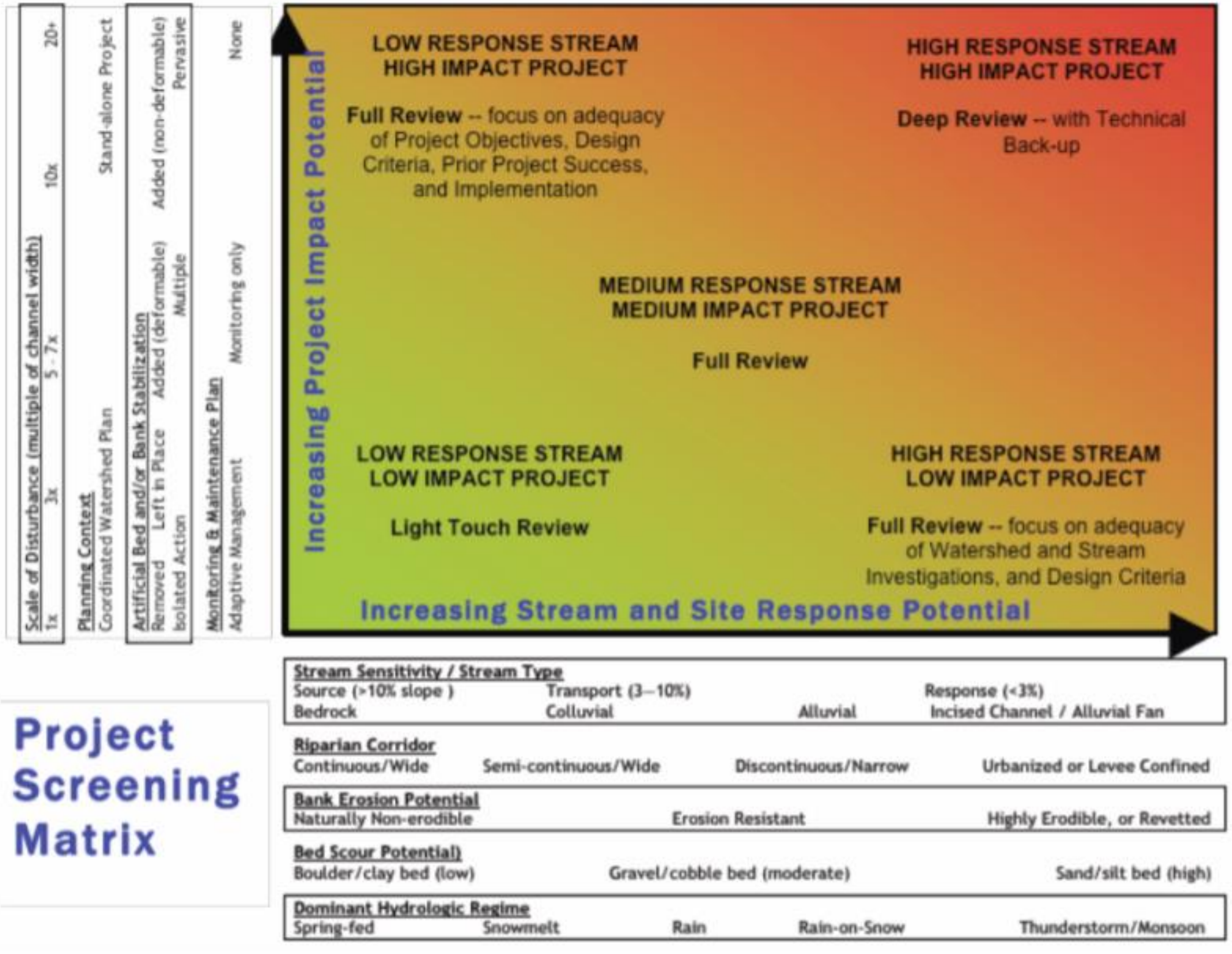
- Process based assessment of river systems
- Captures nuanced relationships between geologic, hydrologic, *and* biologic controls
- Forecasts responses to spatial and temporal perturbations, even in complex systems

- Qualitative assessment of relative contributions from dominant stream controls
- Lack of "scorable" metrics precludes from use in debit/credit assessments

Identifying Tools for Varying Stream Response Potential

Skidmore et., al, 2011; Thorne et. al., 2014

Project Goals, Constraints, and Impact



Physical Characteristics, Processes, Response

- In reality, level of effort and assessment detail vary based on physical characteristics and processes and project constraints
- As Practitioners, we need to determine the appropriate tools and frameworks <u>*and*</u> get stakeholders, stream managers, and regulators on board?

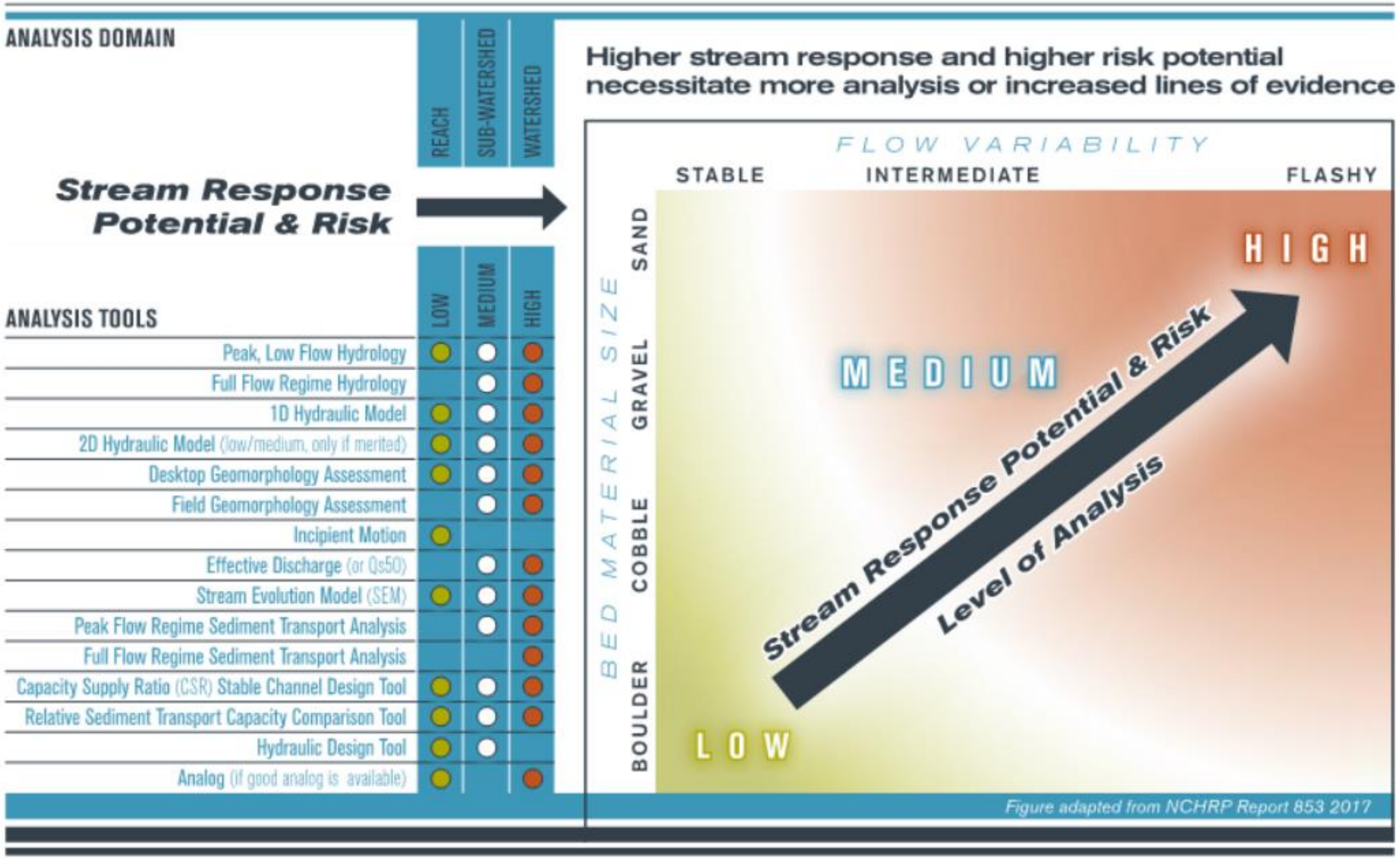
Assessment Framework Balance: Need tools to help determine the right tool for the job

- Simple, Low Response Systems
- Rapid Assessment
  (Low level of effort)
- Meet Regulators Mandates and Needs

VS.

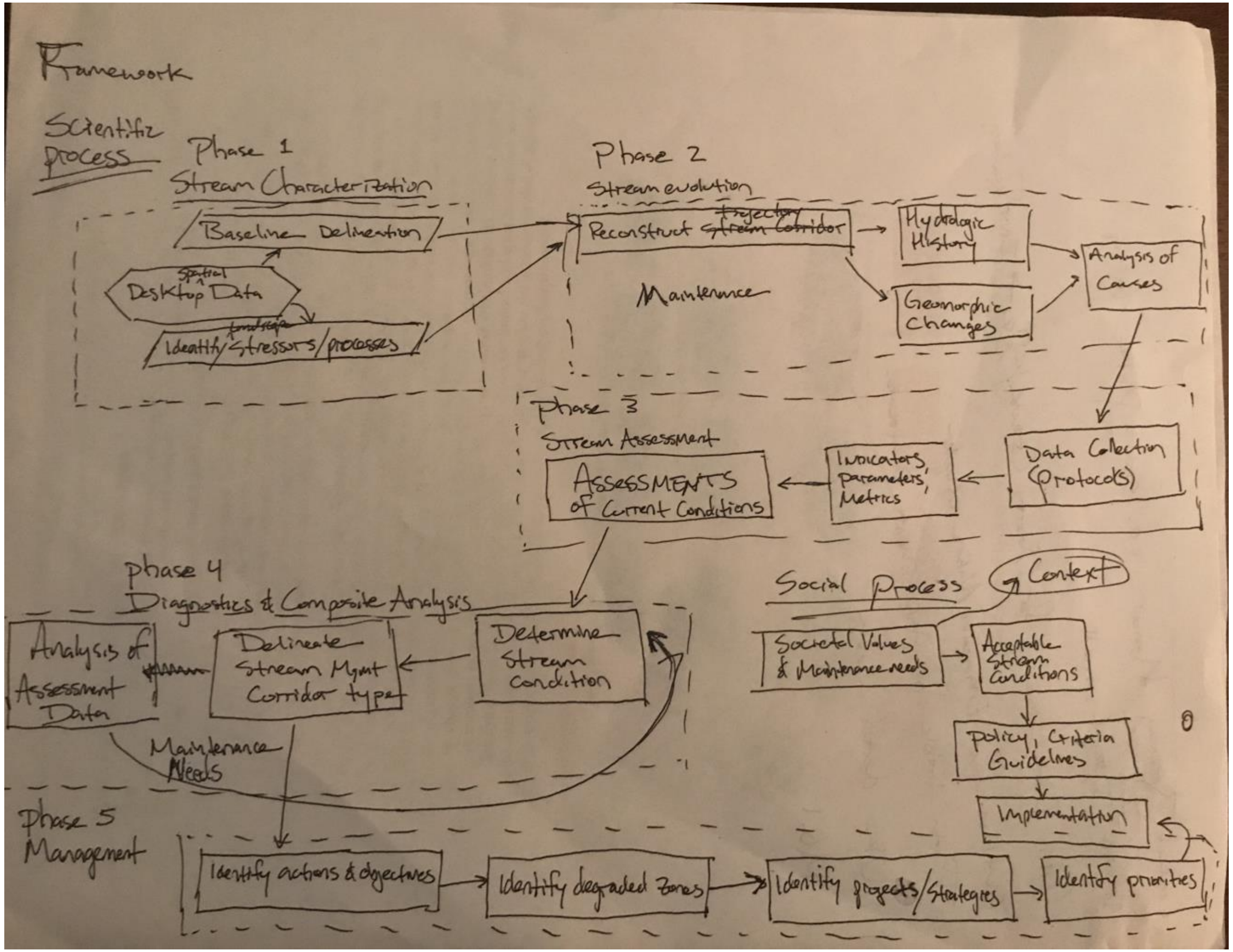
- Complex, High Response Systems
- Detailed Assessment
  (High Level of Effort)
- Accurate/Meaningful Measures and Improve Scientific Understanding

Identifying Tools for Varying Stream Response Potential



- In its simplest form, stream response potential varies with hydrologic and sediment regimes (and biologic)
- Flashy, storm driven, fine grained systems are highly responsive. Stable flow in course bed systems are less responsive.
- Level of effort, applied tools, and assessment detail vary with stream response potential

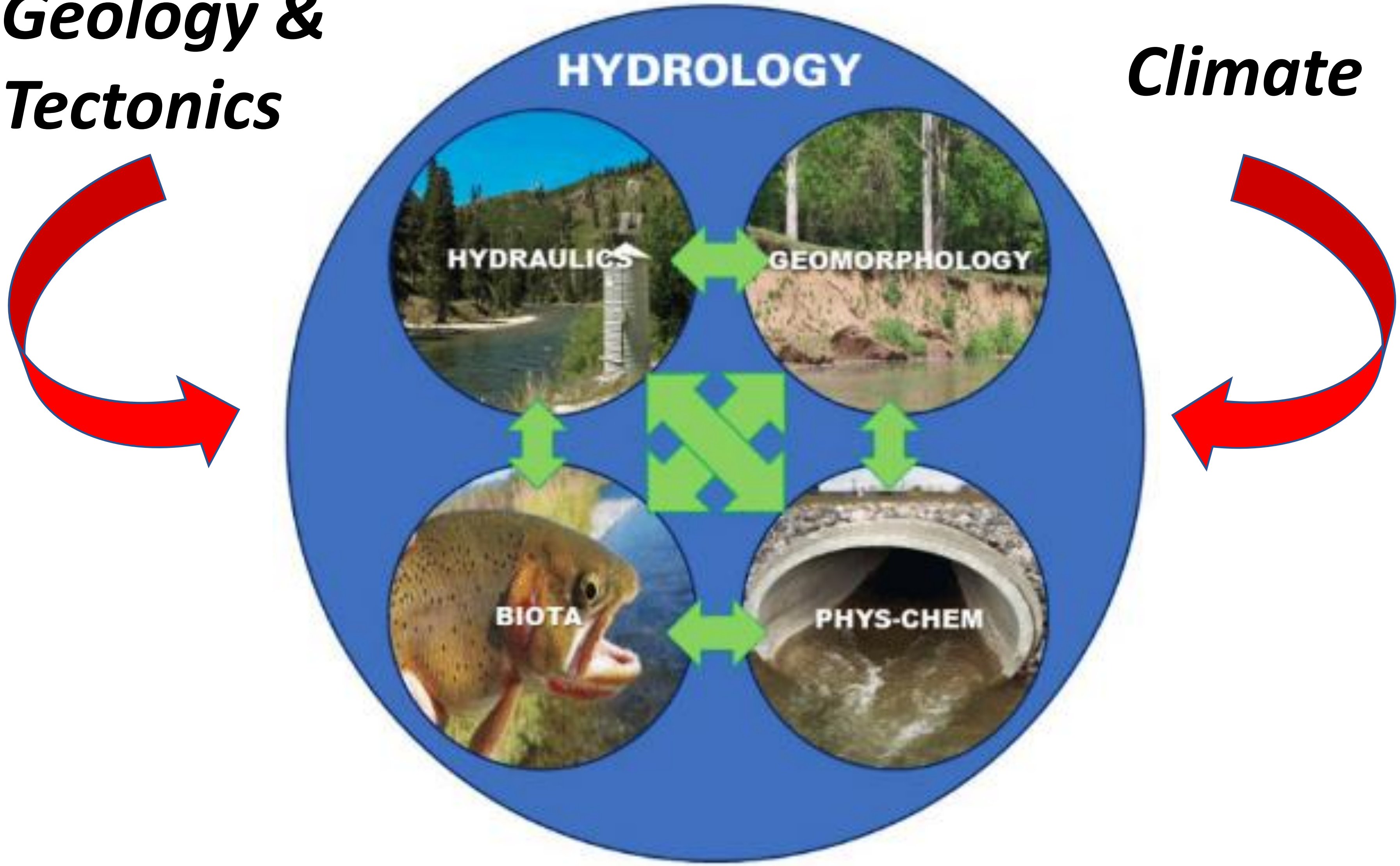
Challenges of Complexity



COSHAF - Functional Feedbacks

Geology & Tectonics

Climate



Based on COSHAF: Mark Beardsley and Brad Johnson