Functional Objectives for Stream Restoration

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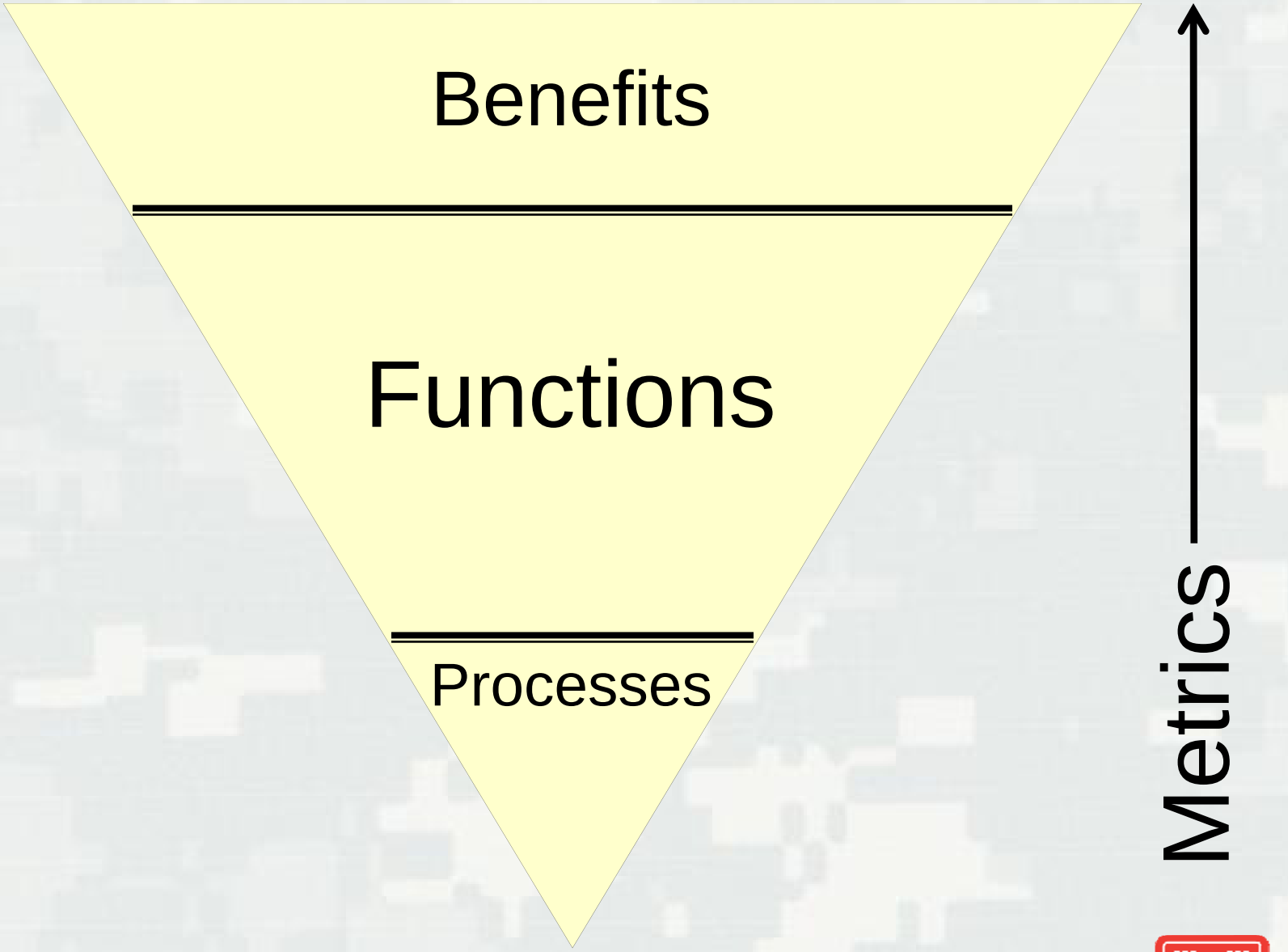
Benefits
Functions
Processes
Metrics

White Marsh Run

Functional Basis

Functional Objectives for Stream Restoration

by J. Craig Fischenich[1]

September 2006

Complexity	Value as Planning Tool	Cost
Low Moderate High	Low Moderate High	Low Moderate High

OVERVIEW

The National Research Council (1996) defined restoration as "the return of the form and function of an ecosystem to its pre-disturbance condition…" This definition presents two challenges when working in today's environment.

First, the significant hydrological changes and infrastructure encroachments found in many watersheds often prevent the reestablishment of the stream form to a condition prior to disturbance. These streams have a new form consistent with the altered conditions, and may not be able to maintain functions associated with a pre-disturbance condition.

Second, while the general concept of "functions" can be grasped by most, the specific functions provided by streams and riparian corridors have yet to be defined in a manner that can serve as a basis for assessment, design, and management.

The recommendations presented in this document center on the recognition that the character of stream systems (and, thus, their value or potential to support certain uses) is a result of a set of dynamic and interrelated processes referred to as functions in this report. Fifteen critical functions were identified by a committee of U.S. and international scientists, engineers, and practitioners, and were synthesized into a framework for ecosystem evaluation.

Understanding the basic functions of streams and riparian corridors provides planners and designers with a concise and effective basis from which to evaluate proposed projects, and offers several powerful advantages over assessments that focus upon beneficial uses. Use of functions and processes can be elegantly incorporated within a systems approach, enhancing understanding, enabling predictions, and supporting management decisions.

This report presents the functional framework and discusses ways in which the framework can be applied to support the Corps' Ecosystem Restoration and Urban Flood Damage Reduction Programs.

Figure 1. Healthy streams and riparian zones support important functions, even if their form has been altered from historic conditions.

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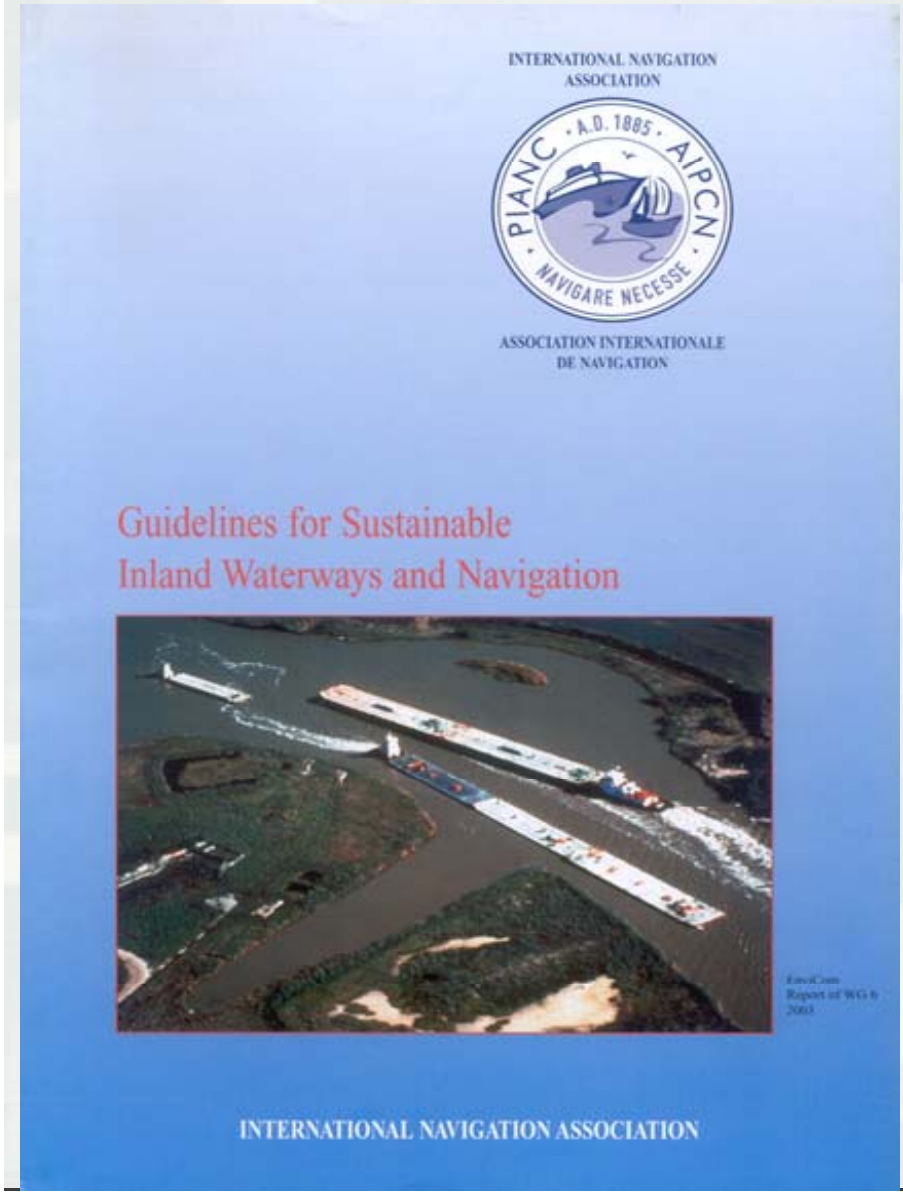
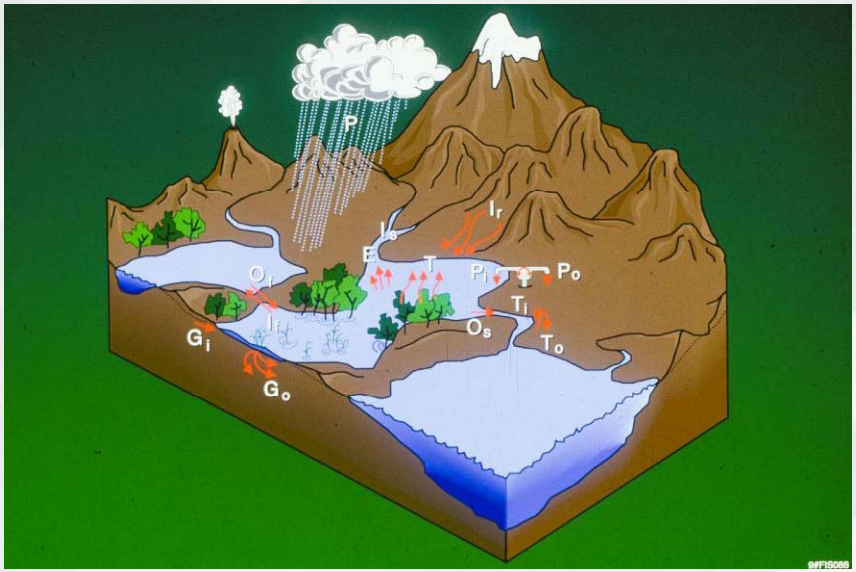


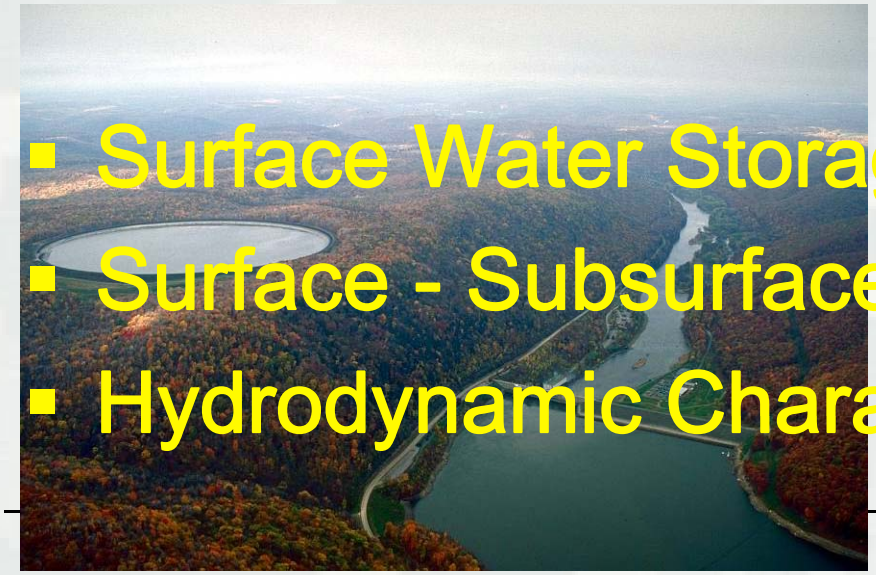
System Dynamics

- Evolution Processes
- Energy Processes
- Riparian Succession

Function	Description	Indicators	Measurements
Maintain stream evolution processes	➢ Necessary process to maintain appropriate energy levels in the system. ➢ Promotes normally occurring change necessary to maintain diversity and succession. ➢ Provides for genetic variability and species diversity of biotic communities.	Systemic changes to channel cross-section, planform, or grade. Magnitude, frequency, and duration of flow changes. Bed armoring or sorting. Evidence of bed erosion or deposition. Bank erosion. Diverse riparian vegetation and aquatic biota. Presence of pioneer vegetation species. Stream stability. Changes in the composition of the aquatic community.	Stability assessment techniques that quantify bed and bank stability. Channel evolution model stage and change. Rates of change of channel geometry parameters. Time-series aerial photo analysis of stream pattern. Quantity, densities, ages, types, % cover of different vegetation. Abundance and distribution of pioneer species, as well as rate of succession. Flood history polygons (exceedance intervals). Other disturbance process measures (e.g., fire).
Energy management processes	➢ Spatial and temporal variability in cross section, grade, and resistance allows for conversion between potential energy and kinetic energy through changes in physical features, hydraulic characteristics, and sediment transport processes. ➢ Provides habitat, generates heat, oxygenates flows.	Changes in physical stream features, such as width, depth, slope, and bed and/or bank roughness. Changes in flow state or condition. Erosion/deposition pattern change. Alternate and diverse reach classifications (riffle, pool, run). Watershed disturbance patterns. Changes in terrestrial and aquatic biota.	Determine energy grade line and hydraulic grade line and compare with bed slope at different flows. Quantify variability in physical stream features or hydraulic features along the channel and compare to reference channels. Measure channel/floodplain constrictions.
Provide for riparian succession	➢ Changes in vegetation structure and age promote diversity and ecological vigor by initiating change, which is important to long-term adaptation of ecosystems. ➢ Zones of mature riparian vegetation are necessary for system stability, LWD recruitment, and nutrient cycling.	Presence of pioneer species. Diversity of vegetation. Varied age classes. New sediment deposition and active erosion.	Measures of species diversity, composition, age, and structure. Riparian zone width. Seedling distribution. LWD recruitment rate.

Hydrologic Condition

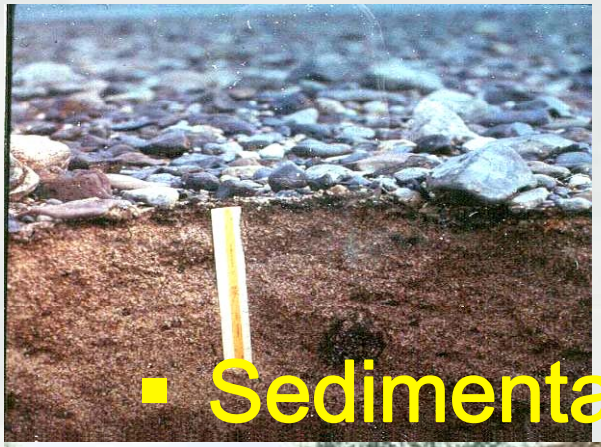


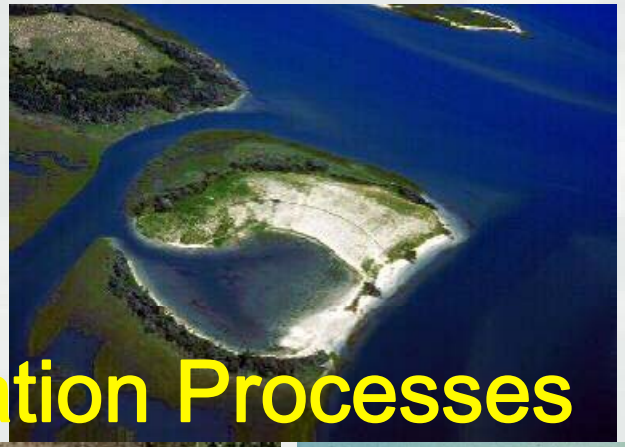


- Surface Water Storage Processes
- Surface - Subsurface Exchange Processes
- Hydrodynamic Character

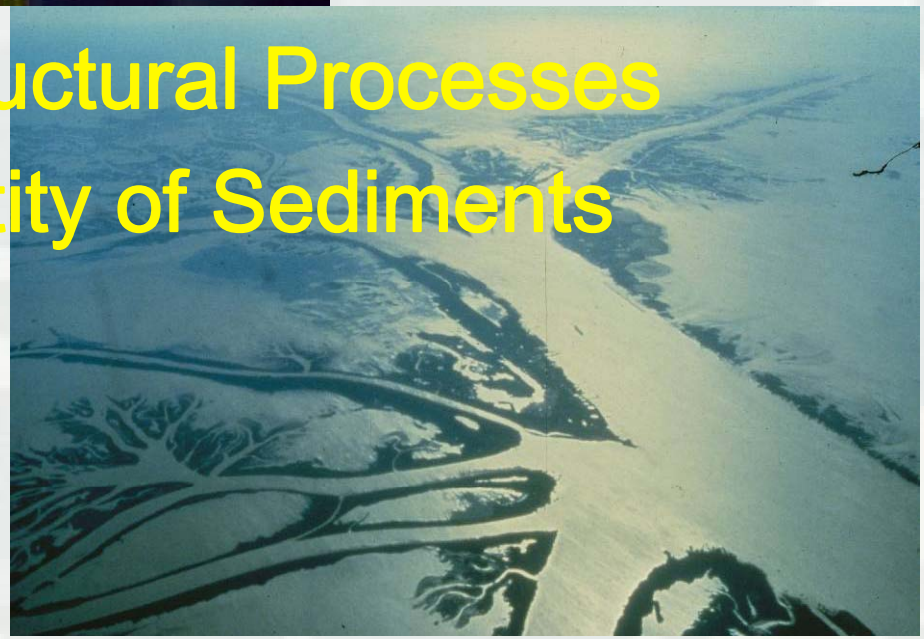
Function	Description	Indicators	Measurements
Surface water storage processes	➢ Provides temporary water storage during high flows. ➢ Regulates discharge and replenishes soil moisture. ➢ Provides pathways for fish and macroinvertebrate movement. ➢ Provides low-velocity habitats. ➢ Maintains base flow and soil moisture. ➢ Provides contact time for bio-geochemical processes.	Presence of perennial flood-plain topographic features, such as floodplain lakes, ponds, oxbows, wetlands, and sloughs. Riparian wetlands, depres-sions, and microtopog-raphic changes in active floodplain. Presence of floodplain-spawning fishes. Presence of macroinvertebrate and amphibian indicator species. Watershed % impervious surface. Riparian debris patterns. Detrital accumulations.	Backwater computations. Hydrologic routing models. Stream entrenchment surveys. Rating curves. Floodplain species spawning success. Topographic surveys. Infiltration rates, com-paction surveys. Gage and well records.
Maintain surface / subsurface water connections and processes	➢ Provides bi-directional flow pathways from open channel to subsurface soils. ➢ Allows exchange of chemicals, nutrients, and water. ➢ Moderates low and high in-channel flows. ➢ Provides habitat and pathways for organisms. ➢ Maintains subsurface capacity to store water for long durations. ➢ Maintains base flow, seasonal flow, and soil moisture.	Invertebrates found in the hyporheic zone under floodplains. Presence of floodplain topographic features that connect the channel to groundwater recharge areas by free-draining soils. Occurrence of flows sufficient to allow connection. Presence of layers of silt or organics in soil profile. Moist soil conditions, hydro-phytic vegetation. Adjacent wetlands, hydric soil indicators. Groundwater elevation fluctuations. Watershed % impervious surface.	Flux in groundwater levels. Stream baseflow. Hyporheic macroinver-tebrate distribution, density, and diversity. Complexity of microtopography. Isotope dating. Soil porosity. Water chemistry profiles. Temperature recording. Texture, structure, moisture, redox, and porosity of adjacent soils.
General hydro-dynamic balance	➢ Rivers have a unique hydrologic signature important in ensuring proper flow conditions at the appropriate seasons for support of the biotic environment.	Presence of an active floodplain. Associated wetlands. Redoximorphic features and other indicators of hydric soils. Hydrophytic vegetation, drift line, and sediment deposits	Flow duration analyses. Rating curves. Spawning success.

Sediment Processes/Character



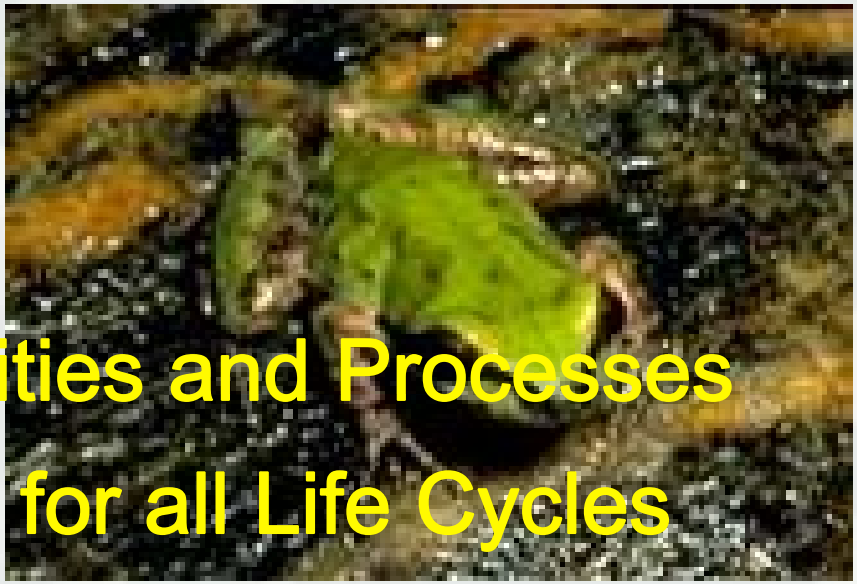


- Sedimentation Processes
- Substrate and Structural Processes
- Quality and Quantity of Sediments



Function	Description	Indicators	Measurements
Sediment continuity	➢ Provides for appropriate erosion, transport, and deposition processes. ➢ Maintains substrate sorting and armoring capabilities. ➢ Provides for the establishment and succession of aquatic and riparian habitats. ➢ Important part of nutrient cycling and water quality maintenance.	Bed sediment character. Evidence of recent channel or floodplain sediment and detrital deposits. Recent bed or bank erosion. Channel planform, section, or grade changes. Active bars. Changes in supply, erosion and deposition patterns. Diversity in aquatic and riparian biota. Watershed disturbance patterns. Composition and diversity of macroinvertebrates. Changes in magnitude, duration, or frequency of flow.	Bed material sediment loads and gradations. Suspended sediment load assessments. Stability assessment techniques. Temporal changes in channel geometry. Sediment yield measures. Sediment transport modeling and/or incipient motion analysis. Lower bank angle surveys. Stream bed core sampling.
Maintain substrates and structural processes	➢ Stream channels and riparian zones provide substrates and structural architecture to support diverse habitats and biotic communities. ➢ Complex habitats naturally attenuate the effects of irregular disturbance processes such as fire and floods.	Presence and health of indigenous biota. Distribution, abundance, health and diversity of biota. Relative complexity of substrates. Structural complexity and distribution. Abundance and distribution of large woody debris. Habitat diversity and complexity. Population trends of indicator species. Disturbance history.	Presence, composition, frequency, and distribution of physical characteristics such as pools, riffles, bedforms, specific depths and velocities, cover and substrate features, riparian corridor widths, etc. Aquatic and riparian habitat assessment methods such as PHABSIM, RCHARC, RBPS, HEP, IBIs. Distribution and frequency of key physical parameters. Riparian and in-channel woody debris surveys. Aquatic macrophyte surveys. Periphyton samples. Stream substrate composition. Soil compaction, displacement, or erosion. Detrital mass surveys. Bacterial counts. Fungal surveys. Fire and flood history mapping.
Quality and quantity of sediments	➢ Organisms often evolve under specific sediment regimes and these must be preserved for the ecological health of the system. ➢ Sediment yield and character are primary variables in determining the physical character of the system.	Change in banks, pools, and bars acceptable relative to other similar streams. Distribution, abundance, health, and diversity of biota. Presence of indicator species.	Sediment grain size distribution. Embeddedness. Sediment yield. Bedload. Suspended sediment load. Sediment concentration. Secchi depth. Armor layer size and thickness. Depth to bedrock. Sediment mineralogy. Macroinvertebrate surveys. Redd counts.

Biological Support

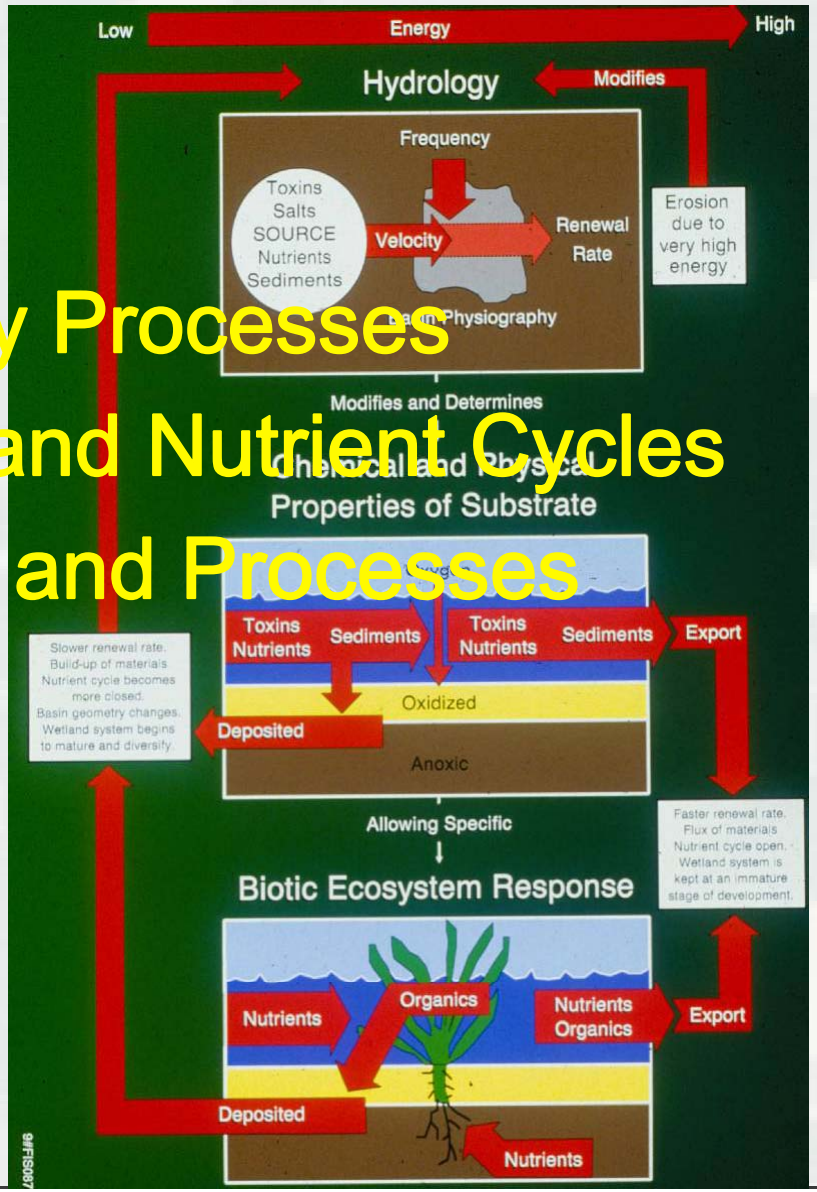


- Biological Communities and Processes
- Necessary Habitats for all Life Cycles
- Trophic Structures and Pathways

Functions	Description	Indicators	Measurements
Support biological communities and processes	➢ Provides for diverse assemblages of native species. ➢ Maintains natural predator/prey relationships. ➢ Maintains healthy physiological conditions of biotic communities. ➢ Maintains genetic diversity. ➢ Maintains age class and life form structures. ➢ Provides for natural reproduction and long-term biotic persistence.	Changes in population trends. Changes in health or condition of individuals or populations. Abnormal behaviors. Unbalanced predator/prey communities. Changes in growth or reproduction. Unbalanced age class or life form structures. Unusual species occurrence outside of normal ranges or preferred habitats. Presence of non-native species. Hybridization.	Population and individual growth rates and condition factors. Disease histories, bacterial and viral profiles. Species diversity and other IBIs. Species assemblages relative to reference conditions. Viability analyses. Population surveys, including density, age-class structure, life-form composition, etc. Bioassays. Stomach content analyses. Genetic testing and mapping. Species distribution relative to reference.
Provide necessary aquatic and riparian habitats	➢ Produces and sustains habitats to support vigorous aquatic and riparian biotic communities. ➢ Provides for basic food, air, light, water and shelter needs of dependant species. ➢ Provides habitats suitable for reproduction. ➢ Supports migration and staging areas. ➢ Provides key temporal habitats during periods of population stress.	Presence/absence/complexity of habitat features. Presence/absence/health of key indicator species, and native, non-native, surrogate, or invasive species. Observations of surrogate signs: remains, nests, dens, trails, feces, fur, prints, etc. Evidence of predator/ prey or reproductive, cooperative, or social behaviors. Presence of critical microhabitat features. Distribution, diversity, and quality of habitats throughout species ranges and over time. Secure recruitment pathways. Disease, extreme population fluctuations.	Measures from Rapid Stream Assessment Procedure, or other habitat modeling such as RCHARC, PHABSIM, HEP. Comparison of biotic counts to reference Indices of Biotic Integrity (IBI). Composition, structure, extent, variability, diversity, abundance of habitat features, key indicator species, native, non-native, surrogate, or invasive species relative to reference conditions. Habitat suitability, complexity, and diversity measures/models. Limiting habitat factor surveys. Refugia network mapping. Terrestrial and aquatic temperature studies. Corridor connectivity assessment. Habitat fragmentation surveys.
Maintain trophic structure and processes	➢ Promotes growth and reproduction of biotic communities across trophic scales. ➢ Maintains contact time for biotic and abiotic energy processes. ➢ Maintains equilibrium between primary autotrophs and primary microbial heterotrophs. ➢ Supports food chain dynamics to convert energy to biomass. ➢ Supports characteristic patterns of energy cascade and pooling. ➢ Provides nutrient levels capable of sustaining indigenous biologic communities.	Presence/ absence of producers and consumers. Evidence of periphyton growth on substrate. Evidence of detrital shredding and decomposition. Presence/absence of a balance and variety of nutrients and organisms to convert carbon, nitrogen, and/or phosphorus between forms. Presence/absence/abundance of snags, previous season's plants, leaf litter, detritus. Evidence of detrital shredding and decomposition. Organic horizon and organic layers in soil. Presence/absence/abundance of native, non-native, and invasive indicator species.	Aquatic and riparian vegetation density. Periphyton biovolume. Density, composition, and biomass of invertebrate consumers, diversity indices, and other IBIs. Measure of N:P ratios in water. Diversity and composition of stream biota. Measure of primary productivity. Measure of detritus production, CPOM, FPOM, DOM. Measure of large woody debris frequency and density. Comparison of above- and below-ground biomass R/S ratio. Biomass production of stream-dependant species. Biomass profile.

Chemical Processes & Pathways

- Water and Soil Quality Processes
- Chemical Processes and Nutrient Cycles
- Landscape Pathways and Processes



FUNCTIONS	Description	Indicators	Measurements
Maintain water and soil quality	➢ Water quality parameters are directly tied to support of biologic community. ➢ Riparian communities trap, retain, and remove particulate and dissolved constituents of surface and overland flow, improving water quality. ➢ Regulates chemical and nutrient cycles. ➢ Controls pathogens and viruses. ➢ Maintains chemistry and equilibrium conducive to reproduction, behavior, development and sustainability of a diverse aquatic ecosystem. ➢ Supports important chemical processes and nutrient cycles.	Watershed conditions and disturbance features. Stream order. Presence/absence/abundance of key indicator biota. Presence/absence of trophic indicators. Abnormal forms or behaviors; unusual mortalities of indicator species. Plant, fish, and invertebrate density, diversity, distribution, and health. Wetland and riparian aerial and positional changes. Geology and soils - availability of a range of surface textures and areas for reactions. Presence/ absence of riparian sediment deposits. Density, diversity, and distribution of microbial, fungal, and invertebrate communities.	Conventional water quality measures (e.g., D.O., pH, conductivity, turbidity, TDS, salinity, temperature, suspended sediment). Bacterial counts. Metals and trace element sampling. Nutrient (N, P) tests. Examination of soil profiles. Soil profile elemental composition surveys. Rates of sediment deposition in channel and riparian corridor. Detrital mass surveys. Large woody debris counts. Infiltration rates. Compaction, displacement, and erosion surveys. Bacterial counts. Trace element sampling. Nutrient (N, P) tests. COM levels.
Maintain chemical processes and nutrient cycles	➢ Provides for complex chemical reactions to maintain equilibrium and supply required elements to biota. ➢ Provides for acquisition, breakdown, storage, conversion, and transformation of nutrients within recurrent patterns.	Presence of seasonal debris in riparian area. Presence/ absence of indicator species and their health. Presence/absence of photosynthesis, fecal matter, biofilms, and decomposition products. Presence/absence of particulates on vegetation. Riparian vegetation composition and vigor. Changes in algae, periphyton, or macrophyte communities. Changes in trophic indicators.	BOD (CBOD & NBOD) and DOC. Stable carbon isotope analyses -- identify energy pathways. Cell counts, ATP concentration, respiration rates, uptake of labeled substances. Water and soil buffer capacity. Complexation. Redox potential. Ion exchange capacity. Adsorption capacity. Dissolution/precipitation rates. Decomposition rates. Plant growth rates, biomass production.
Maintain landscape pathways	➢ Maintains longitudinal and latitudinal connectivity to allow for biotic and abiotic energy process pathways. ➢ Serves as barriers, corridors, or buffers to plant and animal migration. ➢ Provides source and sink areas for maintaining population equilibrium of plant and animal species.	Presence of animal trails along corridor. Observations of migratory species use. Flood tolerance of vegetation species on floodplains. Presence/absence of key indicator species in portions of the adjacent landscape. Recent deposits of sediments and detrital matter in the riparian corridor. Distribution, density, diversity, and age class composition of riparian vegetation. Accumulation of species during high stress periods.	Relative scale of stream to riparian corridor as a function of stream order or slope. Width, density, and composition of riparian vegetation community. Frequency and duration of floodplain inundation. Migratory bird surveys. Measures of sediment deposition and detrital flux in the riparian corridor. Migration barrier surveys. Genetic analyses. Canopy cover measurements of various life forms. Temperature.

Summary 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
Riparian Succession	Hydrodynamic Character	Quality and Quantity of Sediments	Trophic Structures and Processes	Landscape Pathways


Functions and Uses

Beneficial Uses	Function				
	System Dynamics	Hydrologic Balance	Sediment Processes and Character	Biological Support	Chemical Processes and Pathways
Sink					
Cooling water	O	O	O	I	I/O
Drainage	O	I/O	I/O	I	I/O
Flood storage / attenuation	I/O	I/O	I/O	I/O	I/O
Wastewater	O	O	O	I	I
Consumptive					
Aggregate withdrawal	I/O	I/O	I/O	I/O	I/O
Drinking water	O	I/O	O	I/O	I/O
Fishing and hunting	O	O	O	I/O	I/O
Hydropower	I/O	I/O	I/O	I/O	I
Industrial water supply	I/O	I/O	I/O	I	I/O
Irrigation	I/O	I/O	I/O	I	I/O
Groundwater withdrawal	-	I/O	-	I	I/O
Riparian timber harvest	I/O	I/O	I/O	I/O	I
Non-consumptive					
Aesthetics	O	-	O	-	-
Ecosystem protection	I/O	I/O	I/O	I/O	I/O
Housing	I/O	I/O	I/O	I	I
Landscape feature	O	-	O	I	I
Recreational boating	I/O	O	O	I/O	I/O
Commercial transport	I/O	I/O	I/O	I/O	I/O
Navigation service	I/O	O	I/O	I/O	I
Non-boating recreation	O	O	O	I/O	I/O
Spatial corridor	I/O	I/O	I/O	I/O	I/O

Key:

- - No discernible impact.
- I - Use may impact indicated function.
- O - Use may be impacted by indicated function.

Function Hierarchy

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	-

[1] Listed by number, according to ranking (e.g. Function #6 is Energy Management)

Note: The interactions among functions are such that the relations presented in Table 8 can change with the type of ecosystem, and the nature and magnitude of the impact, and the specific temporal and spatial scales utilized in the relevant analysis. This is particularly true for the indirect impacts.

MTM Implications
Functional Pyramid