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The Active River Area

A Conservation Framework for Protecting Rivers and Streams

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THE ACTIVE RIVER AREA

A Conservation Framework for Protecting Rivers and Streams

April 2008

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CHAPTER 1: INTRODUCTION

> *"Riparian corridors possess an unusually diverse array of species and environmental processes. This "ecological" diversity is related to variable flood regimes, geomorphic channel processes, altitudinal climate shifts, and upland influences on the fluvial corridor. This dynamic environment results in a variety of life history strategies, and a diversity of biogeochemical cycles and rates, as organisms adapt to disturbance regimes over broad spatio-temporal scales. These facts suggest that effective riparian management could ameliorate many ecological issues related to land use and environmental quality. We contend that riparian corridors should play an essential role in water and landscape planning, in the restoration of aquatic systems, and in catalyzing institutional and societal cooperation for these efforts." (Naiman et al., 1993)*

Freshwater systems are among the most biologically diverse and rich systems in the world (Decamps, 1997; Master et al., 1998). This richness and diversity is in large part a result of the highly dynamic nature of river systems which creates a mosaic of shifting habitat types that vary in age, species composition, and structure and provide a broad range of natural conditions around which the life cycles of species and natural communities have evolved (Ward et al., 2002).

Since the rich and unique biodiversity values of rivers are related to the dynamic nature of these systems, effective river conservation must include the protection of key physical and ecological processes. These processes are driven in large part by the movement of water and the associated movement of sediment, energy, materials and organisms. They are also driven by energy inputs to these systems, including the contribution of organic and other materials that provide the foundation on which the web of life within these systems is built.

River health depends on a wide array of processes that require dynamic interaction between the water and land through which it flows. The areas of dynamic connection and interaction provide a frame of reference from which to conserve, restore and manage river systems. We choose the term *active river area* to define this framework. "Active" indicates the dynamic and disturbance-driven processes that form and maintain river and riparian systems and their associated habitats and habitat conditions. "River area" represents the lands that contain both of aquatic and riparian habitats and those that contain processes that interact with and contribute to a stream or river channel. The *active river area* framework offers a more holistic vision of a river than solely considering the river channel as it exists in one place at one particular point in time. Rather, the river becomes those lands within which the river interacts both frequently and occasionally.

The *active river area* provides a systematic means for conceptualizing and protecting the river as a dynamic system with a broad range of conditions that are typical of natural river systems. The *active river area* is spatially explicit and can be readily identified – narrow in some areas, wider in others – and captures the living, dynamic processes and places that define these systems. The *active river area* includes a number of distinct components which provide specificity to guide actions for protection, restoration and management (Figure 1.1).

The Active River Area as the Basis for Action

The understanding of the importance of riparian lands and floodplains as integral to rivers and river health is not new. Naiman, et al. (1993) describe in great detail these important functions and values:

> *Planning based on isolated components (e.g., fish, vegetation, or restoration of specific stream sections) is ecologically incomplete. Consideration must be given to maintaining hydrologic connectivity and variability of riparian corridors from the headwaters to the sea. This means that better riparian corridor protection must take place in the numerous headwater streams as well as in the broad floodplains downstream. (Naiman et al., 1993).*

The *active river area* is designed to answer this call by providing a spatially-explicit framework based on watershed position and key geomorphic components to provide a tool to inform conservation, restoration and management. The framework provides a means to broaden work on river conservation that often focuses almost solely on individual instream processes like sedimentation or on protecting vegetated buffer strips in order to mitigate the water quality impacts of agriculture, urbanization and other human land uses. The framework also provides the context for mitigating the long legacy of efforts to control and harness rivers and to cultivate and settle the fertile floodplains and riparian lands they create. These efforts disrupt the natural processes and disconnect rivers from their riparian lands and floodplains with a cascading series of impacts (Burcher et al., 2007) that threaten river and riparian habitat and the broad range of benefits that thesee areas provide.

The *active river area* framework adds an important approach to efforts to protect and restore natural hydrologic regimes, restore and maintain connectivity within and along rivers, and mitigate other threats such as pollution sources, invasive species, over-harvest of fish and other resources, mineral and material extraction, and the conversion of riparian areas to other land uses. Without the protection and restoration of key physical and ecological processes and the areas within which they occur, efforts to protect rivers are likely to fall short of their goals and expectations. Healthy rivers also provide a broad range of other social and economic benefits to society as discussed in Chapter 3.

Document Overview

Chapter 2 of this document describes the five components of the *active river area*, and the dominant physical processes and habitat values associated with each of these components. Chapter 3 describes the broad range of ecosystem services gained by society by having *active river areas* maintain most of their natural features and conditions, including reducing flood and erosion risks to human infrastructure, water quality protection and recreation opportunities. Chapter 4 describes approaches to delineating the *active river area* at various scales and provides a case study of an approach for the Connecticut River watershed. Chapter 5 provides a list of existing assessment protocols that can help provide more detailed evaluations of the condition of *active river areas* as the basis for protection, restoration and management actions. Chapter 6 describes how the *active river area* can be used as the basis for designing protected area networks, for informing river restoration activities and informing river management programs and policies. Chapter 7 presents an overview of how the *active river area* framework forms an approach to identifying and planning on-the-ground restoration projects. Chapter 8 provides a short conclusion to the paper.

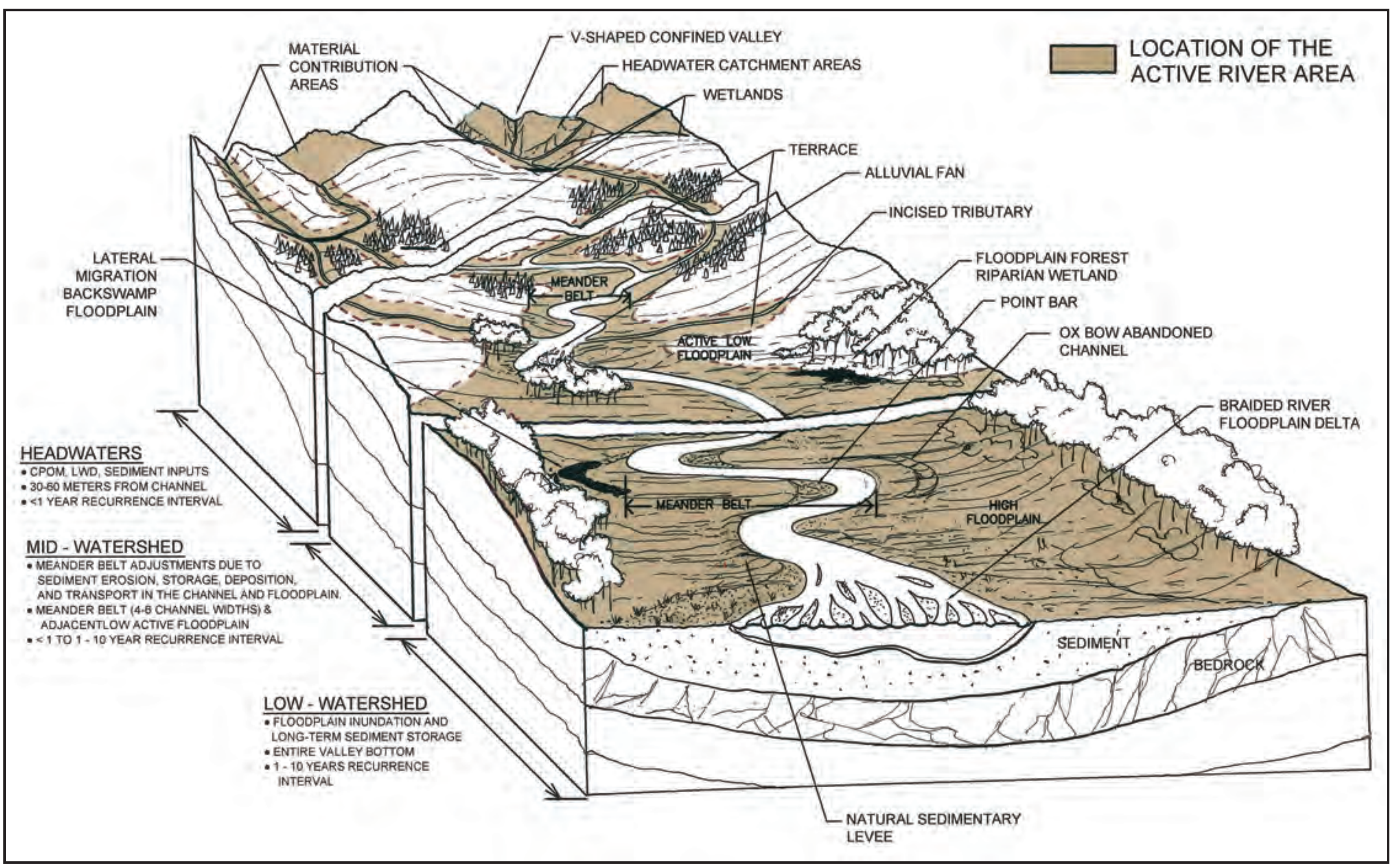


Figure 1.1 – The domminant processes and disturbance regimes of the *active river area.*

CHAPTER 2: DEFINING THE ACTIVE RIVER AREA

> *"Ecologically effective ecosystem management will require the development of a robust logic, rationale, and framework for addressing the inherent limitations of scientific understanding. It must incorporate a strategy for avoiding irreversible or large scale environmental mistakes that arise from social and political forces that tend to promote fragmented, uncritical, short-sighted, inflexible, and overly optimistic assessments of resource status, management capabilities, and the consequences of decisions and policies."*
> *(Frissell and Bayles, 1996)*

Introduction

The *active river area* framework is a spatially explicit, holistic view of rivers that includes both the channels and the riparian lands necessary to accommodate the physical and ecological processes associated with the river system. The framework informs river conservation by providing an approach to account for the areas and processes that form, change and maintain a wide array of habitat types and conditions in and along rivers and streams (Table 2.1).

Linking Ecology and River Processes

Dynamic processes collectively form, disturb, and maintain different habitat components over a range of spatial and temporal scales (Steinman and Denning, 2005; Lowe et al., 2006). Research continues to reveal the many fundamental links between physical processes, aquatic, riparian, and wetland habitat, and aquatic biota in rivers and streams (e.g., Booker, 2003; Clarke et al., 2003; Coulombe-Pontbriand and LaPointe, 2004; Sullivan et al., 2004a; Sullivan et al., 2004b). To maintain rivers and stream ecosystems in a naturally functioning and sustainable state we need an integrated approach that considers the processes and attributes of flow and sediment regimes, physical habitat structure, water quality, energy source and transfer, and

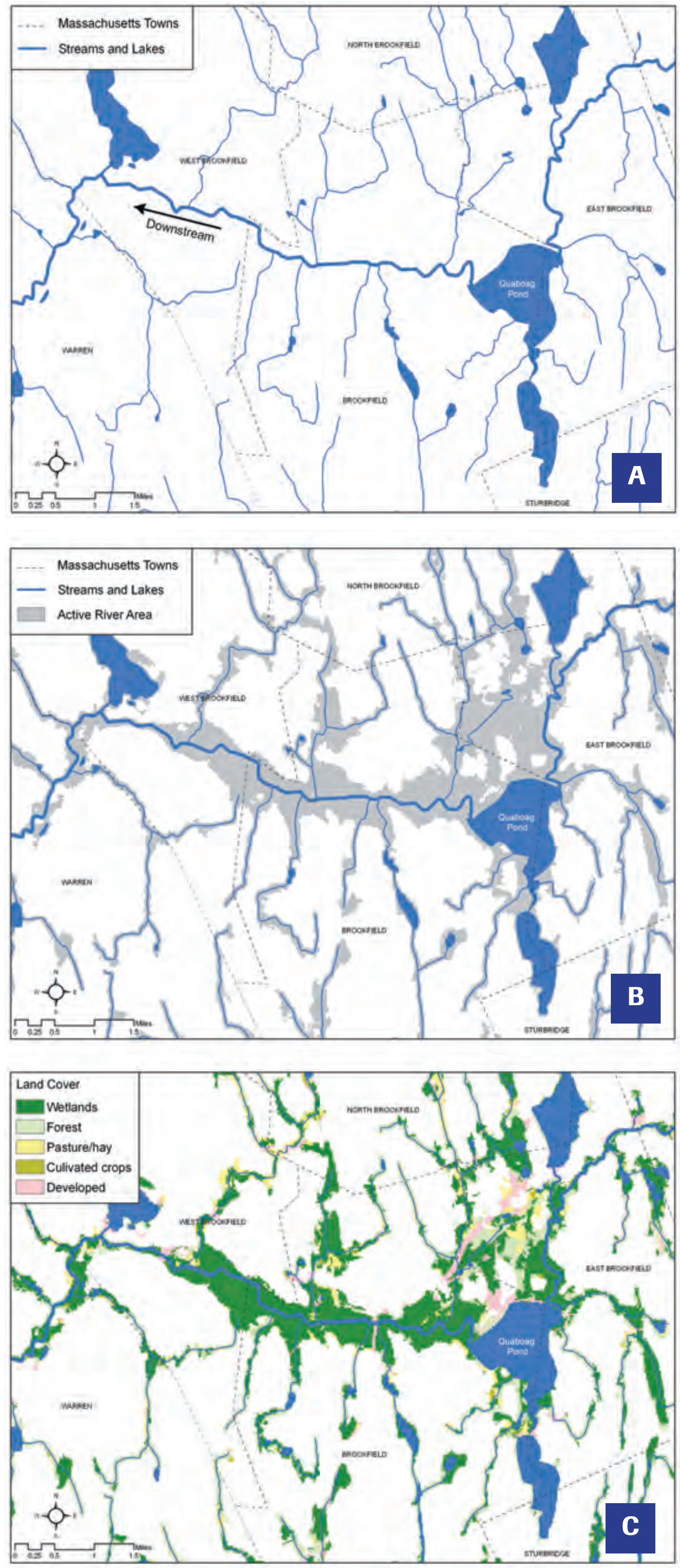


Figure 2.1 – *Active river area:* Quaboag River and Pond, MA: (A) Pond and channel; (B) Including the *active river area,* (3) with land cover showing the *active river area* as predominantly wetlands.

Table 2.1 Natural Processes in Rivers and Streams ***(adapted from VTANR, 2005)***

Natural Processes/ Key Attributes	Description	*Active River Area* Components
Hydrologic flow regime	The timing, volume, duration, and distribution of flow events over the hydrologic year that are influenced by climate, geology, watershed land cover, connectivity, and valley / stream morphology.	Meander belt, riparian wetlands, floodplains, terraces, material contribution areas.
Sediment transport	The size, quantity, sorting, and distribution of sediments that are a function of geology, hydrology, connectivity and valley / stream morphology.	Meander belt, riparian wetlands, floodplains, terraces, material contribution zones.
Processing and transport of organic materials	The abundance, diversity, and physical retention of organic material available for biological uptake and physical refuge that are a function of bank and riparian vegetation, climate, hydrology, connectivity, and valley / stream morphology.	Material contribution areas, meander belt, floodplain.
Establishment of connectivity	The maintenance of connectivity in and between the channel and riparian zone to support the unimpeded movement of water, sediment, organic material, and organisms longitudinally up and down the watershed and laterally / vertically between the stream channel and its floodplain.	Meander belt, riparian wetlands, floodplains.
Water quality maintenance	Transformation and transport of suspended sediments, ions, and nutrients that are a function of geology, climate, hydrology, and watershed land cover.	Material contribution areas, meander belt, riparian wetlands, floodplains, terraces.
Regulation of the thermal regime	The maintenance of daily and seasonal instream water temperatures influenced by climate, hydrology, riparian canopy, and valley / stream morphology.	Material contribution areas, meander belt, riparian wetlands, floodplains, terraces.
Energy transport	Sources of nutrient and energy inputs, primarily in the form of sun and changes to organic compounds via bond breaking (respiration) and bond assembly (production or photosynthesis), and the associated ecosystem reponses such as changes to dissoveld oxygen and pH.	Meander belt, riparian wetlands, floodplains, material contribution areas.

biological interactions (Karr and Dudley, 1981; Karr and Chu, 1999; Mattson and Angermeier, 2007).

By explicitly considering processes such as system hydrologic connectivity (Pringle, 2001), floodplain hydrology (Booth et al., 2006), and sediment movement along the river corridor (Steiger et al., 2005), the *active river area* framework identifies places where these processes occur. The framework provides a systematic approach to identifying these areas based on valley setting, watershed position and geomorphic stream type and can be used to identify conservation targets and guide the management of freshwater resources.

Components of the Active River Area

We identify five primary components of the *active river area*: 1) material contribution areas; 2) meander belts; 3) floodplains; 4) terraces; and 5) riparian wetlands. These areas are defined primarily by the type and frequency of interaction with the river. These areas often overlap – for example, many floodplains include extensive riparian wetlands and meander belts usually include parts of the low floodplains. But they can also be distinct – for example, headwater streams in confined valleys may include narrow material contribution areas with limited nearby floodplain.

We describe the *active river area* framework by first describing these five components, then discussing the dominant physical processes that drive these systems and describing how these processes can generally be characterized relative to their position in the watershed. As part of this description we identify how these processes and components together form and maintain the rich mosaic of habitat types and conditions that exist in rivers and riparian lands (see Table 2.2 on page 18).

1) Material Contribution Areas

Headwater areas and certain upland areas directly adjacent to the stream channels regularly contribute significant amounts of material, both organic and inorganic, to river and stream systems. We identify two types of material contribution areas. The first are the small headwater water-

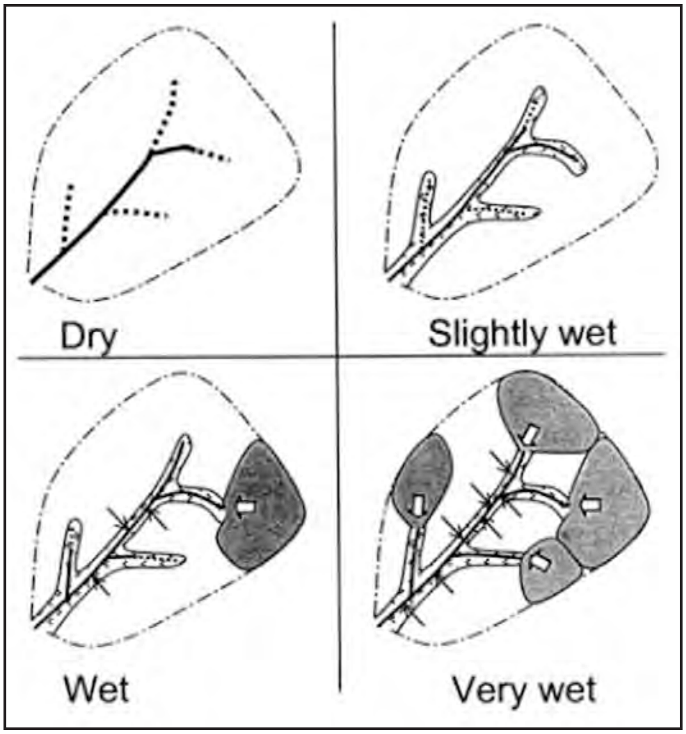


Figure 2.2 – "Conceptual view of dynamic, hydrologically active areas in headwaters. For dry conditions, riparian zones and direct precipitation on channels are the only active sites of flow generation. Throughflow from the soil matrix at the foot of hillslopes and riparian areas gradually activates with increasing wetness. Zero-order basins (shaded areas) with relatively shallow soils begin to contribute surface runoff (broad white arrows) during wet conditions, while preferential flow (thin black arrows) from hillslopes contributes less to stream flow. Water begins to flow in transitional channels emerging from zero-order basins. Zero-order basins and preferential flow actively contribute to storm flow during very wet conditions" ***(From Sidle et al., 2000; Gomi et al., 2002). (Copyright American Institute of Biological Sciences.)***

sheds in the uppermost reaches of the watershed where stream channels are first formed. These headwater areas are important sources of the organic and inorganic materials which serve as the basic building blocks for the food web of the stream system. It is within these small watersheds that1st order streams are formed from overland flows, intermittent and zero order streams and gullies, and from springs (Hack and Goodlett, 1960; Gomi et al., 2002). For this reason, and because mapped streams have been found to under represent the presence and role of streams in these areas (Gomi et al., 2002), we use small watersheds to define these areas (Figure 2.2). These headwater areas have been shown to have a long-term influence on channel morphology (Davies et al., 2005) and thus aquatic habitat locally and downstream.

The second type of material contribution areas is the upland areas immediately adjacent and along rivers and streams that are not a floodplain, terrace or riparian wetland. These are generally upland areas along steep banks, bluffs or other situations that limit out-of-bank of river flows but where these areas contribute materials, shade and other structural features to the river. We have define these as areas within 30 to 50 meters of the stream channel as studies have found that large woody debris and other organic materials in rivers and streams generally originates from areas within this distance from the stream channel (May and Gresswell, 2003; Webb and Erskine, 2003). The contribution of materials also occurs within meander belts, floodplains, terraces and riparian wetlands and is one of many functions of these other *active river area* components.

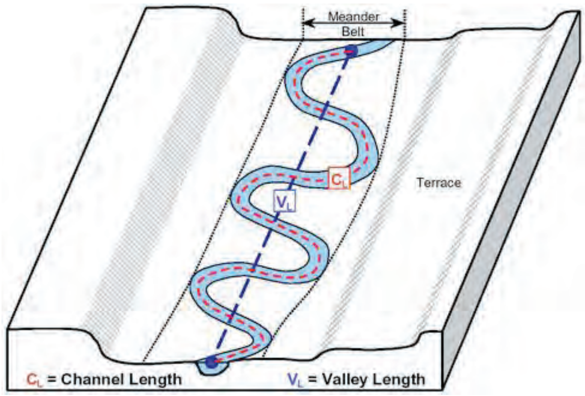
2) The Meander Belt

The meander belt is the area within which the channel or channels will migrate or 'meander' over time and represents the most active part of the *active river area*. The meander belt width is defined by the cross-channel distance that spans the outside-most edges of existing or potential meanders (Figure 2.3). The width of the meander belt can be readily calculated and mapped for healthy and altered rivers, thus providing a reference template on which to base protection and restoration decisions. Channels and banks are part of the meander belt and thus not considered separately.

3) Floodplains

Floodplains are generally expansive and low slope areas, often with multiple channels and deep deposits of sediments and other materials. Nanson and Croke (1992) define floodplains as "the largely horizontally-bedded alluvial landform adjacent to a channel, separated from the channel by banks and built of sediment transported by the present flow-regime. They describe three generic types of floodplain based on stream power (high, medium or low) and alluvial cohesiveness (cohesive = silt and clay; non-cohesive = sands to gravels): 1) high energy non-cohesive floodplains that erode in response to extreme episodic events and generally found in headwaters and other confined areas; 2) medium energy non-cohesive floodplains formed by regular flows across broad valleys where erosion is a function of sediment texture; and 3) low-energy cohesive floodplains formed by regular flows across broad valleys but with more stabilize banks of erosion resistant materials (Table 2.3).

A



B

Figure 2.3 – (A) A schematic showing the meander belt width, as well as the channel length (CL) and the valley length (VL) used to get the channel sinuosity (CL/VL) ***(City of Austin Texas Watershed Protection and Stream Restoration Program and Ayres Associates, Fort Collins, CO).*** **(B) A photo of a large meander belt in a broad valley setting on the Red River in Manitoba, Canada. Note the common variations in local meander belt width towards the top of the photograph.** ***(Reproduced with the permission of Natural Resources Canada 2008, courtesy of the Geological Survey of Canada).***

We describe floodplains as either low or high floodplains. Low floodplains are generally immediately adjacent to the river or stream and are inundated by river flows on a regular basis (e.g., annually). Low floodplains overlap with the non-channel portions of the meander belt and tend to flood even during moderate storms. High floodplains are at a slightly higher elevations and are also inundated on a regular, yet less frequent basis (e.g., every 1 – 10 years).

4) Terraces

Terraces are former floodplains from when the river was flowing at higher levels (Ward 2002). Terraces typically are deposited materials from large landscape forming events such as uplift or glacial retreat. They may still be inundated rarely and may, depending on local conditions, continue to support natural communities of floodplain species such as floodplain forests. Terraces can have important roles in temporarily storing waters during very large flood events (e.g., 20-100 year floods).

5) Riparian Wetlands

Riparian wetlands are generally low-gradient areas with inundated or hydric soils that support wetland plant species. Soil inundation is a result of either adjacent stream and river water levels or as a result of high groundwater levels, or both. There are a wide range of wetland types that might exist in these areas, often depending on local geology, landscape position, and climatic conditions. Riparian wetlands are typically areas of high plant diversity and serve important aquatic and terrestrial habitat functions (Table 2.4).

Dominant Physical Processes and Attributes

The physical processes and key attributes described below are key drivers of riverine and riparian habitat formation, habitat conditions and of their ecological integrity. River and riparian habitat is constantly being created, changed, destroyed, and maintained as a result of the processes associated with the hydrologic regime, sediment transport, and organic and inorganic material processing (Table 2.5). Such changes may occur within a dynamic 'equilibrium' where a natural balance is maintained with some range of natural variability. "Habitat equilibrium" can be described as the balance of habitat type and abundance and its formation and maintenance by physical and ecological processes. For stream channels this

Table 2.3 Floodplain Classification ***(adapted from Nanson and Croke, 1992)***

	Low Energy	Medium Energy	High Energy
Dynamics	slow, inactive	gradual activity	extremely active
Flood Frequency	1-5 years	1-5 years	>25 years
Stream Power (ft-lbs/sec)	<20	20-400	>400
Dominant Accretion Process	vertical fine strata	lateral point bar or braided	coarse vertical
Dominant Sediment	cohesive, clay to sand	sand to gravel	coasre sand to cobble

equilibrium is analogous to and closely tied to the known balance between water and sediment (Figure 2.4).

Table 2.4 Functions of Riparian Wetlands *(Brinson et al., 1995)*

Hydrologic	Biogeochemical
Dynamic Surface Water Storage	Nutrient Cycling
Long-Term Surface Water Storage	Removal of Imported Elements and Compounds
Energy Dissipation	Retention of Particulates
Subsurface Storage of Water	Organic Carbon Export
Moderation of Ground Water Flow or Discharge	
Plant Habitat	**Animal Habitat**
Maintain Characteristic Plan Communities	Maintain Spatial Structure of Habitat
Maintain Characteristic Detrital Biomass	Maintain Interspersion and Connectivity
	Maintain Distribution and Abundance of Invertebrates
	Maintain Distribution and Abundance of Vertebrates

It is important to note that river equilibrium is not a static condition for the channel or other features. Rather it is an equilibrium within which rivers are expected to change (Schumm, 1994). The equilibrium of rivers changes over very long time scales (e.g., adjustment as a result of climate change such as glacial retreat or global warming), medium time scales (e.g., recovery from land use disturbance such as widespread logging in a watershed), and very short time scales (e.g., response to severe events such as floods and landslides). This understanding of 'dynamic equilibrium' helps inform the overview of the following key processes.

Hydrology

Hydrology has been described the master variable influencing the physical processes and attributes in aquatic ecosystems (Poff et al., 1997). Natural water flows consist of a broad range of flows, from floods to droughts, with variation of several orders of magnitude between the volumes of low flows to those of flood flows. The natural variation in magnitude, frequency and duration of these flows are essential for preserving the ecological integrity of freshwater systems (Sparks et al., 1990; Richter et al., 1998) and these water flows directly influence physical habitat, life cycle strategies, connectivity, and species composition (Bunn and Arthington, 2002).

The characteristics of these flows are determined, in large part, as a result of slope, form, and composition of the lands through which the water flows. Hydrology, along with sediment regime, and valley / channel morphology, determines the hydraulics of rivers – that is the combinations of water depth and velocity. The continuity equation $Q = V * A$ (where Q is discharge, V is water velocity and A is the cross-sectional flow area) indicates that for a given discharge velocity will be lower for larger cross sectional flow areas. This fundamental theory is important for understanding the different hydrologic regimes between channels in confined and unconfined valleys and the importance of out-of-bank flows and of access to floodplains, riparian wetlands and other areas for maintaining the natural range of conditions. At the scale of the valley floor, out of bank and floodplain access increases cross-sectional flow area so water velocity during floods is lower for unconfined streams across the entire valley. At the scale of the bankfull channel, hydraulics can be quite variable due to a varied shape of the channel bottom where benches and low-flow channels change the cross-sectional flow area during different flow conditions.

A related concept is stream power $\phi = \gamma * Q * S$ (where ϕ is the stream power, γ is the specific weight of water, Q is the discharge and S is the slope of the water surface assuming normal flow) which is the ability of the flowing water to do work or cause erosion. Stream power is a function of hydrology and channel morphology. In very broad valleys when water spills onto a floodplain, the slope of the water surface tends to be lower over the floodplain than in the channel, which in turn reduces erosion. For smaller valley widths, velocities are higher and the slope tends to be more uniform across the channel and floodplain so more erosion tends to take place.

Sediment Transport

Sediment transport is an important driver of physical processes and habitat formation in river and riparian ecosystems. Sediment transport and watershed hydrology collectively determine the dynamic equilibrium for alluvial channels (Lane, 1955). Sediment is continually moving through stream and river channels as source material is moved from headwaters, deposited, and eroded in mid-watersheds, and eventually deposited in the lower water-

Table 2.5 Typical Habitat Features of *Active River Area* Components

***Active River Area* Component**	**Typical Habitat Features**
Material contribution areas	Seep or saturated source area Spring Wetland (forested, meadow, etc.) Forest canopy / overhanging vegetation Bluff, cliff and steep slopes
Meander belt	Step, riffle, run, pool, glide, dune, ripple Sediment & gravel bars (point, mid-channel, etc.) Hydraulic refugia from tributaries and oxbows Undercut bank Beaches and scour areas Physical refugia from LWD, debris jam, CPOM Forest canopy / overhanging vegetation
Floodplain	Oxbows Meander scar Floodplain lake Wetland Backwater swamp Island Natural levee Floodplain forest Forest canopy / overhanging vegetation Clay plug (filled oxbow)
Terraces	Wet meadow Ridges (old natural levee) Troughs (dry oxbow) Meander scars Prairie Remnant floodplain forest
Riparian wetlands	Forested, meadow, etc. Vernal pool Backwater swamp Beaver pond flowage

shed before finally being transported to the ocean. Large infrequent sediment input events such as landslides, most common in the upper watershed, can influence the downstream channel network for extended periods of time as sediment is continually deposited and re-suspended. More frequent flow events, such as bankfull flows that typically have a recurrence interval of about 1.5 years, effectively transfer sediment downstream and therefore play a major role in dictating channel pattern (Wolman and Miller, 1960). Excessively high or low amounts of sediment can change stream hydrology and disrupt the natural dynamic equilibrium between hydrology and sediment and result in either excessive sediment erosion or in excessive sediment storage and deposition. Either situation fundamentally alters the sediment load in the river or stream and can lead to widespread changes in the shape and location of the channel.

Through the process of being moved downstream, the sediment is sorted by particle size with different particle sizes being deposited in different locations. The distribution of these different material types establish important scour and deposition areas and with them, varying habitat types and conditions. These features in turn form hydraulic units such as steps, pools, and riffles that support different species throughout their life-cycles. Therefore, altering the sediment regime not only disrupts channel stability, but also can impair habitat. For example, excessive sedimentation that coverts a riffle-pool stream type to a uniform plane bed channel can reduce habitat stability and homogenize the channel bed, changing a cobble or gravel substrate to a substrate to a silt or embedded substrate. Hydrology and sediment regimes fundamentally work together to create and maintain habitat.

Transport and Transformation of Organic and Inorganic Materials

Organic materials such as coarse particulate organic matter (CPOM), large woody debris (LWD), and inorganic materials, such as minerals, constitute the building blocks of life in rivers and riparian areas. These inorganic and organic materials are the 'energy' on which the web of life in the river and riparian systems are built. In headwater areas and small streams, riparian areas are the primary source of these materials. In medium and large rivers, the primary source of these organic and inorganic materials is from upstream (Vannote et al., 1980) rather than the immediately surrounding riparian areas.

In addition to serving as the raw material for aquatic life, some materials, such as large woody debris (LWD), have profound physical effects on river processes such as sediment transport (Wallerstein and Thorne, 2004), local hydraulics (Daniels and Rhoads, 2004) and retention of CPOM (Allouche, 2002). LWD plays important roles in dictating the local sediment regime, increasing hydraulic diversity, and influencing the abundance and dominant feeding mechanism of aquatic organisms (Nislow and Lowe, 2006). Watershed topography, stream size, tree species, and tree size influence the amount of LWD inputs (May and Gresswell, 2003; Webb and Erskine, 2003).

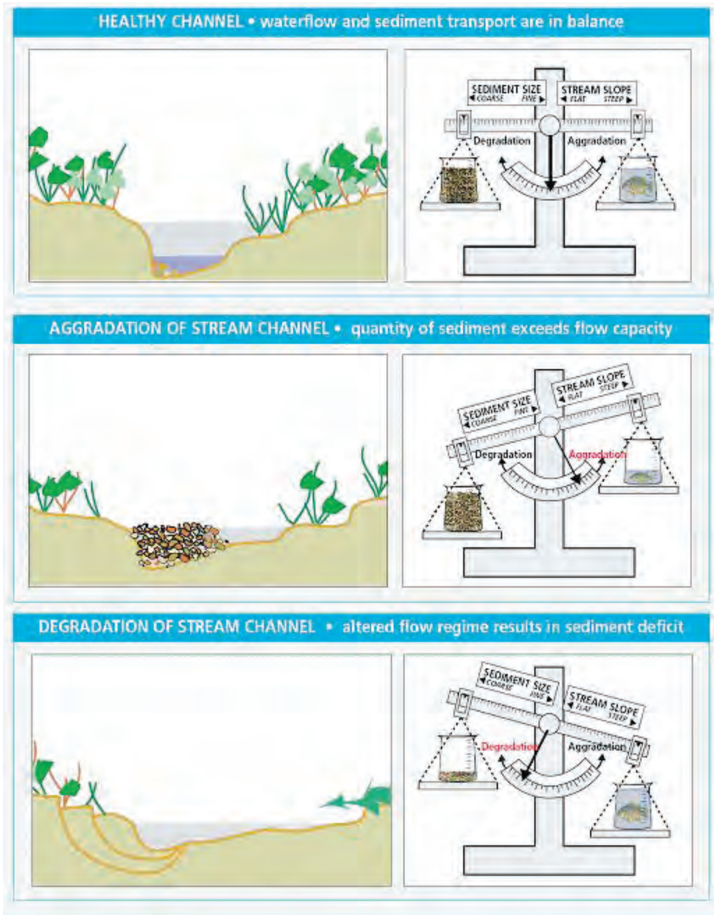


Figure 2.4 – Schematics illustrating the equilibrium and disruption of the balance between water and sediment leading to aggradation or erosion *(From Ontario Ministry of Natural Resources (OMNR), 2001).*

This processing of inorganic and materials is a key ecological process for river systems and depends on the hydrology and sediment regimes of a river or stream and the interaction of these physical processes with the surrounding riparian areas and with in-channel conditions.

Connectivity

One key attribute necessary to allow the processes associated with hydrology, sediment transport, and the transformation of organic and inorganic materials in river and riparian systems is the existence of connections within river systems – both up and down channels and between channels and riparian areas and floodplains. Longitudinal connections up and down the channel allow the movement of organisms between habitats and affects the movement of water, sediment and organic materials (Pringle, 2001). Lateral and vertical connectivity between the channel and floodplain has a strong influence on hydrologic and sediment regimes both within the river and on the floodplain and thus are an important component of both channel stability and aquatic habitat. Flood storage, sediment deposition and nutrient uptake are all important processes that require good connectivity between the channel and floodplain (Noe and Hupp, 2005).

These connections are often driven by hydrologic events. High water seasons are often associated with the migration of fish and other species that take advantage of these high flows to move up and down rivers and streams to areas not accessible during lower flows. Resident fish may also move into floodplain features during high flows to seek refuge (Schwartz and Herricks, 2005). Floodplain connections between different parts of the floodplain and between the floodplain and the channel can be sporadic, occurring frequently in the low floodplain and less frequently for higher areas of the floodplains. These flow events temporarily link important habitat areas like oxbow lakes and backswamps with the river and other wetland areas that are used for refuge, spawning, and nursery grounds (Hohausova and Jurajda, 2005). These temporary connections allow both the movement of species between these areas but also, during times when the hydrologic connection is not present, provide isolated areas that may have standing or slow moving, warmer, and less turbid waters than the river. In addition, these isolated water bodies are often free from some predators, making them important nursery and specialized habitat types.

Table 2.6 Dominant Process and Disturbance Regime Based on Valley Setting, Watershed Position and Geomorphic Stream Type

Confined to narrow valley

Broad valley

General Description of Location*

Watershed Position and Process1	**Headwaters, source**	**Middle, transfer**	**Lower, deposition**
Stream Type	Straight, steep, narrow, hillslope/debris	Straight/meandering, wide, fluvial	Meandering, flat, very wide
Floodplain Connection	Non-existent or local to channel	Local to channel or wide, important connection	Wide, important connection
Typical D_{50}	Boulders, bedrock, cobbles	Cobbles, gravels, sands, boulders	Sands, silts, gravels

Geomorphic Classification*

Stream Type[5]	Bedrock/ Cascade	Step-Pool	Riffle-pool	Plane bed	Braided/ Multi**	Dune-ripple
Rosgen Classification[6]	A	A, B	B, C	B, C, other	D, D_A	E, F

Dominant Process and Disturbance Regime*

Process	LWD, CPOM, and sediment inputs	Meander belt adjustment to accommodate sediment and slope through erosion, storage, deposition, and transport of sediment in the channel and floodplain		Floodplain inundation and long-term sediment storage
Primary location	30 - 60 meters from channel[2,3]	Meander belt (6-8 channel widths[4]) and adjacent low active floodplain		Entire valley bottom
Recurrence interval (years)	< 1	< 1	1 - 10	1 - 10

Water Quality, Temperature, and Energy Transport

The processes that occur within the *active river area* in combination with the geology, climate, and vegetation together create the background water chemistry of rivers and riparian areas, including acidity, suspended sediments, nutrients, and metals (Hynes, 1975). The resultant water quality influences all stream habitat as well as the biological processes that take place in the channel.

Water temperature is a product of the amount of solar radiation reaching the water surface through the vegetative canopy and the abundance and temperature of groundwater and upstream inputs. Together with the concentration of organic matter, the sunlight governs the amount of photosynthesis and respiration (energy transfer) taking place as organic compounds are assembled and simplified. The energy transfer influences the concentration of dissolved oxygen, rates of organic material processing, and nutrient uptake.

Watershed Position

The interaction and relative importance of these physical and ecological processes and key attributes can be more specifically understood in the context of their position within the watershed. A watershed is often described as having three parts--headwater/source areas, mid-watershed/transfer areas, and lower watershed/deposition areas (Figure 2.5) (Schumm, 1977; Vannote et al., 1980). These divisions provide an idealized structure to understand the key processes of hydrology, sediment transport, connectivity, transport and transformation of organic and inorganic materials, and water quality. Here we use Schumm's system (1977) to organize the *active river area* components with channel characteristics, dominant processes, key ecological attributes, important ecological processes and habitat features (Table 2.6).

It is important to note that across the landscape river systems often deviate from this idealized model of steep headwaters, declining slope through mid and lower watershed areas, and decreasing confinement from headwaters to low-gradient deposition areas. For example, large, flat, and unconfined wetland complexes are common in the headwaters of some river systems and can serve as important retention areas for water, sediment, and organic material and as important habitat features. Such wetland complexes may also be present at the base of steep terrain leading to the establishment of local depositional zones in the mid-watershed. It is also common to find local areas where valley confinement that deviates from the idealized model, such as a valley pinch point due to a rock intrusion in the mid or lower watershed. Scale also influences the interpretation of the Schumm model such as when a small source tributary meets a large depositional reach of river in the lower part of a large watershed. The tributary may be confined and lack transfer and deposition zones thus behaving solely as a source location typical of headwaters.

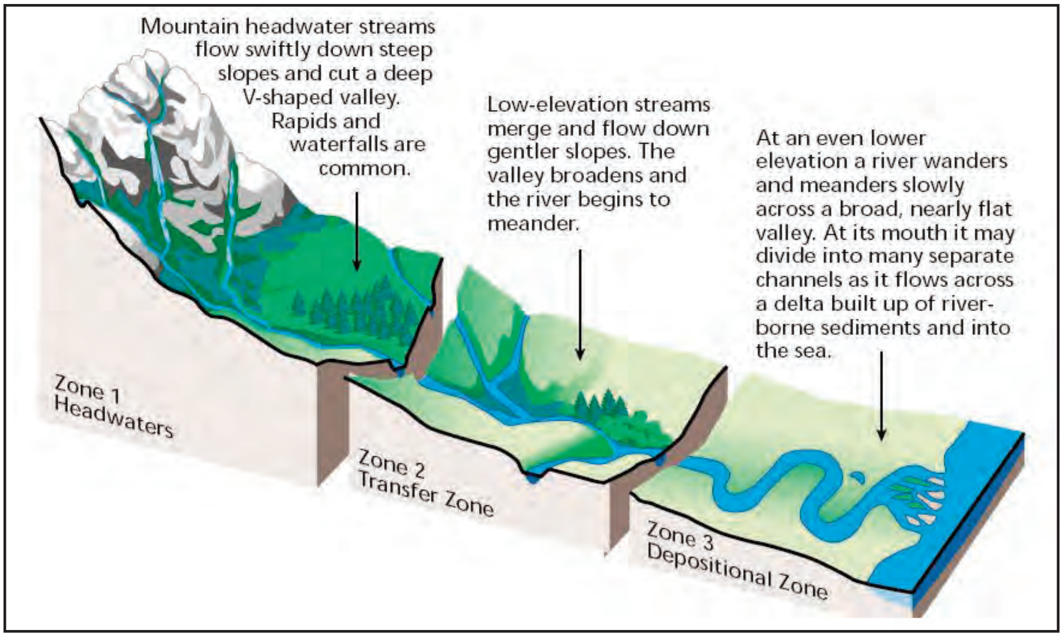


Figure 2.5– Longitudinal zones of a river corridor *(From FISRWG, 1998; Schumm, 1977)*

However, the Schumm model is appealing for describing the *active river area* because it frames the dominant processes, attributes, and disturbance regimes under different settings to provide a general understanding of these dynamics. These insights can be used as a basis for understanding the dynamics and features as they express themselves across a broad range of sites, configurations and watersheds and be a basis informing and adapting conservation and project planning accordingly.

Figure 2.6 - Step-pool channel type on a tributary of Roaring Brook. Killington, Vermont. *(Photo: Roy Schiff)*

Active River Area Components and Watershed Position

This section discusses the dominant processes and important habitat features of each *active river area* component based on its watershed position.

Upper Watershed

Material Contribution Area

The uplands in the uppermost watershed areas where intermittent streams form and come together to form the first and second order perennial streams are significant areas that contribute material such as inorganic and organic material, including sediment, CPOM and LWD, to the river system. Small headwater catchment processes and attributes support the biological diversity of the entire river network (Meyer et al., 2007). Small steep streams get LWD mostly from slope instability such as landslides and bank failure, where LWD that influences channel structure and habitat typically originates from within 50 meters of the channel (May and Gresswell, 2003; Webb and Erskine, 2003). Windthrow is another mechanism that delivers

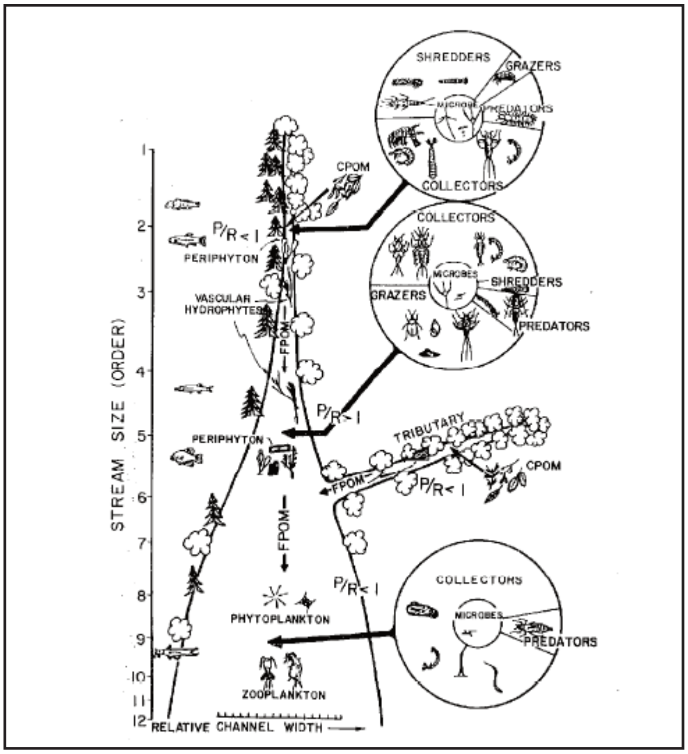


Figure 2.7 – The River Continuum Concept *(From Vannote et al., 1980)*

LWD to a channel, where wood typically originates from within 30 meters of the channel. Sediment input can also be influenced by channel rejuvenation, or the growth of the channel network in the upper watershed. In headwater wetlands the accumulation, processing, and eventual downstream transport of organic material is an important energy transfer process that influences the entire watershed.

Meander Belt

In the idealized context of Schumm's watershed model, the meander belt is narrow in small, straight, and steep headwater channels flowing through confined valleys. In these streams substrate is typically dominated by cobbles, boulders, and bedrock, with these large particles also being abundant on the banks. Step-pool channel types are common in steep headwaters where large trees fall across and span the small channels creating a series of steps and plunge pools (Chin and Wohl, 2005) (Figure 2.6). The flow in headwater channels, gathered from the upper watershed largely via nearby overland runoff, establishes the background water chemistry and often regulates the thermal regime by supplying cold water to downstream locations where more sunlight reaches the water surface.

Confined valleys and coarse particles on the bed and banks limit the lateral movement of the meander belt leading to high energy and frequent longitudinal disturbances. Intense storms can produce a rapid increase in the water depth and velocity in the channel that can return towards baseflow conditions soon after the precipitation has ended. A longer disturbance, on the order of weeks, common in headwaters in colder climates is the spring flood associated with snowmelt.

The small watershed area of headwater channels limits the magnitude of the disturbance associated with flooding. It is estimated that one or more events typically occur each year (i.e., recurrence interval < 1 year) that disturb and scour small headwater channels. The frequent disturbance is a function of the concentration of flows, sediment, and debris in the upper watershed. Less common large disturbances associated with landslides that introduce significant amounts of sediment to the system can influence channel form and processes locally and downstream for extended periods of time (Miller et al., 2003).

LWD decomposition takes place via physical abrasion, decomposition, and consumption by detritavores (Figure 2.7) (Vannote et al., 1980). CPOM processing typically takes place via physical abrasion, microbial colonization and consumption by macroinvertebrates (Allan, 1995). Shredding insects are closely tied to riparian vegetation and deliver smaller processed material downstream that other organism then consume (Cummins et al., 1989).

In wetland-dominated headwaters multi-or single-thread riffle-pool or dune-ripple channels are common. The meander belt is wider in these low-gradient headwater systems often spanning several channels flowing on the valley bottom. The disturbance regime in wetland-dominated systems may be less frequent than in mountainous streams due to the presence of more storage in the wider and often ponded channels. Wetland-dominated headwaters typically serve as important source areas of water, sediment, and organic material for downstream.

Stream Habitat Conditions

The steps, pools, snags, and channel heterogeneity create many small crevices and pockets suitable for small fish, macroinvertebrates, and plants to live. Headwaters support local residents, species that live both locally and in larger channels downstream, species that use headwater channels periodically for refuge, species that use headwater channels seasonally such as for spawning, and species that live nearby and are linked to headwaters (Meyer et al., 2007).

The aquatic plant community in headwaters is often dominated by diatoms, microscopic plants with silica shells that are able to exist with limited sunlight under the dense forest canopy. Headwaters in steeper undisturbed watersheds typically have clean, cool, well-oxygenated water, while those in flatter terrain can contain ponded water rich in minerals leached from watershed soils and submerged vegetation.

Floodplains and Terraces

A confined and steep geomorphic setting in the upper watershed generally inhibits floodplain development. In this case, small level areas immediately adjacent to the channel may form patches of active low floodplain; however, high floodplains and terraces are typically minimal. This physical setting leads to the majority of water, sediment, and organic materials entering the channel to be transported downstream.

In wider valleys in the upper watershed meander belt widths can range from 4 to 6 times the channel width and a low active floodplain is present. The small amount of floodplain that is available to the stream may be critical to the vertical stability of the channel and is critical for maintaining local and downstream channel and habitat stability. Should encroachment in narrow valleys become extensive, sediment loads may increase as a result of incision and lead to channel disequilibrium in mid- and low-watershed reaches fundamentally altering habitat.

Riparian Wetlands

Steep confined valleys tend to have limited riparian wetlands while broad, flat headwater areas can contain large swamps and other wetland types. Small bordering vegetated wetlands may exist in isolated locations with gradual sloping terrain, or where groundwater seeps out of the ground and flows overland towards the channel. Beaver flowages, fens, bogs, high-elevation sedge meadows, and vernal pools are all ecologically significant low-gradient systems that can be interspersed with the steeper gradient channels most often associated with the headwaters. These wetlands play important roles in the direct and indirect retention and downstream delivery of organics and nutrients.

Mid-Watershed

Material Contribution Areas

For the mid-watershed, the majority of organic and inorganic materials generally come from upstream head-water/source areas (Vannote et al., 1980). Other material contribution areas in the mid-watershed area include uplands and steep slopes along small tributary streams emerging from confined valleys and along steep valley walls and bluffs (often on only one side of a river) where no floodplain, terraces or wetland exist. These material contribution areas (as well as those within the other *active river area* components) also contribute LWD to the system which influence hydrology and channel structure and, as result, local and downstream habitat conditions.

The Meander Belt

The meander belt is typically wider and more dynamic in the mid-watershed as compared to the upper watershed due to a broader range of stream mobility within the valley. The degree of valley confinement determines the amount of space available for the meander belt and floodplains to occupy and thus the valley ultimately controls channel slope, pattern, and floodplain access. The meander belt is wider in broader valleys, so channels tend to be more sinuous and connected to the low active floodplain. In narrow valleys, the meander belt is narrow and contains relatively small, straight channels with limited floodplains.

The dominant processes in the mid-watershed are the downstream transfer of water, sediment, and energy in either confined or unconfined valley settings. This most often takes place via active channel adjustment as it seeks to attain dynamic equilibrium (Lane, 1955). The continuous erosion and deposition leads to the natural movement of the channel across the meander belt as well as in the vertical direction relative to the level of the floodplains. Channels in confined valleys with deformable bed and banks may thus be susceptible to more frequent change than those with banks up against valley walls or a naturally armored bed. The meander belt width is typically approximated as 6 to 8 bankfull widths (Williams, 1986) and can be used to define the lateral extent of the primary disturbance regime in the mid-watershed.

The disturbance magnitude and frequency in the mid-watershed (flooding, sediment erosion and deposition, ice flows, and land slides) are variable, largely based on valley confinement. In a narrowly confined mid-watershed channel the disturbance may be similar to that in a steep upper watershed, being high intensity but limited in spatial extent with a recurrence interval of $<$ 1 year. In an unconfined channel, the increased flow area across the low active floodplain will reduce the degree of disturbance yet increase the lateral spatial extent. One or more disturbance events typically take place every 1 to 10 years that disturb an unconfined mender belt and low floodplain in the mid-watershed. Less common large disturbances such as landslides or long-duration storms can produce disturbances that alter channel form and processes locally and downstream for years as the return towards equilibrium takes place.

Particle sizes in stream beds in the mid-watershed can vary, with steeper channels consisting of cobble and gravel, while gently sloping channels are dominated by sand and silt. Bank texture fluctuates but is often dominated by sand and silt, with coarser materials near the normal water surface. The riffle-pool channel type is most common in the mid-watershed zone, with plane bed, braided, and other channel types present as well. Plane bed channels lack the bed features and hydraulic diversity developed by scour and deposition while braided channels consist of large aggradational features and multiple flow paths that have a large overall bankfull channel width and thus meander belt. Braided channels occur in locations where high sediment load combined with specific combinations of channel slope and bankfull discharge are present (Leopold and Wolman, 1957; Watson et al., 1999).

Although largely identified as a transfer zone, erosion, storage, and deposition do naturally take place in the mid-watershed as sediment is continually produced, sequestered, and eventually transported through the system. The more confined the meander belt the more likely the downstream outputs from the channel will be equal to the inputs to the channel from upstream over the short term.

Stream Habitat Conditions
The increased variation in disturbance regime in mid-watershed meander belt and low active floodplain translates to increased stream and riparian habitat variation. The expansion of available habitat types, increased hydraulic diversity and a wider food base relative to headwater streams typically leads to increased species richness of plants, macroinvertebrates and fish in mid-watershed channels.

The constant erosion and deposition lead to the formation of scour and depositional features used by many aquatic organisms for a broad range of life-cycle functions. For example, the establishment of large, deep pools associated with the riffle-pool stream creates important refuge habitat for fish and macroinvertebrates. Hydraulic diversity is often high with a wide range of depth-velocity combinations suitable for many species at different life stages. Channel pattern has a strong influence on all habitat features (e.g., hydraulics, substrate characteristics and bank stability) (Brierley and Fryirs, 2005). For example, both braided and plane bed channels can be unstable, in which case habitat is frequently adjusting limiting colonization and survivorship of perennial species.

The food base in mid-watershed channels is also more diverse relative to headwater channels. Fine particulate organic matter (FPOM), largely from the processing of upstream CPOM, contributes to the local food supply as do aquatic plants as wider channels allow photosynthesis to take place in the channel. Herbivorous and filtering macroinvertebrates typically make up more of the assemblage in mid-watershed channels and thus the food source for fish that feed on macroinvertebrates is more diverse (Vannote et al., 1980; Allan, 1995).

Floodplains and Terraces
As mentioned, the presence of floodplains and terraces in the mid-watershed is a function of valley confinement. In confined valleys, the floodplain is often limited to only small low active floodplains near the channel. In wider valleys, the width of the floodplain increases.

Floodplain inundation is an important mid-watershed process that determines flood water, sediment, and organic material storage regimes, as well as nutrient uptake. The extent and frequency of floodplain inundation is a function of where the channel sits vertically in relation to the floodplain (i.e., entrenchment). The frequency of inundation decreases in the various floodplain components moving from the meander belt to the valley wall. Terraces are not commonly inundated and is typically located next to the valley wall.

Varying dynamics and inundation lead to a range of floodplain types (Nanson and Croke, 1992) (see: Table 2.3). This physical setting produce a specific composition of floodplain vegetation primarily based on inundation (Balian and Naiman, 2005). Naturally functioning floodplains not only support diverse assemblages of natural communities, but also support natural channel morphology, bank stability, and habitat diversity (Naiman et al., 1993). The regulation of stream power via flood storage on floodplains stabilizes aquatic habitat, and water quality is maintained via deposition of fine sediments and nutrient uptake on floodplains.

Floodplain habitat conditions

Floodplains and terraces serve as critical habitats for aquatic, floodplain, and terrestrial species and communities. For example, natural floodplain dynamics are important for the persistence of floodplain forests and establishment of seasonal spawning and feeding habitats for fish, macroinvertebrates, amphibians, birds, and mammals. Many organisms rely on niche floodplain habitats such as the riparian wetland types that are commonly located within floodplains to complete parts of their life cycles. Floods that remove vegetation make way for pioneers that support channel health and diversify plant communities (Parsons et al., 2006). LWD stranded in the floodplain is a critical substrate for housing propagules and promoting re-growth following disturbance (Pettit and Naiman, 2005). The resultant heterogeneous floodplain communities are an important part of the migration corridors often located in valley bottoms. In addition, seed dispersal is linked to flood cycles as are the disturbances that remove trees, shrubs, and herbs making way for pioneers (Parsons et al., 2006).

Riparian Wetlands

In less-confined valleys, riparian wetlands are often present in the low active and to a lesser degree in high floodplains. Riparian wetlands may include floodplain forests, shrub wetlands, and open wetlands adjacent to channels in the floodplains. Wetlands bordering streams are a direct link between channel and floodplains, stabilizing banks and providing local inputs of LWD and CPOM to the channel. Channel flow, water ponded in the wetlands, and groundwater are all typically connected. The dynamics of riparian wetlands are similar to those of the low active floodplain with regular periods of inundation. They also serve as important water storage areas to reduce stream power downstream.

Riparian Wetland Habitat Conditions

Dense vegetation makes riparian wetlands good refuge locations during floods where water velocities are lower than in the main channel. The dense cover in riparian wetlands is also used for avoiding predation. Wetlands with abundant groundwater may contribute cool water to the channel and create thermal refuge during periods of low flow. The interactions between surface and groundwater in riparian wetlands promotes plant succession and diversification of plant communities (Tabacchi et al., 1998).

Floodplain hardwood and softwood forests are important habitat features, more so because limited intact examples remain due to floodplain development. These forests contain unique species assemblages of trees and herbs that are adapted to periodic inundation, erosion, and deposition.

Lower Watershed

Material contribution areas

Most of the materials in the river and riparian areas in the lower watershed come from upstream sources (Vannote et al., 1980) and from areas within other *active river area* components. Areas along bluffs and other steep banks and along small tributaries emerging from confined watersheds contribute organic and inorganic materials and physical habitat features that may be locally important in the lower watershed.

The Meander Belt

The meander belt is often very wide and sinuous in the lower watershed. Fine sediment deposition is common in the large, winding, gradually sloping channels, and thus the channel bed and banks usually consist of sand and silt. Dune-ripple channel types in broad, flat valleys are common in the lower watershed, with other channel types previously described in more confined settings. Multi-thread channels can be present due to localized braiding, alluvial fans, and stream junctions (Benda et al., 2004) where sediments tend to accumulate at breaks in slopes. As in the mid-watershed, channels remain stable as long as slope, pattern, and channel dimensions are free to adjust to balance water and sediment.

The dominant processes and attributes in the lower watershed in the meander belt are sediment and flood storage, which take place in conjunction with the same processes in the valley bottom floodplains. With a large upstream watershed area flooding can last for relatively long periods of time in the low—watershed relative to upstream locations, and the disturbance often covers large areas across the low and high floodplains and on rare occasion the terraces as well. Intense local storms, annual snowmelt or wet seasons, and less common large storms all disturb channels and floodplains in the lower watershed. One or more large disturbances tend to occur every 1 to 10 years. The broad floodplain reduces the likelihood of local landslides, yet the collapse of terraces due to undermining may influence the channel if a large storm moves excessive sediment downstream. Channel avulsions, the sudden creation of a new river channel where flow cut a new channel during large flows, can take place in the lower watershed due to the large volumes of water moving through the flat sinuous channels. Avulsions can influence the channel for long periods of time as sediment is moved through the system. Avulsions typically occur when flood waters carve a new flow path across a sharp meander bend (i.e., a meander chute cut-off), access a nearby low spot such as an old gravel pit, impinge on the banks due to the formation of a large debris jam or overtop an under-sized channel (Schiff et al., 2007). The resulting features such as meander chute cut-offs, oxbow lakes, and temporarily connected pools and ponds contribute to the habitat diversity of the floodplains.

Stream Habitat Conditions

Habitat diversity is high in the wide meander belt, low active floodplain, and associated riparian wetlands in the low-watershed. The broad alluvial channels, varied disturbance regime, and unique food source form important habitat for aquatic organisms that differs from smaller upstream channels (Wilhelm et al., 2005). Large pool formation is an important habitat process associated with the large channels in the lower watershed. Periodic disturbance in the lower watershed regenerates instream habitat by moving fine sediments up onto the floodplain or further downstream and eventually out of the watershed. This process is important as excessive deposition of fine particles can impair macroinvertebrate and fish habitat (e.g., Zweig and Rabeni, 2001).

The abundance of FPOM, suspended organic matter, and fine sediments makes the lower watershed ideal for organisms that collect, gather and filter. Macroinvertebrates and fish that require soft substrate also reside in the lower watershed. With the increased channel width comes more incident solar radiation which warms water temperatures and allows for increased plant growth, particularly along the edges of the channel where velocity is lowest. Small and large aquatic plants support herbivorous fish and macroinvertebrates as well as create substrate for additional plant colonization.

Floodplains and Terraces

Floodplains in the lower watershed tend to be broad, flat, and have low to medium energy (see Table 2.3). Long-term sediment storage leads to dominant textures of clay, silt, or sand for low energy floodplains and sand and gravel for medium energy floodplains. The lower watershed generally responds to upstream inputs of water, sediment, and debris via extensive floodplain inundation and sediment storage. The wide channels in the lower watershed are typically connected to wide floodplains unless artificially disconnected by human infrastructure such as transportation embankments or excessive channel incision.

Floodplain inundation and storage of the fine sediments transported from upstream locations are the key processes in the lowlands. Sediment storage usually extends over long time periods but can also be temporary. This stable channel requirement is closely linked to the need for a wide floodplain within which the stream can freely move across the valley floor. When water spills onto the floodplain, flow velocity is reduced which allows sediment deposition and ultimately dynamic equilibrium to be maintained.

Floodplain Habitat Conditions

Floodplains associated with large rivers in the lower watershed can contain a variety of habitat types such as backwaters, swamps, and oxbows (Sparks, 1995). Inundated floodplains form refuge locations for small fish and nursery grounds for juveniles. Naturally vegetated floodplains create a local supply of LWD and CPOM to add to the FPOM moving downstream. Via maintenance of the dynamic equilibrium between water and sediment, floodplains contribute to stable aquatic habitat. Floodplain dynamics also form and maintain heterogeneous migration corridors and floodplain forests that a host of terrestrial species rely on.

Riparian Wetlands

Riparian wetlands in the lower watershed can be wide extending across the broad, flat valley floor and are generally within the floodplain of the river. These wetlands are often integrally linked to river hydrology by surface and groundwater, and thus have a strong influence on the disturbance regime of the channel and floodplain. This results in a fundamental link between the condition of riparian wetlands, banks, channel geomorphology, and many important habitat features (Naiman et al., 1993). With their large size in the lower watershed, riparian wetlands can perform substantial water, sediment, and debris storage outside of the channel. Because of their dense and complex vegetation, upon recession of a flood, water is slowly released back to the channel with fine sediment and nutrients remaining on land to naturally support plant growth.

Riparian Wetland Habitat Conditions

The periodic wetting and drying in large riparian wetlands creates unique habitats having high plant diversity and

Table 2.7 Ecological Functions of the *Active River Area*

Instream habitat formation	Hydraulic / thermal refuge
Habitat diversification	Physical isolation shelter
Flow storage	Food sources
Sediment transport / storage	Establishment of buffer vegetation
Channel / habitat stability	Nutrient uptake
Formation of hydraulic units	Water quality regulation
Creation of reproduction /nursery areas	Thermal regime regulation
Seasonal niche habitats	Floodplain forest inundation
Establishment of buffer vegetation	Microclimate formation
Migration pathways	Groundwater recharge

quality food, shelter, and migration pathways used by fish and wildlife. Riparian wetlands tend to be densely vegetated and thus provide a local supply of large trees for LWD and smaller debris for CPOM to the channel. The functions riparian wetlands perform influence watershed processes and locally diversify aquatic habitat.

Watersheds as a Nested Framework

These general descriptions of *active river area* components and watershed position provide a means for understanding the key processes of a river system along its continuum from headwaters to lower watershed. Yet it is also well understood that watersheds are nested hierarchies, with small watersheds nested within larger watersheds (Frissell et al., 1986). These relative watershed positions and *active river area* components will play out at each of these scales. Consider two small streams, one located in the upper watershed and another a tributary to a large channel in the lower watershed. Although of a similar size, the two channels will likely have unique habitat due to differences in local geology, slope, climate, hydrology, hydraulics, source material inputs, and channel geomorphology. They will also have differences in the relative amount of material they contribute to their immediate downstream reach. The small stream in the upper watershed generally contribute a significant amount of the material available in its downstream reach while the contribution of the small stream to a large river in the lower watershed will be small compared to the inputs of all the areas upstream. Also, the small tributary streams in the lower watershed will generally be more biologically rich and diverse as it will contain not only resident species but, as a result of its proximity to the large river, also contain species from the larger system that use the tributary stream for part of its life cycle or as a temporary refuge or travel corridor.

Conclusion

The *active river area* framework is designed to guide efforts to protect the key features of rivers, streams and riparian areas important for both physical and ecological processes and that include important habitat features by describing a spatially explicit area within which these important processes take place and where these key attributes exist (Table 2.7). Together, these key processes and attributes determines habitat characteristics, and therefore the biodiversity, that can be supported in the channel (Naiman et al., 1993) and in riparian and floodplain areas (Sparks, 1995; Ward, 1998). By defining spatially explicit areas of interaction between flowing waters and land we are able to add a both a place based and processed based component to the existing set of conservation tools.

Table 2.2 Components of the *Active River Area*

Component	Description	Habitat Characteristics and Functions	Natural Processes and Key Attributes
Material contribution areas†	Land that is not frequently inundated that is typically hilly or mountainous above the valley floor that commonly contributes sediment and organic materials such as large wood and coarse particulate organic matter to headwater channels via bank erosion, senescence, land slides, flooding, and windthrow.	Organic material inputs leading to steps, plunge pools, LWD, and debris jams	Origin of both dissolved and particulate forms material including CPOM and LWD from upper watershed at various scales and processes that influences habitat throughout the channel network via local storage and process further downstream
		Instream habitat stability	Relatively large particles span channel and create sediment and organic storage locations while at the same time establishing heterogeneous habitat
		Channel and bank stability	Upstream inputs of sediment are a critical part of the dynamic equilibrium between water and sediment and thus regulate stability in the upper watershed and downstream
		Water quality	Headwater hydrology, sediment inputs, and channel network formation processes strongly influence water quality in terms of turbidity and SPM, as well as the baseflow chemical signature of the watershed
Meander belt (low flow and bankfull channels, the banks, and portions of the active low floodplain)	The meander belt is the linear distance across the channel that spans the outside edges of meanders that curve in opposite directions. All habitat features and natural rocesses found in the low flow and bankfull channels, the banks, and portions of the low active floodplain thus occur in at least one location in every cross section of the meander belt, and if allowed will move across the meander belt as the channel evolves. For unconfined streams, channel slope is adjusted via changes in channel pattern to maintain the water-sediment equilibrium, which fundamentally determines channel stability.	Full range of hydraulic units and associated diversity of velocity depth combinations	Hydrologic and sediment transport regimes that are a function of valley and watershed setting, longitudinal channel and lateral floodplain connectivity, and having a relatively high disturbance regime due to the dynamic flowing environment
		Scour and depositional features	Scour and deposition feature formation due to resistance of bed and bank materials and range of hydraulics, longitudinal channel and lateral floodplain connectivity, dynamically adjusted via channel aggradation and degradation
		Retained organic material in the form of debris jams, LWD, and CPOM	Importation and retention of organics from both upstream and adjacent riparian areas via flooding cycles, senescence and windthrow, longitudinal channel and lateral floodplain connectivity, interactions with vegetation on the banks and in adjacent vegetated buffers, and connections to wetland features in the nearby floodplain
		Near-bank refugia	Interactions with bank and buffer material and vegetation, along with nearby wetland features to establish thermal, isolation, and hydraulic refuge locations
		Water quality	Transport of suspended particles, dissolved ions from watershed geology, and nutrient processing; water temperature regulation from over-hanging bank and buffer vegetation and bed features, longitudinal channel and lateral floodplain connectivity to store sediment
Riparian wetlands	Wetlands, including open, shrub and forested wetlands, that are hydrologically connected to the channel and located in the floodplain. These features experience erosion and deposition of sediments and form niche habitats that support life cycle functions of aquatic and terrestrial species at various flood stages.	Bank stability	Interactions between wetlands and banks influence bank hydrolgy, collapse, and stability
		Channel and habitat stability	Hydraulically rough storage areas reduce flood velocities during disturbance and promote depostion of sediment and long-term storage
		Water quality	Nutrient uptake and fine sediment storage during and after large floods, increase flow path for inputs from watershed to buffer water chemistry

Table 2.2 Components of the *Active River Area (continued)*

Component	Description	Habitat Characteristics and Functions	Natural Processes and Key Attributes
Floodplains (low floodplains are partially in the meander belt*)	The flat land immediately adjacent to a river or stream that, on average, is prone to periodic inundation at least once every 10 years, if not every year. Note that the active low floodplain typically includes all of the land in the meander belt that is outside of the bankfull channel.	Channel stability	Lateral floodplain connectivity preserves natural channel evolution by allowing for floodplain access that reduces the discharge and velocity in a channel for a storm of a given size, and allows for fine sediment storage on the floodplain
		Bank stability and refuge areas	Bank stability is influenced by roots of vegetation and hydrologic interactions in the floodplain near the channel, the hydraulics resulting from hydrologic and sediment regimes interact with bank materials and increase the stability of local habitat
		Water quality	Nutrient capture, fine sediment storage and thermal regulation of water temperature via seeps and shading from floodplain vegetation, increase flow path for inputs from watershed to buffer water chemistry
		Riparian wetlands	Aquatic-terrestrial ecotone used by range of species for migration pathways, access to sources of food, heterogeneous surfaces good for refugia, flood storage, nutrient uptake, sediment capture, and general buffering of external influences on the aquatic ecosystem from the terrestrial landscape
Terraces	The land up-gradient of the high floodplain and a steep terrace riser that is a large flat remnant floodplain landform from pre-glacial landscape formation. This feature is not prone to inundation, and can collapse and deliver sediment to the channel when flood waters undermine the base of the terrace.	Channel and bank stability	Terrace collapse (i.e., mass failure) can introduce large quantities of sediment into a river or stream that could initiate widespread channel adjustment by altering the balance between sediment and water
		Instream habitat stability	Mass failures also lead to habitat degradation due to smothering by fines and widespread channel instability
		Water quality	Fine sediment inputs can impair water and habitat quality

Notes:
**As the meander belt migrates across the valley bottom, it is closely associated with the low active floodplain.*
†Sediment/organics regime locations that could be adjacent to the channel, floodplains, and riparian wetlands where sediment and organic materials are likely to originate from and temporarily be stored. Sediment/organics regime locations play an important role in determining the extent of the network of headwater channels and determining channel and habitat stability in the upper and remaining parts of the watershed. Headwater catchments are also included in the ARA.

CHAPTER 3: SERVICES FROM FUNCTIONING ACTIVE RIVER AREAS

"Flowing waters contain a tiny fraction of the stored water in the biosphere, yet they are of great importance to our physical, chemical, and biological world. Rivers and streams play a critical role in the continuous water cycle and in the flux of minerals and nutrients from higher to lower land and eventually to the sea. They provide humankind with clean drinking water, harvestable plants and animals, routes of travel and transport, waste removal, and renewable energy. Flowing water also provides spiritual uplift and cleansing. Everywhere on Earth, from the smallest village to the largest metropolis, the life of people is intimately intertwined with fresh, and often flowing, water." (Allan and Flecker, 1993)

Introduction

The *active river area* framework is a tool to inform efforts to protect and restore the ecological integrity of rivers, streams and riparian areas. This goal is accomplished by providing a means for explicitly considering the spatial area necessary for natural processes and disturbance regimes to occur and thereby allow the natural formation, modification, and maintenance of aquatic and riparian habitat to occur. Equally importantly, a naturally functioning *active river area* provides a range of important benefits to society, including providing other habitat values, the reduction of risk from flood and erosion hazards, water quality protection, and providing scenic and recreation amenities. We briefly describe these benefits so that the protection, restoration and management of active rivers areas is undertaken to meet the needs of both people and nature.

Other Habitat Values

The *active river area* was designed to protect the area and processes associated with river and riparian systems. However, many of these areas also provide important habitat values for terrestrial species. Many terrestrial species travel through or spend a portion of their lives in the *active river area*. The link between terrestrial habitats and riparian habitats is not distinct but rather has been described as a terrestrial-aquatic continuum (Fisher and Welter, 2005).

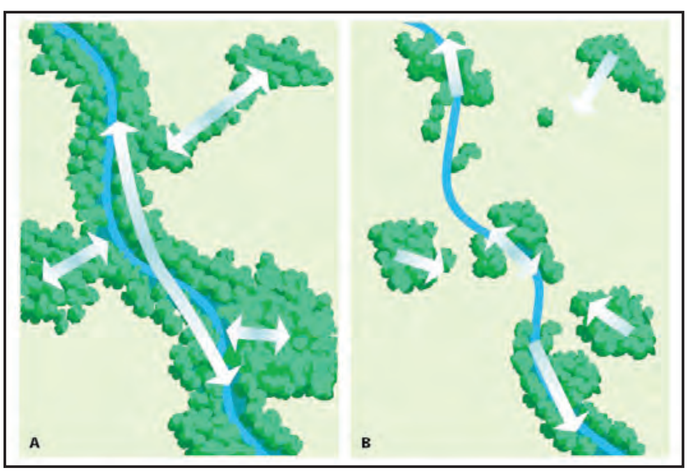


Figure 3.1 – "Landscapes with (A) high and (B) low degrees of connectivity. A connected landscape structure generally has higher levels of functions than a fragmented landscape." ***(From: FISWRG 1998.)***

Birds and mammals also move through rivers and their floodplains (Naiman and Decamps, 1997). These travel corridors in the landscape allow open space for movement as well as nearby complex habitat for refuge and foraging (Figure 3.1). The edge and nearby interior habitat in riparian areas is an important niche that many species of amphibians (Olson et al., 2007), birds (Peak and Thompson, 2006), forest-floor invertebrates (Rykken et al., 2007), and mammals (Osbourne et al., 2005) rely on in a natural condition. For example, debris piles that stabilize and become vegetated in the floodplain after floods are preferentially used as refuge by birds and small mammals (Steel et al., 1999). The nature of the dynamic heterogeneous edge habitat makes riparian zone the most diverse and complex biophysical habitats on the terrestrial portion of the Earth (Naiman et al., 1993).

It is important to note that the spatial extent of the *active river area* as developed to capture river and riparian processes is not the always the same as area required for terrestrial species and for species travel corridors. When designing protected areas, the *active river area* framework can be considered for riparian, floodplain, and aquatic habitat protection, while at the same time other habitat needs must be considered for protecting terrestrial species. This is especially important in areas with confined streams where natural riverine processes can be protected within narrow material contribution zones of the *active river area* while more area may be needed to protect other habitat and species values.

Avoidance and Reduction of Flood and Erosion Hazards

Humans have long sought to control the dynamic nature of rivers to reduce the devastation to life and property caused by floods. A major cause of damage from rivers and floods is from erosion associated with an active river – erosion which can undermine structures, remove fertile agricultural soils, and clog waterways with silt and sediments.

Protecting and restoring *active river areas* can help to address these issues and mitigate the associated costs. When a river channel is connected to a naturally functioning floodplain, flood waters are stored over a large area reducing the power of flows and reducing the peak flow levels downstream, thereby reducing potential damage to communities and improving stream stability. For example, the U.S. Army Corps of Engineers Charles River Natural Valley Storage Project protected over 8,000 acres of riparian wetland areas in eastern Massachusetts after determining this was a cost-effective way to mitigate flood damages to Boston and other downstream communities (USACOE, 2008).

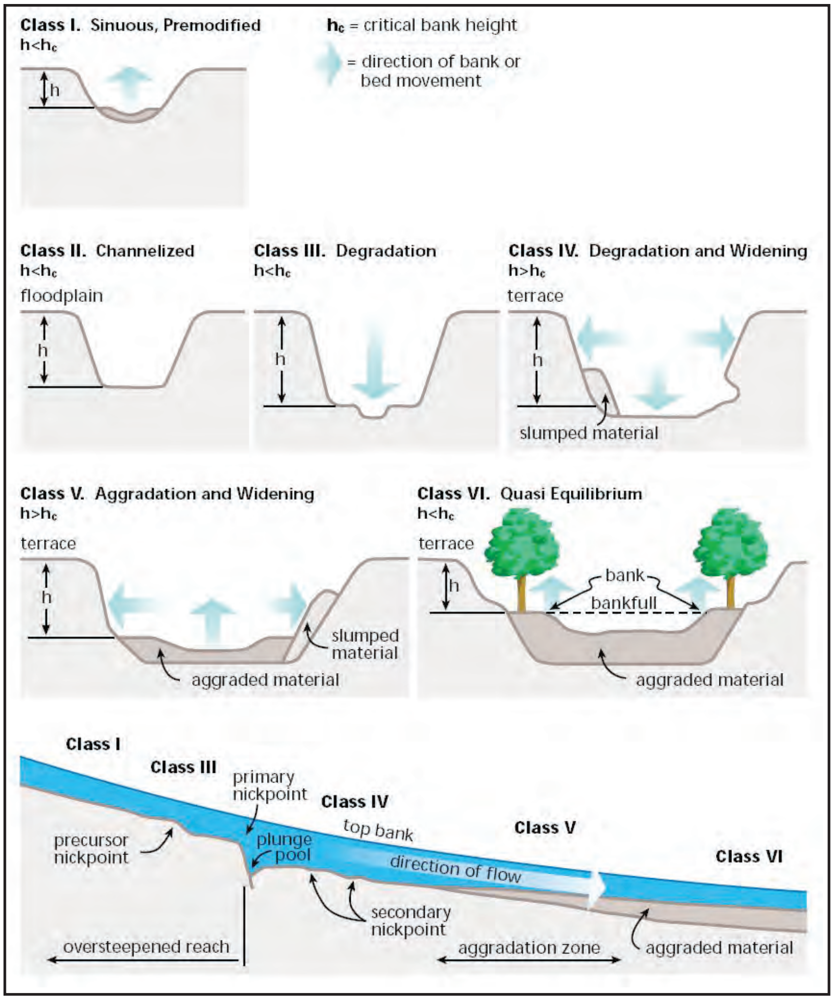


Figure 3.2 – A schematic of the Schumm (1984) incised channel evolution model *(From: FISRWG, 1998; Simon, 1989).*

Protecting the *active river area* in a more natural condition can reduce the erosion hazards that can result from channel migration and avulsions (flows creating new river channels). The cost of repairing damages from flooding and fluvial erosions hazards is very high, with current expenditures in the Unites States at approximately $6 billon dollars a year (King, 2005). Preserving the *active river area*, particularly those associated with more frequent disturbance frequencies such as the meander belt and active low floodplain, can benefit society by flood attenuation, flood water storage and the reduction of damaging erosion events.

Infrastructure placed in the *active river area* often prevents natural river processes from taking place. Bridges, culverts, roadways, recreation paths, and buildings not only impede these natural processes but often are the casualty of floods and erosion. The building of infrastructure and the practice of stream channelization to gain developable land or protect existing infrastructure often exacerbates flood and erosion hazards and leads to incision, or down-cutting, which disconnects channels from their floodplains. As the channel cuts down lower than the floodplain, the stream power in the channel increases over the full range of flows as floods no longer can spill into floodplains. The result is often channel instability with continued incision in sediment transport locations or excessive aggradation in sediment deposition locations. As the channel attempts to return to equilibrium by meandering across the valley to gain the necessary slope to transport its water and sediment, armoring is often prescribed where infrastructure is present. This activity is exactly opposite of the natural channel evolution as the channel attempts to widen and build new floodplain at a lower elevation (Figure 3.2) (Schumm et al., 1984; Simon, 1989). The cycle of channelization, excessive erosion and deposition, and continued armoring is both costly and in contrast to natural processes, and typically increases the frequency and extent of impacts due to flooding and erosion events.

Repairing and replacing such infrastructure becomes costly, and often repetitive, obligations for municipalities, states, and nations. The most effective means of reducing risks in the river corridor and the associated funding for infrastructure protection is to locate and design these structures to allow the river the necessary room to attain its equilibrium via natural processes. A move towards proactive management of the *active river area* is a major social benefit that is beginning to be recognized and implemented in the Unites States (e.g., Kline and Cahoon, 2006).

Adapting to Climate Change

Floodplain access and the services of flood attenuation and reduction of erosion hazards gained from *active river area* protection will become more important in the face of global climate change. In many locations climate predictions suggest more intense and frequent storm events and expanded droughts – sometimes in the same area. The Intergovernmental Panel on Global Climate Change has compiled data showing an increase in precipitation in the temperature regions across the globe, and decreasing precipitation in arid regions (IPCC, 2007). Tellingly, expenses associated with recovery from extreme weather events, a major component of which is floods, has increased approximately 6 times over the past decade (reviewed on the Internet on 11/26/2007 at www.ipcc.ch). Total annual precipitation in the northeast United States has increased over the past century, with an apparent rise in frequency of more intense storm events (Markham and Wake, 2005). In light of these trends, protecting and restoring *active river areas* is an important strategy to reduce future risks and management costs and along rivers. Naturally vegetated *active river area*s, especially in floodplain areas, can store flood waters and sediment to reduce flooding and erosion damages. In addition, maintaining and restoring these areas to a more natural condition can foster the infiltration to recharge groundwater aquifers that ultimately support baseflow and help to mitigate the impact of low flows associated with more frequent drought conditions.

Water Quality Protection

Protecting and restoring *active river area*s are important aspects of restoring and maintaining good water quality. There is extensive literature on the value of intact riparian and headwater areas for maintaining and improving water quality. Vegetation in riparian corridors helps protect surface and groundwater by creating long, complex flow paths that increase opportunities for storage, uptake, and transformation of dissolved chemical constituents and storage of sediment (Dabney et al., 2006). The longer flow paths typically allow more time for infiltration to recharge groundwater supply and support baseflow that is critical for water temperature regulation. Riparian corridor vegetation generally protect rivers from the influences of watershed land use change (Naiman and Decamps, 1997).

The value of riparian and watershed lands in protecting water quality is well understood by the water supply industry. Watershed protection of source waters is considered the first and most fundamental step to protecting drinking water. The improved water quality that results from keeping watersheds in natural condition results in substantial cost savings related to the treatment of water. A study of 27 water suppliers conducted by the Trust for Public Land and the American Water Works Association in 2002 found that for every 10 percent increase in forest cover in the source area, treatment and chemical costs decreased approximately 20 percent (Ernst, 2004).

A common technique for protecting the water quality of rivers is the use of vegetated buffers (e.g., Correll, 2005; Dabney et al., 2006). These areas are often a set width as measured from the top of bank or channel center. Vegetated buffers would, in most areas of the watershed, be narrower than the *active river area*. Buffer width sizing is variable, often ranging between 20 and 200 feet, depending on the system, with the primary objective being to buffer impacts to water quality (Schueler, 1994; FISRWG, 1998; Correll, 2005). These buffer width recommendations typically fall in the actively adjusting meander belt or low floodplain in the mid and lower watershed. Rather than attempting to size buffers to achieve selected water quality or other objectives (Palone and Todd, 1998; TWC, 2003), preserving the broader *active river area* protects a full range of functions to allow for natural river form, process, and disturbance regime.

Sediment

The *active river area* can, for some water quality concerns, be more effective than fixed width buffers. Sedimentation is a common threat to water quality (USEPA, 2002a), which can smother benthic habitats and complicate life cycle functions of aquatic organisms.

Bedload and suspended sediment concentrations increase as channels are disconnected from their floodplains where critical natural sediment storage areas are located. In a review of urban streams around the world, Chin (2006) found that channels in developed areas tended to initially have increased sediment deposition and then became starved of sediment leading to excessive erosion. Both phases of departure from the natural sediment regime generate channel instability, degrade aquatic habitat, and impair natural life cycle functions of aquatic organisms. Streams adjacent to re-vegetated buffers tended to have higher water clarity and increased channel stability (Parkyn et al., 2003). *Active river area* protection and restoration provides a tool for maintaining natural sediment transport characteristics, particularly long-term storage of sediment that can protect water quality and habitat.

Temperature

Shade from river corridor vegetation is an important control on summer water temperatures (Gaffield et al., 2005). Overhanging vegetation offers shade and thermal refuge and provides organic material inputs and visual isolation. Parkyn et al. (2003) found that increases in the health of macroinvertebrate communities following buffer re-vegetation were most closely linked to decreases in water temperature. Larger areas of vegetated land allows for increased groundwater recharge that will support baseflow and cooler water temperatures. In addition, a preserved *active river area* will maintain long and complex surface water flow paths across floodplains and into the meander belt that provide overland run-off with natural temperatures.

Figure 3.3 – Fly-fishing on the Westfield River, MA.

Nutrients

Vegetation in the river corridor absorbs dissolved nutrients flowing towards the channel that originate in up-gradient parts of the landscape (Fisher and Welter, 2005). If vegetation is removed or nutrient concentrations in runoff are unusually high, water quality degrades as streams will become more eutrophic. The increased nutrients can lead to excessively high primary productivity in the channel at which point aquatic plants (e.g., algae, moss, and macrophytes) can grow vigorously and smother and impair benthic habitat. Extremely large standing crops of aquatic plants can cause wide daily fluctuations in dissolved oxygen and pH associated with photosynthesis and respiration. If the fluctuations of dissolved oxygen and pH get large enough they can become detrimental to the aquatic biota. Nutrient dynamics play an important role in determining water quality and a preserved *active river area* allows for more natural nutrient processes than a vegetated buffer alone, especially if coupled to an upland nutrient management plan. Vegetated floodplains, riparian wetlands, and the meander belt all offer locations for natural nutrient transport, transformation, and uptake to occur.

Recreation Opportunities

Recreational fishing is an enormous ecosystem service that provides both recreational and economic benefits (Figure 3.3). There are 25 million freshwater anglers in the United States and they generate over $31 billion in retail expenditures each year. The economic activity associated with freshwater angling produces $11.5 billion in state and federal revenues annually. In addition, dedicated funding from the sale of fishing licenses for all types of fishing provided an $600 million to support state fish and wildlife agencies and the special federal excise taxes and import duties on fishing gear, boats and boat fuel generated an additional $600 million in 2006 (ASA, 2008). Protecting the integrity of rivers by protecting the *active river area* to allow key physical and ecological processes to continue improves aquatic habitat condition and healthy fish population levels and thereby directly supports angling and the associated economic and social benefits.

Open Space

The *active river area* also provides social benefits from naturally functioning open space. There are significant economic benefits associated with protection and restoration of natural river systems and the resultant recreation opportunities (McDonald and Johns, 1999). The economic benefits of protecting rivers and parks include an increase in local property values, more spending by residents, expanded tourism, additional agency spending, the ability to attract and retain businesses, and the reduction of risks and costs associated with infrastructure in the river corridor (USNPS, 1995). Open space often gains more in municipal tax revenues than required for expenditures (Miller, 1992) and thus there frequently is a willingness to support natural river corridors for open space and recreation. Both passive and active recreation can mesh well with *active river area* protection, though in a naturally functioning *active river area* there are times inundation will preclude access to certain areas. If natural processes are protected and restored in the *active river area*, these areas can serve the innate human desire to be spiritually connected to wilderness (Jordan, 2000). There is growing desire for humans to re-connect to the natural world (Light, 2000) and recreation is one means of meeting this need.

Conclusion

A functioning *active river area* provides many benefits beyond those directly associated with the ecological integrity of river, streams and riparian areas. The protection and management of these areas for flood prevention, hazard avoidance, recreation, open space and other habitat values should provide numerous avenues and opportunities for maximizing both ecological and social benefits.

CHAPTER 4: DELINEATING THE ACTIVE RIVER AREA

> *"Perhaps most important, we urgently need increased research into identifying which lands will be most critical for protecting focal freshwater systems, the configuration of those lands to each other and to freshwaters, and the amount of land required for protection." (Abell, 2002)*

Introduction

The need to protect river corridors to preserve the ecological integrity of the aquatic ecosystem has been widely acknowledged (e.g., Naiman et al., 1993; Saunders et al., 2002; Abell et al., 2007), yet few techniques for doing so have been offered. The authors call for application in a basin-wide context, and the need to develop new methods using advancing technologies with consideration of environmental, social, and economic considerations over a range of scales. The *active river area* framework offers a scientifically based approach to meet this need.

The *active river area* framework provides a spatially explicit delineation of areas that contain physical habitat and provide space for key processes and disturbance regimes necessary for the protection of biodiversity. The framework explicitly incorporates watershed position (i.e., headwater, mid-watershed, and low-watershed) with key physical processes such as hydrology and sediment transport as represented by the spatial extent of the disturbance regime and with material and energy input areas. As such, the framework provides a robust and refined approach to the protection, management, and restoration of river and riparian ecosystems.

Delineation of the Active River Area

As previously discussed, the spatial extent of the *active river area* is based largely on hydrology, stream power, and sediment transport capacity, which are directly related to channel and valley morphology. The use of Geographic Information Systems (GIS), digital elevation models (DEM) and stream line networks makes it relatively straightforward to identify the spatial extent of the *active river area* at the reach, subwatershed and watershed scales. While the accuracy of the results depends on the quality of data, these techniques are applicable worldwide. DEM's are now available globally (see Shuttle Radar Topography Mission at: http://srtm.usgs.gov/). Stream line networks, if not otherwise available, can be derived based on DEMs.

We outline the following technique not as a definitive technique for delineating *active river areas,* but rather to illustrate one viable approach. We expect that continued refinement of data, tools and techniques will improve on these methods.

Three GIS techniques are used here to identify the *active river area*. First, a modified version of the riparian habitat modeling approach described by Strager et al. (2000) is employed for collectively identifying the meander belt, floodplains, and terraces. This approach uses a 30-m resolution DEM and the PATHDISTANCE method (ESRI, 2006) (Figure 4.1) to create a surface of the relative costs of traveling upslope from the stream. The cost is a computation of the elevation and distance from the channel, with higher costs for greater elevation and distances. The cost surface is continuous and therefore the technique requires that cost cut-offs be identified beyond which the area is no longer likely to be dynamically linked to the river or stream (as described by Strager et al., 2000). As Strager did, we found that using greater thresholds for larger rivers than for smaller rivers reflects the increasing size and power of a river in the lower watershed areas and therefore the larger extent of the *active river area*. This approach considers the dominant processes and disturbance regime in each part of the watershed (see Table 2.6).

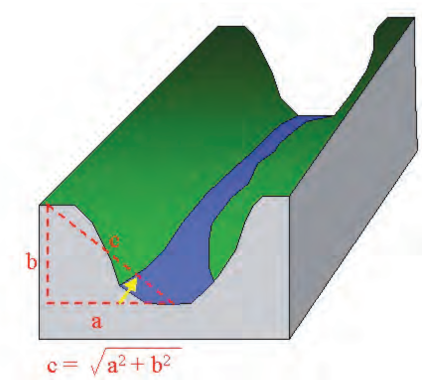


Figure 4.1 – Schematic stream valley cross-section, showing the inputs to PATHDISTANCE modeling: distance (c), slope (yellow arrow), and source (stream) ***(From Strager et al., 2000).***

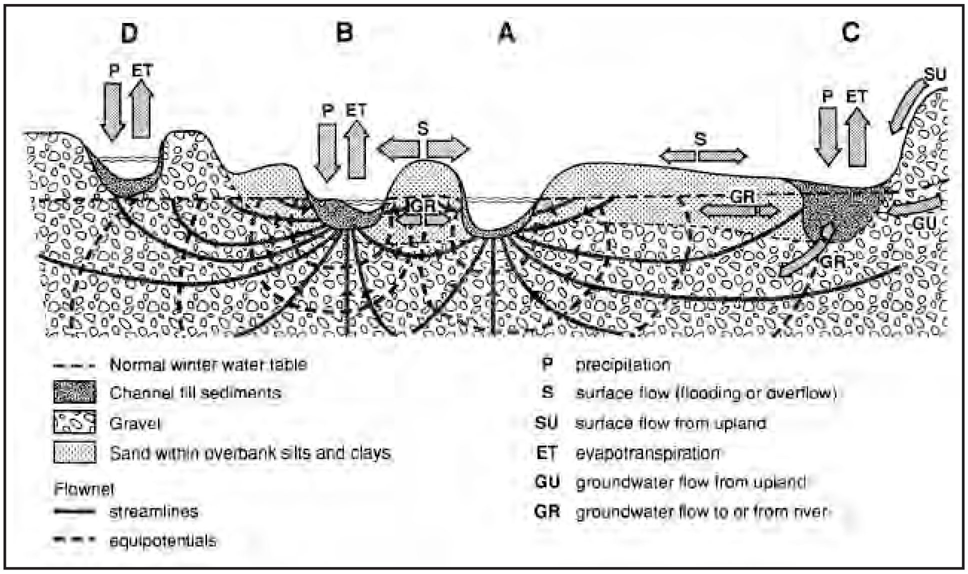


Figure 4.2 – Model of floodplain groundwater and soil water movement, as well as the hydrologic cycle on the floodplain surface *(From Gurnell, 1997).*

Second, to refine the extent of the *active river area* beyond those influenced by out-of-bank flows we included a technique to identify riparian areas likely to be 'wet' as result of high groundwater and overland runoff from adjacent uplands. We added this step in recognition of the fact that the extent of floodplains and riparian wetlands are a result of both out of bank flows and high groundwater levels (Figure 4.2) (Gurnell, 1997). The inclusion of the wet areas expanded the extent of the *active river area* by including current and historic wetland locations.

To identify these additional 'wet' areas a flow accumulation model was used with the 30-m DEM to identify locations that are permanently wet based on a high flow moisture index and a low (i.e., < 2%) slope. These areas were combined with known wetland occurrences from the National Wetland Inventory and the National Land Cover Data (NLCD). Cut-off distances for riparian wetlands were determined for small, medium, and large rivers to exclude areas beyond which the occurrence of wet areas was no longer considered riparian associated.

The third step adds the material contribution areas, which are identified as both headwater areas at the top of watersheds and areas 30-60m along each side of stream channels that are not otherwise captured by steps 1 and 2 above. To identify headwater areas, the SLICE method (ESRI, 2006) was used to divide the 30-m DEM into 10 equal elevation groups. Through this method pixels are grouped according to relative elevation, and thus identification of 10%-relative elevation increments are determined for the entire watershed. Headwater catchments of appropriate size (relative to the watershed) can be defined based on their inclusion within the appropriate elevation increment. For the stream side material contribution areas, a 30m width was selected because several studies (e.g., May and Gresswell, 2003; Webb and Erskine, 2003) suggest that most organic material and large woody debris within a stream originate from within 30-50 m of the edge of channel.

These three techniques provide the ability to differentiate several of the *active river area* components within the active river. The approach can specifically define the material contribution areas and riparian wetland areas. However, at this scale and with these tools they do not distinguish the meander belt from the low and high floodplains and terraces (Figure 4.3). The modeling produces these as a single polygon that collectively represents meander belt, floodplains and terraces. Chapter 6 provides an overview of various on-the-ground assessment techniques that can be used to specifically identify and characterize these components at the reach or subwatershed scale.

Model Verification

To verify the results and help to define the appropriate cost cut-offs in the model we compared our results to digitized FEMA 100-year floodplain maps and to known areas of floodplain inundation (Figure 4.4). In general, the model was able to capture 65-90% of the mapped FEMA floodplains, while including 25-55% of areas not mapped as FEMA floodplains. These size of these ranges depend on the cut-off of cost values for the PATHDISTANCE model. While the range is quite broad, it provides a reasonable verification that our methods are able to capture areas expected to be inundated under defined conditions. Visual inspection of the analysis shows areas where results are closely aligned as well as areas where significant differences occur (See Figure 4.4 B). We hypothesize that the differences result from a combination of the limitation of our data sources (the 30m DEM simplifies the contours of the landscape) and the details of the FEMA mapping approach, including the fact that they do not complete maps for every stream segment (while our method does) and the fact that their method takes into account conveyance, flood storage, levees, and other flood-proofing measures. Our goal was not to replicate the FEMA mapping efforts yet the inclusion of these 100 year flood areas verifies the approach.

We also looked to see how our mapped areas related to inundated areas of floodplains. To identify inundated areas we used satellite imagery to compare dry and wet season images to identify areas of standing water shortly after high water events (Anderson et al., in review). While areas of standing water are expected to be a very small portion of the entire *active river area* it did build confidence that areas of visible inundation generally feel within the modeled *active river areas* (Figure 4.4 C).

Case Study: Connecticut River Example

To demonstrate the *active river area* modeling approach we applied the framework to the Connecticut River watershed in the northeastern United States (Figure 4.5 A). This work was undertaken solely a demonstration rather than a planned conservation effort involving a stakeholder process or the gathering of additional data that would greatly inform such an analysis.

GIS Analysis

The *active river area* was delineated through use of the PATHDISTANCE, FLOW ACCUMALATION, and 30-m material contribution areas (Figure 4.5 B). Headwater catchments were identified using the SLICE method, capturing small watersheds (i.e., watershed area ≤ 10 mi^2) that represent the highest 40% of the watershed elevations (Figure 4.5 C). To capture the headwaters of all large watersheds we ran the analysis for both the entire watershed and for large tributaries (i.e., watershed area 200-1,000 mi^2. Small catchments along the outer-most edge of the entire watershed are also included. For a prioritization we used a simple condition analysis based on NLCD to identify the land use of each catchment. This simplistic approach is only for use in illustrating the concept of how the *active river area* can define critical building blocks of freshwater protected area networks by considering fragmentation by land use (Figure 4.5 D). As mentioned, for an actual analysis much more information would be included in the ranking of key areas.

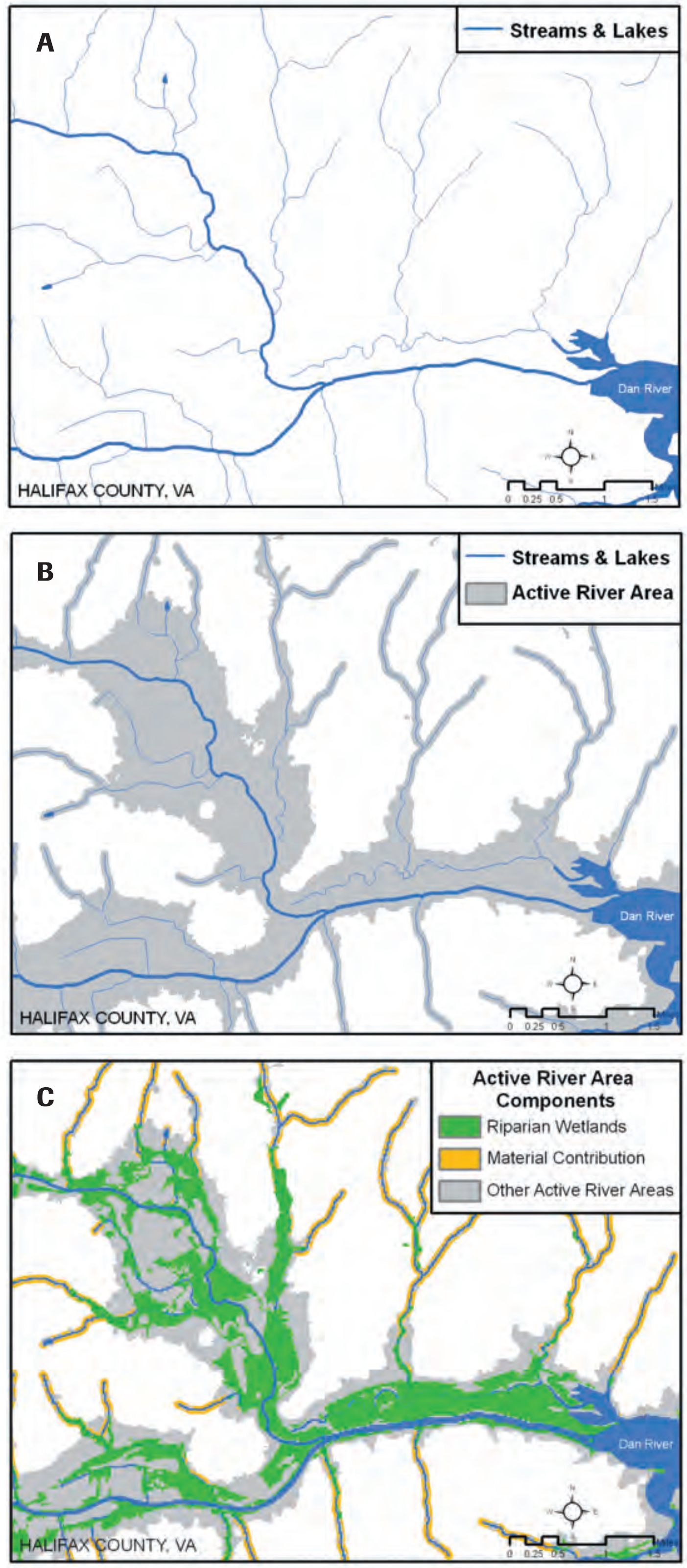


Figure 4.3 – Delineation of active river area components on the Dans River, VA: (A) River as channel and open water; (B) including the *active river area;* and (C) showing wetlands from NLCD (green) and material contribution areas (orange).

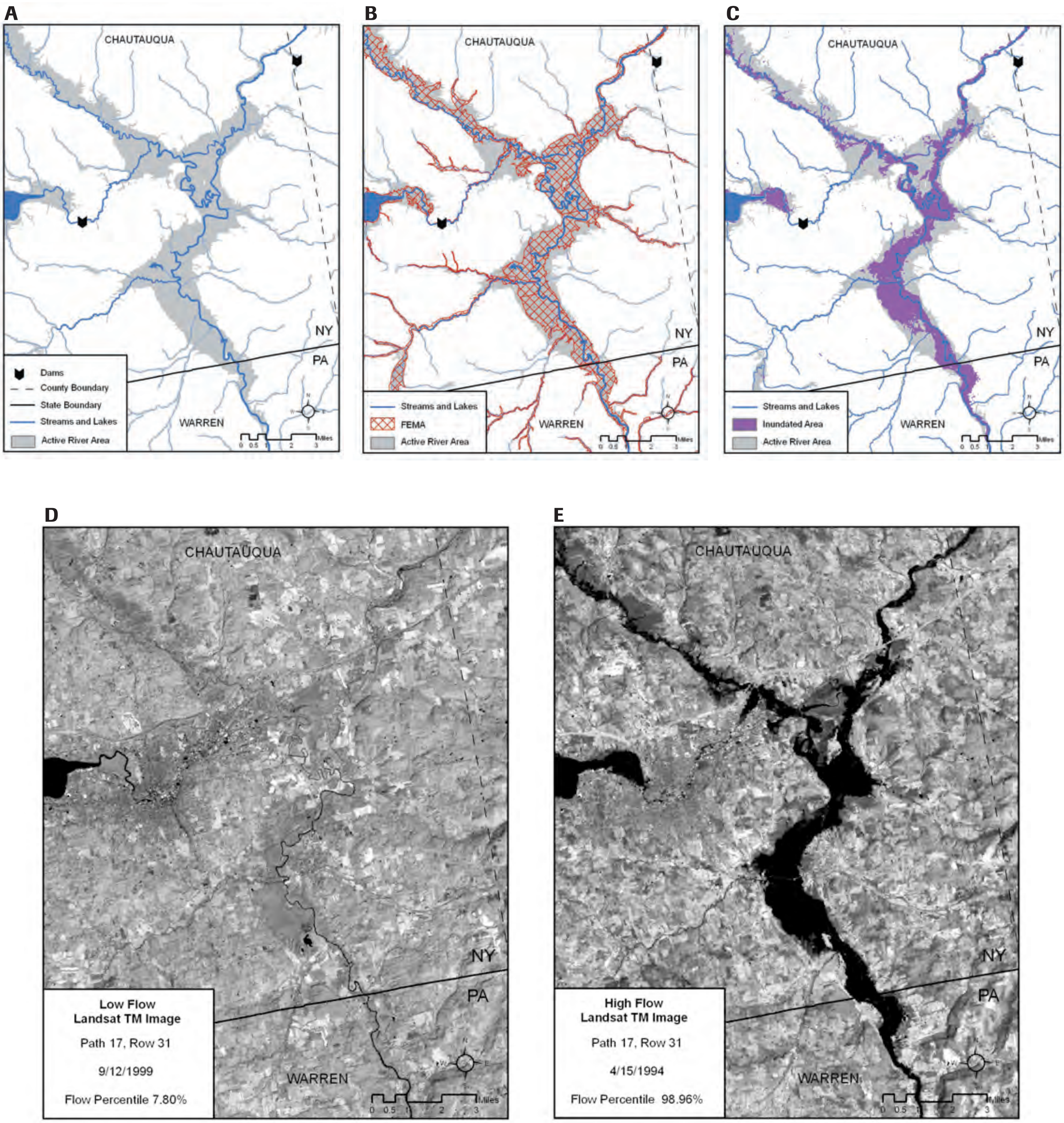


Figure 4.4 – Verification of the *active river area* delineation on the Conewango Creek, PA/NY: (A) active river area; (B) *active river area* and FEMA 100 year floodplain; and (C) *active river area* and areas of regular inundation. The areas of regular inundation were determined by comparing two remote-sensing images: (D) during a low water period; and (E) during a high water period (black = open water).

For headwater areas two conditions of 'very good' (< 1% impervious surface and < 5% agriculture) and 'good' (< 3% impervious and < 25% agriculture) were used as these land cover scenarios represent viable potential conservation targets to maintain natural processes. In addition, the 100 largest riparian area polygons within each of the three watershed positions: upper watershed (i.e., watershed area < 30 mi^2); middle watershed (i.e., watershed area 31-1,000 mi^2); and lower watershed (watershed area > 1,000 mi^2) were explored. Since these polygons were previously created by removing developed areas, the resulting analysis shows these areas based on whether they had more or less than 25% agriculture land. The resulting areas derived from the *active river area* approach (Figure 4.5 D) provide a simple example of how one could prioritize land and approach the design of protected area networks that would maintain key physical and ecological processes.

Table 4.1 *Active River Area* of the Connecticut River Watershed

Active River Area	Area (mi^2)	Area (%)
Riparian Area	1,555	14
Riparian area without open water	1,354	12
Top 100 largest areas	261	2
Headwater areas	4,923	44
Headwaters in very good condition	3,089	27
Headwaters in good condition	1,642	15

(Area = 11,270 sq mile)

The riparian components of the *active river area* (i.e., meander belt, floodplains, terraces, and some material contribution areas) cover 14% of Connecticut River watershed area, of which 12% are land areas and 2% are open water (Table 4.1). The top 100 largest *active river area* polygons within the upper, mid-, and low-watershed cover approximately 2% of the watershed area. This subset of the *active river area* components alone is an insufficient area to protect physical and ecological processes throughout the watershed, but shown here to demonstrate how key areas throughout the watershed, but particularly in lower reaches, can be identified to prioritize protection and restoration. The headwater areas included in the *active river area* represent approximately 44% of the total Connecticut River watershed area. Once delineated, the *active river area* (Figure 4.4 D) can be the basis for identifying important areas for use in policies and programs that seek to protect and restore rivers and their functions using a better understanding of key physical and ecological processes and spatially defining them at the watershed scale.

Subwatershed and Reach Delineations

The GIS approaches used for regional and watershed scales provide important tools for conservation planning and analysis. However, for protection, restoration and management at smaller scales, more accurate and detailed delineations are necessary. At these smaller scales, more detailed mapping of the relevant parts of the *active river area* components and assessment of their condition can be accomplished using a variety of well-established techniques for evaluating geomorphology, habitat, and biology (see chapter 5) or even, for specific projects, with land surveying techniques. Such reach-based and small scale assessment work can also be used fine-tune the *active river area* conservation recommendations made at larger scales, forming an adaptive procedure as new information becomes available. As with any GIS planning effort, on the ground verification of mapping efforts are a perquisite to conservation action.

There are good examples of geomorphic assessment protocols for such finer scale delineations and evaluations. In particular, the Vermont Agency of Natural Resources has developed a Stream Geomorphic Assessment that consists of protocols for watershed, reach and site assessment (VTANR, 2007). The reach-scale assessment fully integrates geomorphic and habitat components and is based on expected natural stream processes. This approach was deemed the most comprehensive of all such protocols in a review by the U.S. Army Corps of Engineers and U.S. Environmental Protection Agency (Somerville and Pruitt, 2004). This type of rapid, yet thorough, assessment provides a solid understand of historic and current physical and ecological process and facilitates the development of comprehensive river corridor management plans to guide conservation and implementation projects (Kline, 2007). Conservation and restoration actions based on such careful understanding of processes and places have a greater likelihood of success (Schiff et al., 2007).

Upper White River Case Study

The Vermont assessment protocol and river management planning approach was used to create a management plan for the Upper White River in the headwaters of the

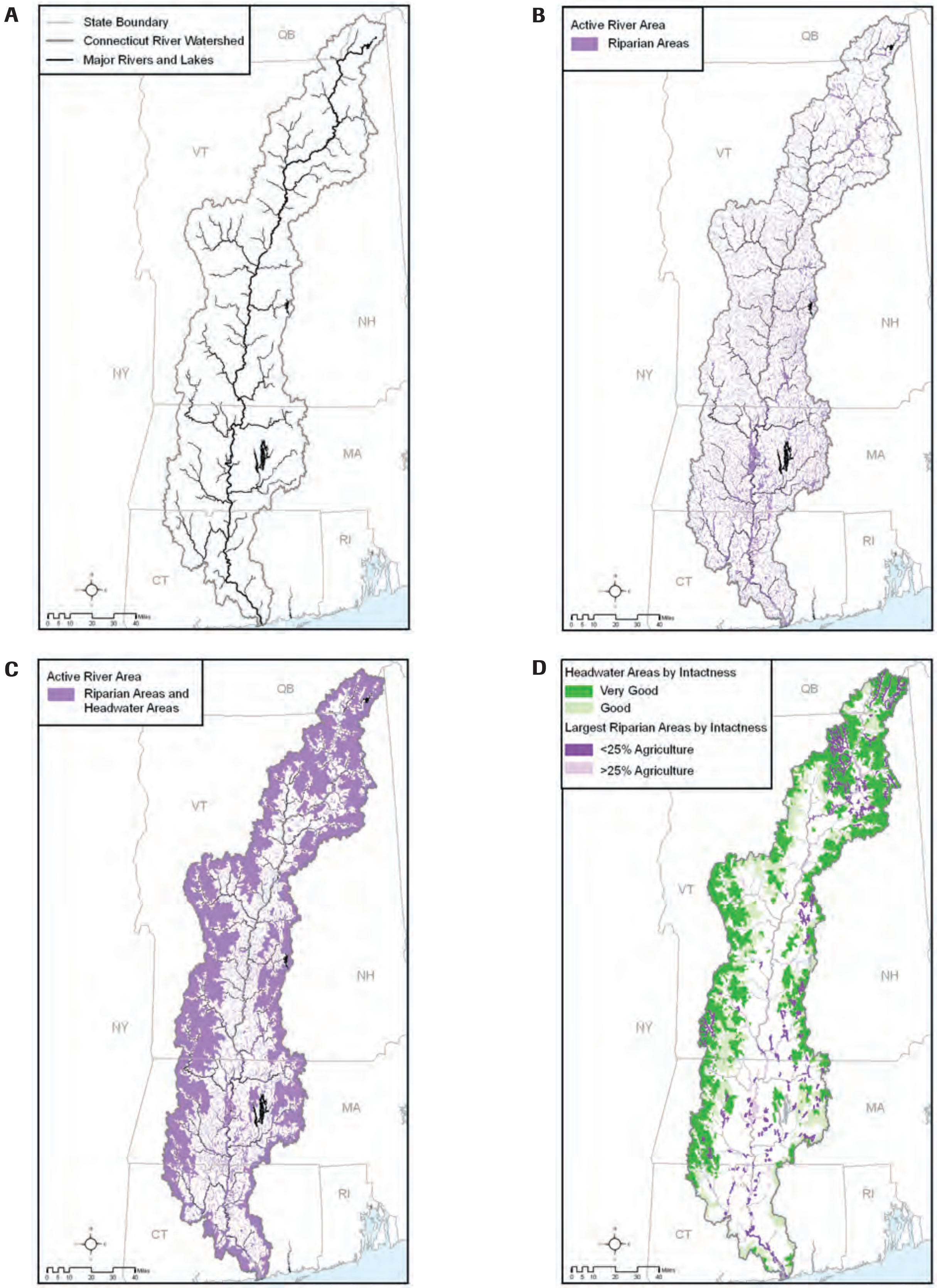


Figure 4.5 – Connecticut River watershed showing: (A) watershed; (B) delineation of the riparian areas of the *active river area;* (C) delineation of the headwater areas of the active river area; and (D) simple example showing relatively intact areas of the *active river area* components.

Connecticut River basin (Ruddell et al., 2007). The study found that most of the channels are incised and have lost access to historical floodplain that once provided flood storage, sediment deposition area, and nutrient uptake. Most of the channel has been previously straightened and is attempting to widen as it evolves. Channelization has energized the stream making it more prone to lateral migration increasing the risk to aquatic habitat, water quality, and nearby human infrastructure. The channel is very sensitive to change suggesting that protection and passive restoration are well-suited approaches for this watershed. Findings suggest that a key component of restoring the upper White River will be to conserve a river corridor, protecting remnant naturally functioning floodplain, and providing, at minimum, a belt-width corridor to accommodate and re-establish floodplain connection in other locations where possible.

Conclusion

The delineation of the *active river area* at both the regional and subwatershed scale can be used to inform the development of protected area networks, inform river management policies, and guide restoration efforts. By ensuring these efforts explicitly consider the lands within which key riverine interactions and disturbance regimes occur the approach will improve their likelihood of achieving their desired outcomes.

CHAPTER 5: ASSESSING THE ACTIVE RIVER AREA

> *"Many approaches and techniques can be used to reach [these] goals, but a good understanding of the living and nonliving components of the stream ecosystem, its watershed, how they interact and affect each other, and the timeframes over which stream processes occur will improve the probability of desirable outcomes." (NRCS, 2007)*

Introduction

To move from conservation planning to implementing protection and restoration projects requires specific assessment of individual or multiple reaches and subwatersheds. Numerous existing tools are available to assess the components of the *active river area* to identify existing conditions, alterations from natural processes and attributes, and the potential for protection and restoration projects. Data and information from field assessments (Table 5.1) can constitute a substantial part of the information used for project planning and design and often guides additional data collections required for more complex projects. A key element of these assessments for river protection and restoration is to gain an understanding of the physical and ecological processes, often at reach and watershed scales, prior to planning, design, and implementation. This section summarizes some of more relevant existing assessment methods for river corridor restoration, habitat assessment, geomorphic assessment, and biomonitoring methods.

Table 5.1 Common Assessment Needs for Protecting and Restoring the *Active River Area*

Regional and Watershed	Multiple to Single Reach	Single Reach to Local
Climate	Channel geomorphology	Channel geomorphology
Geology	Channel lateral confinement	Channel lateral confinement
Valley geomoprology	Base flood levels	Habitat assessment
Channel lateral confinement	Water quality	Biotic integrity
Watershed hydrology	Habitat assessment	Natural reference conditions
Sediment and debris transport	Biotic integrity	Deviation from natural conditions
Habitat Ecoregions	Natural reference conditions	Protection opportunities
Water quality	Deviation from natural conditions	Passive restoration opportunities
Human activity	Protection opportunities	Active restoration opportunities
Energy zones	Passive restoration opportunities	
Rare and endangered species	Active restoration opportunities	
Biodiversity		
Natural reference conditions		
Deviation from natural conditions		
Protection opportunities		
Passive restoration opportunities		
Active restoration opportunities		

Stream Corridor Restoration

Most of the commonly used manuals are public domain documents and can be acquired from the internet. Several assessment and design manuals for projects in the corridor that emphasize restoring natural processes are listed below.

Stream Corridor Restoration: Principals, Processes, and Practices (FISRWG, 1998), available on the internet at http://www.nrcs.usda.gov/technical/stream_restoration/ An overview of river processes, disturbances, restoration project planning, project design, and implementation. Processes such as watershed hydrology and sediment transport are presented along with other important aspects of geomorphology that are the basis for the *active river area* concept. Chapter 7, *Analysis of Corridor Condition,* outlines assessment methods in hydrology, geomorphology, water chemistry and biology. This information is helpful for exploring the extent of a problem and beginning to formulate alternatives to analyze. Chapter 8, *Restoration Design,* presents guidance on tools used to create channel and bank restoration projects. These two chapters, along with Chapter 9 covering implementation and monitoring, are useful for solving problems at the reach scale that has been identified to impair the natural functioning of an *active river area* component.

The Stream Restoration Design Handbook (NRCS, 2007)
A manual covering the details of designing and constructing stream restoration projects. Building upon *Stream Corridor Restoration: Principals, Processes, and Practices* (FISRWG, 1998), the handbook covers many important assessment and design topics in detail such as hydrologic analysis, open-channel hydraulics, channel design tools, sediment transport, implementation, and permitting. This manual is available as part of the USDA NRCS National Engineering Handbook, Part 654.

Draft Vermont Agency of Natural Resources River Corridor Planning Guide to Identify and Develop River Corridor Protection and Restoration Projects (Kline, 2007)
A tool to assemble and integrate information from assessments, planning efforts, and applied projects to identify underlying causes of channel instability and encourage a stream's return to equilibrium conditions. Plans guide management and protection efforts toward long-term solutions that are in harmony with natural stream processes and channel form. River corridor planning provides the following benefits.

- River science and societal benefits of managing streams toward equilibrium conditions.
- Methods for assessing and mapping stream geomorphic conditions.
- Methods for identifying and prioritizing river corridor protection and restoration projects.
- Methods for examining project feasibility and negotiating management alternatives.
- Information to help landowners, towns, and other interested parties to implement river corridor protection and restoration projects.

In a river corridor plan the results of watershed, geomorphic, and habitat assessments are analyzed through the use of stressor, departure, and sensitivity analysis to identify the current conditions and recommend projects and overall management strategies.

Habitat Assessment

Habitat assessment is important to link biotic integrity to channel form and processes. Due to the fact that physical processes form and maintain both channel characteristics and aquatic habitat in a dynamic equilibrium, channel geomorphology and habitat are integrally related, if not one in the same. For example, hydraulic units such as riffles and pools, side channels, and bed substrate particles of various sizes all constitute important habitat features. The inputs and retention of large wood and debris are a determined by valley and channel morphology. Habitat monitoring can be used to initially determine conditions, track quality, and inform adaptive management once a restoration program is implemented.

Several components of the *active river area* lie outside of the wetted channel and meander belt, and thus many habitat and fluvial geomorphology-based assessment tools that focus primarily on river channels do not investigate the full system. We thus present several assessment protocols useful for floodplain components of the *active river area* after the habitat assessments focused on instream conditions. Many low floodplains consist of riparian wetlands due to being subject to flooding, sustained high ground water levels, and sediment and debris deposition, and consequently can be evaluated using wetland assessment methods.

Vermont Reach Habitat Assessment *(RHA)* (VTANR, 2007)
A truly integrated assessment where geomorphic and habitat data are collected and assessed at the same time as part of theVermont Stream Geomorphic Assessment Protocols. The size distributions of large woody debris and jams, pools, undercut banks, and refuge areas are identified over a reach. The assessment then continues at a representative channel cross section where scores are assigned to variables describing woody debris cover, bed substrate cover, scour and depositional features, channel morphology, hydrologic characteristics, connectivity, river banks, and riparian areas. One of the strengths of this protocol is that it will be regularly performed with a rapid geomorphic assessment offering an indication of how sensitive the channel is to change, and thus how likely habitat will be stable.

U.S. EPA EMAP Physical Habitat Characterization
(Kaufmann and Robison, 1998)
The assessment collects data on channel dimensions, gradient, substrate size and type, habitat complexity and cover, riparian vegetation cover, anthropogenic alterations, and channel-riparian interactions. This protocol begins to look at basic geomorphic variables with habitat, and is also useful for characterizing habitat features such as the size breakdown of large woody debris.

U.S. EPA Rapid Bioassessment Protocols** (RBP) **Habitat Assessment (Barbour et al., 1999)
The RBP contains a qualitative habitat assessment of 10 variables that are scored and summed to determine an overall estimation of habitat quality based on quick observations. Variables on bed substrate cover, embeddedness, water velocity-depth combinations, sediment deposition, channel flow, channel alteration, frequency of riffles, bank stability and vegetation, and riparian vegetation are assessed. Additional more quantitative measures are also available as part of this protocol that are typically needed before actions are taken.

***Qualitative Habitat Evaluation Index** (QHEI)*
(OhioEPA, 2001)
The QHEI assessment contains 6 metrics (substrate, instream cover, channel morphology, riparian zone and bank erosion, pool/glide and riffle/run quality, map gradient) to characterize habitat quality over a stream reach. The assessment includes a useful set of questions and guidance on scoring to collect data relevant to habitat restoration and understanding deficiencies on the reach.

***Stream Visual Assessment Protocol** (SVAP)* (NRCS, 1998)
The SVAP qualitative assessment of habitat features and stream conditions was designed for use by land-owners and assessors with limited training. Scores are assigned and questions answered about the perceived habitat condition on a short form to guide future assessments and indicate the potential for activities. Additional assessments are typically needed to build upon this introductory data.

***Basinwide Visual Estimation Technique** (BVET)*
(Hankin and Reeves, 1988)
A method of estimating habitat presence in a watershed. The two-step technique includes making visual observations of habitat characteristics at reaches within the study area to identify the general habitat, and then conducting actual measurements of features and surface areas taken at repeated sections for each habitat type to determine their abundance (Dolloff et al., 1993). Size categories of features such as large woody debris are recorded along with the survey of hydraulic units such as riffles and pools. This assessment method is comprehensive and serves as the fundamental basis for many habitat mapping protocols (e.g., Cox, 2001).

The Hydrogeomorphic Approach to Wetland Assessment
(Brinson, 1993),
A foundation for assessing physical, chemical, and biological functions. Assessments compare the characteristics of a specific wetland with the characteristics of a group of reference wetlands in the region. This system has direct application to floodplain assessments to identify wetland geomorphology (i.e., landform, topographic setting and geologic evolution), hydrology (i.e., water source, direction of flow through the system and storage), and hydrodynamics (i.e., energy level). Assessment methods are in place for the class of riverine wetlands that are directly associated with a floodplain or riparian geomorphic setting (Brinson et al., 1995). A specific set of 15 riverine wetland functions exists (Table 5.7). The HGM approach entails scoring a host of variables on a 0 (no function) to 1 (reference condition) scale and then plugging the variables into an equation for determining a score for each of the functions.

Geomorphic Assessment

Understanding a channel's past, current, and future geomorphology increases the odds of establishing successful protection and restoration strategies, and implementing sound projects. With the increase in popularity of the reference reach approach to restoration design geomorphic assessment has become an integral component of many projects. In addition, the close link between channel morphology and formative processes allows for a design that is connected to both channel structure and function. Assessment and design of projects with the full consideration of natural processes and disturbance regime is the current thrust of designing naturalistic channels (Schiff et al., 2007; Simon et al., 2007).

Stream Analysis and Fish Habitat Design: A Field Manual (Newbury and Gaboury, 1993)
One of the first multidiscipline approaches to assessing fluvial systems, including floodplains and aquatic habitat. Although it focuses upon improving stream habitat, this manual does address watershed-wide hydrology and water quality. The geomorphic assessment method includes cross-section surveys, longitudinal profiles, and establishment of hydraulic geometry relations. Many of these steps later appear in the Rosgen method (Rosgen and Silvey, 1996) but lack a formal alphanumeric classification step. The Newbury approach to geomorphic assessment and restoration is primarily based on identifying recommended habitat for specific species, as well as instream flow requirements.

The Rosgen Method (Rosgen and Silvey, 1996)
A popular geomorphic assessment protocol that is used extensively across the United States. Many assessment protocols utilize some or all aspects of this stream classification and restoration system. This assessment technique is largely responsible for bringing the science of fluvial geomorphology to the forefront of the stream assessment, restoration, and management, as well as the rapid growth in the popularity of designing restoration projects with a reference reach. The Rosgen technique contains ten valley types (I, II, III, IV, V, VI, VII, VIII, IX, X) and eight channel types (A, B, C, D, DA, E, F, G) with channels being classified primarily as a function of pattern, entrenchment ratio, width / depth ratio, channel sinuosity, channel slope, and dominant substrate size.

Level I of the Rosgen technique is a desktop investigation with aerial photographs and topographic maps to create a preliminary geomorphic classification based on channel pattern, shape, and slope. Level II assessments involve selecting one or more channel segments representing each type of channel (A through G) that is present and performing site measurements. The substrate is identified by sieve test or pebble count. Cross-section widths and depths are measured and bankfull dimensions and discharges computed. The channel's physical condition is assessed during Level III investigations, with further classification of bank stability, vegetation, empirical stability, and meander patterns. Level IV is a system to verify field data.

The Rosgen classification system is a useful tool for channel and bank components of the *active river area*; however, the system is limited on floodplain functions and sediment processes. Another limitation of the Rosgen technique is that it has no mechanism to plan or predict the impact and response to future watershed conditions. As with all assessment and design tools, this method is recommended in combination with others to confirm findings.

Watershed Assessment of River Stability and Sediment Supply *(WARSSS)* (Rosgen et al., 2006)
(available on the Internet at http://www.epa.gov/warsss/)
A three-level approach including reconnaissance, screening, and prediction. Reconnaissance includes problem identification and gaining a general understanding of the watershed sediment budget. Screening identifies more information about the sediment budget and high risk places and processes for further study. The prediction level estimates sediment yield via a basic sediment transport model, the level of departure from reference conditions, and begins to identify management alternatives. The WARSSS method leads to a prediction of channel changes due to aggradation, degradation, or bank erosion. The model does not evaluate floodplain or biological processes.

The River Styles Framework (Brierley and Fryirs, 2005)
A spatially comprehensive geomorphic assessment tool developed in New Zealand. Stage 1 is a baseline survey conducted from aerial photographs where the catchment and smaller scale units are identified moving down the valley profile. Stage 2 is the more detailed geomorphic assessment to identify the variation in expected geomorphology at smaller scales than investigated in the baseline analysis. Stage 3 is the prediction of the likely evolution of the channel versus a healthy reference, and if recovery is possible based on limiting factors in the catchment. Stage 4 is the river management component where plans for the catchment are made, implementation and evaluation is performed, and adaptive management is carried out.

The Vermont Stream Geomorphic Assessment *(SGA)* ***Protocols*** (VTANR, 2007) (available on the Internet at http://www.anr.state.vt.us/dec/waterq/rivers/)
Phase 1 of the Vermont protocols consist of a map-based assessment to identify the expected channel condition based on the valley. Phase 2 of the protocols is a reach scale assessment where channel measurements are taken to investigate the departure from the expected reference conditions. One of the major strengths of this protocol is the simultaneous assessment of process-based geomorphic and habitat condition over a river reach. Phase 3 of the Vermont protocols consist of a survey assessment to gather additional detailed information for project design and implementation. In a review of U.S. physical assessment protocols (Somerville and Pruitt, 2004) this protocol ranked highest for its classification, objectivity, quantitative methods, emphasis on fluvial geomorphology, and data management. The Vermont River Corridor Planning Guide (Kline, 2007) provides a structured way to use data generated from assessments such as this geomorphic protocol for stressor and project identification.

Biomonitoring

Biomonitoring is needed to directly determine the status of biological communities that are the main response variables in river ecosystems. Dynamic processes throughout the *active river area* dictate aquatic habitat quality, which in turn is ultimately reflected in the species composition at each level of the aquatic food web. For example, altering hydrologic, geomorphic, and sediment regime via land use conversion can lead to cascading effects that change natural trophic structure (Burcher et al., 2007). Biomonoitoring can be used to determine species and community composition, track populations using biological indicator metrics, identify and monitor to the presence of rare and endangered species, and inform adaptive management once a restoration program is implemented. Species expansions and contractions that are likely with climate change can also be tracked via biomonitoring.

Biomonitoring is common in scientific research, resource management, regulatory reporting, and general monitoring of stream health. In the United States, 57 of 65 entities (50 states, District of Columbia, four territories, six tribes, and four interstate commissions) have bioassessment programs for streams and wadeable rivers leading to the assessment of approximately 440,000 channel miles (USEPA, 2002b).

The current trend in aquatic biomonitoring is to look at a combination of fish, macroinvertebrates, and small aquatic plants to gain different information as well as overlapping indicators of stream health. As the typical top predator and management target, fish are commonly monitored and assessed. Due to longer life spans than macroinvertebrates and their ability to move greater distances in both the up and downstream directions, fish assemblages represent channel conditions over longer time periods and larger spatial scales. Macroinvertebrates are typically residing near the streambed for 1 to 3 years and thus represent a shorter duration than fish, yet longer than most small aquatic plants. The ubiquitous nature of benthic macroinvertebrates makes them easy targets for sampling, and provides useful information for the middle of the aquatic food web. Although identification is complex due to their size, small aquatic plants such as diatoms, mosses, and small algae offer useful information from the base of the food web. Small plants are quite prone to disturbance so their collection reflects shorter seasonal trends than larger organisms.

U.S. EPA Rapid Bioassessment Protocols *(RBP)*
(Barbour et al., 1999).
An assessment of fish, macroinvertebrates, and periphyton in wadeable streams that compares biological indicator metrics to those empirically derived at reference sites. Results are analyzed mostly using combined multi-metrics to obtain one overall score for a site to facilitate comparisons. Many states typically utilize some or all aspects of the RBP that are refined for specific use in their location and programs.

The Index of Biotic Integrity *(IBI)* (Karr and Chu, 1999)
A popular multi-metric index representing the health of fish populations at a site. Regional assessment data are used to identify and quantify metrics that track changes with the human disturbances of interest. Once individual metric data are plotted versus disturbance, each portion is assigned a score resulting in a scoring system by which to quantify stream health at sites assessed in the same region in the future. A similar index (Benthic or B – IBI) is also commonly used to assess the health of benthic macroinvertebrates. Many states use IBI and B-IBI indices as part of their biomonitoring programs.

Conclusion

There are many assessment tools and techniques that are available for assessing river and riparian conditions and processes that can provide the detailed information necessary for project planning and implement. Protection projects may focus more on assessments to understand the types and condition of biological resources and the extent to which natural processes are intact. Restoration projects will, in addition to these assessments, include assessments of geomorphic and reference conditions to help guide project planning and implementation.

CHAPTER 6: PROTECTING RIVER PROCESSES

> *"There is an increasing need for innovative new strategies to manage hydrologic connectivity across the boundaries of biological reserves as they become remnant natural areas in human-dominated landscapes." (Pringle, 2001)*

The *active river area* framework offers a lens through which to analyze river conservation efforts that focuses on both places and processes. The framework provides a visualization of the river as an interconnected system of areas where key physical and ecological processes occur and places the associated biological resources within the context of these areas and these processes. This spatially explicit and visual representation of key river and riparian areas is important in designing freshwater protection strategies, particularly to inform conservation planning, the design of protected area networks, and informing river management policies and programs.

The information generated by the *active river area* framework can allow decision-makers at all levels to take actions that protect the health and resiliency of these important resources. Managing the components of the *active river area* in ways that allow for and are compatible with natural process can be achieved by:

- ensuring that material contribution zones, meander belts, riparian wetlands and floodplains, are connected and in a natural or near natural state,
- ensuring that channel processes and movement are anticipated and allowed for within meander belts and low floodplains, and
- ensuring that the regular inundation of floodplain areas is anticipated and allowed.

Including the *active river area* as a discrete management unit adds a new tool to efforts to protect and restore rivers, streams and riparian areas (Table 6.1). This chapter provides a discussion of the how the *active river area* framework can improve freshwater protection strategies, particularly the creation of protected area networks. The ability to delineate *active river areas* at both large and small scales provides an important tool for design of protected area networks and informing river management policies and programs that seek to ensure healthy and sustainable river and riparian resources.

Complementary to Other Freshwater Conservation Strategies

Though protecting *active river areas* is necessary for the long-term health of these systems, the protection of these areas alone is not sufficient. Protecting the hydrologic regime, the master driver of many physical and ecological processes in and along rivers, is obviously a key conservation strategy as it drives much of the 'activity' within the *active river area*. Human needs for irrigation, water supply, power and flood control all can threaten the hydrologic regime. Similarly, maintaining and restoring connectivity, both longitudinally up and down rivers and laterally between rivers and riparian areas, is another key conservation strategy that is necessary for river health. Dams, culverts and bridges can, if not properly designed, located and constructed, reduce longitudinal connectivity. Levees, roads, railroads and other structures can form barriers to the lateral connection of the river and its floodplain. Other threats, such as invasive plant and animal species, water pollution, and atmospheric

Table 6.1 Processess to be Protected within the *Active River Area*

River Process	Key Active River Area Component
Base flow conveyance	Meander belt (low flow channel)
Flood flow conveyance	Meander belt (bankfull flow channel), low floodplain
Flood water storage	Low floodplain, riparian wetlands
Ground water recharge	Low floodplain, high floodplain, terrace
Channel migrationy	Meander belt, low floodplain
Sediment storage	Low floodplain, high floodplain
Floodplain widening	High floodplain, terrace
Riparian buffer zones	Meander belt (river bank), low floodplain
Vernal and isolated pools	Low and high floodplains
Organic material input	Material contribution zone, meander belt, low floodplain

deposition of pollutants also must be mitigated to ensure healthy river and stream systems.

However, the protection and restoration of the *active river area*, when linked to other efforts to protect and restore natural flows, restoring connectivity, managing nutrients in uplands, and minimizing invasive species, can promote the re-establishment of self-sustaining natural ecosystem structure and function (NRC, 1992).

Freshwater Conservation Planning

The systematic protection of freshwater systems, like all conservation biology and conservation planning, is based on an extensive literature of conservation approaches and techniques. This work is often done at multiple scales (Poiani et al., 2000; Higgins et al., 2005), and is undertaken for purposes of both system classification, GAP analysis, and conservation action planning. The *active river area* framework can inform all of these activities.

The use of the *active river area* in conservation planning, like with other delineations of natural area, is facilitated by dividing the single area into discrete units for analysis. The *active river area* framework provides several ways in which to do so. One approach is to separate the *active river area* into the individual *active river area* components, including the material contribution areas, riparian wetland areas, and meander belt-floodplain-terraces areas in order to design conservation strategies appropriate for each type of area. Another approach is to stratify the *active river area* into areas based on the three watershed positions – upper watershed, mid-watershed and lower watershed. Yet another strategy can based on vegetation type, separating upland and wetland communities and identifying distinct natural community types within each. Such approaches can help protect key physical and ecological processes, as well as ensure that areas of high ecological importance, are represented throughout the watershed.

The development of discrete *active river area* polygons is possible through any number of techniques. One of the most common is to divide areas based on land-cover condition – natural or near natural condition, agricultural, and developed areas can thus be managed in unique ways. The resulting polygons can be sorted and prioritized through any number of approaches such as size, condition, geomorphic sensitivity, species richness, rarity or endemism, or any other factors that may be brought into the analysis to identify priorities for protection and restoration.

The *active river area* will complement existing methods for freshwater classification and planning that are used to organize information for ecological assessments. The existing classification approaches capture geomorphic variability through attributes such as water body size, slope, geology, and hydrology (e.g., Higgins et al., 2005; Sowa et al., 2007) and more specific valley segment types (VSTs) based on local physical factors and their position within the watershed. VSTs are designed to identify similarities in fluvial processes, including sediment transport and riparian conditions, based on stream size, flow, gradient, temperature, geology and watershed position – all attributes linked to geographic variation of species composition (Sowa et al., 2005). By including the *active river area* in these types of planning efforts the condition and ecological attributes and relative role in maintaining processes can be used to classify and prioritize riparian systems. These regional and watershed plans are often the template on which conservation strategies, including the design or protected area networks, are built.

Designing Freshwater Protected Area Networks

Protected area networks are recognized as one of the means to conserve biodiversity (Saunders et al., 2002). While protected area networks have been used effectively for terrestrial systems and with increasing frequency for marine systems they have been applied less often for conservation of freshwater systems (Abell et al., 2007). With a few notable exceptions, such as the RAMSAR Convention's goal for protection of wetland systems, the protection of freshwater systems is often coincidental to the development of protected areas for other reasons. A key goal of river-focused reserves should be to restore ecosystem heterogeneity by setting aside enough land to maintain multiple ecological pathways necessary for natural processes to take place (Brookes et al., 2005; Fisher and Welter, 2005).

The *active river area* framework offers an approach to substantially improve the ability to design protected area networks specifically for river and stream systems that protect areas of high ecological importance and areas necessary for key physical and ecological processes to occur. The framework provides a spatially explicit footprint of a river systems enhance and refine existing approaches, five of which are briefly described.

Frissell (1993) outlines an approach to identifying areas that should be prioritized for protection by describing six

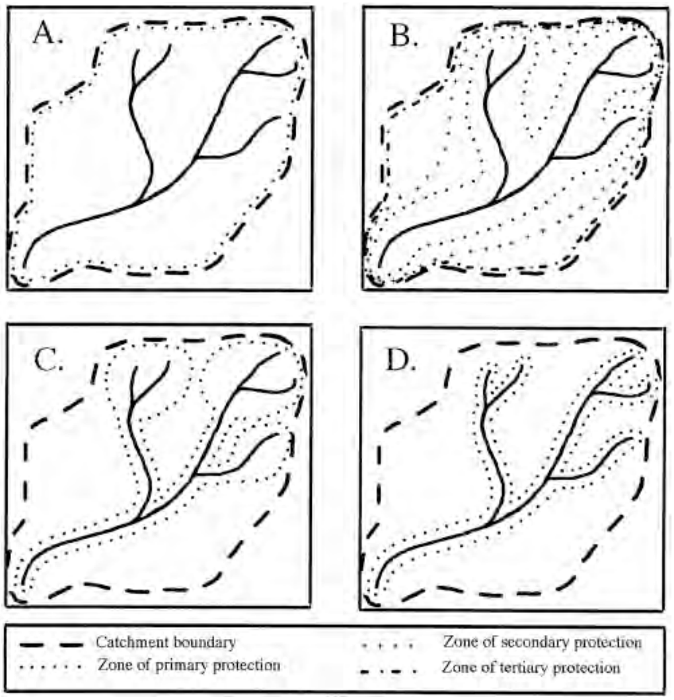


Figure 6.1 – Strategies for protection against land-use disturbances: (A) whole catchment management, (B) multiple-use modules (MUMs), (C) River Continuum Concept (Vannote et al., 1980), and (D) vegetated buffer strips *(From Saunders et al., 2002).*

types of habitats based on primarily on their condition and relationship to intact areas. These types are: focal habitats (intact habitats, typically refugia, often headwaters); adjunct habitats (directly adjacent, typically downstream); nodal habitats (areas outside the refugia but key for certain life history functions); critical contributing areas (sources of high quality water and stable watershed conditions); grubstake habitats (heavily disturbed habitats, generally in the lower reaches); and lost cause habitats (where restoration is generally cost-prohibitive or likely to be ineffective).

Pringle (2001) discusses the importance of hydrologic connectivity to the viability of protected area systems. She describes the role of these connections and threats posed by disturbances to these connections for idealized reserves located in the upper, middle and lower watersheds. Pringle concludes there is a need for new strategies to manage hydrologic connectivity in association with protected areas.

Saunders et al. (2002) describe four basic approaches to freshwater protected area designs, including: whole catchment management; multiple use modules; a longitudinal continuum based on the River Continuum Concept (Vannote et al., 1980) and vegetated buffer strips (Figure 6.1). Saunders describes protected areas as one key component among several necessary for protecting freshwater habitats.

Sowa et al. (2007) undertook a detailed classification and Gap Analysis Program (GAP) analysis to identify 'Conservation Opportunity Areas' that seek to conserve adequate numbers of representative target species, system types, dominant VSTs, headwater types and an interconnected network of dominent valley types. This approach identified catchments of various sizes spread throughout the ecological drainage unit (Figure 6.2)

Abell et al., (2007) recommend a set of three management layers that include: freshwater focal areas (areas of high importance); critical management areas (areas critical to protecting the focal areas, such as areas needed for connectivity); and catchment management zones (areas upstream of focal and critical areas) as a hierarchical approach to freshwater protected areas.

The *active river area* approach resembles the continuum concept as described by Saunders et al. (2002) but takes the conceptual idea and provides a spatially explicit and specific approach to defining such an area. The components of the *active river area* offer a natural process-based approach to help in identifying the focal, adjunct and contributing areas (Frissell, 1993), critical management areas (Abell et al., 2007) and conservation opportunity areas (Sowa et al., 2007). The framework also offers a means to evaluate in spatially explicit terms the intactness of hydrologic connections and their role in ecological integrity as described by Pringle (2001).

By designing freshwater protected areas based on the components of the *active river area*, protected networks can be comprised of appropriate size and shape in the upper, mid, and low-watershed that support dominant environmental disturbance regimes, accommodate the natural range of variability of hydrology and sediment transport, and build a connected network of sites that offers resiliency to a variety of natural and human induced disturbance regimes. These three attributes – dominant environmental regimes, natural range of variability, and connected networks – are key to establishing functional conservation areas (Poiani et al., 2000).

The *active river area* framework directly builds upon existing reserve design ideas for freshwater resources by using natural processes and disturbance regimes to guide design. Such an approach can acheive the important goals of setting up freshwater reserves for the preservation of native fish species, invertebrate, and plant (Filipe et al., 2004), key habitats (Abell et al., 2007), instream flows (Saunders et al., 2002), and hydrologic connectivity (Pringle, 2001).

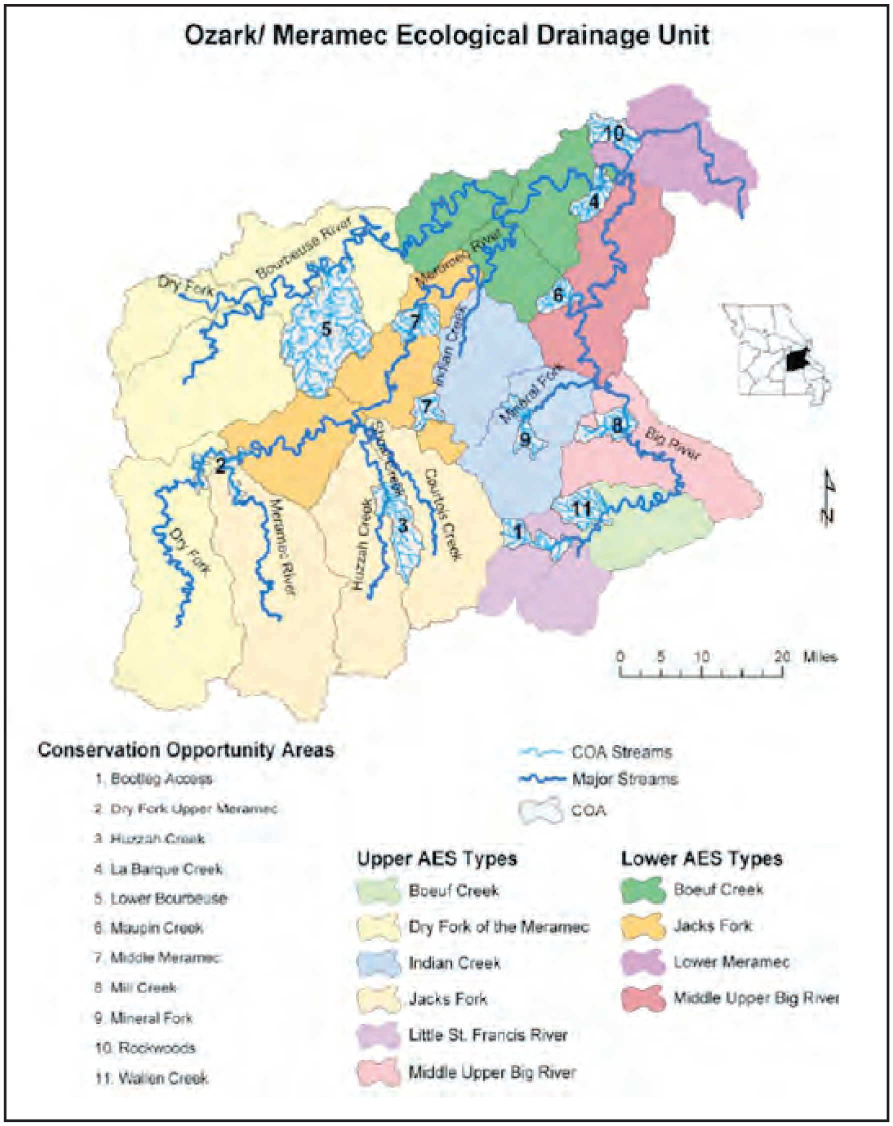


Figure 6.2 -- Map of Conservation Opportunity Areas within the Ozark/Meramec Ecological Drainage Unit in Missouri. The figure also shows the Aquatic Ecological System Types *(From Sowa et al., 2005).*

Clearly, the protection of whole catchments or watersheds for biodiversity purposes, which are inclusive the *active river areas*, offers the most comprehensive and complete protection. Such opportunities continue to arise globally as nations work to build new protected area networks under agreements (e.g., the United Nations Environmental Program COP 7 Decision (UNEP, 2004)). However, when protecting an entire catchment area is not possible, the *active river area* framework provides a lens through which to see the river and riverine resources as a visual representation of key processes and key places. Hierarchical protection strategies (e.g., Abell et al., 2007) will be necessary to protect entire systems of places and processes.

Improving River Policies and Programs

While protected area networks are an important conservation strategy, there are numerous policies and programs related to river and riparian area management that can be improved by integrating the *active river area* concept into their management goals and implementation tools. For example, many programs define riparian areas or riparian buffers as 'set-backs' from the river bank or high water mark. This includes the delineation of river areas under programs such as the U.S. National Wild and Scenic Rivers Program (1968) (0.25 mile of high water mark); or in state programs such as the Rivers Protection Act in Massachusetts (200 or 25 feet from mean annual high water line); or in agricultural management programs (35 feet minimum width under the U.S. Department of Agriculture Conservation Reserve Enhancement Program (CREP) (VTDEC, 2004)). In such cases these programs might more effectively achieve their desired results if boundaries are based on the components of the *active river area* rather than a single distance from the channel center line, bank, or high water mark. By identifying active process areas where the river and riparian lands interact through contribution of materials and/or through hydrological and sediment processes, these programs could more effectively protect both the river associated ecosystem and achieve significant ecosystem services such as hazard mitigation.

The *active river area* framework could also expand the utility of the Federal Emergency Management Agency (FEMA)

National Flood Insurance Program (NFIP), which is primarily based on a delineated 100-year floodplain by identifying the area (i.e., floodway) where an encroachment would lead to a 1-foot increase in water depth (FEMA, 2002). This program could be an important component of both river conservation and flood damage avoidance, the later being its intended purpose, if the designation of the managed area was based on a more holistic consideration of channel, riparian, and floodplain processes. By focusing on preventing increases in flood elevations local to the river rather than in keeping channels and floodplains in their natural state, riparian wetlands and other parts of the *active river area* continue to be altered and have diminished ability to dissipate and absorb floodwaters, minimize erosion and landslides, and provide protection to other ecosystem attributes. The *active river area* identifies areas additional to the FEMA floodplain that are important conservation targets and locations where valuable ecosystem services originate.

The concept of floodplain management in the United States is primarily defined by its emphasis on reducing economic losses and is often silent on ecological functions and values. In contrast, the European Union concept of floodplain and wetland management has recently placed greater emphasis upon preserving natural functions and restoring the full fluvial system rather than just the channel (e.g., Acreman et al., 2007).

In the United Stats, the Vermont River Management Program within the Agency of Natural Resources is among the leaders in developing comprehensive approaches to managing the *active river area* through a broad range of programs. For example, the Vermont Fluvial Erosion Hazard (FEH) zoning tool is starting to be applied in municipalities to go beyond existing federal regulations to limit risks to the public, protect natural processes, and reduce the cost of managing rivers (VTDEC, 2007). The FEH zoning overlay is based on the meander belt width, or 4-8 bankfull channel widths, the likelihood of channel adjustment, and the geomorphic sensitivity. As with the NFIP, incentives are recommended to encourage towns to participate in the program, with anticipated savings for the state with the reduction of risks and less need for disaster recovery (Kline et al., 2006). Vermont is also using the meander belt width approach to improve upon minimum buffers required under the Conservation Reserve Enhancement Program (CREP) and has developed an easement program to purchase development and channel management rights within the river corridors at key sediment attenuations areas within a watershed.

Conclusion

The *active river area* framework offers an important conceptual, visual and spatially explicit understanding of river areas and river processes that allows for a more holistic inclusion of rivers and rivers processes in protecting river and riparian systems. By fostering the development of protected area networks and improving river management programs society can start to protect, restore and manage rivers with key processes and the places these processes occur as explicit goals and expected outcomes. While balancing human needs and interests while protecting natural riverine processes will remain a challenge, these challenges will be more manageable to the extent we can be explicit about where conflicting goals need to be reconciled and where complementary outcomes can be accommodated.

CHAPTER 7: USING ACTIVE RIVER AREA CONCEPTS FOR RESTORING RIVER PROCESSES

> *"Restoration projects should be planned and designed based on an understanding of geomorphological and ecological processes,…." (Kondolf, 1998)*

Introduction

The use of the *active river area* framework can improve the ability to identify and design river restoration projects. By understanding how and where the river interacts (or would interact if restored) with areas outside of its banks, project managers can better recognize the processes involved with restoration efforts and how to design these efforts to more effectively restore these natural processes.

Human actions have impaired natural river form and processes for centuries, and continue to do so today. Dams for drinking water, hydropower and flood control are abundant on rivers, leading to the disruption of hydrology and sediment transport. The International Commission on Large Dams indicates that less than 40% of the large rivers in the world (i.e., those longer than 1,000 km) are free flowing. Dams are ubiquitous on smaller streams as they are easily built to create small pools to harness water power or meet irrigation and other water needs. Dams also alter thermal regime by cold-water bottom releases or warm-water spillway flow (Lessard and Hayes, 2003).

Flood levees, elevated transportation embankments elevate roads and rails, and utility easements above normal water levels channelize rivers and streams disconnecting them from their floodplains. Disconnection of a channel from

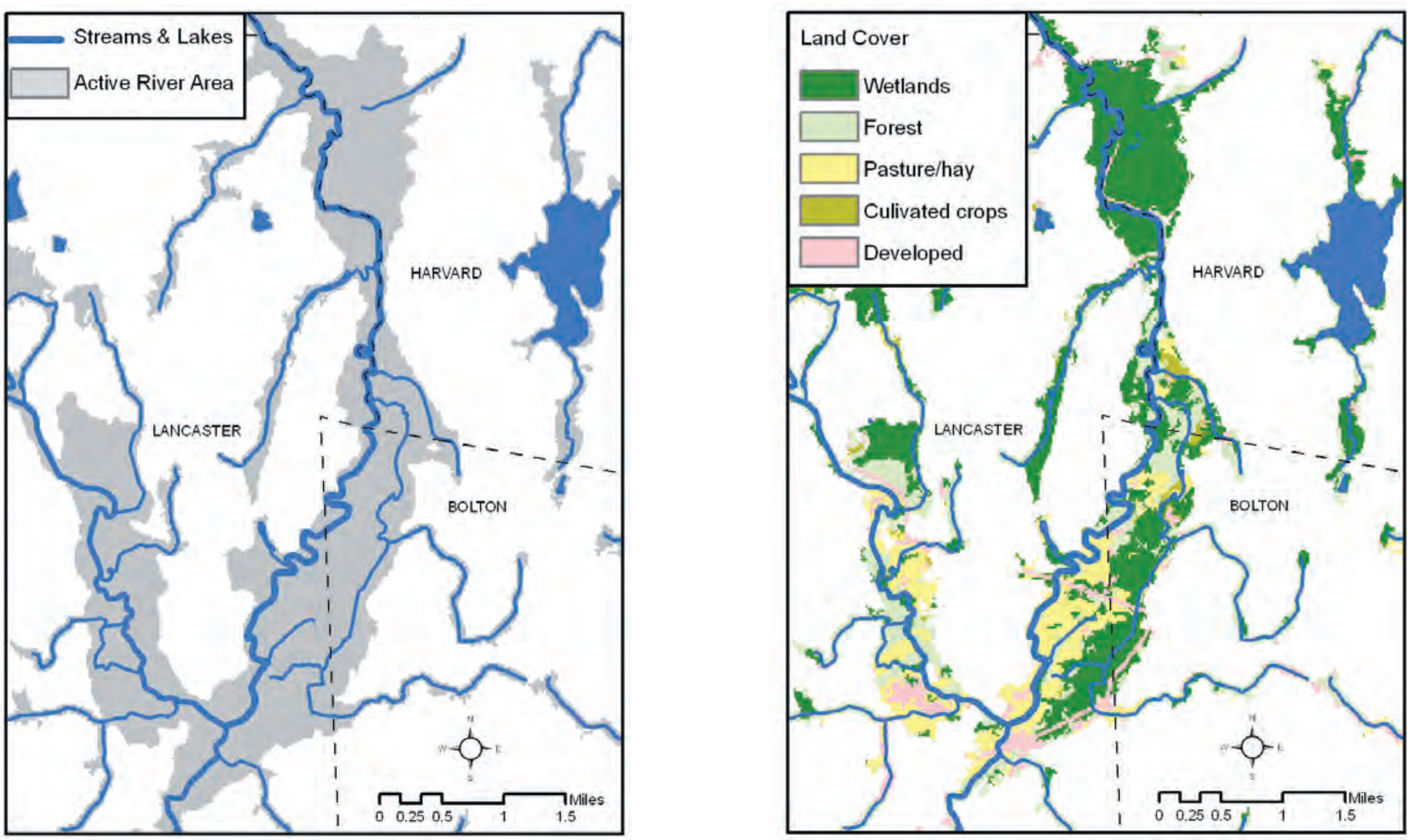


Figure 7.1 – Using the *active river area* to identify potential restoration sites. The NLCD land cover within the *active river area* shows existing agricultural lands (yellow) adjacent to the river and surrounded by wetlands. Such sites might warrant investigation for restoration potential.

Table 7.1 How Components of the *Active River Area* May Be influenced by Channel Evolution.

Channel Evolution[1,2]

Stage	I	II	III	IV	V
Channel description	Stable, in regime	Degradation, floodplain rise	Degradation and widening	Aggradation and widening	Stable, back in regime
Channel-floodplain connection	Non-existent or local to channel	Reduced	Limited to lost	Limited to lost	Restored at lowe elevation

Active River Area* Components

Meander Belt - Low-flow channel	Tending towards expected morphological conditions for stream type.	Relatively similar, small increase in width	Riffle-pool	Plane bed	Braided/ Multi**
Meander Belt - Bankfull channel[3]		Erosional, down-cutting, slightly wider, entrenched, more stream power for given storm size	Erosional, down-cutting, much wider, highly entrenched, more stream power for given storm size, variable pattern	Depositional, decreasing width, less entrenched, less energized during floods, variable pattern	Re-stabilized at lower elevation, width often remains slightly wider than original channel
Meander Belt - Banks		Localized erosion on outside of meanders and other hydraulic stress points	Widespread erosion and instability	Widespread erosion and instability	Stabilized with normal erosion and deposition
Riparian wetlands		Stable, with potential loss of some hydrology	Erosion possible as channel moves, hydrologic disconnect increases	Erosion continues as channel expands	If in tact after stabi-lization perched with decreased hydrologic connection
Floodplains - Low [3,4]		Elevated relative to channel	Actively eroding due to changing channel, connection to flood-plain weakening, cutoffs present	Continued erosion, some new deposition begins, old floodplain disconnected and new one beginning to form, cutoffs present	New floodplain at lower elevation stabilized along with channel
Floodplains - High		Less frequently inundated	Less frequently inundate	Less frequently inundate	If incision was extensive high flood-plain could no longer be inundated
Terraces		not influenced	not influenced	not influenced	not influenced
Material Contribution Areas		not influenced	not influenced	not influenced	not influenced

**Indicated responses are for vertically and laterally unconfined channels. Confinement along these boundaries will reduce the amount of change in that direction, and possibly increase adjustment along the other boundary.*

1Schumm, S. A., M. D. Harvey, and C. Watson, 1984. Incised Channels: Morphology, Dynamics and Control, Water Resources Publications, Littleton, CO.Simon, A., 1989. 2A Model of Channel Response in Disturbed Alluvial Channels. Earth Surface Processes and Landforms 14(1):11-26. 3Rosgen, D., L. Silvey, and D. Frantila, 2006. Watershed Assessment of River Stability and Sediment Supply (WARSSS), Wildland Hydrology, Fort Collins, CO.4Brierley, G. J. and K. A. Fryirs, 2005. Geomorphology and River Management, Blackwell Publishing, Malden, MA.

its floodplain leads to unstable channels as the stream power is increased and more erosion and deposition can take place. Other physical alterations of channels include straightening, floodplain filling, and dredging (Mount, 1984; MacBroom, 1998). The legacy of dam construction, channel and floodplain alteration, and placement infrastructure in and along rivers are primary impediments to holistic river restoration. Controlling and harnessing rivers has been an almost continuous aspiration of humans. Therefore, the challenge in restoring rivers is to restore their natural form and processes to the extent possible and to protect and restore the *active river areas* within which these process do or could take place.

Millions of dollars are spent annually in the U.S. on stream restoration (Moerke et al., 2004), and this expenditure is likely to grow substantially during the next few decades (Malakoff, 2004; Palmer et al., 2005). Although structural fixes to restore the river channel are common, these projects often result in a high rate of damage of the installed structures and few benefits from instream work alone (Frissell and Nawa, 1992; Chapman, 1996; Pelley, 2000; Bernhardt et al., 2005). Recent studies (e.g., Schiff, 2005) suggest that the ultimate source of failure of many restoration projects is likely the result of the continued absence of natural processes and associated disturbance regimes after project implementation. The projects have tried to fix a symptom of a problem, rather than the cause of the problem.

The *active river area* framework can guide restoration efforts by facilitating the accurate identification of a deficient process or missing attribute of the river system (Figure 7.1). By understanding alterations to natural systems – channelization, loss of connectivity between the river and the riparian and floodplain areas, encroachment of riparian areas and floodplains by roads, buildings and other structures placed in the river corridor–projects can be designed to both restore key process and to be effective within the altered state in which most rivers exist today. Over the long term, this approach to restoration will be more successful and cost-effective than common piece-wise methods.

This section provides a brief discussion of some of the key considerations and approaches to river restoration projects. The section illustrates how river restoration projects can be identified and undertaken as part of an approach that considers a holistic view of the river and the key physical and ecological processes of the river and riparian areas.

Table 7.2 Natural and Human Stressors to the *Active River Area (adapted from Schiff et al., 2007)*

NATURAL DISTURBANCE PROCESSES / ATTRIBUTES

Regional and Watershed	Multiple to Single Reach	Single Reach to Local
Intense precipitation	Ice jams	Tree blow-downs
Ice storms	Floods	Bend scour
Drought	Base level changes	Meander chutes
Floods	Channel degradation	Sediment bars
Landslides	Channel aggradation	Landslides
Climate change	Channel widening	Invasive species
Changing geology	Log jams	
Forest fires		

HUMAN STRESSORS

Regional and Watershed	Multiple to Single Reach	Single Reach to Local
Large dams	Small dams	Bridges
Water withdrawal	Channelization	Culverts
Forest clearing	Deforestation	Docks
Urbanization	Channel realignment	Channel fill
Impervious cover	Channel enlargement	Channel enclosure
Storm drains	Gravel mining	Channel linings
Wetland filling	Floodplain fill	Bank erosion/armoring
Nonpoint source runoff	Flow fiversions	Stormwater outfall
Drainage ditches	Dikes & levees	
	Channel clearing	
	Thermal exposure	
	Waste discharges	

Restoration of Rivers and Active River Areas

A restoration project generally includes problem identification, determining goals and objectives, design, implementation, and evaluation and monitoring. In order to gain an understanding of the historical and present watershed processes, the project team will identify the most probable pre-disturbance natural conditions, inventory and classification of existing conditions, and the amount of time that has passed between natural and existing conditions (Table 7.1). The assessment of *active river area* components and their geomorphic and ecological condition can be performed with existing assessment tools and protocols.

Stressor Identification

The *active river area* is subject to many natural stressors, or forces that act upon the meander belt and floodplain. It is these stressors and the response to them that create the dynamic conditions and diversity that characterize fluvial systems. Simple examples are the floods that carve and reshape fluvial systems and droughts that alter the composition of plant and animal communities. Understanding both natural and human-induced stressors and the response of the aquatic ecosystem to the disturbance regime is a key element of restoring rivers and riverine processes.

Natural disturbance processes/attributes and human stressors occur in a variety of spatial and temporal scales (Table 7.2). For example, regional floods and droughts may impact an entire watershed for months or years, while a localized thunderstorm may create a flash flood in a single tributary that lasts 6 hours. The varied dynamics of natural disturbance processes and resultant attributes in river systems makes for challenging management via purely controlling and static methods (e.g., installation of instream structures), and underscores the utility and importance of using a process-based framework such as the *active river area* to guide conservation and restoration.

Human activities influence the *active river area* in many ways, both intentional and inadvertently. Regional and watershed scale human stressors are often related to changes in land use that effect hydrology and sediment transport. Before any type of restoration is prescribed, stressors influencing the components of the *active river area* must first be identified to help identify potential solutions (see Appendix A). Stressors may occur over short or long time periods, and combined with the spatial scale of the disturbance, dictates whether passive or active responses are possible.

Restoration Approaches

Restoration alternatives can be categorized into three groups – "no action", passive, or active. The **"no action"** alternative, where the river is left to recover without any assistance, should be considered first (Table 7.3) to capitalize on the inherent recovery potential of flowing water environments. However this strategy does not often achieve full recovery if the alterations to the river, the *active river area* or other areas of the watershed are so great that restoration will not likely be achieved. "No action" alternatives typically play out over long time scales as natural recovery moves forward unassisted. Continued broad sources of impairment, or "press" disturbances (Parkyn and Collier, 2004), prohibit moving into a recovery cycle unless a passive or active restoration approach is utilized to remove or reduce the dominant stressors.

Passive restoration is when natural processes are encouraged to return via a change that will reduce a stressor but no

Table 7.3 General Approaches to River Restoration

General approach*	Strategy	Example
"No action"	Do nothing and hope river is able to recover from minor disturbance	On-going natural disturbance such as a floods move river channel towards stable equilibrium over long time frame
Passive	Implement protection measures and allow channel to respond naturally once	Purchase of land in the river corridor to allow the channel space to move naturally through the meander belt
Active	Rectify severe impairment with intervention to change recovery trajectory towards channel stability and speed the rate of recovery. Best used in conjunction with passive approaches	Re-alignment and bank stabilization using naturalized river channel design combined with purchase of development rights in the river corridor to allow the channel to naturally fine-tune its slope and pattern

**Listed from top to bottom in the recommended order of consideration.*

direct human intervention to the river itself is performed. Examples of passive approaches include conservation of the low active floodplain or changing local zoning regulations to avoid the placement of infrastructure in the meander belt. Passive approaches are desirable as they minimize the potential of doing additional temporary or permanent harm to the resource while attempting to promote recovery. In many projects a combined approach is used where passive approaches are performed to reduce stressors over the long term and active approaches are installed to improve conditions and initiate recovery in the short term. When only one phase of a larger project is feasible, passive approaches should generally be performed first so that stressors are eliminated and active approaches should be performed when deemed necessary to assist the channel/floodplain towards recovery.

Severe human or natural disturbance can prevent restoration of natural processes in desired time scales or may not be possible in the landscape context of the river system. In this case **active** approaches are often prescribed to rapidly help move the channel towards a stable equilibrium. Active approaches should typically be used in conjunction with passive approaches that seek to return natural physical and ecological processes to the system. The use of both hard and soft (i.e., bioengineering) practices (see Appendix A) are often used in restoration projects. If not part of a larger analysis, these efforts can result in local rehabilitation at smaller spatial and temporal scales but not likely to obtain long-term recovery. For example, structural failure is often cited (e.g., Shields et al., 2003a) as a common cause for lack of recovery following the installation of structural practices. The best use of active practices alone is to address minor problems that are known to have a local origin. When applied in conjunction with passive techniques that reduce or eliminate the underlying cause of stressors, active practices are useful to speed recovery.

Design Approaches

A common issue facing restoration projects is how much and how detailed the planning design must be to achieve the restoration goals and objectives. There are many useful technical manuals that provide both general and specific design guidance (see Appendix A). Design tools are classified into three types – empirical, analog and analytical.

Empirical tools are most commonly presented as hydraulic geometry equations, where channel width, depth, and cross-sectional area are plotted versus watershed area. Empirical data is also available to help forecast if and where rivers have a meandering or braided pattern (Leopold and Wolman, 1957). The specific geometry of meander wave lengths, amplitude, and bend radius has been documented (Williams, 1986). Empirical design approaches are apparently easy to use and have limited data collection requirements. Yet with these benefits come some drawbacks, primarily the limited application of relationships outside of the system in which they were established. Data requirements for generating empirical relationships in the project watershed are typically large.

Analog designs are based upon observing healthy channels and then replicating their key features. The approach requires the ability to locate a similar undisturbed channel reach to use as a model, measuring its pattern and dimensions, and then applying them at the restoration site. The reference reach being used as a model must have similar longitudinal slopes, substrate material, and bank vegetation. The bankfull discharge dimensions of width, depth, and cross-sectional area are proportionally adjusted to the restoration site, as are planform features such as meander wave length, width, and radius. Analog techniques have been advocated by Newbury and Gaboury (1993) and Rosgen and Silvey (1996), each offering step-by-step assessment and design manuals. The analog approaches are popular for their visual field-based assessment tools. Drawbacks include the difficulty in finding a suitable reference reach, the reliance on a single design flow, and dependency on past river form rather than future form and explicit processes.

Analytical methods are based on physical equations (i.e., Manning's equation) and are generally used in computer models to estimate hydrology, hydraulics, and sediment transport to evaluate channel stability and design alternatives. Models use equations for the conservative of energy (Bernoulli equation), mass (continuity equation), and momentum to calculate velocity, discharge, stable channel dimensions, and sediment transport rates to design projects. The use of computer models to include spatial and temporal scales is invaluable to restoration design. The main drawback of analytical approaches is that they are relatively abstract compared to other design approaches and require good data, knowledge and intuition to make sound assumptions and predictions.

The appropriate choice of design tools is generally based on a combination of project goals, size, risks, ecological risk, and societal acceptance goals (Schiff et al., 2007) (available

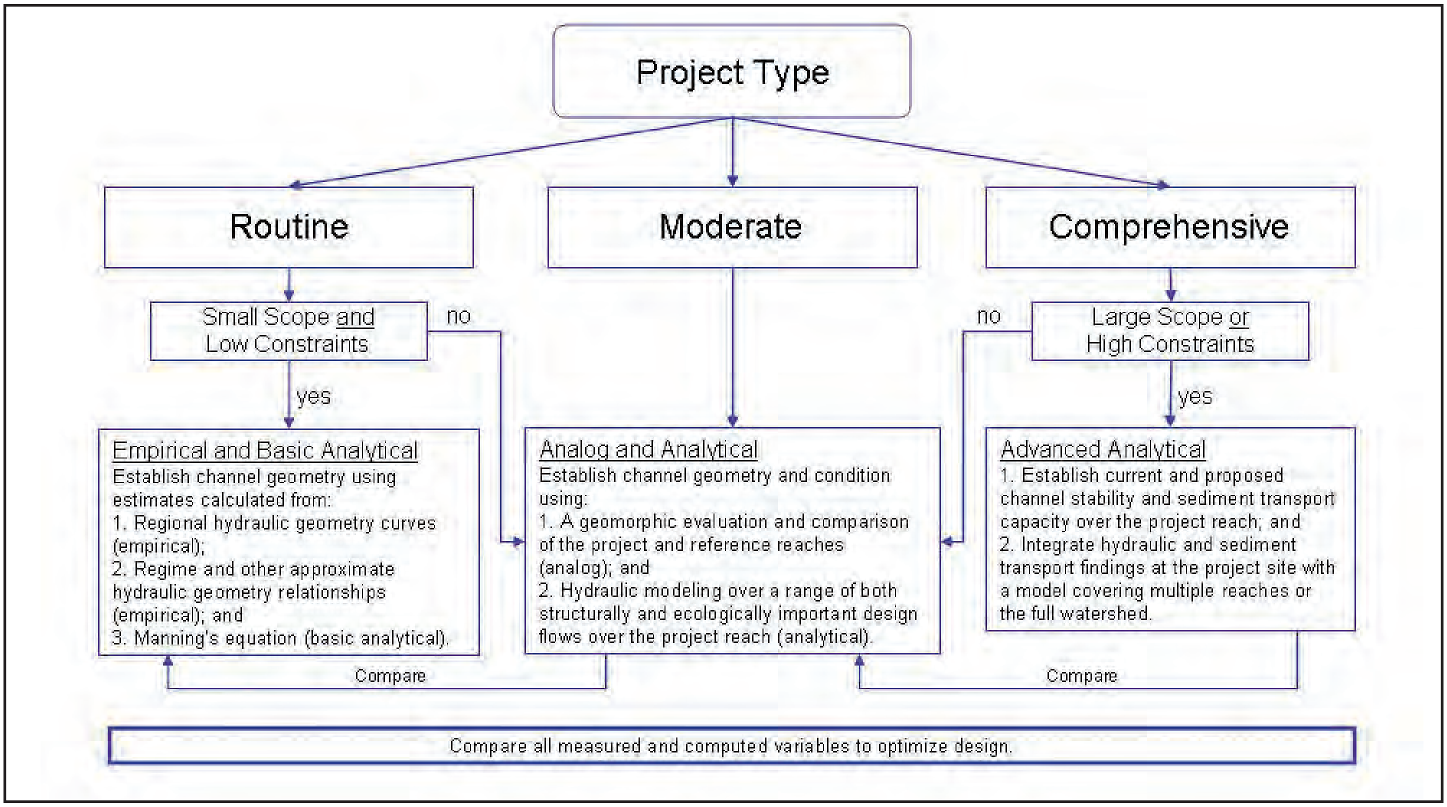


Figure 7.2 – Computational tools recommended for routine, moderate, and comprehensive projects *(From Schiff et al., 2007).*

for download at http://www.des.state.nh.us/rivers/). For example, simple empirical and basic analytical tools can be used for routine projects that are less risky, while more involved analog and analytical tools are needed to expand the design for more complex and risky projects (Figure 7.2). Generally, a combination of empirical, analog, and analytical approaches is recommended to overcome the limitations of each of the three methods, establish a likely range of designs solutions, and to check work via multiple methods.

Conclusion

The more a restoration project allows natural processes and disturbance regime to take place, the more likely ecosystem recovery will take place. "Work with, not against, a stream's natural form and function" (KST, 2002) when planning projects. Restoration reestablishes the self-sustaining dynamic structure and function of the ecosystem through a holistic procedure that is more complex than the isolated manipulation of individual elements (NRC, 1992; Brookes and Shields, 1996; FISRWG, 1998; Shields et al., 2003b). Restoration must take place at the appropriate large scale to accomplish process and attribute recovery.

The early planning phases of restoration projects should assess the potential for success through a range of alternatives that include "no action", passive, and active practices, while seeking to restore the dominant processes identified to be taking place in the components of the *active river area*. The planning and design of restoration projects is performed at different levels of effort and investment depending on the specifics of the project (Schiff et al., 2007). Monitoring and evaluation should also be performed at levels that are commensurate with the complexity of the project.

CHAPTER 8: CONCLUSION

> *"Although stream systems have long been recognized as having a hierarchical spatial structure, there is a need for more empirical research that exploits this structure to generate an understanding of population biology, community ecology, and species-ecosystem linkages across spatial scales." (Lowe et al., 2006)*

The *active river area* framework builds upon previous studies of aquatic ecosystems and approaches to river protection and management by explicitly using dominant processes and disturbance regimes to identify important protection, management, and restoration areas at reach, watershed and regional scales. The framework identifies material contribution zones, meander belts, riparian wetlands, floodplains and terraces as critical conservation targets. The extent and frequency of the disturbances associated with the natural process occurring in the *active river area* in the upper, mid and lower watershed creates a science-based framework for maintaining the ecological integrity of rivers and riparian areas and the accompanying benefits to society.

Consideration of each of the *active river area* components, which span multiple spatial and temporal scales of disturbance, is required to allow natural ranges of variability to system hydrology, sediment transport, processing and transport of organic materials, connectivity, water quality, and thermal regime to continue. Protection of these natural processes leads to the formation and maintenance of aquatic habitat, which is critical to preserving biodiversity in a sustainable fashion. The protection of *active river area* also provides benefits for terrestrial species that rely on floodplains, wetlands, travel corridors, edge habitats and other conditions that exist near rivers to carry out parts of their life cycles. The *active river area* is thus a useful template for informing conservation planning, establishing freshwater protected area networks, improving river management policies, and guiding restoration activities.

Protection of the *active river area* offers a host of benefits to society in addition to the benefits of habitat protection and preservation of aquatic biodiversity. One of the most notably is ability to combine the goals of habitat protection with the reduction of flood and erosion hazards that currently lead to large expenditures of public funds. Keeping *active river areas* in more natural condition, placing or moving human infrastructure out of floodprone and dynamic locations in a watershed and re-connecting floodplains to their channels leads to a lower level of risk of damage to public and private infrastructure and property. This will become increasingly important as global climate change alters hydrology and other watershed processes.

Protection of natural processes also supports a high level of water quality, improving the amount and composition of both ground- and surface waters, many of which are used as sources of community water supplies. Stored sediment and nutrient uptake on naturally functioning floodplains plays an important role in water quality maintenance. Preservation of the *active river area* also provides opportunities for recreation and supports the important social and economic benefits that recreation provides.

The *active river area* framework provides both a conceptual and a spatially explicit basis for an integrated and hierarchical approach to the assessment, protection, management, and restoration of freshwater and riparian ecosystems. With consideration of the *active river area*, river protection efforts such as establishment of freshwater protected areas, parks, and bioreserves can be based on the understanding of the physical and ecological processes associated with particular places in a watershed. In addition, the *active river area* can help a broad range of river management policies and programs to consider natural processes and disturbance regimes when working to meet goals and objectives. Finally, the *active river area* allows river restoration efforts to be performed in the context of restoring not just places but also restoring system-wide dynamic processes.

By combining the well-established understanding of places and equally well-established understanding of processes into an integrated and holistic approach to protecting, managing and restoring rivers and streams the *active river area* framework can help ensure healthy and self-sustainable river systems that support rich and viable natural biodiversity and provide a broad range of social and economic benefits.

APPENDIX A

A1 Stressors and Common Restoration Techniques *(adapted from Kline, 2007; Schiff et al., 2007)*

Stressor	Process Influenced	Restoration Technique	Rehabilitation Technique
Deforestation	H, S, O, W, T	Re-vegetation, maintain buffer	
Wetland loss	H, O, W, T	Wetland protection	Created wetlands
Dams and dam operations	H, C, T	Dam removal	Maintenance of natural instream flows
Water withdrawals and diversions	H, W, T	Cease water removal	Allocate water for channel processes and habitat
Land use change (tilled crop lands and impervious surfaces)	H, S, O, W, T	Retain natural vegetation, reduce flood-plain fill, limit and reduce infrastructure in river corridor	Best management practices to limit impacts
Road and ditch networks	H, S, C, W, T	Reduce floodplain fill, remove / replace undersized bridges and culverts, maintain transport of flow, sediment and organics	Replace failed structures
Mass wasting and gullies	S, O	Give river space to move on the valley floor	Bank stabilization
Straightening, Channelization and Excessive bank armoring	S, O, C	Re-establish floodplain connection or low flood benches within the active channel to restore incised / aggraded reach	Create naturalize channels with meanders, arrest head cuts and nick points
Grade controls and channel constrictions	S	Re-establish floodplain connection or low flood benches within the active channel to restore incised / aggraded reach	Create naturalize channels with meanders, arrest head cuts and nick points
River corridor encroachments	S, O, C	Prevent future encroachments, land or easment purchase to give river space to move	In-channel structural practices
Berms – including elevated roads, railroads	S, C	Remove berms and other constraints to flood and sediment load attenuation	Install larger culverts
Stormwater outfalls	H, S, W	Eliminate direct discharges, promote infiltration and overland flow	Best management practices to trap fine sediment and improve water quality
Gravel mining and bar scalping	S, O, C	Eliminate gravel extraction, promote natural sediment transport	
Historic snagging and windrowing	S, O, C, T	Eliminate channel clearing, promote bed substrate heterogeneity and retention of organics	Re-introduce channel roughness elements
Areas of excessive active bank erosion	S, O, T	Allow space for natural river movement to take place	Stabilize banks where necessary

Natural Processes: H = Hydrology, S = Sediment Regime, O = Organics Regime, C = Connectivity, W = Water Quality and T = Thermal Regime

Table A2 Common Practices Used in Restoration Projects and References for Descriptions and Application Notes *(adadpted from Schiff et al., 2007).*

Application	Practice	Reference 1	Reference 2	Reference 3
Grade Control	Channel Shaping	(Cramer et al., 2003)	(Saldi-Caromile et al., 2004)	
	Check Dams	(Flosi et al., 2002)	(MDE, 2000)	
	Cross Vanes (Log or Rock)	(Doll et al., 2003)	(MDE, 2000)	(Rosgen and Silvey, 1996)
	Drop Structures	(Cramer et al., 2003)	(Saldi-Caromile et al., 2004)	(FISRWG, 1998)
	Step Pools	(MDE, 2000)		
	Wiers (Vortex, W, log)	(Cramer et al., 2003)	(MDE, 2000)	(Doll et al., 2003)
Bank Stabilization	Bank Re-shaping	(Cramer et al., 2003)	(GASWCC, 2000)	(FISRWG, 1998)
Soft (Bioengineering)	Branch Packing	(Eubanks and Meadows, 2002)	(NRCS, 1996)	(GASWCC, 2000)
	Brush Layering	(Eubanks and Meadows, 2002)	(MDE, 2000)	(Walter et al., 2005)
	Brush Mattress	(Eubanks and Meadows, 2002)	(MDE, 2000)	(NRCS, 1996)
	Channel Shaping	(Cramer et al., 2003)		
	Coconut Fiber Rolls	(Eubanks and Meadows, 2002)	(MDE, 2000)	(NRCS, 1996)
	Dormant Post Planting	(LCSMC, 2002)	(Walter et al., 2005)	(FISRWG, 1998)
	Erosion Control Fabric	(Eubanks and Meadows, 2002)	(LCSMC, 2002)	
	Hay Bale Breakwater	(Eubanks and Meadows, 2002)		
	Joint Planting	(Eubanks and Meadows, 2002)	(NRCS, 1996)	(GASWCC, 2000)
	Jute-mat Rolls	(Eubanks and Meadows, 2002)		
	Live Cribwall	(Eubanks and Meadows, 2002)	(MDE, 2000)	(NRCS, 1996)
	Live Fascine	(Eubanks and Meadows, 2002)	(MDE, 2000)	(NRCS, 1996)
	Live Post	(Eubanks and Meadows, 2002)		
	Live Siltation	(Eubanks and Meadows, 2002)	(LCSMC, 2002)	(Walter et al., 2005)
	Live Stake	(Eubanks and Meadows, 2002)	(MDE, 2000)	(NRCS, 1996)
	Log Breakwater	(Eubanks and Meadows, 2002)		
	Log Toe	(Cramer et al., 2003)	(Flosi et al., 2002)	
	Plant Mat	(Eubanks and Meadows, 2002)		
	Plant Roll	(Eubanks and Meadows, 2002)		
	Root Wad	(Eubanks and Meadows, 2002)	(MDE, 2000)	(NRCS, 1996)

continued on next page

	Engineered Log Jams	(Saldi-Caromile et al., 2004)		
	Rooted Stock	(Eubanks and Meadows, 2002)		
	Snow Fence	(Eubanks and Meadows, 2002)		
	Terraced Crib	(Eubanks and Meadows, 2002)		
	Tree and Log Revetment	(Eubanks and Meadows, 2002)	(NRCS, 1996)	(LCSMC, 2002)
	Trench Pack	(Eubanks and Meadows, 2002)		
	Vegetated Geogrid	(Eubanks and Meadows, 2002)	(NRCS, 1996)	(FISRWG, 1998)
	Woody plantings	(Cramer et al., 2003)		
Hard (Traditional)	Block Revetment	(NRCS, 2005)		
	Boulder Revetment	(NRCS, 1996)	(LCSMC, 2002)	(FISRWG, 1998)
	Concrete Bulkheads	(NRCS, 1996)		
	Concrete Celular Blocks	(NRCS, 1996)		
	Concrete Jack	(NRCS, 1996)		
	Floodplain Grade Control	(Cramer et al., 2003)		
	J-hook Rock Vane	(Doll et al., 2003)	(MDE, 2000)	(Rosgen and Silvey, 1996)
	Piling Revetment/Wall	(NRCS, 1996)	(NRCS, 2005)	
	Riprap	(NRCS, 1996)	(MDE, 2000)	(Cramer et al., 2003)
	Rock Gabions	(LCSMC, 2002)	(MDE, 2000)	
	Rock Riffle	(LCSMC, 2002)		
	Single Rock Vane	(Doll et al., 2003)	(Rosgen and Silvey, 1996)	
	Slotted Board Fencing	(NRCS, 1996)		
	Groins (Barbs or Dikes)	(Cramer et al., 2003)	(NRCS, 1996)	(LCSMC, 2002)
	Stream Jetty	(NRCS, 1996)		
	Wing Deflectors (Rock/log)	(FISRWG, 1998)	(MDE, 2000)	(Flosi et al., 2002)
Combination	Vegetated Rock Gabions	(NRCS, 1996)	(FISRWG, 1998)	
	Vegetated Rock Walls	(NRCS, 2005)		
	Toe Protection	(FISRWG, 1998)	(MDE, 2000)	
Habitat Enhancement	Channel/Meander Shaping	(Cramer et al., 2003)	(FISRWG, 1998)	
	Boulders (Erratics/ Clusters)	(Doll et al., 2003)	(MDE, 2000)	(Saldi-Caromile et al., 2004)
	Debris Jam	(Cramer et al., 2003)		
	Large Woody Debris/Jams	(Doll et al., 2003)	(NRCS, 2005)	(Saldi-Caromile et al., 2004)
	Side/Off-Channel Habitats	(Saldi-Caromile et al., 2004)		
	Spawning/Rearing Habitat	(Cramer et al., 2003)	(Saldi-Caromile et al., 2004)	
Riparian Vegetation	Buffer Management	(Cramer et al., 2003)		
	Floodplain Roughness	(Cramer et al., 2003)		
	Re-vegetation	(Eubanks and Meadows, 2002)	(Saldi-Caromile et al., 2004)	(Walter et al., 2005)

A3 Examples of Commonly Used Stream Restoration Manuals ***(adapted from Schiff et al., 2007)***

Name	Citation
CHANNEL DESIGN	
Stream Restoration Design	(NRCS, 2007)
Channel Restoration Design for Meandering Rivers	(Soar and Thorne, 2001)
Guidelines for Natural Stream Channel Design for Pennsylvania Waterways	(KST, 2002)
Stream Restoration: A Natural Channel Design Handbook	(Doll et al., 2003)
BANK STABILIZATION	
A Soil Bioengineering Guide for Streambank and Lakeshore Stabilization	(Eubanks and Meadows, 2002)
Chapter 16 of the Engineering Field Handbook: Streambank and Shoreline Protection	(NRCS, 1996)
Effects of Riprap on Riverine and Riparian Ecosystems	(Fischenich, 2003)
Integrated Streambank Protection Guidelines	(Cramer et al., 2002)
HYDRAULICS AND CHANNEL STABILITY	
Hydraulic Design of Stream Restoration Projects	(Copeland et al., 2001)
Channel Stability Assessment for Flood Control Projects	(USACOE, 1994)
Channel Rehabilitation: Processes, Design, and Implementation	(Watson et al., 1999)
River Engineering for Highway Encroachments: Highways in the River Environment	001)
HABITAT IMPROVEMENT	
Stream Habitat Restoration Guidelines	(Saldi-Caromile et al., 2004)
California Salmonid Stream Habitat Restoration Manual	(Flosi et al., 2002)
CONSTRUCTION	
Maryland's Waterway Construction Guidelines	(MDE, 2000)
FISH PASSAGE AT CULVERTS	
DRAFT Design of Fish Passage at Bridges and Culverts (HEC-26)	(FHWA, 2007)
Fish Habitat Manual: Guidelines and Procedures for Watercourse Crossings in Alberta	(TRANS, 2001)
Massachusetts River and Stream Crossing Standards: Technical Guidelines	(MARSCP, 2006)
Maine Fish Passage Policy & Design Guide	(MEDOT, 2004)
SITE MEASUREMENTS	
Stream Channel Reference Sites: An Illustrated Guide to Field Technique	(Harrelson et al., 1994)
Sampling Surface and Subsurface Particle-Size Distributions …	(Bunte and Abt, 2001)

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