The Umatilla River Vision

Confederated Tribes of the Umatilla Indian Reservation
Department of Natural Resources

Vision: The Umatilla basin includes a healthy river capable of providing First Foods that sustain the continuity of the Tribe's culture. This vision requires a river that is dynamic, and shaped not only by physical and biological processes, but the interactions and interconnections between those processes.

By:

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October 1, 2008

Revised May, 2011 by Eric J. Quaempts

Preface

In January of 2007, the Confederated Tribes of the Umatilla Indian Reservation (CTUIR) Department of Natural Resources (DNR) adopted the following mission:

> *To protect, restore, and enhance the First Foods - water, salmon, deer, cous, and huckleberry - for the perpetual cultural, economic, and sovereign benefit of the CTUIR. We will accomplish this utilizing traditional ecological and cultural knowledge and science to inform: 1) population and habitat management goals and actions; and 2) natural resource policies and regulatory mechanisms.*

The First Foods are considered by the Confederated Tribes of the Umatilla Indian Reservation (CTUIR) Department of Natural Resources (DNR) to constitute the minimum ecological products necessary to sustain CTUIR culture. The CTUIR DNR has a mission to protect First Foods and a long-term goal of restoring related foods in the order to provide a diverse table setting of native foods for the Tribal community. The mission was developed in response to long-standing and continuing community expressions of First Foods traditions, and community member requests that all First Foods be protected and restored for their respectful use now and in the future.

This document will assist Tribal and non-Tribal managers in moving the First Foods mission from concept to application. It identifies processes and conditions needed to sustain aquatic First Foods, information needed to inform their management, and potential management implications. It is my expectation that in applying the First Foods approach and the river vision, managers can focus on appropriate ecological processes that provide and sustain First Foods, and plan management actions accordingly.

While the vision described herein uses the Umatilla River as an example of how the First Foods approach can be used to guide water and water quality management, I anticipate that the “touchstones” described in this vision will have applications to other rivers in the CTUIR’s areas of interest and co-management authority.

This document is not intended to replace or substitute for any other basin planning document developed by the Umatilla Tribes. Instead the ideas presented here are intended as touchstones for managers, to help ensure that planned management activities account for an appropriate breadth of ecological considerations and are aligned with one another in pursuit of the goals and needs of the Tribal community that depend upon rivers.

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Director, CTUIR Department of Natural Resources

Acknowledgements

The development of the Umatilla River Vision was made possible by a generous and anonymous donation provided through Stoehl-Reeves. Conditions of the donation were that the funding be used to responsibly support water quality improvement efforts. By creating a unique, community-related vision that for years will guide and link the water-related work of multiple CTUIR programs, I hope that we have satisfied the donor’s intentions.

Table of Contents

Authors

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Introduction

The Department of Natural Resources (DNR) of the Confederated Tribes of the Umatilla Indian Reservation (CTUIR) has adopted a mission based on First Foods ritualistically served at tribal meals (Figure 1). This framework for natural resource management seeks to reflect the unique tribal values associated with natural resources and to emphasize ecological processes and services that are undervalued by westernized Euro-American natural resource strategies. The First Foods framework prioritizes efforts to re-naturalize processes that sustain First Foods and provides a direct and culturally appropriate means for monitoring and reporting restoration progress to the tribal community.

Sound river management and restoration are predicated upon the need to develop a systemic and holistic vision of a functional river (Independent Scientific Group 1996; Stanford et al. 1996; Ward et al. 2001; Jungwirth et al. 2002; Nilsson et al. 2007). Such a vision provides a framework for planning management or restoration efforts and an initial benchmark for assessing management success or failure. Similarly, a river vision provides the context necessary for understanding the role of any specific management decision or action in the context of other decisions or actions.

Our vision is as follows: *The Umatilla basin includes a healthy river capable of providing First Foods that sustain the continuity of the Tribe's culture. This vision requires a river that is dynamic, and shaped not only by physical and biological processes, but the interactions and interconnections between those processes.*

In this report, we outline a vision for desired ecological characteristics of the Umatilla River's water quality and water resource management, which will facilitate the sustained production of First Foods within the Umatilla Basin. These characteristics are founded on five fundamental "touchstones," including; 1) hydrology, 2) geomorphology, 3) connectivity, 4) native riparian vegetation, and 5) native aquatic biota.

The First Foods management framework adopts a broad definition of "water quality," incorporating the physical, chemical, biological, and ecological targets to assess the quality of water in the Umatilla River. Essentially, according to this framework, the ecological function and health of the Umatilla River become a holistic measure of water quality, and provide a pathway toward the restoration and maintenance of First Foods production.

Managing for First Foods

To provide context for the First Foods management framework, we begin by describing changes to ecosystem processes of the Umatilla River Basin resulting from the shift from a subsistence economy to an industrialized economy. We then present a "river vision" by highlighting attributes of the Umatilla River's hydrology, geomorphology, habitat and network connectivity, riverine biotic community, and riparian vegetation that are essential in the sustained production of First Foods for tribal consumption. Finally, we discuss implications of a mission focused on First Foods for management and restoration strategies.

In the tribal creation belief, the Creator asked the foods "who will take care of the Indian people?" Salmon was the first to promise, then other fish lined up behind

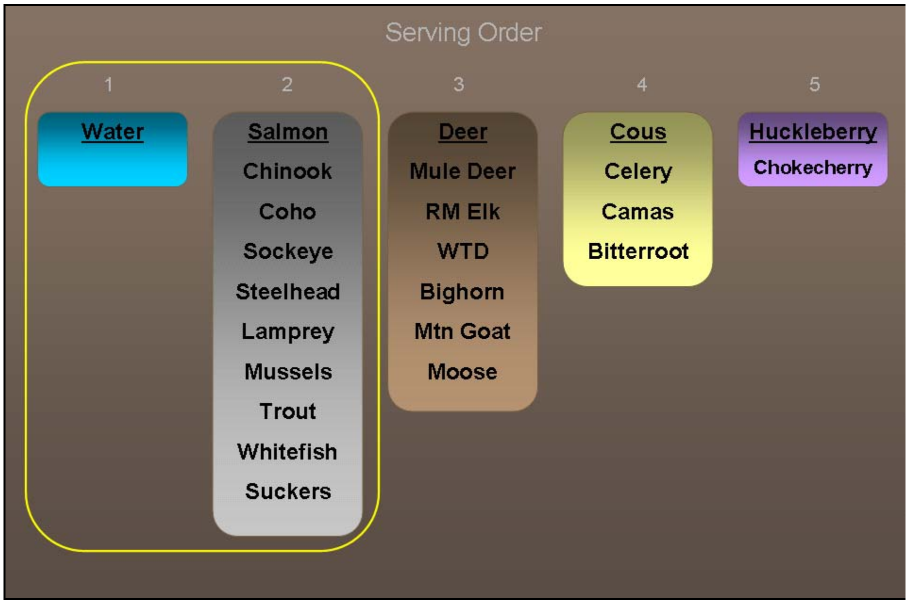

Figure 1. The First Foods serving order with a partial list of ecologically related species for each serving group. The yellow box highlights primary components guiding development of the river vision.

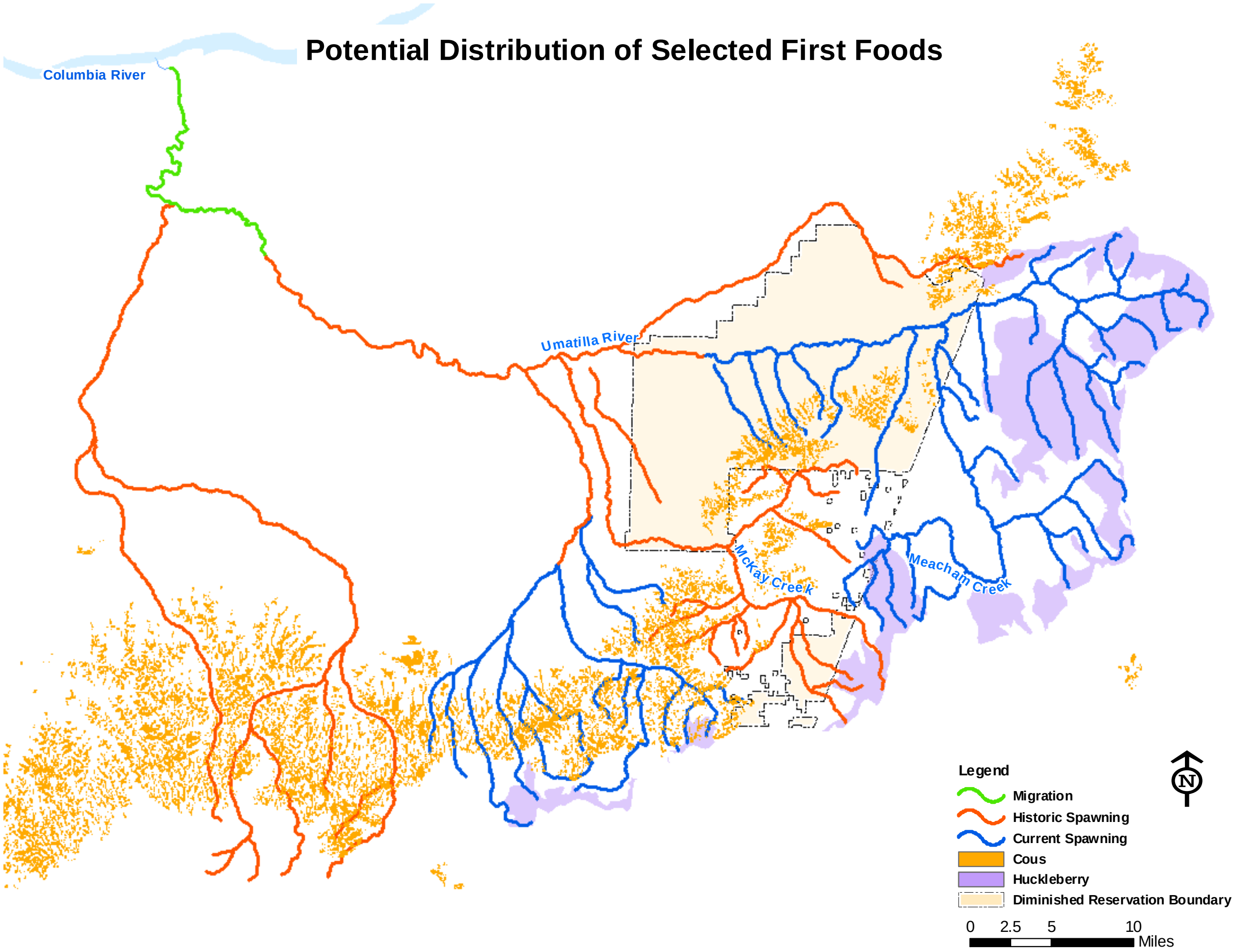

Figure 2. Potential distribution of First Foods across the Umatilla Basin, including historically salmonid-bearing streams and potential cous and huckleberry habitats.

salmon. Next was deer, than cous, then huckleberry. Each "First Food" represents groupings of ecologically related foods (Figure 1). The First Food serving ritual in the longhouse is based on this order and reminds people of the promise the foods made and the people's reciprocal responsibility to respectfully use and take care of the foods. The longevity and constancy of these foods and serving rituals across many generations and their recognition through First Food ceremonies demonstrate the cultural and nutritional value of First Foods to the CTUIR community. Even though the means to pursue, acquire, process, and prepare First Foods have changed dramatically following Euro-American settlement, the First Foods and their serving order have remained constant. First Foods have not been replaced in the serving ritual despite the availability of new, introduced foods. For instance, bass and wheat have not replaced salmon and cous. When new foods are served at tribal meals, they are not recognized in the serving ritual; instead, they are served after First Foods and with no formal order or sequence.

Historically, the availability of habitats for the propagation and harvesting of First Foods was facilitated by a usufruct land ownership system; tribal lands were a commons that tribal people could access and harvest. The tribe gathered First Foods from the river, floodplain, and upland habitats across the Umatilla Basin (Figure 2) and throughout the annual cycle. Water from the Umatilla River and tributaries supported river-derived foods (e.g., water and salmon) and sustained the tribe.

Euro-American settlement in the 1800s, culminating in the CTUIR's Treaty of June 9, 1855 (creating the Umatilla Indian Reservation; henceforth referred to as the Treaty of 1855), introduced an alternative paradigm of land ownership and resource use into the Umatilla Basin. In the Treaty of 1855, the United States government acquired 6.4 million acres of tribal lands, which were divided into parcels and distributed as property to mostly Euro-American settlers. Unlike the tribal system of common use of the land, the new proprietary system of land ownership created landowner rights to privately own, control, and exclusively determine use of property. Associated with this private ownership is an emphasis on resource extraction for the exclusive benefit of the owner, rather than the sustainable utilization of natural resources by and for the benefit of community members. Resource use following Euro-American settlement of the Umatilla Basin has primarily been privatized and extractive. For example, the riverscape has been altered by the channelization of the river network to facilitate farming, housing development, gravel mining, and other land uses (Figure 3). Water is extracted from the river and floodplain aquifer for crop irrigation and domestic use. River and floodplain gravels are mined and sold for use elsewhere.

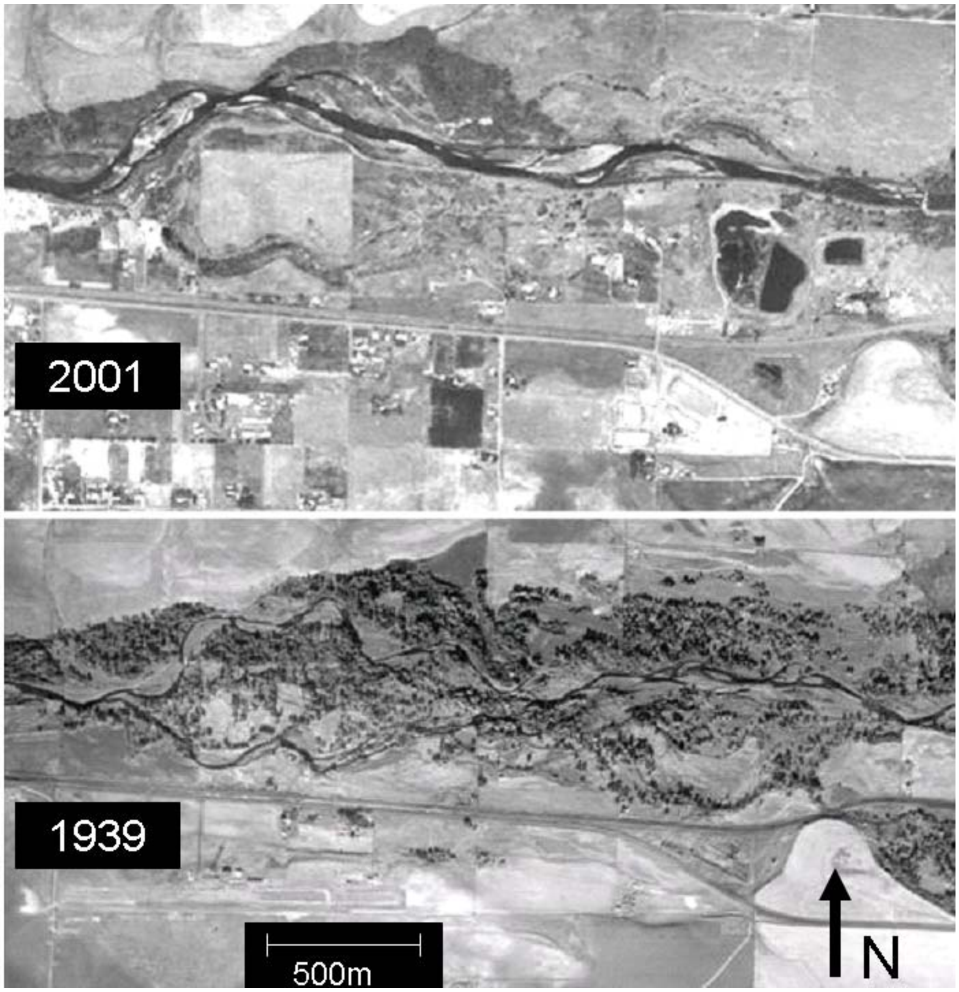

Figure 3. Images of the lower portion of the Mission Floodplain of the Umatilla River taken over the same extent from 1939 and 2001. The channel was dredged multiple times prior to 1965, simplifying the channel structure and reducing channel diversity.

Privatized and extractive use of natural resources has environmental consequences for the Umatilla Basin, including the degradation of ecosystem processes that once supported the natural production and harvesting of First Foods for consumption by tribal members. Additionally, private land ownership and extractive resource use have created challenges to basin-wide management of resources necessary to sustain First Foods. Foremost, the full First Food order cannot be realized within the boundaries of the Umatilla Indian reservation; the reservation is too small and does not provide the diversity of habitats necessary to acquire all First Foods (Figure 2). Recognizing this limitation, the Treaty of 1855 preserved a large aboriginal use area, "usual and accustomed" fishing stations, and rights to hunt and gather roots and berries so that tribal members could harvest and fulfill the First Foods order. The distribution of First Foods throughout the usual and accustomed areas creates relationships (including some conflicts) among the tribal community and private, state, and federal entities, particularly parties with explicit trust responsibilities to protect and sustain treaty-reserved resources. Thus, maintaining First Foods for tribal use requires integrative, holistic management of resources across the basin and cooperation between basin stakeholders.

Restricted access and degradation of the Umatilla River Basin can reduce the availability (and potentially nutritional quality) of First Foods, impacting the health of the tribal community. Restricted access to harvesting areas could eliminate First Foods from the longhouse if habitats supporting a First Food are rare and found only on private lands. Meanwhile, degradation results in reduced water quality, requiring additional purification of river water for drinking to remove pathogens, nutrients, and contaminants. Diminished abundances of fishes are insufficient to sustain the tribal community. Fish under physiological stress and with low prey abundance are apt to have reduced body fat and nutritional quality (McCullough et al. 2001). Contaminant loads in fishes may impede their safe consumption by the tribe (e.g., accumulation of Polybrominated Diphenyl Ether in Columbia River Whitefish; Rayne et al. 2003). This loss of traditional food resources exacerbates tribal health issues (e.g., poor fitness, diabetes). Studies have shown that food resource loss is associated with lifestyle changes (e.g., increasing sedentary lifestyle while decreasing cultural-specific activities and food diversity) and health concerns (e.g., increased diabetes, obesity, heart disease) (Kuhnlein and Receveur 1996). Thus, restoring tribal food resources is apt to benefit the health and culture of Umatilla tribe by providing traditional food choices and promoting activities (e.g., hunting, gathering, and fishing) that draw on tribal knowledge and skills.

First Foods is a cultural strategy for natural resource management that may be a useful counterweight to address limitations and unintended ecological consequences of privatized and extractive resource use. It incorporates spatial and phenological considerations because resources are used throughout the basin and year based on availability. It also integrates natural resources management with tribal resource needs. The initial presentation of water in tribal ceremonies underscores the importance of water both as a resource in its own right and as a critical resource for supporting the production of remaining First Foods. The range of river-derived foods in the salmon category reveals the use of the native aquatic community as First Food resources throughout the annual cycle. Additionally, First Foods may provide the appropriate context in which to report management and restoration progress to the tribal community. Each First Food and its grouping could be considered a potential unit for reporting metrics such as abundance, distribution, restoration efforts, restoration achievements, and policy and regulatory mechanisms. Ultimately, the most direct and culturally appropriate indication of the CTUIR DNR's progress is measured by the CTUIR community's continued ability to access, harvest, process, preserve, and share First Foods at the longhouse and in their homes.

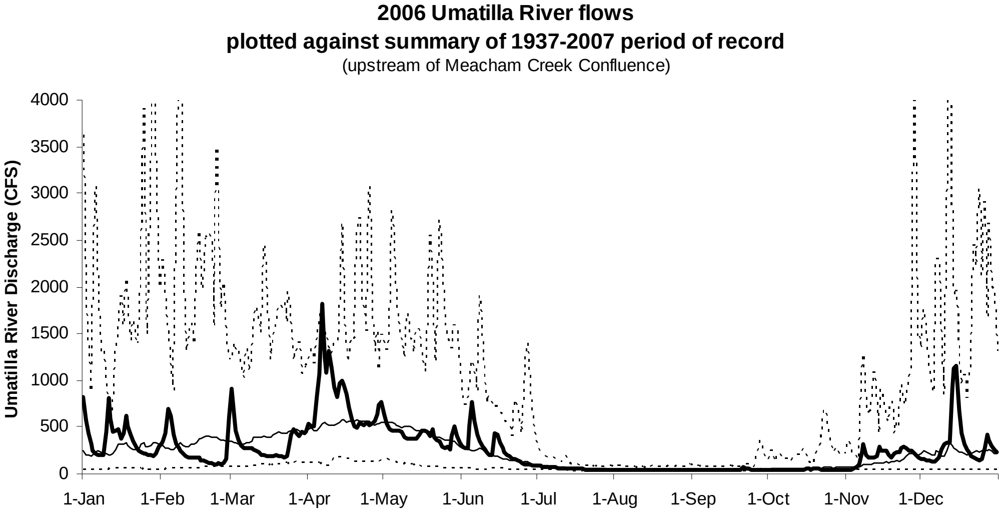

Figure 4. Umatilla River discharge at USGS Gauge upstream of Meacham Creek confluence. Heavy line represents discharge during 2006, a rather typical flow year with a large peak flow event during April. Flood spates are typically brief in the Umatilla River, and absent from July through October. Thin solid line shows average discharge for period of record (1937-2007). Thin dashed lines depict maximum and minimum flows observed for each date over period of record.

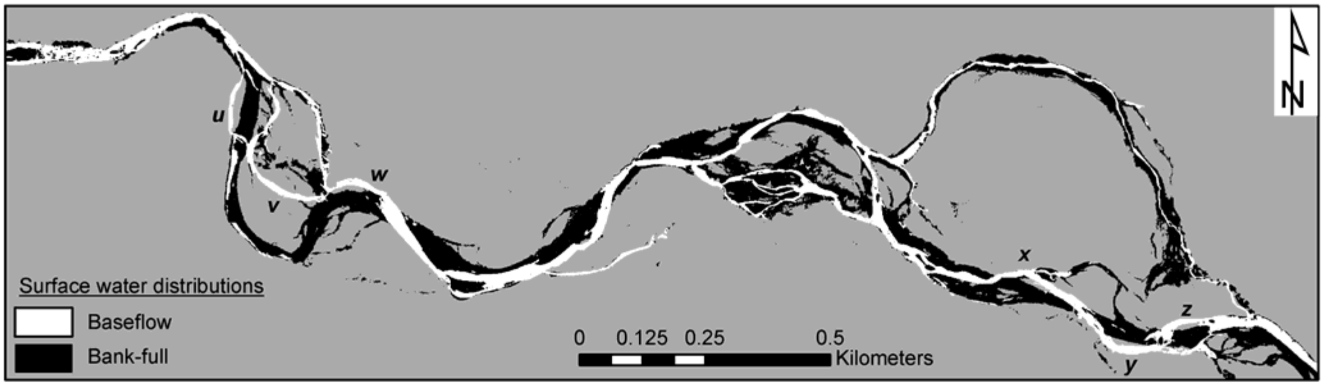

Figure 5. Surface water distributions derived from remote sensing data at bank-full flow (March 2003) and baseflow (July 2004) on the eastern portion of the Mission Floodplain (upstream from Mission, Oregon) on the Umatilla River,. Letters u-z show locations of channel migration that occurred between the two dates of data collection (Figure modified from Jones et al. In Press. Copyright © 2008 by Elsevier. Reprinted with permission from Elsevier).

The Umatilla River

The long-term production of riverine First Foods within the Umatilla Basin and across the usual and accustomed harvesting areas requires an ecologically healthy, or "functional" river. Although a functional river may be defined in many ways, for the purposes at hand, we define a functional Umatilla River as a dynamic river ecosystem that incorporates and expresses ecological processes that support the continued natural production of First Foods and utilization by the CTUIR community. This section provides a general overview of five components associated with a functional Umatilla River (water, geomorphology, habitat and network connectivity, riverine biotic community, and riparian vegetation) and changes in these components following Euro-American settlement that jeopardize the sustained availability of First Foods.

Water

Water is both a First Food, and a resource required to produce all other First Foods. Thus, within the First Foods management framework, the concept of "water quality" takes on a broader meaning. In addition to using conventional physio-chemical measures, evaluation of water quality in the Umatilla Basin must also include appropriate measure of biotic communities (e.g. native species abundance and diversity) (Karr 1993) and hydrologic processes (e.g., flow regime) associated with high ecological health (Poff et al. 1997). To be successful, then, the First Foods paradigm must integrate the methods and means of water resource management into the concept of "water quality." Regardless of water physio-chemistry, water quality is low anywhere water is managed in ways that are incompatible with the ecological integrity (or "health") of the river. Thus, high quality water must be adequate to support the sustainable production of First Foods in terms of its physical properties (e.g., appropriate temperature regime); chemical composition (free of pollutants), biotic constituents (native biotic community), and hydrology (e.g., timing and volume of river flow and spatial distribution of water throughout the Umatilla Basin).

Physiochemical aspects of water quality are well understood and closely managed and monitored under the U.S. Clean Water Act. In the 1990's managers started to address biotic aspects of water quality (Karr 1993). More recently, scientists have underscored the need to address hydrologic aspects of water quality (Stanford et al. 1996; Poff et al. 1997). Hydrologic aspects of water quality within the Umatilla River Basin center on the flow regime (pattern of water discharge) in the river, which follows a distinctive seasonal pattern (Figure 4). Substantial flood pulses occur in late winter and early spring following rain-on-snow and warm "Chinook" winter wind events. Low flows occur in the summer when groundwater inputs and occasional rain events in the Blue Mountains maintain river baseflows. Minimum flows observed in the dry months represent the approximate lower limit of discharge ranges necessary to sustain aquatic and riparian communities. Higher flows are important because they reshape the river channel, provide periodic hydrologic connections between the main channel and floodplain via flooding (Figure 5), and influence distributions of habitats for aquatic and riparian biota. Additionally, the spatial distribution of surface water across the floodplain drives the active and continuous exchange of water between the river channel and river gravels, as well as subsurface movement of river water through river gravels (Figure 6; see also: Jones et al. 2008; Poole et al. In Press).

Alterations to water: Both the quantity and physiochemical characteristics of water in the Umatilla River have been changed by land use activities. The historical timing and volume of surface water have been altered by water withdrawals for irrigation and domestic use (Figure 7). Changes to surface water flows affect a variety of river functions, including connections between habitats for aquatic biota and patterns of floodplain water movement (Poff et al. 1997; Malard et al. 2006). Water quality has been degraded by inputs of sediment, fertilizers, pesticides, and other contaminants. These inputs have possible consequences, such as altering the food web by increased growth of noxious weeds and algae and leading to the accumulation of contaminants in water, sediment, and aquatic organisms.

Geomorphology

The river channel is naturally "anabranched" (having multiple channels separated by stable islands), like many of the remaining free-flowing alluvial rivers in the western U.S. At baseflow, the main channel frequently divides into multiple channels and then re-converges (1939 image in Figure 3). Common geomorphic features within the bank-full scour zone include mid-channel and lateral bars and small spring channels. During peak discharge, flow in these multiple channels merge into a single main channel, while flood channels (which are inactive during baseflow) are activated, creating a different pattern of channel braiding (Figure 5). Channel structure is dynamic; in a natural state, the channels migrate laterally across the floodplain (Figure 5; see also

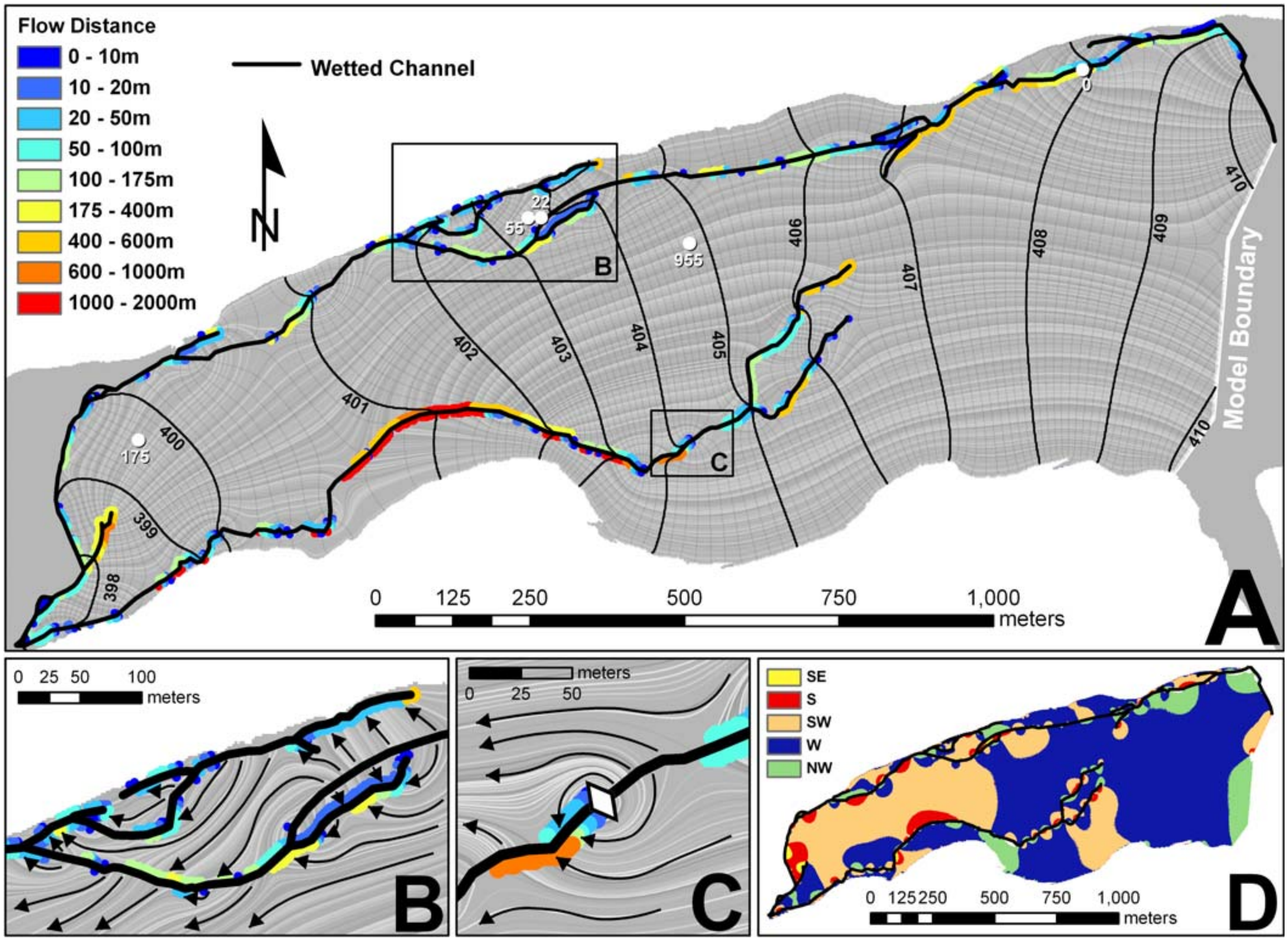

Figure 6. Model results from two-dimensional MODFLOW simulation of groundwater movement in the hyporheic zone of the Minthorn Springs section of Umatilla River Floodplain. (A) Map of simulated hyporheic flow paths. Heavy black lines show the center of active channels during baseflow 2004. Colors along the channels denote hyporheic flow path length at each point of hyporheic discharge to the channel. Lack of color along the channel denotes points of hyporheic recharge (i.e., hyporheic flow path length = 0). White dots show locations of hyporheic temperature loggers; white labels show length (m) of simulated flow path to each temperature sampling point. Black contours represent simulated water table elevations (m). Streamlines (background striations) indicate shape of groundwater flow paths. Inset boxes show locations of B and C. (B) Patterns of groundwater movement driven by differences in surface water elevation among the main and secondary channels. Colors and streamlines are as described in A. Arrows show direction of groundwater movement along flow paths. (C) Groundwater flow patterns and enhanced hyporheic exchange associated with a sharp "step" in the surface water elevation longitudinal profile; white diamond represents location of a beaver dam. Colors, streamlines, and arrows are as described in B. (D) Map of simulated groundwater flow direction across the alluvial aquifer, categorized into the 5 predominant cardinal and intercardinal directions of water movement on the floodplain (Figure and legend from Poole et al. In Press. Copyright © 2008 by John Wiley & Sons, Inc. Reprinted by permission of John Wiley & Sons, Inc.).

Latterell et al. 2006; Whited et al. 2007). The streambed consists of boulders, cobbles, gravels, pebbles, and sand, with finer particles being more prevalent in low gradient reaches. Following winter freshets, sediments are transported both longitudinally from the headwaters to the lower river system and laterally between the main channel and floodplain.

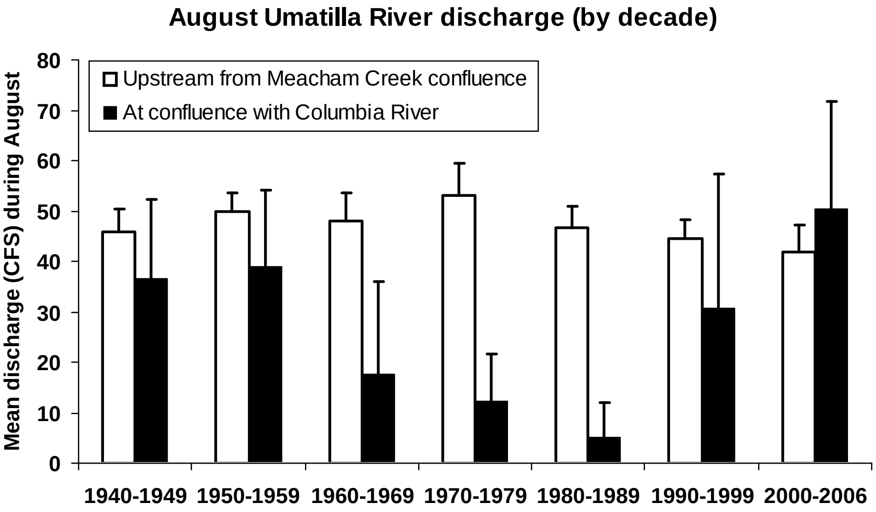

Figure 7. Inter-decadal variation in Umatilla River flows (±S.D.) Water draining from the Blue Mountains has provided the Umatilla River with consistent base flows over time (white bars). However, especially during the 1960s – 1980s, irrigation withdrawals captured most of this water, at times even drying up the Umatilla River before it reached its terminus at the Columbia River (black bars). In the early 1990s, anadromous salmon mitigation ensured that base flows were maintained in the lower section of the river. Despite the return of base flows to the river, the hydrology and channel condition over the majority of the river is still highly managed and altered. Agricultural withdrawals are still substantial. To mitigate for these withdrawals, river base flows have been augmented with water from McKay Reservoir and pump exchanges with the Columbia River

Alterations to geomorphology: Construction of flow control structures (e.g., levees and dikes) and dredging have simplified the complex geomorphology of the Umatilla River, which results naturally from both hydrologic processes and sediment transport. For instance, the lower half of the Mission Valley Floodplain was dredged repeatedly from the mid 1940's to the mid 1960's. Photos from 1939 and 2001 (Figure 3) illustrate the associated substantial loss in channel diversity. Such geomorphic alterations affect hydrologic patterns (e.g., flows are largely contained with the simplified channels), geomorphic processes, and water linkages between surface water habitats for aquatic biota (Malard et al. 2006; Poole et al. 2006; Poole et al. In Press).

Connectivity among habitats and across the river network

A functional Umatilla River is supported by flows of surface water and groundwater that physically transfer nutrients, sediment, energy, and organisms among stream habitats and across the Umatilla River network (Kondolf et al. 2006). This "hydrologic connectivity" (Ward and Stanford 1995; Pringle 2003) occurs longitudinally as tributaries flow into the larger Umatilla river system, laterally as river water during high flow events spreads out onto the adjacent floodplain (exchanging water between the main channel and secondary channels; Malard et al. 2006), and vertically as water moves bi-directionally between the river and underlying river gravels (Figure 6). Latteral connectivity is critical for maintaining biological diversity of floodplains and rivers (Amoros and Bornette 2002). Longitudinal connectivity flushes fine sediments downstream to depositional areas, maintaining clean, coarse benthic gravels for macroinvertebrate habitat and spawning habitats for First Foods fishes. Vertical connectivity moves nutrients between the main channel and hyporheic zone, where microbes can remove nutrients, improving water quality. Lastly, connectivity creates routes for aquatic organisms to move between instream habitats and migrate throughout the river network.

Alterations to connectivity: While longitudinal, lateral, and vertical connections are integral to the functioning of rivers such as the Umatilla River (Ward 1998), they are diminished by the construction of flow control structures (e.g., levees and dikes), channel incision, dredging, and increasing fine sediment inputs that reduce the vertical exchange of water (Kondolf et al. 2006).

Riverine biotic community: native community structure and health

The river's food web is supported in part by the primary production of periphyton, phytoplankton, and macrophytes and the breakdown of both terrestrial and aquatic derived organic matter by microbes, fungi, and bacteria (Vannote et al. 1980). Higher trophic levels, which rely upon this primary productivity, include macroinvertebrates, mussels, and fishes. Historically and recently, the Umatilla River has supported several salmon species (e.g chinook, coho, and steelhead), lamprey, trout, whitefish, suckers, and amphibians. Native fauna are adapted to specific instream conditions (e.g., temperature, flow, and streambed sediment) and supported by intact food web linkages (Ward and Tockner 2001; Woodward and Hildrew 2002).

Alterations to the native riverine community: Many native fishes have been extirpated (e.g., coho and chinook salmon, Nehlsen et al. 1991; Weitkamp et al. 1995; Myers et al. 1998), whereas others have declined dramatically because of reductions in surface water flow, available habitats, and network connectivity (e.g., steelhead, Nehlsen et al. 1991; Busby et al. 1996). Amphibians such as the Columbia spotted frog and Northern leopard frog are at-risk due to the loss of floodplain wetland habitats. Beaver populations have declined in the basin due to unregulated trapping. Meanwhile, non-native species have been introduced into the system, potentially adversely affecting the native community via predation and competition.

Riparian vegetation: native community structure and health

Willow, cottonwoods, conifer, and alder are common riparian trees along the Umatilla River. Growth and success of riparian vegetation are linked to river hydrology patterns. Life histories of riparian vegetation tend to depend on high flow events that inundate the floodplain for germination and seed dispersal. In addition, riparian vegetation uses river baseflows and groundwater for water sources in the dry, hot summer months. Beaver also influence riparian vegetation conditions in numerous ways, such as creating floodplain wetlands that expand habitats for different types of riparian vegetation (Figure 8). Riparian vegetation influences instream conditions by increasing bank stability, shading, inputs of large woody debris, and seasonal inputs of allocthonous material that fuel the river's food web (Gregory et al. 1991). Large wood is an important structural component in rivers, increasing habitat complexity and inducing pool formation (Gurnell et al. 2002). Floodplain wetlands provide habitat for salmonids (Pollock et al. 2004; Pollock et al. In Press). In particular, on the Umatilla River Floodplain, cottonwood is a keystone species that provides bank stability, cavities for nesting birds, and large wood inputs for aquatic habitat.

Figure 8. (a) Ponded water behind beaver dams in river side channels creates unique floodplain habitats that are substantively different from (b) free-flowing habitats of the main channel.

Alterations to native riparian vegetation: Following Euro-American settlement, native riparian vegetation has been dramatically reduced while some introduced riparian species (Table 1) have become established. Such changes in riparian abundance and composition affect the Umatilla River by altering large wood inputs, bank stability, leaf litter inputs that contribute organic matter to the river's food web, and habitats for riverine and riparian organisms.

The River Vision

Because the production of First Foods is tied to the hydrology, geomorphology, habitat and network connectivity, riverine biotic community, and riparian vegetation of the Umatilla River, a River Vision must address each of these topics. Here, we highlight attributes of these functional components and associated critical data needs relevant to the management of the Umatilla River for First Foods.

Water and Water Quality

A functional Umatilla River requires preserving or restoring the seasonal timing and volumes of river flows (Poff et al. 1997; Ward et al. 2001) necessary to support the production and harvest of First Foods. Baseflow conditions (low flows during the late summer and early autumn) in the Umatilla River determine the availability of aquatic habitats within the river as well as summertime hydrologic connectivity within the river network. Thus, summertime migrations of salmon, lamprey, and other species are influenced by the magnitude of baseflow. Baseflow in any given year also influences water quality (since concentrations or pollutants are influenced by flow volume) and even the temperature regime of the river. Importantly, prior to Euro-American settlement, baseflows were subject to natural climate cycles; baseflows in wet years were higher than baseflows in drought years. Thus, to support summertime connectivity with the rest of the Columbia River Basin and maintain summertime aquatic habitats, a functional Umatilla River would experience interannual variation in high and low baseflow conditions similar in magnitude and frequency to the interannual occurrence of high and low baseflows prior to Euro-American settlement.

In addition to baseflows, management planning for desired flow regimes in the Umatilla River requires consideration of the magnitude and frequency of peak flow events. Peak flow events maintain the dynamic nature of the floodplain morphology and channel pattern (Latterell et al. 2006; Whited et al. 2007), which facilitates the flux of river water through floodplain gravels and maintains a variety of aquatic habitats in the channel and across the floodplain. For examples, floods that are sufficient to mobilize the streambed are critical to the ecological function of the Umatilla River. Such high-flow events provide temporary surface water connections between main-channel and off-channel aquatic habitats, build and rearrange important channel and gravel-bar features across the floodplain thereby maintaining habitat diversity, enhance water movement through the floodplain aquifer by cleaning and sorting river sediments thereby facilitating hyporheic water flux, and recharge the alluvial aquifer with water (Stanford et al. 2005). A functional river, then, is dependent on the sufficient magnitude and frequency of flood events to maintain dynamic channel patterns and adequate water exchange rates between the channel and floodplain sediments.

Table 1. Some invasive plant species found on the Umatilla River Floodplain.

Common Name	Scientific Name
Diffuse knapweed	*Centaurea diffusa*
Spotted knapweed	*Centaurea maculosa*
Russian knapweed	*Acroptilon repens*
Vipers bugloss	*Echium vulgare*
Reed canarygrass	*Phalaris arundinacea*
Purple loosestrife	*Lythrum salicaria*
Canada thistle	*Cirsium arvense*
Indigo bush	*Dalea fremontii*
Dalmatian toadflax	*Linaria dalmatica*
Perennial pepperweed	*Lepidium latifolium*
Yellow iris	*Iris pseudacorusis*
Russian olive	*Elaeagnus angustifolia*
Black locust	*Robinia pseudoacacia*

Finally, the transitional periods between peak and baseflows are also ecologically important. The "falling lim" (reduction in river flow after a period of high water) of the annual hydrograph during the early summer can be ecologically important for spawning of fishes, establishment of cottonwoods, and maintenance of vernal pools on the floodplain for floodplain amphibians. Additionally, when rivers drop too rapidly from a peak flow to base flows, fish can be trapped in transient off-channel habitats on the floodplain that may dry up as the flood recedes. The hydrograph of a functional river, then, would include transitions between high flow events and low flow events that are compatible with maintenance of the native aquatic community of the river.

In addition to the volume of water in the channel, a functional river is defined by the physical, chemical, and biological aspects of water quality. The river should be free from pollutants (e.g., toxicants or excess nutrients) that impair drinking water supplies, alter stream water pH, and stress or kill native aquatic fauna. Maintenance of appropriate water temperature regimes (Poole et al. 2004), including cool temperatures during the summer, is especially important because water temperature influences dissolved oxygen concentrations, stress levels of aquatic organisms, growth of pathogens, and the competitive abilities of non-native fishes vs. native fishes. In short, a functional Umatilla River would have nutrient and contaminants levels that do not impede First Foods production and the utilization and safe consumption of First Foods by the tribal community.

Geomorphology

River morphology: A functional Umatilla River channel must be dynamic over time as peak flow events periodically reworked the channel pattern (Petts 2000). Such morphogenic processes create a variety of diverse channel features (e.g., riffles, pools, side channels, spring channels, and backwaters). Associated channel complexity also increases habitat heterogeneity (Stanford et al. 2005). Aquatic organisms often require different habitats for spawning, rearing, and adulthood. These habitats may be located in the main channel, tributaries, and off-channel habitats and utilized at various times throughout the day and/or various times of the year (Amoros and Bornette 2002). Such channel complexity also promotes hyporheic exchange (the bidirectional exchange of river water) between the channel and floodplain gravels (Figure 6; see also Poole et al. 2006). Within the hyporheic zone (the subsurface portion of floodplain gravels saturated by water from the river channel), bacteria, fungi, and other microbes process nutrients, such as nitrogen. Plants rooted in floodplain gravels also take up nutrients. Thus, where channel patterns are complex and hyporheic fluxes are high, plants and microbes have the opportunity to improve water quality (Brunke and Gonser 1997) as river water continually spirals between the channel and hyporheic zone on its downstream journey (Poole et al. In Press). A functional river, sustaining such physical and biological processes and river-dependent First Foods, would have a channel network maintained and reshaped over time by the river's hydrology.

Sediment: Alterations to the river's sediment regime also influence the availability of riverine First Foods (Megahan et al. 1992; Waters 1995). Historically, winter freshets drove pulses of coarse sediment from upland and headwater sources into the main Umatilla River and flushed fine sediments out of the system. Now, the sediment regime includes summertime pulses of fine sediments, resulting from small, intense storms that carry fine sediment into the main Umatilla channel from eroded banks on the lower tributaries and agriculture sources (e.g., along Wildhorse creek). These increasing fine sediment loads affect the aquatic community by smothering benthic habitats, thereby decreasing oxygen concentration within spawning gravels and affecting the macroinvertebrate community, and increasing turbidity, thereby reducing the foraging efficiency of

Box 1: Critical data needs for managing water and water quality.
- Sources of discharge data and associated sites and period of record
- Discharge rate that constitutes a channel-forming event
- Channel-forming events, their frequency, and required discharges
- Floodplain inundating events, their frequency, and required discharges
- Historical variability of low and high flows
- Expected flow conditions given future climate change
- Locations and rates of surface- and groundwater withdrawal
- Locations and duration of river dewatering
- Background nutrient concentrations and annual regimes
- Sources of water quality impairment
- Current toxicant levels in surface water and fishes
- Water quality relative to federal and state water quality standards
- Changes in water quality standards necessary to protect First Foods

fishes (Wood and Armitage 1997). By plugging the spaces between coarse gravels, fine sediments can also decrease the permeability of the streambed and reduce rates of hyporheic exchange (Brunke and Gonser 1997). The timing of these summertime sediment pulses may also affect the spawning, rearing, and migration success of aquatic species. Thus, the timing, volume, and particle sizes of sediment entering the Umatilla River must be managed to maintain aquatic communities that support and provide First Foods.

Box 2: Critical data needs for managing geomorphic processes.

- Location of incised channels within the network
- Locations of levees, dikes, and other flow control structures and dredging along the river network
- Locations of sediment sources (e.g., incised channels, logging, and agricultural lands) and associated timing and depositional areas within the basin
- Historical vs. current locations of spawning gravels
- Controls limiting the availability of spawning gravels
- Distributions of benthic habitats for mussels, lampreys, and fishes
- Riparian analysis to project expected large woody debris supplies across river network.

Connectivity among habitats and across the river network

Habitat linkages: Longitudinal, lateral, and vertical water flow in the Umatilla River network provides habitat connections that are necessary for supporting the riverine food web (Ward et al. 1999; Jansson et al. 2007) and First Foods. These hydrologic linkages may be limited in duration (e.g., when flood stage links floodplain habitats with the main river channel) or available throughout the year (e.g., surface water connections between tributaries and main river channel) (Ward and Stanford 1995). Regardless of duration, these physical connections provide aquatic organisms with "routes" between habitats and are necessary for organisms to complete their life cycles, thus supporting the riverine food web (Amoros and Bornette 2002) and sustaining First Foods. In particular, connectivity facilitates fish movement between habitats and river sections for spawning, feeding, and rearing activities. Facilitating passage for fish movement and migrations involves maintaining the river's hydrologic regime and eliminating potential barriers (such as culverts, diversion dams, and river sections that are dewatered or have temperature conditions lethal to salmon) across the main river channel, tributaries, and floodplain. Additionally, salmonids often use areas where hyporheic water enters the main channel (i.e., locations of high vertical connectivity) for spawning sites (Baxter and Hauer 2000; Geist et al. 2002). Thus, a functional Umatilla River would have connections among floodplain habitats and across the river network that are sufficient to support First Foods fishes throughout the annual cycle and particularly during critical movement and migration periods.

Lateral inundation: Managing the Umatilla River and floodplain to allow lateral inundation contributes to maintaining habitats for native riverine communities (Amoros and Bornette 2002; Malard et al. 2006). Constraining high flows concentrates stream power (and energy to move sediments) within the main channel, resulting in an incised channel with faster flows. Such altered hydrologic and geomorphic conditions reduce the range of habitats with depth and flow conditions suitable to native riverine species and promote channel incision, further diminishing habitat connectivity (Kondolf et al. 2006). Reductions in lateral inundation frequency also prevent suspended fine sediments from being deposited on the floodplain as high flow events recede. These sediments, then, remain within the main channel and are apt to smother benthic and spawning habitats. Thus, a functional Umatilla River would experience lateral inundation events following historical patterns and levels that can shape habitats for riverine organisms and allow for sediment deposition on the floodplain.

Likewise, the native riparian vegetation community is adapted to patterns of floodplain inundation (Rood et al. 2005). Inundation events scour floodplain soils, influence the germination of seedlings, and carry large wood into the river channel. Prevention of such events, then, may favor introduced or even non-riparian species over native riparian species. Thus, since rivers depend upon native riparian vegetation for many ecological functions, lateral inundation events (with seasonal patterns and levels comparable to the historical hydrograph) must be managed in the Umatilla River to contribute to the health and success of native riparian vegetation.

Box 3: Critical data needs for managing connectivity.

- Historical diversity of habitats and channel feature patterns on the floodplain
- Spatial and temporal patterns of tributary connections with the main channel
- Flow event levels influencing various riparian plant communities
- Location and timing of migration barriers, both physical and habitat-based (e.g., thermal barriers), for migratory biota.

Riverine biotic community

The second category of First Foods is salmon. The term “salmon” is used inclusively, and covers salmon species themselves, as well as mussels, lampreys, whitefish, suckers, and trout (Figure 1). These food resources for the tribal community generally require water free of pollutants, a range of water temperature conditions, and clean, coarse benthic gravels for habitat and spawning. These recognized-First Foods also have important ecological functions. For instance, mussels filter surface water, removing some toxicants from the water column, and thus are often considered bio-indicators of water chemistry conditions. Additionally, salmon carcasses are seasonal nutrient inputs to the Umatilla River, fueling the river’s food web and increasing productivity (Gende et al. 2002). Enhanced productivity promotes the growth of the macroinvertebrate community and, in turn, the survival of juvenile salmon. Ecological contributions of First Foods such as mussels and fish feedback into promoting water quality and the success and growth of subsequent riverine First Foods.

Yet, mussels and fish are only a part of the Umatilla River’s community. The Umatilla River also has a diverse macroinvertebrate community that is an integral component of the river’s food web and a food resource for First Foods fishes. Like mussels and salmon, many types of macroinvertebrates (especially those upon which salmonids feed) have low tolerances for water quality impairment and specific benthic habitat requirements (e.g., coarse gravel vs. sand and low vs. high flow conditions) (Wood and Armitage 1997). Thus, management of the Umatilla River should protect water quality and habitat conditions so that native macroinvertebrates thrive in the Umatilla River.

Beaver are semi-aquatic organisms whose dam building activities contribute to a functional Umatilla River and the success of First Foods. In tributaries and secondary channels on floodplains, beavers build dams with riparian vegetation (Figure 8). These dams create pool habitats (increasing habitat complexity), boost sediment retention, promote retention and processing of organic matter and nutrients, and inundate areas making floodplain wetlands. Beavers likewise modify main channels, though beaver dams are rare in larger rivers because they generally cannot withstand flood flows (Pollock et al. 2004). Pools and wetlands created by beaver dams provide rearing habitat for juvenile salmonids such as coho salmon and steelhead (Pollock et al. In Press). Additionally, beaver dams affect hydrology patterns by raising stage and decreasing discharge, which in turn promote groundwater recharge, creation of localized groundwater upwelling (Figure 6C), and cool-water refugia (Pollock et al. 2007). Thus, because of the benefits of beaver activity (e.g., habitat creation, vertical connectivity, and water quality), beaver populations should be restored and managed in the Umatilla Basin.

Box 4: Critical data needs describing aquatic communities.

- Viable population sizes (e.g. VSP as defined for ESA) for First Foods fishes within the network
- Abundance and status of riverine First Foods
- Ecological roles of mussels, lamprey, whitefish, trout, and suckers
- Historic nutrient inputs from salmon carcasses
- Habitat utilization by fishes recognized as First Foods
- Distributions and densities of non-native species
- Distributions and habitat requirements of macroinvertebrates within the network
- Distributions habitat requirements of amphibians within the network
- Historical vs. current numbers and distributions of beaver and associated dam densities on the floodplain.

Riparian vegetation

A functional Umatilla River encompasses a diverse community of self-sustaining wild populations of native riparian vegetation. Vegetation increases bank stability, becomes large wood inputs, and provides shade (Gregory et al. 1991). These functions contribute to promoting First Foods, such as surface water and fishes. Increased bank stability reduces bank erosion, decreasing fine sediment inputs that can smother benthic and spawning habitats. Large wood in the channel, creating pool habitats for fishes, macroinvertebrates, and other aquatic biota (Gurnell et al. 2002). Additionally, large wood inputs can create debris dams (via pools formed by lodged wood or beaver dam construction) that retain sediment and nutrients and organic matter, allowing for processing by microbes and bacteria. Shade by riparian vegetation reduces solar radiation, potentially creating localized pockets of thermal refugia for aquatic organisms (Poole and Berman 2001). Lastly, leaf litter from riparian vegetation provides seasonal inputs of organic matter that fuel the Umatilla's food web (Vannote et al. 1980). Thus, increasing the abundance of native riparian vegetation and their success (via managing for lateral inundation events and beaver populations) are important management considerations for restoring and sustaining a functional Umatilla River.

Implications of the First Foods management framework

The end goal of the First Foods-focused management strategy is the sustainable stewardship of natural systems in CTUIR tribal lands, using the long-term production and harvesting of the full First Foods order by the tribe as a primary benchmark for success. Achieving this goal requires high water quality within the Umatilla River, including ecologically healthy hydrology, geomorphology, habitat and network connectivity, riverine biotic community, and riparian vegetation (Figure 9). Like the First Foods table settings, a functional Umatilla River would be dynamic throughout the annual cycle, yet consistent and reliable across decades. During winter, snowmelt water fills the main channel, causing the river to fill dry channels, inundate the floodplain, scour fine sediments from the streambed, and cut new channels with its high-energy flows. During summer, flows recede and the river abandons some old channels for new channels. These seasonal patterns vary between wet and dry years. The native riverine and riparian communities are adapted to and depend upon these dynamic physical conditions for their growth and survival. Thus, maintaining a functional Umatilla River for First Foods requires managing for the range of dynamic river conditions (and not simply static levels) throughout the year.

Box 5: Critical data needs for riparian vegetation management.
- Assess natural potential and range distributions of species (e.g., cottonwoods and other hardwoods)
- Quantify abundances and distributions of native riparian species
- Quantify abundances and distributions of introduced species
- Determine vegetation community typology and trends over time.
- Determine natural frequencies of cottonwoods and willows
- Quantify recruitment and retention rates for large wood

The inherent dynamic nature of the Umatilla River has the following five management implications:

1) *Commoditization of river resources is a substantial roadblock to the sustainability and longevity of First Foods and their utilization by tribal members.*

Treating river resources as commodities for extractive, private use emphasizes the use and trading of individual resource, rather than the importance of a functional river system supporting both human needs and ecosystem processes. A usufruct view of resource use is more compatible with management and restoration efforts in the Umatilla Basin. The current economic system, based on the concept of private property, is firmly entrenched within the Umatilla Basin. Although it may be neither feasible nor even desirable to attempt to supplant the existing economic system, efforts to maintain and restore tribal access to customary sites for harvesting First Foods is essential, and opportunities to encouraging usufruct land stewardship within the context of the current private property-based economy must be investigated in order to facilitate river restoration.

2) *Key river characteristics are variable throughout the river network. Therefore, while some management goals can be set for the basin, different river reaches require different management and restoration targets depending on the context and structure of the reach.*

For instance, high vs. low gradient reaches within the Umatilla network have different flow conditions and hence different streambed sediment compositions. In addition, reaches confined vs. unconfined by valley walls and bedrock have different hydrologic and channel patterns (Beechie et al. 2006). Unconfined reaches tend to have more distributed flows (and wider and shallower channels) while confined reaches have concentrated flows (and narrower and deeper channels). The range of reaches within the Umatilla River network contributes to the river's functioning and provides a diversity of habitats for First Foods fishes and riparian vegetation. Thus, management and restoration strategies to support the production of First Foods should be tailored to deal effectively with the range of reaches within the Umatilla Basin.

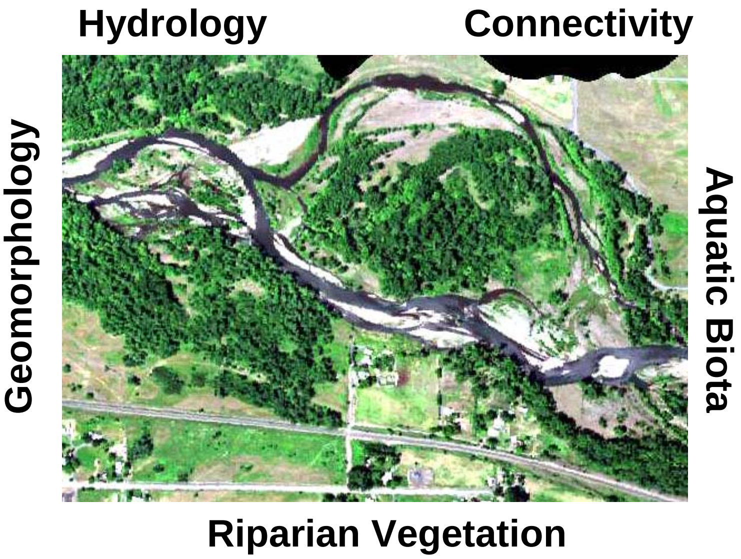

Figure 9: Key water quality management considerations to support First Foods production.

3) *Groundwater and surface water are a single resource and should be managed as such.*

High flow events in the Umatilla River recharge alluvial aquifers. Likewise, aquifers contribute flow to the Umatilla River, especially during the summertime. Thus, levels of groundwater and surface water are intricately linked as reductions in surface water levels may diminish groundwater levels (and vice versa). Where water table elevations are reduced below the elevation of the river surface, hyporheic exchange between the Umatilla River and floodplain and associated removal of nutrients from river water (and improvements to water quality) are lessened because hyporheic return flows to the river channel are reduced. In addition, alterations to the hydrology of the Umatilla River affect riverine and riparian communities; reductions in network and habitat connectivity essentially make habitats inaccessible for fishes while reductions in floodplain inundating events and water levels affect the success of native riparian vegetation. Thus, management of extractive water consumption of both surface water and groundwater must consider the hydrologic regime of the river (low flows, channel forming flows, and flow recession), habitat and network connectivity, inundation patterns, and riparian vegetation.

4) *While native riparian vegetation species are not recognized as First Foods, they are critical attributes of a functional Umatilla River capable of supporting First Foods.*

Native riparian vegetation has several important roles, such as providing shade, bank stability, large wood inputs into the river (which influence channel patterns), leaf litter inputs that are basal resources for the river's food web, and habitats for riparian and aquatic organisms. Thus, preservation and management of native riparian vegetation communities is critical to maintaining and restoring channel patterns, fish habitat, and therefore, a functional Umatilla River.

5) *Management of Umatilla River water quality to support First Foods requires restoration and maintenance of river processes, rather than simply emplacement of in-stream structures. As such, management and restoration strategies must identify mechanisms of influence and address ecological processes at relevant spatial and temporal scales and focus on renaturalization of riverine processes.*

A growing expertise in science-based river restoration approaches has been developing over the last decade. The cornerstone of such approaches is reconnecting rivers with their floodplain by re-establishing normative flow regimes, removing (or setting back, away from the river) flow constraining structures, and re-establishing the geomorphic and hydrological balance that created natural riverine habitats under which native aquatic communities evolved (Stanford et al. 1996; Poff et al. 1997; Beechie and Bolton 1999; Ward et al. 2001; Wohl et al. 2005; Jansson et al. 2007; Nilsson et al. 2007). Consider that management strategies are needed to address bank erosion on some Umatilla tributaries (e.g., Wildhorse Creek) since this erosion results in fine sediments entering the Umatilla River during the summer and possibly filling in salmon spawning and benthic habitats. One strategy may be to add structure such as “rip rap” (e.g., large rocks) to eroded banks to deflect flows and reduce further erosion. While this method may reduce erosion, it does not address the hydrologic mechanisms that lead to bank erosion. Worse still, rip rap creates other management problems by armoring riverbanks, diminishing channel-forming processes and increasing channel incision. An alternative approach would be to identify the possible factors causing high-energy flows (e.g., flow control structures concentrating flows upstream) and erosion potential (e.g., loss of riparian and bank vegetation, cattle access to river) and then determine actions to mitigate identified factors.

In the mainstem Umatialla River habitat restoration efforts should focus on: 1) restoration and maintenance of normative flow regimes (baseflow, peak flow, and flow recession patterns); 2) hydrologic connectivity of the floodplain with the channel, including reversal of past channelization and (where feasible) removal of artificial structures (e.g., dikes and levees) that constrain channel migration; 3) protection of floodplain plant communities; and 4) re-establishment of keystone species, such as beaver, on the floodplain. Such approaches would jumpstart the hydrologic and geomorphic processes (e.g., channel avulsion, large wood delivery, hyporheic water exchange, cottonwood regeneration) that create a healthy, dynamic mosaic of habitats to which native aquatic communities are adapted. The process of identifying and restoring normative river ecosystem processes (at appropriate spatial and temporal scales) is the surest means of achieving sustainable natural production of First Foods (Independent Scientific Group 1996).

Conclusions

The CTUIR DNR’s First Foods-focused mission aims to maintain a functional Umatilla Basin by embracing an expansive view of “water quality” that includes a functional river and associated processes for the sustained longevity of First Foods. This mission calls attention to the maintenance of water quality by focusing on the ecological health of the Umatilla River, which provides riverine First Foods (water and salmon). A target vision for a healthy Umatilla River reflects a river that is highly dynamic and shaped by not only physical and biological processes but also interactions and interconnections among those processes. Such a vision requires that managers incorporate several attributes of the Umatilla River into management and restoration strategies. Strategies should emphasize the importance of: 1) hydrology (including the timing, volume, and quality of water flows); 2) geomorphic processes; 3) longitudinal, lateral, and vertical connectivity among habitats and across the network; 4) the health of the riparian vegetative community; and 5) the health of the native aquatic species.

The First Foods-focused mission highlights direct linkages between the ecological health of the Umatilla River and the health and well-being of Umatilla tribal members. Degradation of the river, water quality, and associated ecological processes results in the loss of traditional tribal foods. This loss of food resources is linked to increasing occurrences of health issues (e.g., poor fitness, diabetes). In additional to providing a clean and healthy natural environment for tribal members and other residents of the Umatilla Basin, improving the availability of First Foods can contribute to sustaining tribal ceremonies, knowledge, and traditions that promote the physical health of tribal members. Finally, the First-focused mission provides resource managers in the basin with a framework for involving tribal members in management dialogues. Within such a framework, monitoring and restoration efforts can concentrate on improving the ecological functionality of the Umatilla River, which ultimately sustains First Foods.

Suggested additional reading (with abstracts)

Amoros, C. and G. Bornette (2002). "Connectivity and biocomplexity in waterbodies of riverine floodplains." Freshwater Biology **47**(4): 761-776.

> 1. In river corridors, water plays a key role in connecting various landscape patches. This 'hydrological connectivity' operates on the four dimensions of fluvial hydrosystems: longitudinal, lateral, vertical, and temporal. The present review focuses on: (1) lateral connectivity that links the main course of a river with floodplain waterbodies; and (2) vertical connectivity, the exchanges between the surface and groundwater via infiltration into the alluvial aquifer and exfiltration of phreatic water from the hillslope aquifer. 2. The biocomplexity of fluvial hydrosystems results from interactions between processes operating at various spatial and temporal scales. Differences in the nature and intensity of hydrological connectivity contribute to the spatial heterogeneity of riverine floodplains, which results in high alpha, beta and gamma diversity. Differences in connectivity also provide complementary habitats that are required for the parts of life cycles and life-cycles of some species. Hydrological connectivity also produces antagonistic effects, even within the same waterbody. 3. Two temporal scales are distinguished in connectivity dynamics. River level fluctuations within years lead to a pulsing connectivity that drives the functioning of floodplain ecosystems, namely the exchange of organic matter and inorganic nutrients and the shift between production and transport phases. On the scale of decades to centuries, the interactions between various processes increase the biocomplexity of floodplains; for example, river dynamics, which create highly connected waterbodies, compensate for succession that tends towards disconnection. Alternatively, river-bed incision leads to the reduction of fluvial dynamics and to the disconnection of waterbodies, although river incision may increase vertical connectivity where waterbodies are supplied by the hillslope aquifer.

Baxter, C. V. and F. R. Hauer (2000). "Geomorphology, hyporheic exchange, and selection of spawning habitat by bull trout (*Salvelinus confluentus*)." Canadian Journal of Fisheries and Aquatic Sciences **57**(7): 1470-1481.

> The distribution and abundance of bull trout (Salvelinus confluentus) spawning were affected by geomorphology and hyporheic groundwater - stream water exchange across multiple spatial scales in streams of the Swan River basin, northwestern Montana. Among spawning tributary streams, the abundance of bull trout redds increased with increased area of alluvial valley segments that were longitudinally confined by geomorphic knickpoints. Among all valley segment types, bull trout redds were primarily found in these bounded alluvial valley segments, which possessed complex patterns of hyporheic exchange and extensive upwelling zones. Bull trout used stream reaches for spawning that were strongly influenced by upwelling. However, within these selected reaches, bull trout redds were primarily located in transitional bedforms that possessed strong localized downwelling and high intragravel flow rates. The changing relationship of spawning habitat selection, in which bull trout selected upwelling zones at one spatial scale and downwelling zones at another spatial scale, emphasizes the importance of considering multiple spatial scales within a hierarchical geomorphic context when considering the ecology of this species or plans for bull trout conservation and restoration.

Beechie, T. and S. Bolton (1999). "An approach to restoring salmonid habitat-forming processes in Pacific Northwest watersheds." Fisheries **24**(4): 6-15.

> We present an approach to diagnosing salmonid habitat degradation and restoring habitat-forming processes that is focused on causes of habitat degradation rather than on effects of degradation. The approach is based on the understanding that salmonid stocks are adapted to local freshwater conditions and that their environments are naturally temporally dynamic. In this context, we define a goal of restoring the natural rates and magnitudes of habitat-forming processes, and we allow for locally defined restoration priorities. The goal requires that historical reconstruction focus on diagnosing disruptions to processes rather than conditions. Historical reconstruction defines the suite of restoration tasks, which then may be prioritized based on local biological objectives. We illustrate the use of this approach for two habitat-forming processes: sediment supply and stream shading. We also briefly contrast this approach to several others that may be used as components of a restoration strategy.

Beechie, T. J., M. Liermann, et al. (2006). "Channel pattern and river-floodplain dynamics of forested mountain river systems." Geomorphology **78**(1): 124-141.

> Channel pattern effectively stratifies the dynamics of rivers and floodplains in forested mountain river systems of the Pacific Northwest, USA. Straight channels are least dynamic, with relatively slow floodplain turnover and floodplains dominated by old surfaces. Braided channels are most dynamic, with floodplain turnover as low as 25 years and predominantly young floodplain surfaces. Island-braided and meandering channels have intermediate dynamics, with moderately frequent

disturbances (erosion of floodplain patches) maintaining a mix of old and young surfaces. Return intervals for the erosion of floodplains increase in the order of braided, island-braided, meandering, and straight (8, 33, 60, and 89 years, respectively). A threshold for the lateral migration of a channel occurs at a bankfull width of 15–20 m. The most likely mechanism underlying this threshold is that larger channels are deep enough to erode below the rooting zone of bank vegetation. Above this threshold, channels not confined between valley walls exhibit channel patterns distinguishable by slope and discharge, and slope–discharge domains can be used to predict channel patterns. Meandering and braided patterns are most consistently identified by the model, and prediction errors are largely associated with indistinct transitions among channel patterns that are adjacent in plots of slope against discharge. Locations of straight channels are difficult to identify accurately with the current model. The predicted spatial distribution of channel patterns reflects a downstream decline in channel slope, which is likely correlated with a declining ratio of bed load to suspended load. Ecological theory suggests that biological diversity should be highest where the intermediate disturbance regime of island-braided channels sustains high diversity of habitat and successional states through time.

Brunke, M. and T. Gonser (1997). "The ecological significance of exchange processes between rivers and groundwater." Freshwater Biology **37**(1): 1-33.

This review focuses on the connectivity between river and groundwater ecosystems, viewing them as linked components of a hydrological continuum. Ecological processes that maintain the integrity of both systems and those that are mediated by their ecotones are evaluated. The hyporheic zone, as the connecting ecotone, shows diverse gradients. Thus it can be characterized by hydrological, chemical, zoological and metabolic criteria. However, the characteristics of the hyporheic zone tend to vary widely in space and time as well as from system to system. The exact limits are difficult to designate and the construction of static concepts is inadequate for the representation of ecological processes. The hyporheic interstices are functionally a part of both the fluvial and groundwater ecosystems. The permeability of the ecotone depends on the hydraulic conductivity of the sediment layers which, because of their heterogeneity, form many flowpath connections between the stream and the catchment, from the small scale of a single microhabitat to the large scale of an entire alluvial aquifer. Local up- and downwellings are determined by geomorphologic features such as streambed topography, whereas large-scale exchange processes are determined mainly by the geological properties of the catchment. Colmation - clogging of the top layer of the channel sediments - includes all processes leading to a reduction of pore volume, consolidation of the sediment matrix, and decreased permeability of the stream bed. Consequently, colmation can hinder exchange processes between surface water and groundwater. Physicochemical gradients in the interstices result from several processes: (i) hyporheic flow pattern and the different properties of surface and groundwaters; (ii) retention, caused by the filtering effect of pore size and lithologic sorption as well as the transient storage of solutes caused by diminished water velocities; (iii) biogeochemical transformations in conjunction with local residence time. Each physicochemical parameter may develop its own vertical dynamics laterally from the active channel into the banks as well as longitudinally because of geomorphologic changes. The river-groundwater interface can act as a source or sink for dissolved organic matter, depending on the volume and direction of flow, dissolved organic carbon concentrations and biotic activity. Interstitial storage of particulate organic matter is influenced mainly by grain size distribution and by spates involving bedload movement that may import or release matter, depending on the season. After initial transient and abiotic storage, hyporheic organic matter is mobilized and transformed by the biota. Micro-organisms account for over 90% of the community respiration. In subterranean waters most bacteria are attached to surfaces and remain in a biofilm. Hyporheic interstices are functionally significant for phreatic and riverine metazoans because they act as a refuge against adverse conditions. The net flow direction exerts a dominant influence on interstitial colonization, but many other factors also seem to be important in structuring the hyporheos. The hyporheic corridor concept emphasizes connectivity and interactions between subterranean and surface flow on an ecosystem level for floodplain rivers. It is a complementary concept to others which focus on surficial processes in the lateral and longitudinal dimensions. The ecological integrity of groundwater and fluvial systems is often threatened by human activities: (i) by reducing connectivity; (ii) by altering exchange processes; and (iii) by toxic or organic contamination.

Busby, P. J., T. C. Wainwright, et al. (1996). Status review of west coast steelhead from Washington, Idaho, Oregon, and California. Springfield, VA, U.S. Dept of Commerce.

After considering available information on steelhead genetics, phylogeny and life history, freshwater ichthyogeography, and environmental features that may affect steelhead, the BRT identified 15 ESUs—12 for coastal steelhead and 3 for the inland form. The BRT reviewed population abundance data and other risk factors for these steelhead ESUs and concluded that five (Central California Coast, South-Central California Coast, Southern California, Central Valley, and Upper Columbia River) are presently in danger of extinction, five (Lower Columbia River, regon Coast, Klamath Mountains Province, Northern California, and Snake River Basin) are likely to become endangered in the foreseeable future, and four steelhead ESUs (Puget Sound, Olympic Peninsula, Southwest Washington, and Upper Willamette River) are not presently in significant danger of becoming extinct or endangered, although some individual stocks within these ESUs may be at risk. The BRT

concluded that the remaining steelhead ESU (Middle Columbia River) is not presently in danger of extinction but was unable to reach a conclusion as to its risk of becoming endangered in the foreseeable future.

Geist, D. R., T. P. Hanrahna, et al. (2002). "Physiochemical characteristics of the hyporheic zone affect redd site selection by chum salmon and fall Chinook salmon in the Columbia River." North American Journal of Fisheries Management **22**: 1107-1085.

Chum salmon Oncorhynchus keta and fall chinook salmon O. tshawytscha spawned at separate locations in a side channel near Ives Island, Washington, in the Columbia River downstream of Bonneville Dam. We hypothesized that measurements of water depth, substrate size, and water velocity would not sufficiently explain the separation in spawning areas and began a 2-year investigation of physicochemical characteristics of the hyporheic zone. We found that chum salmon spawned in upwelling water that was significantly warmer than the surrounding river water. In contrast, fall chinook salmon constructed redds at downwelling sites, where there was no difference in temperature between the river and its bed. An understanding of the specific factors affecting chum salmon and fall chinook salmon redd site selection at Ives Island will be useful to resource managers attempting to maximize available salmonid spawning habitat within the constraints imposed by other water resource needs.

Gende, S. M., R. T. Edwards, et al. (2002). "Pacific salmon in aquatic and terrestrial ecosystems." BioScience **52**(10): 917-928.

Pacific salmon subsidize freshwater and terrestrial ecosystems through several pathways, which generates unique management and conservation issues but also provides valuable research opportunities. In A Sand County Almanac, Aldo Leopold (1949) described the incremental movement of atom X from headwaters to ocean, driven by the forces of gravity and discharge, to its ultimate “prison”in the sea. Understanding the implications and controls of “nutrient spiraling,” as this phenomenon has been termed, has driven much of recent stream ecosystem research (e.g., Peterson et al. 2001). Our current understanding of the phenomenon of salmon-derived nutrient input clearly shows that a small but important proportion of those atoms escape their “prison” to return in the bodies of ocean-dwelling organisms,whose behavior drives them back against gravity and stream discharge to penetrate the continent. Quantifying the ecological effects of this phenomenon and translating that understanding into useful conceptual and practical tools to better manage oceanic, freshwater, and terrestrial ecosystems -- without reference to the jurisdictional, organizational, and conceptual boundaries that currently inhibit us -- remains a challenge for scientists and managers alike.

Gregory, S. V., F. J. Swanson, et al. (1991). "An ecosystem perspective of riparian zones." Bioscience **41**(8): 540-551.

Riparian zones are the interfaces between terrestrial and aquatic ecosystems. As ecotones, they encompass sharp gradients of environmental factors, ecological processes, and plant communities. Riparian zones are not easily delineated but are comprised of mosaics of landforms, communities, and environments within the larger landscape. We propose a conceptual model of riparian zones that integrates the physical processes that shape valley-floor landscapes, the succession of terrestrial plant communities on these geomorphic surfaces, the formation of habitat, and the production of nutritional resources for aquatic ecosystems.

Gurnell, A. M., H. Piégay, et al. (2002). "Large Wood and Fluvial Processes." Freshwater Biology **47**: 601-619.

1. Large wood forms an important component of woodland river ecosystems. The relationship between large wood and the physical characteristics of river systems varies greatly with changes in the tree species of the marginal woodland, the climatic and hydrological regime, the fluvial geomorphological setting and the river and woodland management context. 2. Research on large wood and fluvial processes over the last 25 years has focussed on three main themes: the effects of wood on flow hydraulics; on the transfer of mineral and organic sediment, and on the geomorphology of river channels. 3. Analogies between wood and mineral sediment transfer processes (supply, mobility and river characteristics that affect retention) are found useful as a framework for synthesising current knowledge on large wood in rivers. 4. An important property of wood is its size when scaled to the size of the river channel. 'Small' channels are defined as those whose width is less than the majority of wood pieces (e.g. width < median wood piece length). 'Medium' channels have widths greater than the size of most wood pieces (e.g. width < upper quartile wood piece length), and 'Large' channels are wider than the length of all of the wood pieces delivered to them. 5. A conceptual framework defined here for evaluating the storage and dynamics of wood in rivers ranks the relative importance of hydrological characteristics (flow regime, sediment transport regime), wood characteristics (piece size, buoyancy, morphological complexity) and geomorphological characteristics (channel width, geomorphological style) in 'Small', 'Medium' and 'Large' rivers. 6. Wood pieces are large in comparison with river size in

'small' rivers, therefore they tend to remain close to where they are delivered to the river and provide important structures in the stream, controlling rather than responding to the hydrological and sediment transfer characteristics of the river. 7. For 'Medium' rivers, the combination of wood length and form becomes critical to the stability of wood within the channel. Wood accumulations form as a result of smaller or more mobile wood pieces accumulating behind key pieces. Wood transport is governed mainly by the flow regime and the buoyancy of the wood. Even quite large wood pieces may require partial burial to give them stability, so enhancing the importance of the sediment transport regime. 8. Wood dynamics in 'Large' rivers vary with the geometry of the channel (slope and channel pattern), which controls the delivery, mobility and breakage of wood, and also the characteristics of the riparian zone, from where the greatest volume of wood is introduced. Wood retention depends on the channel pattern and the distribution of flow velocity. A large amount is stored at the channel margins. The greater the contact between the active channel and the forested floodplain and islands, the greater the quantity of wood that is stored.

Independent Scientific Group (1996). Return to the River: Restoration of Salmonid Fishes in the Columbia River Ecosystem. Portland, OR, Northwest Power Planning Council.

The conceptual foundation presented here represents a new approach to salmon management and restoration in the Columbia River basin. It is one with which the region has little experience. The approach is based on the relationship between natural ecological functions and processes, including habitat diversity, complexity, and connectivity, and salmonid diversity and productivity.

Jansson, R., C. Nilsson, et al. (2007). "Restoring freshwater ecosystems in riverine landscapes: the roles of connectivity and recovery processes." <u>Freshwater Biology</u> **52**(4): 589-596.

1. This paper introduces key messages from a number of papers emanating from the Second International Symposium on Riverine Landscapes held in August 2004 in Sweden, focusing on river restoration. Together these papers provide an overview of the science of river restoration, and point out future research needs. 2. Restoration tests the feasibility of recreating complex ecosystems from more simple and degraded states, thereby presenting a major challenge to ecological science. Therefore, close cooperation between practitioners and scientists would be beneficial, but most river restoration projects are currently performed with little or no scientific involvement. 3. Key messages emanating from this series of papers are: The scope, i.e. the maximum and minimum spatial extent and temporal duration of habitat use, of species targeted for restoration should be acknowledged, so that all relevant stages in their life cycles are considered. Species that have been lost from a stream cannot be assumed to recolonize spontaneously, calling for strategies to ensure the return of target species to-be integrated into projects. Possible effects of invasive exotic species also need to be incorporated into project plans, either to minimize the impact of exotics, or to modify the expected outcome of restoration in cases where extirpation of exotics is impractical. 4. Restoration of important ecological processes often implies improving connectivity of the stream. For example, longitudinal and lateral connectivity can be enhanced by restoring fluvial dynamics on flood-suppressed rivers and by increasing water availability in rivers subject to water diversion or withdrawal, thereby increasing habitat and species diversity. Restoring links between surface and ground water flow enhances vertical connectivity and communities associated with the hyporheic zone. 5. Future restoration schemes should consider where in the catchment to locate projects to make restoration most effective, consider the cumulative effects of many small projects, and evaluate the potential to restore ecosystem processes under highly constrained conditions such as in urban areas. Moreover, restoration projects should be properly monitored to assess whether restoration has been successful, thus enabling adaptive management and learning for the future from both successful and unsuccessful restorations.

Jones, K. L., G. C. Poole, et al. (2008). "Geomorphology, hydrology, and aquatic vegetation drive seasonal hyporheic flow patterns across a gravel-dominated floodplain." <u>Hydrological Processes</u>. Forthcoming.

Across 1.7 km2 of the Umatilla River floodplain (Oregon, USA), we investigated the influences of an ephemeral tributary and perennial ‘spring channel’ (fed only by upwelling groundwater) on hyporheic hydrology. We derived maps of winter and summer water-table elevations from data collected at 46 monitoring wells and 19 stage gauges and used resulting maps to infer groundwater flow direction. Groundwater flow direction varied seasonally across the floodplain and was influenced by main channel stage, flooding, the tributary creek, and the location and direction of hyporheic exchange in the spring channel. Hyporheic exchange in the spring channel was evaluated with a geochemical mixing model, which confirmed patterns of floodplain groundwater movement inferred from water-table maps and showed that the spring channel was fed predominantly by hyporheic water from the floodplain aquifer (87% during winter, 80% during summer), with its remaining flow supplied by upslope groundwater from the adjacent catchment aquifer. Summertime growth of aquatic macrophytes in the spring channel also influenced patterns of hyporheic exchange and groundwater flow direction in the alluvial aquifer by increasing flow resistance in the spring channel, locally raising surface water stage and adjacent water-table elevation, and thereby altering the slope of the water-table in the hyporheic zone. The Umatilla River floodplain is larger than most sites where hyporheic hydrology has been investigated in detail. Yet, our results corroborate other research that has identified off-channel geomorphic features as important drivers of hyporheic hydrology, including previously published modeling efforts from a similar river and field observations from smaller streams.

Jungwirth, M., S. Muhar, et al. (2002). "Re-establishing and assessing ecological integrity in riverine landscapes." Freshwater Biology **47**(4): 867-888.

1. River-floodplain systems are among the most diverse and complex ecosystems. The lack of detailed information about functional relationships and processes at the landscape and catchment scale currently hampers assessment of their ecological status. 2. Intensive use and alteration of riverine landscapes by humans have led to severe degradation of river-floodplain systems, especially in highly industrialised countries. Recent water-related regulations and legislation focussing on high standards of ecological integrity back efforts to restore or rehabilitate these systems. 3. Most restoration projects in the past have suffered from a range of deficits, which pertain to project design, the planning process, the integration of associated disciplines, scaling issues and monitoring. 4. The so-called 'Leitbild' (i.e. a target vision) assumes a key role in river restoration and the assessment of ecological integrity in general. The development of such a Leitbild requires a multistep approach. Including explicitly the first step that defines the natural, type-specific reference condition (i.e. a visionary as opposed to an operational Leitbild), has great practical advantages for restoration efforts, primarily because it provides an objective benchmark, as is required by the European Water Framework Directive and other legal documents. 5. Clearly defined assessment criteria are crucial for evaluating ecological integrity, especially in the pre- and postrestoration monitoring phases. Criteria that reflect processes and functions should play a primary role in future assessments, so as to preserve and restore functional integrity as a fundamental component of ecological integrity. 6. Case studies on the Kissimmee River (U.S.A.), the Rhine River (Netherlands and Germany), and the Drau River (Austria) are used to illustrate the fundamental principles underlying successful restoration projects of river-floodplain systems.

Karr, J. R. (1993). "Defining and assessing ecological integrity - beyond water quality." Environmental Toxicology and Chemistry **12**(9): 1521-1531.

Emphasis in environmental protection is shifting from primary attention to human health to a more balanced consideration of human and ecological health. This shift provides opportunities and challenges to the scientific community. For example, success depends on development of operational definitions of ecological health and programs to measure that health. Ecological health is inextricably tied to concepts such as biological diversity and biological integrity. Water chemistry and toxicity testing have dominated water-quality programs for decades. Success in protecting the ecological health of water resources depends on our ability to supplement those methods with ecologically robust approaches. Existing definitions and approaches for measuring the quality of water resources provide a template to guide development of procedures to assess ecological health. Critical components of successful monitoring programs should include evaluations relative to regional expectations, use multimetric indexes that reflect the multivariate nature of biological systems, and include index components (metrics) that evaluate conditions from individual, population, assemblage, and landscape perspectives.

Kondolf, G. M., A. J. Boulton, et al. (2006). "Process-based ecological river restoration: Visualizing three-dimensional connectivity and dynamic vectors to recover lost linkages." Ecology and Society **11**(2): 5.

Human impacts to aquatic ecosystems often involve changes in hydrologic connectivity and flow regime. Drawing upon examples in the literature and from our experience, we developed conceptual models and used simple bivariate plots to visualize human impacts and restoration efforts in terms of connectivity and flow dynamics. Human-induced changes in longitudinal, lateral, and vertical connectivity are often accompanied by changes in flow dynamics, but in our experience restoration efforts to date have more often restored connectivity than flow dynamics. Restoration actions have included removing dams to restore fish passage, reconnecting flow through artificially cut-off side channels, setting back or breaching levees, and removing fine sediment deposits that block vertical exchange with the bed, thereby partially restoring hydrologic connectivity, i.e., longitudinal, lateral, or vertical. Restorations have less commonly affected flow dynamics, presumably because of the social and economic importance of water diversions or flood control. Thus, as illustrated in these bivariate plots, the trajectories of ecological restoration are rarely parallel with degradation trajectories because restoration is politically and economically easier along some axes more than others.

Kuhnlein, H. V. and O. Receveur (1996). "Dietary change and traditional food systems of indigenous peoples." Annual Review of Nutrition **16**: 417-42.

Traditional food systems of indigenous peoples are defined as being composed of items from the local, natural environment that are culturally acceptable. Rapid dietary change of indigenous peoples worldwide is posing threats to use of this food and the traditional knowledge required for traditional food system maintainance. This review describes the many influences on choice of food by indigenous peoples, the qualities of traditional food systems, the forces of nondirected dietary change causing decline in use of traditional food systems, and the consequences of change for indigenous peoples. Several examples are given of dietary change research with indigenous peoples.

Latterell, J. J., J. S. Bechtold, et al. (2006). "Dynamic patch mosaics and channel movement in an unconfined river valley of the Olympic Mountains." Freshwater Biology **51**(3): 523-544.

1. River valleys resemble dynamic mosaics, composed of patches which are natural, transient features of the land surface produced by the joint action of a river and successional processes over years to centuries. They simultaneously regulate and reflect the distribution of stream energy and exchanges of sediment, wood and particulate organic matter between riparian and aquatic environments. 2. We determined the structure, composition, dynamics and origin of seven patch types at the reach scale in the Queets River valley in the temperate coastal forests of the Olympic Mountains, Washington (U.S.A.). Patch types included: (1) primary and (2) secondary channels; (3) pioneer bars; (4) developing and (5) established floodplains; and (6) transitional and (7) mature fluvial terraces. 3. Lateral channel movements strongly shape patch distribution, structure and dynamics. The primary channel moved laterally 13 m year(-1), on average from 1939 to 2002, but was highly variable among locations and over time. Mean lateral movement rates ranged from 1 to 59 m year(-1) and moving averages (2 km) ranged from 3 to 28 m year(-1) throughout the valley. 4. Each patch type exhibited characteristic vegetation, soil and accumulations of large wood. Pioneer bars contained peak stem density (69 778 stems ha(-1)) and volume of large wood (289 m(3) ha(-1)). Mature fluvial terraces contained the highest mean stem (1739 m(3) ha(-1)) and canopy volume (158 587 m(3) ha(-1)). These patches also contained the most soil nitrogen (537 kg ha(-1)) and carbon (5972 kg ha(-1)). 5. Patch half-life (the time required for half of the existing patches to be eroded) ranged from 21 to 401 years among forested patch types. Erosion rates were highest in pioneer bars (2.3% year(-1)) and developing floodplains (3.3% year(-1)), compared with only 0.17% year(-1) in mature fluvial terraces. New forests formed continually, as pioneering vegetation colonised 50% of the channel system within 18 years, often unsuccessfully. 6. In the Queets River, the structure, composition, and dynamics of the patchy riparian forest depends on the interplay between channel movements and biophysical feedbacks between large wood, living vegetation and geomorphic processes. The cycle of patch development perpetuates a shifting-mosaic of habitats within the river valley capable of supporting diverse biotic assemblages.

Malard, F., U. Uehlinger, et al. (2006). "Flood-pulse and riverscape dynamics in a braided glacial river." Ecology **87**(3): 704-716.

River ecosystems are increasingly viewed as dynamic riverscapes; their extent, composition, and configuration vary in response to the pulsing of discharge. Although compositional and configurational shifts in riverscapes are thought to control ecosystem processes and biodiversity, attempts to quantity riverscape dynamics of braided rivers are scarce. We Measured monthly changes in the length, spatial arrangement, and age distribution of clear (groundwater-fed) and turbid-water (glacial-fed) channels during two annual cycles in a braided glacial river. Biological data from concurrent studies were used to assess the effects of seasonal changes in the size and pattern of the riverscape on local zoobenthic density, Standing crop of epilithic algae, and spatiotemporal distribution of the hyporheos. The hydrological processes involved in the expansion-contraction cycle of the riverscape resulted in a complex, albeit predictable. pattern of change in the proportion and spatial arrangement of clear and turbid channels. On average, 30% of the riverscape was renewed at monthly intervals. Surface hydrological connectivity and the length Of turbid channels increased logarithmically with increasing discharge. The length of clear channels increased up to a threshold discharge of 1.5 m(3)/s, above which surface flooding resulted in the contraction and fragmentation of clear water bodies. Turbid channels exhibited a unimodal age distribution, whereas clear channels had two cohorts that appeared during the expansion and contraction phases. The renewal pattern and configuration of the riverscape changed little between years despite differences in discharge and the occurrence of several rainfall-induced spates. The density of benthic invertebrate communities in the main channel decreased with increasing size of aquatic habitats indicating that local zoobenthic density was Liffected by dilution-concentration effects. The disproportionate Increase in the proportion of glacial-fed habitats during summer high flows limited the standing crop of epilithic algae in this braided river. The spatial arrangement of inhospitable glacial-fed habitats probably impeded the colonization of newly created suitable habitats by invertebrates with poor dispersal capacities. Quantification of riverscape dynamics is critical to understanding how changes in size, composition, and configuration of braided rivers affect biodiversity, bioproduction, and ecosystem processes.

McCullough, D. A., S. A. Spalding, et al. (2001). Summary of Technical Literature Examining the Physiological Effects of Temperature on Salmonds. Seattle, US Environmental Protection Agency**:** 114.

The distribution, health, and survival of our native fish species are inextricably linked to the thermal environment. Temperature, perhaps more than any other environmental parameter, greatly affects the status of fish and other aquatic life. With respect to thermal effects, lethal temperatures do occur in the field and can be locally problematic in defining usable and unusable habitat. Sublethal effects of temperature determine the overall well-being and patterns of abundance of our native fish populations. Temperature exerts its control through its effect on the physiology of the individual species and their life stages. In addition, individuals within a species population vary in their responses (e.g., lethal, growth) to temperature, generally according to a bell-shaped distribution. As species individually or relative to one another experience temperatures outside their physiological optimum range, the mix of species present in any given waterbody may drastically change. Aside from direct mortality caused by very high temperatures, temperature influences the abundance and well-being of organisms by controlling their metabolic processes. Every species, including disease organisms, has optimal metabolic ranges. Community composition is shaped by the level of numerous components of the habitat system, including temperature, food, water, light, substrate, and so on, each of which can provide optimal or suboptimal conditions. Temperature is one of the single most influential determinants of habitat quality and can also act synergistically with other habitat elements. Temperature through its effect on physiology influences the ability of fish to grow, reproduce, compete for habitat, and escape predators. This issue paper examines the role of temperature in the physiology of the salmonids native to the Pacific Northwest, and the importance of lethal temperature effects compared with various types of sublethal effects in controlling the survival and health of native fishes.

Megahan, W. F., J. P. Ptoyondy, et al. (1992). Best management practices and cumulative effects from sedimentation in the South Fork Salmon River: an Idaho case study. <u>Watershed Management: Balancing Sustainability and Environmental Change</u>. R. J. Naiman. New York, Springer-Verlag**:** 401-414.

Poor land use, including intensive unregulated logging from 1940 through the mid-1960s, contributed to massive cumulative effects from sedimentation in Idaho's South Fork Salmon River (SFSR) by 1965. Severe damage to valuable salmon and steelhead habitat resulted. The BIOSED sediment yield prediction model was used to evaluate the effects of historical and alternative land management on Dollar Creek, a representative 46.1 km2 tribuatry watershed in the SFSR watershed. Present day management practices, properly implemented, have the potential of reducing sediment yields by about 45 to 94% compared with yields caused by the historical land use in Dollar Creek. Cumulative effects analysis is a useful tool for evaluating management alternatives. Some increases in sedimentation are unavoidable even using the most cautious logging and roading methods. However, much of the sediments in the SFSR and other drainages could have been avoided if logging and road construction had followed current best management practices.

Myers, J. M., R. G. Kope, et al. (1998). Status review of chinook salmon from Washington, Idaho, Oregon, and California. Springfield, VA, U.S. Department of Commerce**:** 443.

Previous status reviews conducted by the NMFS have identified three ESUs of chinook salmon in the Columbia River: Snake River fall-run (Waples et al. 1991), Snake River spring- and summer-run (Matthews and Waples 1991), and mid-Columbia River summer- and fall-run chinook salmon (Waknitz et al. 1995). In addition, prior to development of the ESU policy, the NMFS recognized Sacramento River winter chinook salmon as a "distinct population segment" under the ESA (NMFS 1987). In reviewing the biological and ecological information concerning west coast chinook salmon, the Biological Review Team (BRT) identified 11 additional ESUs for chinook salmon from Washington, Oregon, and California. Genetic data (from protein electrophoresis and DNA analysis) and tagging information were key factors considered for the reproductive isolation criterion, supplemented by inferences about barriers to migration created by natural features. Life-history differences were another important consideration in the designation of ESUs. The BRT utilized the classification system developed by Healey (1983, 1991) to describe the two races of chinook salmon: 1) ocean-type populations which typically migrate to seawater in their first year of life and spend most of their oceanic life in coastal waters, and 2) stream-type populations which migrate to sea as yearlings and often make extensive oceanic migrations. Genetic differences, as measured by variation in allozymes, indicate that the ocean- and stream-type races represent two major (and presumably monophyletic) evolutionary lineages. A number of additional factors were considered to be important in evaluations of ecological/genetic diversity, with data on life-history characteristics (especially ocean distribution, time of freshwater entry, age at smoltification and at maturation) and geographic, hydrological, and environmental characteristics being particularly informative.

For the purposes of this review, the BRT did not evaluate likely or possible effects of conservation measures and therefore did not make recommendations as to whether identified ESUs should be listed as threatened or endangered species. The BRT did, however, draw scientific conclusions about the risk of extinction faced by ESUs under the assumption that present conditions will continue.

With respect to the 11 newly-identified ESUs, the BRT concluded that two (Sacramento River Spring Run and Upper Columbia River Spring Run) are at risk of extinction, primarily due to seriously depressed abundance. Five ESUs (Central Valley Fall Run, Southern Oregon and California Coast, Puget Sound, Lower Columbia River, and Upper Willamette River) are at risk of becoming endangered, due to a variety of factors. Only four ESUs (Upper Klamath and Trinity Rivers, Oregon Coast, Washington Coast, and Middle Columbia River Spring Run) are not at risk of extinction or endangerment.

Nehlsen, W., J. E. Williams, et al. (1991). "Pacific salmon at the crossroads: stocks at risk from California, Oregon, Idaho, and Washington." Fisheries **16**: 4-21.

The American Fisheries Society herein provides a list of depleted Pacific salmon, steelhead, and sea-run cutthroat stocks from California, Oregon, Idaho, and Washington, to accompany the list of rare inland fishes reported by Williams et al. (1989). The list includes 214 native naturally-spawning stocks: 101 at high risk of extinction, 58 at moderate risk of extinction, 54 of special concern, and one classified as threatened under the Endangered Species Act of 1973 and as endangered by the state of California. The decline in native salmon, steelhead, and sea-run cutthroat populations has resulted from habitat loss and damage, and inadequate passage and flows caused by hydropower, agriculture, logging, and other developments; overfishing, primarily of weaker stocks in mixed-stock fisheries; and negative interactions with other fishes, including nonnative hatchery salmon and steelhead. While some attempts at remedying these threats have been made, they have not been enough to prevent the broad decline of stocks along the West Coast. A new paradigm that advances habitat restoration and ecosystem function rather than hatchery production is needed for many of these stocks to survive and prosper into the next century.

Nilsson, C., R. Jansson, et al. (2007). "Restoring riverine landscapes: The challenge of identifying priorities, reference states, and techniques." Ecology and Society **12**(1): 16.

This special issue of Ecology and Society on restoring riverine landscapes draws together nine presentations from the Second International Symposium on Riverine Landscapes, convened in August 2004 in Storforsen, Sweden. We summarize three themes related to river restoration: (1) setting priorities, (2) identifying relevant reference conditions, and (3) choosing appropriate techniques. We discuss ways of developing river restoration and provide examples of future needs in sustaining functioning river ecosystems that can support human societies.

Petts, G. E. (2000). "A perspective on the abiotic processes sustaining the ecological integrity of running waters." Hydrobiologia **422**: 15-27.

Using selected examples of recent research, this paper illustrates the role of abiotic components within running-water ecosystems. The important role of temperature is acknowledged but the paper focuses on another key driver: physical stability, defined in relation to hydrological (frequency, duration and timing of inundation) and substratum parameters (channel dynamics, bedform and sediment size). The importance of this driver is illustrated by reference to four spatial scales. At the scale of the bedform, surface-water and groundwater interactions play an important role not least in driving energy exchanges and determining the temperature dynamics within the ecologically important surface layer of the bed sediments. At the reach scale, bedform development, channel form dynamics, and associated changing hydraulic conditions determine both benthic and riparian community patterns. At the catchment scale, new research has shown that the processes responsible for the formation of islands and divided channels play important roles in the functioning of fluvial hydrosystems. Finally, at the regional scale, the flow regime modified by the geomorphological history of the river over at least the past 16 000 years explains ecological patterns. The integration of hydro-geomorphological knowledge from all four scales of analysis is shown to be fundamental for understanding the ecological characteristics of running waters and for managing ecological integrity.

Poff, N. L., J. D. Allan, et al. (1997). "The natural flow regime. A paradigm for river conservation and restoration." BioScience **47**(11): 769-784.

The ecological integrity of river ecosystems depends on their natural dynamic character. The natural flow regime organizes and defines river ecosystems. In rivers, the physical structure of the environment and, thus, of the habitat, is defined largely by physical processes, especially the movement of water and sediment within the channel and between the channel and floodplain. To understand the biodiversity, production, and sustainability of river ecosystems, it is necessary to appreciate the central organizing role played by a dynamically varying physical environment. The physical habitat of a river includes sediment size and heterogeneity, channel and floodplain morphology, and other geomorphic features. These features form as

the available sediment, woody debris, and other transportable materials are moved and deposited by flow. Thus, habitat conditions associated with channels and floodplains vary among rivers in accordance with both flow characteristics and the type and the availability of transportable materials.

Pollock, M. M., T. J. Beechie, et al. (2007). "Geomorphic changes upstreams of beaver dams in Bridge Creek, an incised stream channel in the interior Columbia River basin, eastern Oregon." Earth Surface Processes and Landforms **32**: 1174-1185.

Channel incision is a widespread phenomenon throughout the dry interior Columbia River basin and other semi-arid regions of the world, which degrades stream habitat by fundamentally altering natural ecological, geomorphological and hydrological processes. We examined the extent of localized aggradation behind beaver dams on an incised stream in the interior Columbia River basin to assess the potential for using beaver, Castor canadensis, dams to restore such channels, and the effect of the aggradation on riparian habitat. We estimated aggradation rates behind 13 beaver dams between 1 and 6 years old on Bridge Creek, a tributary to the John Day River in eastern Oregon. Vertical aggradation rates are initially rapid, as high as 0.47 m yr(-1), as the entrenched channel fills, then level off to 0.075 m yr(-1) by year six, as the sediment begins accumulating on adjacent terraces. We found that a 0.5 m elevation contour above the stream channel approximately coincided with the extent of new riparian vegetation establishment. Therefore, we compared the area surrounding reaches upstream of beaver dams that were within 0.5 m elevation of the stream channel with adjacent reaches where no dams existed. We found that there was five times more area within 0.5 m elevation of the channel upstream of beaver dams, presumably because sediment accumulation had aggraded the channel. Our results suggest that restoration strategies that encourage the recolonization of streams by beaver can rapidly expand riparian habitat along incised streams.

Pollock, M. M., G. R. Pess, et al. (2004). "The importance of beaver ponds to coho salmon production in the Stillaguamish River basin, Washington, USA." North American Journal of Fisheries Management **24**: 749-760.

The use of beaver (Castor canadensis) ponds by juvenile coho salmon (Oncorhynchus kisutch) and other fishes has been well established. However, the population-level effects on coho salmon resulting from the widespread removal of millions of beaver and their dams from Pacific Coast watersheds have not been examined. We assessed the current and historic distributions of beaver ponds and other coho salmon rearing habitat in the Stillaguamish River, a 1,771-km(2) drainage basin in Washington and found that the greatest reduction in coho salmon smolt production capacity originated from the extensive loss of beaver ponds. We estimated the current summer smolt production potential (SPP) to be 965,000 smolts, compared with a historic summer SPP of 2.5 million smolts. Overall, current summer habitat capacity was reduced by 61% compared with historic levels, most of the reduction resulting from the loss of beaver ponds. Current summer SPP from beaver ponds and sloughs was reduced by 89% and 68%, respectively, compared with historic SPP. A more dramatic reduction in winter habitat capacity was found; the current winter SPP was estimated at 971,000 smolts, compared with a historic winter SPP of 7.1 million smolts. In terms of winter habitat capacity, we estimated a 94% reduction in beaver pond SPP a 68% loss in SPP of sloughs, a 9% loss in SPP of tributary habitat, and an overall SPP reduction of 86%. Most of the overall reduction resulted from the loss of beaver ponds. Our analysis suggests that summer habitat historically limited smolt production capacity, whereas both summer and winter habitats currently exert equal limits on production. Watershed-scale restoration activities designed to increase coho salmon production should emphasize the creation of ponds and other slow-water environments; increasing beaver populations may be a simple and effective means of creating slow-water habitat.

Pollock, M. M., I. Tattam, et al. (In Press). "The association of juvenile steelhead and riparian vegetation with beaver dams in an incised stream in eastern Oregon." North American Journal of Fisheries Management.

In press; abstract not available.

Poole, G. C. and C. H. Berman (2001). "An ecological perspective on in-stream temperature: natural heat dynamics and mechanisms of human-caused thermal degradation." Environmental Management **27**(6): 787-802.

While external factors (drivers) determine the net heat energy and water delivered to a stream, the internal structure of a stream determines how heat and water will be distributed within and exchanged among a stream's components (channel, alluvial aquifer, and riparian zone/floodplain). Therefore, the interaction between external drivers of stream temperature and the internal structure of integrated stream systems ultimately determines channel water temperature. This paper presents a synoptic, ecologically based discussion of the external drivers of stream temperature, the internal structures and processes that insulate and buffer stream temperatures, and the mechanisms of human influence on stream temperature. It provides a holistic perspective on the diversity of natural dynamics and human activities that influence stream temperature, including discussions of the role of the hyporheic zone. Key management implications include: (1) Protecting or reestablishing in-stream flow is critical for restoring desirable thermal regimes in streams. (2) Modified riparian vegetation, groundwater dynamics, and channel morphology are all important pathways of human influence on channel-water temperature and each pathway should be addressed in management plans. (3) Stream temperature research and monitoring programs will be jeopardized by an inaccurate or incomplete conceptual understanding of complex temporal and spatial stream temperature response patterns to anthropogenic influences. (4) Analyses of land-use history and the historical vs contemporary structure of the stream channel, riparian zone, and alluvial aquifer are important prerequisites for applying mechanistic temperature models to develop management prescriptions to meet in-channel temperature goals.

Poole, G. C., J. B. Dunham, et al. (2004). "The case for regime-based water quality standards." BioScience **54**(2): 155-161.

Conventional water quality standards have been successful in reducing the concentration of toxic substances in US waters. However, conventional standards are based on simple thresholds and are therefore poorly structured to address human-caused imbalances in dynamic, natural water quality parameters, such as nutrients, sediment, and temperature. A more applicable type of water quality standard - a "regime standard" - would describe desirable distributions of conditions over space and time within a stream network. By mandating the protection and restoration of the aquatic ecosystem dynamics that are required to support beneficial uses in streams, well-designed regime standards would facilitate more effective strategies for management of natural water quality parameters.

Poole, G. C., S. J. O'Daniel, et al. (In Press). "Hydrologic spirals: the role of multiple interactive flow paths in stream ecosystems." River Research and Applications.

In this paper, we develop and illustrate the concept of “hydrologic spiraling” using a high-resolution (2 x 2 m grid cell) simulation of hyporheic hydrology across a 1.7 km2 section of the sand, gravel, and cobble floodplain aquifer of the upper Umatilla River of northeastern Oregon, USA. We parameterized the model using a continuous map of surface water stage derived from LIDAR remote sensing data. Model results reveal the presence of complex spatial patterns of hyporheic exchange across spatial scales. We use simulation results to describe streams as a collection of hierarchically organized, individual flow paths that spiral across ecotones within streams and knit together stream ecosystems. Such a view underscores the importance of: 1) gross hyporheic exchange rates in rivers, 2) the differing ecological roles of short and long hyporheic flow paths, and 3) the downstream movement of water and solutes outside of the stream channel (e.g., in the alluvial aquifer). Hydrologic spirals underscore important limitations of empirical measures of biotic solute uptake from streams and provide a needed hydrologic framework for emerging research foci in stream ecology such as hydrologic connectivity, spatial and temporal variation in biogeochemical cycling rates, and the role of stream geomorphology as a dominant control on stream ecosystem dynamics.

Poole, G. C., J. A. Stanford, et al. (2006). "Multiscale geomorphic drivers of groundwater flow paths: subsurface hydrologic dynamics and hyporheic habitat diversity." Journal of the North American Benthological Society **25**(2): 288-303.

Application of a hydrogeologic computer model underscored the importance of geomorphic controls on groundwater and surface-water flow dynamics in the Nyack Floodplain, a montane alluvial floodplain in Montana, USA. The model represented the floodplain as a hierarchy of geomorphic patches, which facilitated analysis of model results using independent (predictor) variables at multiple scales. The analyses revealed that geomorphic structures at various spatial scales interact with the flow regime to influence the direction, magnitude, and stability of hyporheic flow within individual floodplain patches. Specifically: 1) the hydrologic flow network within the hyporheic zone is more responsive to seasonal changes in river discharge if floodplain topography is complex and aquifer properties are heterogeneous, 2) simplification of internal patch structure across the floodplain eliminates the influence of fine-scale geomorphic structures on the stability of groundwater flow paths, although the influence of patch context remains, and 3) incremental changes in river discharge can abruptly and substantially restructure the relationship between river discharge and groundwater flow patterns when events such as inundation of previously dry flood channels occur on the floodplain. We believe that ecological theories of biodiversity can be used to understand interactions among geomorphic variation, hydrologic dynamics, and the maintenance of biodiversity in the hyporheic zone if abrupt reorganization and other variations in groundwater flow paths act as disturbances to hyporheic communities. From this perspective, we used model results to develop 4 hypotheses describing the potential for causal linkages among floodplain geomorphology, hyporheic flow-path variation, hyporheic habitat diversity/stability, and hyporheic community diversity.

Pringle, C. (2003). "What is hydrologic connectivity and why is it ecologically important?" Hydrological Processes **17**(13): 2685-2689.

Hydrologic connectivity is used here in an ecological context to refer to water-mediated transfer of matter, energy and/or organisms within or between elements of the hydrologic cycle. Hydrologic connectivity is essential to the ecological integrity of the landscape, and reduction or enhancement of this property by humans can have major negative environmental effects. Some of these effects are immediate, localized and, therefore, obvious. For example, with respect to migratory fish, a given dam may act to reduce hydrologic connectivity (by preventing or impeding migration up or downstream), whereas interbasin river transfers enhance this property by allowing the dispersal of fish into river basins outside of their range. Less obvious, are alterations in hydrologic connectivity that exhibit a time lag and manifest themselves at geographic locations far from the source of disturbance. An example concerns the cumulative effect of dams on transport of the inorganic dissolved solute silica. Dams and associated impoundments can reduce the transport of this compound, which becomes deposited in the bottoms of reservoirs. The cumulative effects of many dams along a river can potentially result in a reduction in the amount of silica delivered to coastal waters, with consequent negative effects on coastal food web structure that contribute to eutrophication.

Rayne, S., M. G. Ikonomou, et al. (2003). "Rapidly increasing polybrominated diphenyl ether concentrations in the Columbia River system from 1992 to 2000." Environmental Science & Technology **37**(13): 2847-2854.

Concentrations and congener patterns of 32 individual PBDE congeners from mono- through hexa-brominated were investigated in two fish species occupying similar habitats-but having different diets and trophic levels-and surficial sediments from several locations on the major river system of western North America, the Columbia River, in southeastern British Columbia, Canada. Total PBDE concentrations have increased by up to 12-fold over the period from 1992 to 2000 in mountain whitefish from the Columbia River, with a doubling period of 1.6 years. The rate at which PBDE concentrations are increasing in whitefish is greater than has been previously reported worldwide. At the current rate of increase, SigmaPBDE will surpass those of SigmaPCB by 2003 to become the most prevalent organo-halogen contaminant in this region. SigmaPBDE in whitefish from the mainstem of the Columbia River range up to 72 ng/g wet weight, concentrations that are 20-50-fold higher than in a nearby pristine watershed affected only by atmospheric contaminant transport. Conversely, SigmaPBDE in largescale suckers were approximately an order of magnitude lower than in whitefish, demonstrating the influence of biomagnification and feeding habits. Congener patterns in whitefish from the Columbia River directly correlated with the two major commercial penta-BDE mixtures in use and represent the first time free-swimming aquatic biota such as fish have been found to contain PBDE congener patterns so similar to commercial mixtures. PBDE concentrations in sediments were not linked to a variety of investigated point sources but were instead inversely correlated with the ratio of organic carbon:organic nitrogen in surficial sediments with a pattern suggesting the dominant influence of septic field inputs from the primarily rural population.

Rood, S. B., G. M. Samuelson, et al. (2005). "Managing river flows to restore floodplain forests." Frontiers in Ecology and the Environment **3**(4): 193-201.

River damming has dramatic environmental impacts and while changes due to reservoir flooding are immediate, downstream impacts are more spatially extensive. Downstream environments are influenced by the pattern of flow regulation, which also provides an opportunity for mitigation. We discuss impacts downstream from dams and recent case studies where collaborative efforts with dam operators have led to the recovery of more natural flow regimes. These restoration programs, in Nevada, USA, and Alberta, Canada, focused on the recovery of flow patterns during high flow years, because these are critical for riparian vegetation and sufficient water is available for both economic commitments and environmental needs. The restoration flows were developed using the “Recruitment Box Model”, which recommends high spring flows and then gradual flow decline for seedling survival. These flow regimes enabled extensive recruitment of cottonwoods and willows along previously impoverished reaches, and resulted in improvements to river and floodplain environments. Such restoration successes demonstrate how instream flow management can act as a broadly applicable tool for the restoration of floodplain forests.

Stanford, J. A., M. S. Lorang, et al. (2005). "The shifting habitat mosaic of river ecosystems." Verhandlungen der Internationalen Vereinigung für Theoretische und Angewandte Limnologie **29**: 123-136.

A useful way to examine the problem of defining habitat per life stage is to think of landscapes as being composed of habitat mosaics. Indeed, landscape ecology in theory and practice attempts to define species (or population) distributions, abundances and productivity in context of patches or mosaics of biophysical space used by those species (or populations).

The dynamics of habitat mosaics and species responses to them, including complex biophysical feedbacks, perhaps is the essence of landscape ecology. Herein we examine river ecosystems in this dynamic habitat context. We present a general typology of floodplain structures or elements as a basis for habitat delineation. We argue that while the elements that define riverine habitats tend to persist in natural river systems (and are constrained or eliminated by human alteration), the distribution of the habitat patches (mosaics) changes spatially over time due to primary drivers, particularly flooding, channel avulsion, cut and fill alluviation (erosion and deposition of fine and coarse sediments), deposition of wood recruitment and regeneration of riparian vegetation. We call this phenomenon the shifting habitat mosaic and argue it is a fundamental process attribute of river ecosystems. We propose that the rather wide array of contemporary theories about river ecosystem structure and function are substantially unified by thinking of river ecosystems as a continuum of 3-dimensional shifting habitat mosaics from headwaters to the ocean.

Stanford, J. A., J. V. Ward, et al. (1996). "A general protocol for restoration of regulated rivers." Regulated Rivers: Research and Management **12**: 391-413.

Large catchment basins may be viewed as ecosystems in which natural and cultural attributes interact, Contemporary river ecology emphasizes the four-dimensional nature of the river continuum and the propensity for riverine biodiversity and bioproduction to be largely controlled by habitat maintenance processes, such as cut and fill alluviation mediated by catchment water yield. Stream regulation reduces annual flow amplitude, increases baseflow variation and changes temperature, mass transport and other important biophysical patterns and attributes, As a result, ecological connectivity between upstream and downstream reaches and between channels, ground waters and floodplains may be severed, Native biodiversity and bioproduction usually are reduced or changed and non-native biota proliferate. Regulated rivers regain normative attributes as distance from the dam increases and in relation to the mode of dam operation. Therefore, dam operations can be used to restructure altered temperature and flow regimes which, coupled with pollution abatement and management of non-native biota, enables natural processes to restore damaged habitats along the river's course. The expectation is recovery of depressed populations of native species, The protocol requires: restoring peak flows needed to reconnect and periodically reconfigure channel and floodplain habitats; stabilizing base-flows to revitalize food-webs in shallow water habitats; reconstituting seasonal temperature patterns (e.g. by construction of depth selective withdrawal systems on storage dams); maximizing dam passage to allow recovery of fish metapopulation structure; instituting a management belief system that relies upon natural habitat restoration and maintenance, as opposed to artificial propagation, installation of artificial instream structures (river engineering) and predator control; and, practising adaptive ecosystem management. Our restoration protocol should be viewed as an hypothesis derived from the principles of river ecology. Although restoration to aboriginal state is not expected, nor necessarily desired, recovering some large portion of the lost capacity to sustain native biodiversity and bioproduction is possible by management for processes that maintain normative habitat conditions. The cost may be less than expected because the river can do most of the work.

Vannote, R. L., G. W. Minshall, et al. (1980). "The river continuum concept." Canadian Journal of Fisheries and Aquatic Science **37**: 130-137.

From headwaters to mouth, the physical variables within a river system present a continous gradient of physical conditions. The gradient should elicit a series of responses within the constituent populations resulting in a continuum of biotix adjustments and consistens patterns of laoding, transport, utilization, and storage of organic matter along the length of a river. Based on the energy equilibrium theory of fluvial geomorphologists, we hypothesize that the structural and functional characteristics of stream communities are adapted to conform to the most probable position or mean state of the physical system. Downstream communities are structured to capitalize on upstream ineffeciencies.

Ward, J. V. (1998). "Riverine landscapes: Biodiversity patterns, disturbance regimes, and aquatic conservation." Biological Conservation **83**(3): 269-278.

The term riverine landscape implies a holistic geomorphic perspective of the extensive interconnected series of biotopes and environmental gradients that, with their biotic communities, constitute fluvial systems. Natural disturbance regimes maintain multiple interactive pathways (connectivity) across the riverine landscape. Disturbance and environmental gradients, acting in concert, result in a positive feedback between connectivity and spatio-temporal heterogeneity that leads to the broadscale patterns and processes responsible for high levels of biodiversity. Anthropogenic impacts such as flow regulation, channelization, and bank stabilization, by (1) disrupting natural disturbance regimes, (2) truncating environmental gradients, and (3) severing interactive pathways, eliminate upstream-downstream linkages and isolate river channels from riparian/floodplain systems and contiguous groundwater aquifers. These alterations interfere with successional trajectories, habitat diversification, migratory pathways and other processes, thereby reducing biodiversity. Ecosystem management is necessary to maintain or restore biodiversity at a landscape scale. To be effective, conservation efforts should be based on a solid conceptual foundation and a holistic understanding of natural river ecosystems. Such background knowledge is necessary to re-establish environmental gradients, to reconnect interactive pathways, and to reconstitute some semblance of the natural dynamics responsible for high levels of biodiversity. The challenge for the future lies in protecting the ecological integrity and biodiversity of aquatic systems in the face of increasing pressures on our freshwater resources. This will require integrating sound scientific principles with management perspectives that recognize floodplains and groundwaters as integral components of rivers and `that are based on sustaining, rather than suppressing, environmental heterogeneity.

Ward, J. V. and J. A. Stanford (1995). "Ecological connectivity in alluvial river ecosystems and its disruption by flow regulation." Regulated Rivers: Research and Management **11**: 105-119.

The dynamic nature of alluvial floodplain rivers is a function of flow and sediment regimes interacting with the physiographic features and vegetation cover of the landscape. During seasonal inundation, the flood pulse forms a "moving littoral" that traverses the plain, increasing productivity and enhancing connectivity. The range of spatio-temporal connectivity between different biotypes, coupled with variable levels of natural disturbance, determine successional patterns and habitat heterogeneity that are responsible for maintaining the eological integrity of floodplain river systems. Flow regulations by dams, often compounded by other modifications such as levee construction, normally results in reduced connectivity and altered successional trajectories in downstream reaches. Flood peaks are typically reduced by river regualtion which reduces the frequency and extent of floodplain inundation. A reduction in channel-forming flows reduces channel migration, an important phenomenon in maintianing high levels of habitat diversity across floodplains. The seasonal timing of floods may be shifted by flow regualtions with major ramifications for aquatic and terrestiral biota. Truncations of sediment transport may result in channel degradation for many kilometers downstream from a dam. Deepening of the channel lowers the water table, which affects riparian vegetation dynamics and reduces the effective base level of tributaries, which results in rejuvenation and erosion. Ecological integrity in floodplain rivers is based in part on a diversity of water bodies with differing degrees of connectivity with the main river channel. Collectively, these water bodies occupy a wide range of successional stages, thereby forming a mosaic of habitat patches across the floodplain. This dieversity is maintianed by a balance between the trend toward terrestrializationa dn flow disturbances that renew connectivity and reset successional sequences. to counter the influence of river regulation, restoration efforts should focus on reestablishing dynamic connectivity between the channel and floodplain water bodies.

Ward, J. V. and K. Tockner (2001). "Biodiversity: towards a unifying theme for river ecology." Freshwater Biology **46**: 807-819.

1. A broadened concept of biodiversity, encompassing spatio-temporal heterogeneity, functional processes and species diversity, could provide a unifying theme for river ecology. 2. The theoretical foundations of stream ecology often do not reflect fully the crucial roles of spatial complexity and fluvial dynamics in natural river ecosystems, which has hindered conceptual advances and the effectiveness of efforts at conservation and restoration. 3. Inclusion of surface waters (lotic and lentic), subsurface waters (hyporheic and phreatic), riparian systems (in both constrained and floodplain reaches), and the ecotones between them (e.g. springs) as interacting components contributing to total biodiversity, is crucial for developing a holistic framework of rivers as ecosystems. 4. Measures of species diversity, including alpha, beta and gamma diversity, are a result of disturbance history, resource partitioning, habitat fragmentation and successional phenomena across the riverine landscape. A hierarchical approach to diversity in natural and altered river-floodplain ecosystems will enhance understanding of ecological phenomena operating at different scales along multidimensional environmental gradients. 5. Re-establishing functional diversity (e.g. hydrologic and successional processes) across the active corridor could serve as the focus of river conservation initiatives. Once functional processes have been reconstituted, habitat heterogeneity will increase, followed by corresponding increases in species diversity of aquatic and riparian biota.

Ward, J. V., K. Tockner, et al. (1999). "Biodiversity of floodplain river ecosystems: ecotones and connectivity." Regulated Rivers: Research and Management **15**: 125-139.

A high level of spatio-temporal heterogeneity makes riverine floodplains among the most species-rich environments known. Fluvial dynamics from floodplain play a major role in maintaining a diversity of lentic, lotic, and semi-aquatic habitat types, each represented by a diversity of successional stages. Ecotones are structurel and functional elements that result from and contribute to the spatio-temporal dynamics of riverine ecosystems. In floodplain rivers, ecotones and their adjoining patches are arrayed in hierarichical seiris across a range of scales. At a coarse scale of resolution, fringing floodplains are themselves complex ecotones between river channels and uplands. At finer scales, patches of various types and sizes form habitat and microhabitat diversity patterns. A broad spatio-temporal perspective, including patterns and processes across scales, is needed in order to gain insight into riverine biodiversity. We propose a hierarichical framework for examining diversity patterns in floodplain rivers. Various river management schemes disrupt the interactions that structure ecotones and alter the connectivity acorss transitions zones. Such disruptions occur both within and between hierarchical levels, invariably leading to reductions in biodiversity. Species richness data from the connected and disconnected floodplain of the Austrialian

Danube illustrate the clearly. In much of the world, species rich riverine/floodplain environments exist only as isolated fragments across the landscpae. In many large rivers, these islands of biodiversity are endangered ecosyste.s The fluvial dynamics that formed them have been severely altered. Without ecolocially sound restoration of disturbance regimes and connectivity, these remnants of biodiversity will proceed on unidirectional trajectories toward senescence, without rejuvenation. Principles of ecosystem management are necessary to sustain biodiveristy in fragmented riverine floodplains.

Ward, J. V., K. Tockner, et al. (2001). "Understanding natural patterns and processes in river corridors as the basis for effective river restoration." Regulated Rivers: Research & Management **17**: 311-323.

Running water ecology is a young science, the conceptual foundations of which were derived largely from research conducted in Europe and North America. However, virtually all European river corridors were substantially regulated well before the science of river ecology developed. While regulation of North American river systems occurred later than in European systems, river ecology also developed later. Therefore, there is a general impression of rivers as being much less heterogeneous and much more stable than they actually are in the natural state. The thesis of this paper is that established research and management concepts may fail to fully recognize the crucial roles of habitat heterogeneity and fluvial dynamics owing to a lack of fundamental knowledge of the structural and functional features of morphologically intact river corridors. Until quite recently, most concepts in river ecology were based on the implicit assumption that rivers are stable, single-thread channels isolated from adjacent floodplains. Unfortunately, many rivers are in just such a state, but it should be recognized that this is not the natural condition. This incomplete understanding constrains scientific advances in river ecology and renders management and restoration initiatives less effective. Examples are given of the high level of spatio-temporal heterogeneity that may be attained in rivers where natural processes still operate on a large scale. The objective of this paper is to promulgate a broader and more integrative understanding of natural processes in river corridors as a necessary prelude to effective river conservation and management.

Waters, T. F. (1995). "Sediment in streams: sources, biological effects, and control." American Fisheries Society Monograph **7**: 251 pages.

Human influence has been an accelerating factor in modifying the North American environment for only about 300 to 400 years. Obvious effects of such anthropogenic erosion and sediment deposition include loss of agricultural soils, decreased water-retention capacity of forest lands, increased flood frequency, and rapid filling of reservoirs. Less obvious, however (and until recently largely ignored), is sedimentation in small streams that affects biotic communities, reduces diversity of fish and other animal communities, and lowers the productivity of aquatic populations. The ultimate objective of this review is to encourage more effective management of sediment inputs to streams and to preserve biological integrity and productivity. The chief pragmatic goal is to assist in the improvement and maintenance of stream fisheries, but for other societal interests as well. Specific objectives are to: (1) identify the main causes or sources of anthropogenic inorganic sediment, (2) summarize the results of recent research on the effect of sediment upon stream biota, and (3) describe sediment control measures aimed at the preservation of viable stream communities and freshwater fisheries.

Weitkamp, L. A., T. C. Wainwright, et al. (1995). Status Review of Coho Salmon from Washington, Oregon, and California. Springfield, VA, U.S. Department of Commerce.

The term threatened species is defined as any species which is likely to become an endangered species within the foreseeable future throughout all or a significant portion of its range. According to the ESA, the determination whether a species is threatened or endangered should be made on the basis of the best scientific information available regarding its current status, after taking into consideration conservation measures that are proposed or are in place. In this review, the BRT did not evaluate likely or possible effects of conservation measures and, therefore, did not make recommendations as to whether identified ESUs should be listed as threatened or endangered species; rather, the BRT drew scientific conclusions about the risk of extinction faced by identified ESUs under the assumption that present conditions will continue. The resulting conclusions for each ESU follow. 1. Central California coast. There was unanimous agreement among the BRT that natural populations of coho salmon in this ESU are presently in danger of extinction. The chief reasons for this assessment were extremely low current abundance, especially compared to historical abundance, widespread local extinctions, clear downward trends in abundance, extensive habitat degradation and associated decreased carrying capacity, and a long history of artificial propagation with the use of non-native stocks. In addition, recent droughts and current ocean conditions may have further reduced run sizes. 2. Southern Oregon/northern California coasts. There was unanimous agreement among the BRT that coho salmon in this ESU are not in danger of extinction but are likely to become endangered in the foreseeable future if present trends continue. Current run size, the severe decline from historical run size, the frequency of local extinctions, long-term trends that are clearly downward, degraded habitat and associated reduction in carrying capacity, and widespread hatchery production using exotic stocks are all factors that contributed to the assessment. Like the central California ESU, recent droughts and current ocean conditions may have further reduced run sizes. 3. Oregon coast. The

BRT concluded that coho salmon in this ESU are not in danger of extinction but are likely to become endangered in the future if present trends continue. The BRT reached this conclusion based on low recent abundance estimates that are 5-10% of historical abundance estimates, clearly downward long-term trends, recent spawner-to-spawner ratios that are below replacement, extensive habitat degradation, and widespread hatchery production of coho salmon. Drought and current ocean conditions may have also reduced run sizes. 4. Lower Columbia River/southwest Washington coast. Previously, NMFS concluded that it could not identify any remaining natural populations of coho salmon in the lower Columbia River (excluding the Clackamas River) that warranted protection under the ESA. The Clackamas River produces moderate numbers of natural coho salmon. The BRT could not reach a definite conclusion regarding the relationship of Clackamas River late-run coho salmon to the historic lower Columbia River ESU. However, the BRT did conclude that if the Clackamas River late-run coho salmon is a native run that represents a remnant of a lower Columbia River ESU, the ESU is not presently in danger of extinction but is likely to become so in the foreseeable future if present conditions continue. 5. For southwest Washington coho salmon, uncertainty about the ancestry of coho salmon runs given high historical and current levels of artificial production prevented the BRT from reaching a definite conclusion regarding the relationship between coho salmon in that area and the historical lower Columbia River/southwest Washington ESU. If new information becomes available, the relationship and status of the ESU will be reexamined.

5. Olympic Peninsula. While there is continuing cause for concern about habitat destruction and hatchery practices within this ESU, the BRT concluded that there is sufficient native, natural, self-sustaining production of coho salmon that this ESU is not in danger of extinction and is not likely to become endangered in the foreseeable future unless conditions change substantially.

6. Puget Sound/Strait of Georgia. The BRT was concerned that if present trends continue, this ESU is likely to become endangered in the foreseeable future. Although current population abundance is near historical levels and recent trends in overall population abundance have not been downward, there is substantial uncertainty relating to several of the risk factors considered. These risk factors include widespread and intensive artificial propagation, high harvest rates, extensive habitat degradation, a recent dramatic decline in adult size, and unfavorable ocean conditions. Further consideration of this ESU is warranted to attempt to clarify some of these uncertainties.

Whited, D. C., M. S. Lorang, et al. (2007). "Climate, hydrologic disturbance, and succession: Drivers of floodplain pattern." Ecology **88**(4): 940-953.

Floodplains are among the world's most threatened ecosystems due to the pervasiveness of dams, levee systems, and other modifications to rivers. Few unaltered floodplains remain where we may examine their dynamics over decadal time scales. Our study provides a detailed examination of landscape change over a 60-year period (1945 - 2004) on the Nyack floodplain of the Middle Fork of the Flathead River, a free-flowing, gravel-bed river in northwest Montana, USA. We used historical aerial photographs and airborne and satellite imagery to delineate habitats (i.e., mature forest, regenerative forest, water, cobble) within the floodplain. We related changes in the distribution and size of these habitats to hydrologic disturbance and regional climate. Results show a relationship between changes in floodplain habitats and annual flood magnitude, as well as between hydrology and the cooling and warming phases of the Pacific Decadal Oscillation (PDO). Large magnitude floods and greater frequency of moderate floods were associated with the cooling phases of the PDO, resulting in a floodplain environment dominated by extensive restructuring and regeneration of floodplain habitats. Conversely, warming phases of the PDO corresponded with decreases in magnitude, duration, and frequency of critical flows, creating a floodplain environment dominated by late successional vegetation and low levels of physical restructuring. Over the 60-year time series, habitat change was widespread throughout the floodplain, though the relative abundances of the habitats did not change greatly. We conclude that the long- and short-term interactions of climate, floods, and plant succession produce a shifting habitat mosaic that is a fundamental attribute of natural floodplain ecosystems.

Wohl, E., P. L. Angermeier, et al. (2005). "River restoration." Water Resources Research **41**: W10301.

River restoration is at the forefront of applied hydrologic science. However, many river restoration projects are conducted with minimal scientific context. We propose two themes around which a research agenda to advance the scientific basis for river restoration can be built. First, because natural variability is an inherent feature of all river systems, we hypothesize that restoration of process is more likely to succeed than restoration aimed at a fixed end point. Second, because physical, chemical, and biological processes are interconnected in complex ways across watersheds and across timescales, we hypothesize that restoration projects are more likely to be successful in achieving goals if undertaken in the context of entire watersheds. To achieve restoration objectives, the science of river restoration must include (1) an explicit recognition of the known complexities and uncertainties, (2) continued development of a theoretical framework that enables us to identify generalities among river systems and to ask relevant questions, (3) enhancing the science and use of restoration monitoring by measuring the most effective set of variables at the correct scales of measurement, (4) linking science and implementation, and (5) developing methods of restoration that are effective within existing constraints. Key limitations to river restoration include a lack of scientific knowledge of watershed-scale process dynamics, institutional structures that are poorly suited to large-scale adaptive management, and a lack of political support to reestablish delivery of the ecosystem amenities lost through river degradation. This paper outlines an approach for addressing these shortcomings.

Wood, P. J. and P. D. Armitage (1997). "Biological effects of fine sediment in the lotic environment." Environmental Management **21**(2): 203-217.

Although sedimentation is a naturally occurring phenomenon in rivers, land-use changes have resulted in an increase in anthropogenically induced fine sediment deposition. Poorly managed agricultural practices, mineral extraction, and construction can result in an increase in suspended solids and sedimentation in rivers and streams, leading to a decline in habitat quality. The nature and origins of fine sediments in the lotic environment are reviewed in relation to channel and nonchannel sources and the impact of human activity. Fine sediment transport and deposition are outlined in relation to variations in streamflow and particle size characteristics. A holistic approach to the problems associated with fine sediment is outlined to aid in the identification of sediment sources, transport, and deposition processes in the river catchment. The multiple causes and deleterious impacts associated with fine sediments on riverine habitats, primary producers, macroinvertebrates, and fisheries are identified and reviewed to provide river managers with a guide to source material. The restoration of rivers with fine sediment problems are discussed in relation to a holistic management framework to aid in the planning and undertaking of mitigation measures within both the river channel and surrounding catchment area.

Woodward, G. and A. G. Hildrew (2002). "Food web structure in riverine landscapes." Freshwater Biology **47**(4): 777-798.

1. Most research on freshwater (and other) food webs has focused on apparently discrete communities, in well-defined habitats at small spatial and temporal scales, whereas in reality food webs are embedded in complex landscapes, such as river corridors. Food web linkages across such landscapes may be crucial for ecological pattern and process, however. Here, we consider the importance of large scale influences upon lotic food webs across the three spatial dimensions and through time. 2. We assess the roles of biotic factors (e.g. predation, competition) and physical habitat features (e.g. geology, land-use, habitat fragmentation) in moulding food web structure at the landscape scale. As examples, external subsidies to lotic communities of nutrients, detritus and prey vary along the river corridor, and food web links are made and broken across the land-water interface with the rise and fall of the flood. 3. We identify several avenues of potentially fruitful research, particularly the need to quantify energy flow and population dynamics. Stoichiometric analysis of changes in C : N : P nutrient ratios over large spatial gradients (e.g. from river source to mouth, in forested versus agricultural catchments), offers a novel method of uniting energy flow and population dynamics to provide a more holistic view of riverine food webs from a landscape perspective. Macroecological approaches can be used to examine large-scale patterns in riverine food webs (e.g. trophic rank and species-area relationships). New multivariate statistical techniques can be used to examine community responses to environmental gradients and to assign traits to individual species (e.g. body-size, functional feeding group), to unravel the organisation and trophic structure of riverine food webs.